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The Effect of Hydration Status on Jump Height in Track and Field Athletes

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THE EFFECT OF HYDRATION STATUS ON JUMP HEIGHT IN TRACK AND FIELD ATHLETES

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ABSTRACT

The maintenance of hydration levels are often a key focus when trying to sustain athletic performance in sport. The amount of fluid intake needed to reach appropriate hydration levels varies widely from a multitude of factors. This ideal hydration level (euhydration) is characterized by an optimal total intracellular and extracellular body water content, which is the ultimate goal of fluid intake protocols within athletics. The aim of this research was to investigate if a specific fluid recommendations for track and field (TAF) athletes, based upon urine specific gravity (USG) classification cutoffs, helps to improve athletic performance. This study also analyzed the influence of body weight (BW) on the amount of fluid and/or electrolyte supplements an athlete needs to consume in order to attain an euhydrated state prior to practice or competition. A total of 35 subjects participated in the study, who were then divided into two groups: a control and experimental each receiving different hydration protocols. Fluid intake needs were assessed using anthropometric measurements and air displacement plethysmography. Urine samples were taken to determine hydration status (HS) and were analyzed through USG measurements. Additionally, the metric of vertical jump height (VJH) was used to evaluate athletic performance within the investigation. The results indicated that HS was increased in both groups upon engagement of the hydration recommendation protocol routine. However, the analysis of HS showed that there was not a statistically significant interaction between the hydration protocol groups. The application of hydration protocols based on BW was not indicated to be necessary to achieve a euhydrated state when TAF athletes followed specific fluid recommendations based upon USG classification cutoffs. The evaluation of both daily USG and weekly VJH measurements through a Pearson's correlation analysis concluded there was not a statistically significant relationship between the HS and VJH within the research study.

There was no significant correlation between the two variables (r = -0.24, p = 0.301). These findings indicate HS is not associated with significant changes in VJH among TAF athletes.

DEDICATION

This dissertation is dedicated to everyone who helped guide my way through graduate school. I could not have completed this journey without your constant support and dedication to the success of my future endeavors.

LIST OF ABBREVIATIONS AND SYMBOLS

1. (HS) Hydration Status
2. (VJH) Vertical Jump Height
3. (TAF) Track and Field
4. (BW) Body Weight
5. (USG) Urine Specific Gravity

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CHAPTER I: INTRODUCTION

Within the world of sport there is a constant effort towards improving athletic performance. The components determining overall athletic success are incredibly complex and dictated by a multitude of factors, one of which is hydration level. Hydration plays a significant role in a variety of factors relating to health, well-being, and physical capacity (Giersch et al., 2020). Additionally, HS is dramatically affected by fluid intake, exercise intensity, and the environmental factors which are vital to performance (Kraft et al., 2011). A major portion of VJH research has focused upon endurance sports such as cycling and distance running (Lee et al., 2014; Backx et al., 2003). These studies have indicated maintenance of proper hydration while completing endurance activities is vital to athletic performance which is heavily dependent upon the body's ability to match energy production with those required by the specific sport (Sawka et al., 2007). This has led to debate regarding optimal fluid guidelines for athletes engaging within various sports (Hew-Butler et al., 2006). Furthermore, this leaves a large gap in the research among specific sports events such as jumping, sprinting, and pole vaulting when analyzing the relationship of VJH and athletic performance.

Physiology of Thermoregulation

The role of temperature and humidity and its effects upon human physiology during exercise has been well documented through numerous studies (Cao et al., 2022; Hein et al., 2018). The ability of the body to maintain thermoregulation is dependent upon several factors including environment, (i.e., ambient air temperature, humidity, wind velocity, and solar radiation), task dependent (i.e., clothing, and metabolic rate), and personal (i.e., age, sex, body mass, morphology, and aerobic fitness). (Periard et al., 2015). A rise in humidity level in the presence of hot temperatures has been well documented to elevate physiological strain through a reduction in evaporation capacity of the environment (Nielsen et al., 1997). The restriction of heat dissipation to the environment from the surface of the skin is a result in the decline in evaporative capacity to the environment, this decrease in sweating efficiency then expands the area of wetness on the skin (Alber-Wallerstrom & Holmer, 1985). A decrease in sweating proficiency leads to increases in skin temperatures during exercise in humid environments resulting in greater skin blood flow and increased circulatory strain (Sawka et al., 2012). Research conducted by Muhamed et al. (2016) analyzing the impact of humidity on thermoregulation and circulatory stress during exercise found that the capacity to perform all-out exercise is limited in the presence of high relative humidity.

Hydration and Environmental Factors

When an individual gradually progresses into higher levels of intensity throughout an exercise activity metabolic demands become greater, as a result heat production rates increase as well. The higher the exercise intensity, the more rapid rise in metabolic heat production and the sharper rise in body temperature (Maughan & Shirreffs, 2010). The environmental factors (temperature and humidity) in which exercise is being performed can greatly influence hydration needs and can pose severe challenges to the human regulatory systems (Gonzalez-Alonso et al., 2012). It has been well established that exercising in warm to hot environments (25-45°C), compared to cooler temperatures (15-25°C) will hinder endurance performance, as a result of the development of hyperthermia (Nybo et al., 2014). For this reason, the importance of hydration for athletic performance cannot be overstated.

In addition to environmental factors that influence thermoregulation, task-dependent factors such as the type of metabolic rate and clothing contribute to the balance between internal metabolic heat production rate and the amount of heat exchanged with the environment (Periard et al., 2021). The metabolic production of heat during exercise from the oxidation of substrates has been shown to significantly promote rises in core body temperature. This occurs because only 20-25% of the metabolic energy is transformed to mechanical energy, as the majority contributes to heat production (Kristoffersen et al., 2019). Clothing also alters heat exchange with the environment through the fit and material properties of the outfit, which affects heat strain during exercise by decreasing heat dissipation and supporting heat preservation (Daanen et al., 2015). It has also been shown that while exercising in the heat, it is essential for ventilation in the air layer between clothing and the skin for heat loss to occur (Havenith et al., 2002).

Personal parameters influencing heat balance include body surface area, body surface to mass ratio, sex, age, aerobic fitness, core, and skin temperature measurement (Periard et al., 2021). The generation of body heat from metabolism is distributed across the surface area of the body, which can be formulated from the following equation: [face area =0.20247 x height $(m)^{0.725}$ x weight $(kg)^{0.425}$] (Tikuisis et al., 2001). Research by Lee et al. (2020) determined that evaporative heat loss is promoted having a large body surface area as the number of active sweat glands is proportional to surface area. Therefore, individuals with large body surface areas have the highest ability for heat loss within an environment (Cramer & Jay, 2016). Body surface area to mass ratio also plays a role in heat storage. This has been shown within individuals having elevated body surface area to mass ratio who experience a reduction in heat storage during uncompensable heat exposure than individuals with a lower ratio, caused by the greater area for dry and evaporative heat loss relative to body mass (Cramer & Jay, 2016).

Differences between sex also effect thermoregulation, a study conducted by Zhai et al. (2018) determined that the body size between males and females differed with men usually being taller and heavier, as well as attaining higher VO_{2max} measures. However, when body surface area was standardized metabolic heat production was comparable among sexes (Havenith et al., 1995). It was also determined that when males and females were matched for fitness level VO_{2max} and body size, thermoregulation measures were similar (Havenith et al., 1995). It was demonstrated by Chester and Rudolph (2011) that aging has an impact on both fluid regulation and thermoregulatory capacity. A subsequent study help to determine that individuals >60 years of age showed to have lowered thermoreceptor sensitivity, a less efficient sweat response, diminished cutaneous vasodilatory capacity, and lower resting core temperatures when compared to younger individuals (Guergova & Dufour, 2011). Research has determined that aerobic fitness level VO_{2max} plays a role in thermoregulation, which indicates that higher fitness levels enhance the ability for heat loss capacity through activation of cutaneous vasodilation at a reduced core temperature and raises skin blood flow for a given core temperature (Beaudin et al., 2009). In addition, aerobic training has also been shown to lower internal temperature thresholds for the onset of sweat production, rise in sweat rate at a given temperature, and a higher maximal sweat rate (Lamarche et al., 2018). Researchers suggest that the improvements in sweating function related with endurance training may also relate to routine aerobic training, which offers a repetitive thermal challenge that leads to enhanced thermoregulation capacity (Ravanelli et al., 2021).

Measures of core and skin temperatures are useful in determining rates of thermoregulation, which has led to the development of the most accurate measure of average internal body temperature: blood located within the pulmonary artery (Moran & Mendal, 2002). Oral temperatures are also used to measure core temperatures because of its ease of access, however this technique often fluctuates through the mouth and may underestimate actual core body temperatures (Erickson, 1980).

Body Water and Hydration Status

Water is one of the most important nutritional ergogenic aids for athletes and limiting dehydration during exercise is an effective strategy to maintain exercise capacity (Kerksick et al., 2018). A term often used to describe hydration level is hypohydration, which refers to body water content deficits >2% beyond normal daily fluctuations (Sawka et at., 2007). Total body water (TBW) variability is primarily due to differences in body composition; lean body mass contains roughly 73% and fat body mass contains roughly 10% of water within the body (Van Loan et al., 1996). Approximately 5-10% of TBW is turned over daily through non-exercise induced fluid loss (Raman et al., 2004). One of these sources of fluid loss occurs through urine excretion with outputs approaching 1-2L per day, which can increase by an order of magnitude when ingesting large quantities of fluid (Sawka et al., 2015). Respiration is also a source of water loss, which is influenced by both temperature and the humidity of inspired air and the pulmonary ventilatory volume (Sawka et al., 2015). However, the formation of metabolic water as a result of oxidation metabolism offsets water losses due to respiration (Sawka et al., 2015). The day-to-day regulation of net body water balance occurs as a product of thirst and hunger drives, which are combined with ad libitum access to beverages and foods to off-set water losses (Cheuvront & Kenefick, 2014). However, it has been demonstrated that intervals of elevated sweating rates during vigorous exercise in hot weather, ad libitum drinking can significantly lead to under consumption of fluids (Greenleaf et al., 1983).

Hypohydration has been well-established to have detrimental effects upon athletic performance and can also be defined by a state of water deficit with insufficient replacement of fluids caused by acute or chronic dehydration (Olzinski et al., 2019). This risk of dehydration can be further increased during consecutive days of training if fluid intake does not adequately replace hydration needs between sessions, which may elevate the risk of chronic progressive dehydration (Maughan & Shirreffs, 2004). Further research has indicated that hypohydration, generally has a negative effect on physical performance as well as overall health (Shirreffs, 2000). In addition to detriments to exercise performance, other adverse effects to human physiology also result from acute hypohydration, which include worsened mood (Adams et al., 2018), reduced cognitive function (Patsalos et al., 2019), altered thermoregulatory function (Tucker et al., 2017), and reduced glycemic regulation (Johnson et al., 2017). These added physiological strains to the body are of particular concern for athletes participating in sports within hot and humid environments, resulting in elevated risk for hypohydration. This occurs because of fluctuations in body water and electrolyte balance (Sawka et al., 2015). As a result, sports being completed within these conditions produce acute changes in body mass during exercise occurring from the formation of sweat, respiratory water loss, and substrate oxidation (Shirreffs, 2000). The relative rates of body water loss incurred from training sessions are highly variable depending upon the sport. Investigations analyzing VJH have indicated that it is common for athletes to train or compete in a hypohydrated state, even showing chronic hypohydration before practices and competition (Osterberg, 2009; Volpe, 2009).

Research conducted by McConell et al. (1997) examined the effect of exercising following mild hypohydration (3% body mass loss via cycling in the heat) and found that participants demonstrated greater increases in heart rate and plasma arginine vasopressin (AVP) compared to subjects receiving adequate fluid replacement to offset losses in body mass. The authors suggested that the hypohydrated participants required greater activation of the sympathetic nervous system during exercise in order to compensate for reductions in both blood volume and pressure to maintain adequate skeletal muscle perfusion (Gonzalez et al., 1995). This research helps to establish the extra physiological strain experienced by the body in a hypohydrated state beyond those required to complete the exercise bout. Fluid loss and resultant hypohydration, not directly occurring as a result of practice or competition, is also of concern for certain sports including track and field (Periard et al., 2017). Often these athletes are required to participate in hot and humid environments, in which the events are held often lasting entire afternoons. During this time there is potential for both performance and health of athletes to be compromised, leading to impairments in exercise capacity and health with the possible occurrence of exertional heat illness (EHI) (Periard et al., 2017). The development of EHI occurs along a range from mild symptoms such as muscle cramps to heat exhaustion, with the progression to more serious and life-threatening conditions such as exertional heat stroke (Leon & Bouchama, 2015). This has led to specific interventions, including heat acclimatization and pre-cooling, which can allow athletes to minimize the loss in performance associated with competing in hot ambient conditions (Racinais et al., 2015). Research by Periard et al. (2017) analyzed the occurrence of heat related illness symptoms within various track and field athletes determining that nearly half of the participating subjects had previously experienced cramping, severe headache, or had been diagnosed with exertional heat illness during their athletic career.

The relatively common occurrence of heat illness symptoms exemplifies the importance of adopting strategies for hydration maintenance, especially in hot and humid environments.

Hydration and Health

Adequate hydration is vital for good health and well-being (Gandy, 2015). The effects of appropriate water intake on both short and long-term health as well as performance indicate the presence of positive effects (Popkin et al., 2010). In spite of the important role water plays in health and nutrition, there is a limited amount of research available for the basis of fluid intake requirements compared to most other nutrients (Popkin et al., 2010). This has led to the development of adequate intake (AI) recommendations by both the Institute of Medicine (IOM) and the European Food Safety Authority (EFSA). Daily total water intakes for healthy adults should range from 2.5-3.5L per day, which can be achieved through the intake of water through both fluids and food (Perrier et al., 2021). Whereas the EFSA established recommendation of 2.5L and 2.0L per day of total water intake, with 2.0L and 1.6L per day of water intake coming from food, for males and females, respectively (Gandy et al., 2015). The differences in daily water intake guidelines help to illustrate the difficulty in developing a well established requirement of water intake. Water requirements and consumption as well as energy intake are linked in fairly complex ways due to the effect of physical activity and energy expenditure on water needs (Popkin et al., 2010).

Optimal daily hydration is indicated by the secretion of large volumes of diluted urine adequate to prevent chronic renal water retention and additional AVP secretion (Perrier et al., 2017). Additionally, daily fluid losses should be replaced allowing the excretion of sufficient urine volume to avoid urine concentration and supersaturation (Perrier et al., 2021). Appropriate fluid intake will also decrease excessive AVP secretion which may be beneficial to the kidneys and lower metabolic risk (Perrier et al., 2021). The use of urinary biomarkers such as urine color can be used to assess hydration with sufficient fluid intake, indicated by a urine color scoring on an 8-point color scale (Armstrong et al., 1994; Perrier et al., 2017; Kostelnik et al., 2021). Also, 24-hour urinary void frequency can be used to assess hydration level, with urination occurring 5-7 times daily indicating ample fluid intake (Birchfield et al., 2015, Tucker et al., 2016). Attaining either of these measures are suggestive of a fluid intake necessary to reach optimal hydration (Perrier et al., 2021).

Physiology of Hydration

Water represents the single largest component of the human body which makes up roughly 60% of BW with a TBW of approximately 42 liters (Essa & Macnab, 2021). However, the body has a limited capacity to store water and water losses due to metabolic processes must be replaced on a daily basis (Johnson et al., 2017). For this reason, water regulation is a major part of human physiology and disturbances to the mechanisms governing it could be the source of many pathological conditions. (Thornton, 2010). The robust control of water balance is facilitated by complex osmotic sensing mechanisms that induce two separate response elements: (1) the release of AVP which stimulates renal water retention when intake of water is low; (2) the triggering of thirst sensation to promote drinking (Perrier et al., 2021). AVP or antidiuretic hormone (ADH) is a peptide hormone synthesized in the hypothalamus and is comprised of nine amino acids (Essa & Macnab, 2021). The role of AVP as a potent regulatory hormone is predominantly secreted in response to shifts in extracellular fluid osmolality, (i.e., solute concentration per kilogram of the solvent water) (Sollanek et al., 2000; Neligan, 2021). Specifically, the secretion response of AVP arises from changes plasma volume, temperature, stress, and nausea (Hew-Butler, 2010). Its primary function allows for the control of plasma osmolality levels within a tight range, which enables the kidneys to adjust water secretion to the body's requirements, while in combination with thirst (Bankir et al., 2017). This mechanism plays a major role in the maintenance of fluid balance throughout the body, which occurs through the regulation of water and sodium homeostasis by its antidiuretic effect on the kidney mediated via V2 receptors (Bankir et al., 2017). Further stimulus of vasopressin secretions occur through reductions in circulating blood volume and stress situations (Antoni, 2015). Osmoreceptors located beside the anterior hypothalamus are highly sensitive to small changes in plasma osmolality which are responsible for the regulation of water intake through stimulation of thirst and AVP release (Watson & Austin, 2021). Additionally, the steroid hormone aldosterone has a role in fluid and electrolyte balance within the kidney that increases expression activity of sodium-potassium ATPase, which results in increased reabsorption of sodium in exchange for potassium and hydrogen (Essa & Macnab, 2021).

Fluid and Electrolyte Balance

The most abundant compound located within the human body is water, which can be divided into three major compartments; intracellular fluid (ICF) which contains roughly two-thirds of TBW and the remaining one-third of TBW in the extracellular fluid (ECF) compartment which is further divided into the intravascular and interstitial compartments (Essa & Macnab, 2021). Ions that have dissociated from a chemical compound are called electrolytes which carry both positive; cation (A^+) and negative; anion (A^-) charges (Watson & Austin, 2021). The characteristics of water make it a highly ionizing polarized solvent, which results in the dissociation of mineral salts into ions, the major electrolytes include sodium (Na^+), chloride (Cl^-), potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}) (Manou et al., 2019).

Sodium is the major cation located within the extracellular fluid compartment and the primary determinant of volume within this space (Watson & Austin, 2021). Chloride and bicarbonate (HCO_3^-) are the main anions located within the extracellular compartment (Watson & Austin, 2021). Additionally, sodium and chloride are free in solution, however significant amounts of calcium and magnesium remain bound to protein (Neligan, 2021). Whereas, potassium, magnesium, phosphate (PO_4^{3-}), and sulfate (SO_4^{2-}) are the most abundant ions within intracellular compartment (Campbell, 2009). Intercellularly there are large differentials favoring potassium and phosphate, whereas extracellularly sodium and chloride are favored with each compartment being maintained through active ions pumps (Neligan, 2021).

Potassium is the major cation located within the intracellular compartment with a concentration of approximately 150 mmol/L (Campbell, 2009). Potassium regulation occurs through aldosterone and AVP within the distal nephron, also by adrenaline and insulin both stimulating reuptake into the cells (Neligan, 2021). Through urinary excretion and in gastrointestinal losses potassium is reduced (Watson & Austin, 2021). Daily dietary intake of potassium in food is typically 100 mmol/day, it is then excreted through feces (10%) and urine (90%), potassium is also excreted through sweat in amounts of roughly 5-10mmol/L (Campbell, 2009). Both insulin and catecholamines stimulate the sodium/potassium-ATPase pump in the cell membrane resulting in potassium to be pumped into the cells (Campbell, 2009).

Chloride is one of the primary extracellular anions, important in the function of secretory and absorptive cells located within the kidney and gastrointestinal tract (Campbell, 2009). Chloride and bicarbonate are both primary extracellular anions, with roles important in the function of secretory cells located within the kidney and gastrointestinal tract and control of pH in carbon dioxide transport, respectively (Campbell, 2009).

Magnesium is an intracellular cation that facilitates phosphate and potassium transport, neuromuscular transmission of action potentials, as well as respiratory and cardiac function (Watson & Austin, 2021). It is primarily stored within bone and renal excretion is not influenced by any particular hormone, with magnesium serum levels ranging from 0.7-1.1 mmol/L (Campbell, 2009). Daily requirements are roughly 9-15 mmol/day, mainly being located intracellularly and is responsible for enzyme systems including oxidative phosphorylation and protein synthesis (Campbell, 2009).

Finally, phosphate is an intracellular anion, with only 20% in total within the compartment; regulates acid-base balance as a buffer binding to hydrogen ions (Watson & Austin, 2021).

Physiology of Hypohydration

During this state of reduced body water, the occurrence of thirst sensation increases, AVP is released, which then promotes renin-angiotensin-aldosterone system activation, resulting in the replenishment of intra- and extracellular fluid stores within the body (Watso & Farquhar, 2019). Hypohydration within humans can be induced through water restriction, prolonged exercise, heat stress and administration of diuretics (Stachenfeld et al., 2017; Adams et al., 2018). As a result, reductions in plasma volume, increases plasma sodium osmolality, the renin-angiotensin-aldosterone system are then stimulated causing increases in thirst sensation, and AVP release increases (Faraco et al., 2014). Low extracellular fluid volumes then initiate increased aldosterone concentrations acting to increase sodium and water retention (Kinsman et al., 2017). This results in an increased thirst sensation promoting the consumption of water to restore body water homeostasis (Leib et al., 2017). If the mechanisms regulating hydration levels are unable to facilitate replenishment of TBW, then the negative impacts of negative water balance will occur (Periard et al., 2021). Dehydration and exercise induced hypohydration lower whole body sweat rate and skin blood flow, resulting in greater heat storage, and exacerbating physiological and perceptual strain (Periard et al., 2021). In particular, hypohydration has been shown to lower endothelial function, hinder cutaneous vascular function, and alter regulation of blood pressure during rest and exercise as well as through periods of orthostatic stress (Watso & Farquhar, 2019).

Complications of Dehydration

If the body is no longer capable of maintaining appropriate thermoregulation within its surrounding environment, then health related issues can then occur (Casa et al., 2015). Exertional heat illness (EHI) is a thermophysiological response to exercise within hot environments, EHI represents a range of medical conditions associated to an increase in body temperature (Armstrong et al., 2007). EHI has a range of symptoms from mild muscle cramps to more significant concerns from heat exhaustion and heat syncope, or even a more severe and life-threatening illness; heat stroke (Casa et al., 2015). Muscle cramping often occurs as a result of excessive heat exposure when fitness and heat acclimatization are low (Cooper et al., 2006). Often a person may experience lightheadedness from heat syncope following periods of prolonged standing in hot temperatures (Binkley et al., 2002). Heat exhaustion occurs when there is inability to continue exercising, symptoms often include nausea, vomiting, headache, weakness, fainting, and clammy skin (Armstrong et al., 1987). The most severe EHI heat strokes occur within individuals with elevated core temperatures >104 °F, which is associated with nervous system dysfunction and organ failure (Armstrong et al., 2007).

Hydration and Performance Metrics

The overall impact of VJH on athletic performance within anaerobic sports is somewhat limited (Naharudin & Yusof, 2013). One such study conducted by Savoie et al. (2015) helped to establish that reductions in anaerobic performance, muscular strength, and anaerobic power occur while an athlete performs in a state of hypohydration. It has been demonstrated that losses of fluids as small as 2% of BW significantly increase physiologic strain, as well as causing decreases in performance (Montain & Coyle, 1992). As ambient environments become warmer and increase cutaneous vasodilation, the negative effect of hypohydration is clearly demonstrated (Sawka et al., 2011). The resultant increase in thermoregulatory and cardiovascular strain experienced while exercising in the heat is associated with the redistribution of blood flow away from internal organs to skeletal muscle and other peripheral tissues of the body (Guy & Vincent, 2018). This represents the most significant physiological burden to support during exercise in the heat as high skin blood flow for heat dissipation occurs (Nybo et al., 2014). Further research has also indicated these losses in fluids hinder the thermoregulatory advantages resulting from high aerobic fitness (Cadarette et al., 1984). Research by Kavouras et al. (2012) has also demonstrated the need to maintain proper VJH throughout the duration of exercise in order to mitigate reductions in athletic performance within running and skill-based movement tests. This can be indicated by both the American College of Sports Medicine (ACSM) and the National Athletic Trainers Association (NATA) respective position statements on fluid replacement recommendations to help minimize impairment of aerobic exercise performance from exercise induced dehydration (Armstrong et al., 2007; McDermott et al., 2017).

However, the effects of hot ambient temperatures on sprint performance has been somewhat less studied (Girard et al., 2015). Several investigations including research by

Cheuvront et al. (2006) concluded no effect of moderate hypohydration; (1.7-3.6% loss in body mass) on anaerobic exercise performance. However, more recently research revealed legitimate performance impairments of individuals within a hypohydrated state (Cheuvront et al., 2010). In addition, reductions in motor-skill performance on sport specific exercise measures in athletes are seen within a hypohydrated state; 1-4% loss in body mass (Baker et al., 2007). The current literature has also shown that particular hydration strategies to minimize the extent of hypohydration experienced by the athlete is highly variable between sport type (Goulet & Hoffman, 2019). The research and meta-analysis conducted by Goulet and Hoffman (2019) revealed that the decision on the appropriate hydration strategy is highly dependent upon personal preference, age, fluid availability, exercise duration, food ingestion, cold exposure, and degree of heat acclimatization. This study highlights the need for more meaningful understanding of the controlling factors of an athlete's VJH throughout a training day and the appropriate measures or strategies to combat the occurrence of hypohydration within anaerobic based sports.

This investigation intends to build upon the understanding of VJH and its resultant effect upon athletic performance. Within this study, athletic performance will be assessed through the measurement of VJH. Specifically, this research will focus upon NCAA Division 1 collegiate athletes competing within TAF events (jumpers, sprinters, and pole vaulters). The aim of this study is two-fold: to assess specific fluid recommendations upon USG cutoffs and their relationship to athletic performance and to determine if BW influences the amount of fluid and/or electrolyte supplements an athlete needs to consume to achieve an optimal TBW content, (i.e., euhydration) (McDermott et al., 2017). Through the measurements of BW, USG, 24-hour dietary recalls, and performance measures of VJH, a better understanding of VJH and its effect on performance will be determined.

Based upon the analysis of USG measurements, fluid recommendations for TAF athletes were made according to USG classification cutoffs, in order to see if performance in practice or competition was improved. In addition, this dissertation investigated if BW influences the amount of fluid and/or electrolyte supplements an athlete needs to consume, to achieve an euhydrated state. The activities within this study comprised of USG measurements, the prescription of fluid recommendations, 24-hour dietary recalls, and jump mat (vertical jump) measurements. The sample size used within this study included all willing and able TAF athletes voluntarily participating within the investigation. Data collected within this study was analyzed using SPSS 26.0 statistical software package (SPSS Inc. Chicago, IL).

CHAPTER II: BACKGROUND

ASSESSMENT OF HYDRATION STATUS

The impact of maintaining proper VJH is vital, not only in sport performance but it also enables the body to perform its various physiological functions on a daily basis. Research conducted by Armstrong et al. (1997) demonstrated that cardiovascular and thermoregulatory responses, and ratings of perceived exertion (RPE) were higher while performing exercise in a hypohydrated state. It has also been determined that the occurrence of hypohydration prior to the start of exercise also increases heart rate, core temperature, and RPE during exercise when compared with starting in a hydrated state (Sawka et al., 1999). VJH is commonly divided into four categories indicating the relative water availability within the body; Once an optimal hydration levels have been achieved it must continually be maintained, euhydration is not a static state but reflected in a dynamic sinusoidal fluctuation of TBW loss and gain (Greenleaf, 1992). The variations in hydration levels seen throughout the day and possible detrimental effects of sub-optimal hydration can have on performance has led to the development of strategies and techniques to accurately assess VJH in an individual. There are five main techniques used to assess VJH: plasma osmolality (Posm), urine osmolality (Uosm), USG, urine color (UC), and BW (Armstrong, 2005).

The application of Posm measurements for hydration assessment are the most widely used index of VJH (Armstrong, 2005). Posm has been found to be the only VJH assessment marker demonstrating effectiveness for identifying dehydration from a static individual value (Cheuvront et al., 2010; Fortes et al., 2011). Which gives Posm an advantage over the hydration assessment measures of USG and change in body mass because they require at least two measurements; using reference change values to accurately assess changes in TBW levels (Cheuvront et al., 2011). Some individuals also consider it to be the only valid index of VJH (Moran et al., 2004). However, the application of this technique in athletics can be difficult because of the equipment required to administer the test and analyze the results, which involve a laboratory setting to complete.

The use of Uosm has also been applied to VJH assessment among athletes because of its accuracy in the measurement of total solute concentration (Dufour, 2001). Yet, the application of this assessment within athletics has been difficult because this method is time consuming and requires a trained technician to complete (Armstrong, 2005). USG measurements are often used because it is a simple, accurate, and valid indicator of whether an athlete is hypohydrated before exercise (Armstrong et al., 1994). UC is also an alternative method commonly used for evaluation of VJH and is a practical indicant of urine concentration and bodily fluids on the field (Armstrong et al., 1998). The relative simplicity of UC assessment makes it easy for sports dietitians, athletic trainers, physicians, athletes, and any other untrained individuals to evaluate daily VJH. (Kavouras et al., 2016). Subsequent research has indicated that UC can be evaluated in an inexpensive, noninvasive, and easily performed manner (Baron et al., 2015). The assessment of urine color occurs through the collection of a 15-30 mL urine specimen in a transparent tube or container, which is then compared with a urine color chart (Wardenaar et al., 2021).

Measurement of body mass change is a frequently used and safe technique to assess VJH routinely during hypohydration occurring within a period of 1-4 hours prior to practice (Kavouras, 2002). Each of these methods can be effectively implemented to assess VJH in a variety of settings with varying amounts of accuracy and precision. However, there is no singular universally accepted technique to determine whether individuals are well hydrated, euhydrated, or hypohydrated because of the complexity of the mechanisms governing the properties of urine (Francesconi et al, 1987).

The utility of a subjective measure of VJH such as thirst has also been used to assess VJH following exercise induced dehydration. Thirst can be defined as a desire to consume fluids as a result of a body water deficit controlled by both neuroendocrine responses to maintain fluid homeostasis (Cheuvront et al., 2013) and psychosocial influences (Stanhewicz & Kenney, 2015). The physiological onset of thirst typically occurs with relative fluid losses of 1-2% of body mass. (Greenleaf, 1992). Research conducted by Hew-Butler et al. (2015) suggests the application of thirst to help guide hydration practices throughout exercise in order to decrease the risk of exertional hyponatremia. However, individualized hydration strategies are found to be optimal for minimizing fluid losses and prevention of dehydration >2% of body mass loss during exercise, supporting the hydration recommendations of both the ACSM and NATA (Adams et al., 2019).

The (ACSM, 2007) does suggest that a urine osmolality ≤ 700 mOsmol/kg can be used as an indicator of euhydration. Research conducted by Shirreffs and Maughan (1998) determined that a urine osmolality > 900 mOsmol/kg is equivalent to a 2% loss in BW from fluid loss. The original validation of the USG and urine osmolality techniques were first demonstrated by (Armstrong et al., 1997). The repeated use of USG measurements to assess VJH has occurred because of its practical use within the field of athletics (Armstrong, 2005). Using this validated assessment as a guide the National Athletic Trainer’s Association (NATA) classify hydration states into four categories; well hydrated (USG ≤ 1.010), euhydrated (USG =1.011-1.020), significant hypohydration (USG ≥ 1.021), and severe hypohydration (USG ≥ 1.030) (Casa et al., 2000). Research by Volpe et al. (2009) analyzing pre-practice VJH through USG measurements of collegiate athletes found that 66% of athletes showed USG levels ≥1.20 indicating a state of hypohydration.

The use of BW assessment as a measure of VJH is another technique often seen because of its ease of use and practical application to sport (Kavouras, 2002). BW measures are commonly taken in order to assess degrees of fluid loss. These measures can then be used to calculate appropriate fluid intake needs for rehydrating following training sessions or competition. Research by Sawka et al. (2007) demonstrated that morning body mass will fluctuate by less than 1% in well-hydrated individuals who maintain energy balance. Administering daily BW measurements in the context of training camps in various sports can allow for the close monitoring of VJH for athletes.

Each of the VJH measures described above have their own distinct methodologies for practical use within particular environments. The approach in selecting the appropriate tool to assess hydration needs to address a number of factors. These include the practicality of use (e.g., cost, required equipment, processing time, etc.), location of the application being assessed (within a clinic or as a field research measure), ease of assessment confounding, and the amount of measurement variation (i.e., imprecision) (Cheuvront & Kenefick, 2014). The prevalence of athletes performing within a suboptimal level of hydration helps to illustrate the need for proper hydration prescription. Providing the athlete with an accurate calculation of fluid intake necessary to achieve proper VJH will allow the athlete to excel and optimally perform within their given sport.

Sex Differences

The influence of sex and the differences it promotes on sports performance has been well established and shows a dose-response relationship between circulating testosterone, muscle mass, strength, and hemoglobin level (Beneke & Leithauser, 2019). Sex differences in hormones pertaining to the menstrual cycle have specific and quantitative influences on both thermoregulation; through cutaneous vasodilation and sweating, as well as volume regulation (Stephenson & Kolka., 1999; Stachenfeld & Keefe, 2002). Hormonal peaks and troughs are also associated with changes in responses to physiological stress, fluid loading, exercise, sleep, and mood (Constanti et al., 2005). Fluctuations in circulating hormones occurring throughout the hormone cycle are also related to changes nutritional needs (Dalvit-McPhillips., 1983). The female sex hormones: estrogen and progesterone both affect fluid balance shifts throughout the body within the intra- and extracellular (Oian et al., 1987). It has also been shown that changes in sex hormones during the menstrual cycle are related to altering "set points" and thresholds for synthesis, as well as the release of volume regulatory hormone; arginine vasopressin (Stachenfeld et al., 2001). The shifting of "set points" that alters internal body temperatures at rest and during exercise occur within the luteal phase and can increase the core by 0.3-0.5°C (Kolka & Stephenson, 1997). This change in core temperature during the luteal phase could potentially increase risk for heat illness, especially if the luteal phase is matched with a situation leading to dehydration (Pivarnik et al., 1985). Further research has indicated that administration of estradiol and progesterone is associated with acute changes in body fluid regulation by altering thresholds for release of AVP to initiate thirst and sodium regulation hormones, resulting in less dehydration required to initiate the fluid retention response and increased thirst in resting females (Statchenfeld, 2008). These fluctuations in fluid regulation could be of significance to anerobic performance because of known decrements observed in dehydrated individuals performing body weight-dependent excise being particularly affected by greater levels of dehydration and body mass lost (Cheuvront & Kenefick, 2014). Further results support that female reproduction hormone alterations across the menstrual cycle have an important effect on thirst and volume regulation, which impacts VJH, physiological responses to dehydration, exercise performance, and fluid needs (Giersch et al., 2020). These alterations in circulating hormones affecting VJH help to illustrate the wide variability in fluid needs of the athlete, which need to be accounted for when developing hydration plans.

Hydration Status and Sweating

The most effective means for the human body to dissipate heat within warm or hot conditions is through evaporative heat loss in the environment (McDermott et al., 2017).
The major variables that impact total sweat loss include body size, exercise intensity, exercise duration, environment, and choice in clothing, these factors make up greater than 90% of the varying amounts of sweat losses seen among athletes (Gagnon et al., 2013). Within environments that are temperate or warmer, dissipation of heat through sweating can account for more than 50% of heat loss, which can nearly approach 100% in very hot environments (Casa et al., 2019). However, the total amounts and rates of sweat loss are highly dependent upon both the characteristics of the individual and the environment in which the activity is being completed (Casa et al, 2019). Trained individuals who are heat acclimatized demonstrate an enhanced thermoregulation with increased sweat production, plasma volume expansion, and a decreased heart rate and core temperature (Periard et al., 2015). It has been further indicated that the majority of heat acclimation, seen in thermoregulation and the cardiovascular system adaptation, occurs within 4-7 days and are optimized within 10-14 days (Periard et al., 2016).

Average whole-body sweating has been documented to occur at a rate of 1.20L per hour (Barnes et al., 2019). Individuals who have been heat acclimatized demonstrate an increased sweat rate, which can allow them dissipate heat and cool more efficiently. However, this leads to the potential risk of elevated losses in electrolytes; sodium (Na^+), potassium (K^+), and magnesium (Mg^+) due to increased sweat rates (Klous et al., 2020). Important factors affecting sweat rates of sodium of athletes include both age group and the season in which exercise is performed, while age group and body mass have been shown to significantly influence whole-body sweat rates (Baker et al., 2016). Exercising within these warm to hot environments (25-45 °C), compared to cool temperatures (15-25 °C), presents severe challenges to thermoregulation (Galloway & Maughan, 1997). As a result of exercising in the heat, blood flow to the skin and sweating rates are shown to increase in order to dissipated heat to the surrounding environment (Racinais et al., 2015). The primary means of heat loss during vigorous exercise is through sweat evaporation, which in certain conditions can be significant (Sawka et al., 2007). Body water losses due to sweating can approach rates as high as 3.18 L/h, depending on the temperature and relative humidity that the sport activity is being completed (Sawka et al., 2007). Additional research conducted by Baker et al. (2019) determined that as exercise intensity increases total sweat losses of electrolytes also occur, with relative increases in (VO_{2max}) from 40 to 65% causing 150% greater loss in both sodium and chloride. This helps to indicate the variations in sweat loss due to exercise intensity alone and illustrates the discrepancies in fluid loss between athletes playing different positions in the same sport.

Another route in which water loss occurs is via diffusion through the skin, which is dependent upon body surface area, and it was determined that individuals with slightly above average body surface areas of $2m^2$ can lose approximately 17mL/h (Dill et al., 1966). Further losses in body mass also occur from substrate oxidation as a result of energy production throughout a training session, during hard bouts of training approximately 200-300 g/h of BW can be lost. (Maughan & Shirreffs, 2010). In fact, research has shown that as much as 3 g of water can be stored per gram of glycogen, which is stored within the skeletal muscle (Maughan & Shirreffs, 2010). During prolonged exercise increased use of muscle glycogen causes removal of water from the glycogen molecule, this release of water then enters into the body water pool (Maughan et al., 2007).

The resultant effect of reductions in body water, sweating also leads to losses in electrolytes, those most dominantly effected being sodium, chloride, and to a lesser degree potassium (Maughan et al., 2007). However, smaller amounts of calcium, magnesium, iron, and other minerals are also lost (Maughan & Shirreffs, 2010). For this reason, it is crucial for the athlete to replace the water and electrolytes lost due to sweating, individuals adequately rehydrating following an exercise session should consume 1.5 L of fluid per kg of BW lost (Sawka et al., 2007). Additionally, the consumption of regular meals and beverages as well as salty snacks will help to restore euhydration (Sawka et al., 2007).

Heat Stress & Performance

It has been clearly indicated that participation of exercise in hot and humid environments inflict raised amounts of thermoregulatory strain compared to cooler or thermoneutral environments (Cao et al., 2022). These increased demands of metabolic heat dissipation through sweating result in the elevation of core temperature (Sawka et al., 2011). Rises in core temperature resulting in increased cardiovascular and thermal perceptual strain show to reduce voluntary power output within endurance exercise (Cheuvront et al., 1985). It has also been indicated by measurements of time to exhaustion that premature fatigue occurs within conditions of increased cardiovascular strain (Flouris et al., 2015). This has led to the adoption of cooling strategies to help reduce heat stress and increase repeated sprint ability and endurance performance (Periard et al., 2021). These cooling techniques can increase heat storage capacity prior to exercise (i.e., precooling) and mitigate the increase in core body temperature during exercise (i.e., per-cooling) (Periard et al., 2021). The drinking of cold beverages at 50° to 75.2°F have been shown to reduce core body temperature (Sawka et al., 2007). Research by Tan et al. (2015) demonstrated that the ingestion of an ice slurry beverage (<32°F) provides a larger surface area for heat transfer to occur between the ice particle and body tissues compared to water (Periard et al., 2021). The intake of cold or icy beverages directly impacts core temperature because the body is required to warm the consumed fluid to body temperature, which results in the lowering of core body temperature (Tan et al., 2015). A review conducted by Cao et al. (2202) determined that external cooling of neck cooling during exercise is another strategy that can improve repeated sprint performance within team sports.

Effects of Hydration Status

While exercising in the heat, athletes experience elevated levels of physiological strain and thermoregulatory adjustments occur through heat dissipation (Racinais et al., 2015). Human physiology allows for this exchange of heat to the surrounding environment through sensible (i.e., convection, conduction, and radiation), and insensible (i.e., evaporation) pathways (Periard et al., 2021). However, during exercise activities the body’s main mechanism to dissipate heat from the body is through evaporation of sweat (Sawka et al., 2007). Depending on the duration of the exercise session, losses in BW due to sweating may cause the individual to enter a state of hypohydration (Racinais et al., 2015). Research by Logan-Sprenger et al. (2015)

demonstrated that athletes losing as little as 2% of their BW through losses in sweat displayed increased heart rate, core body temperature, muscle glycogen utilization, as well as decreases in cardiac output, cognitive awareness, anaerobic power, and time to exhaustion. It has also been established that insufficient intake of electrolytes such as sodium lost through sweat was found to only intensify the negative impact of fluid loss on athletic performance (Black et al., 2012). Additionally, a study conducted by Ayotte and Corcoran (2018) established that hydration programming based upon an individual's sweat rate and sodium loss showed to have markedly improved athletic performance for collegiate athletes engaging in seasonal sports. Studies such as these help to reveal the necessity of an individualized hydration prescription for athletes which have the ability to enhance athletic performance. One such study by Goulet and Hoffman (2019) indicated that the decision on the appropriate hydration strategy is highly dependent upon personal preference, age, fluid availability, exercise duration, food ingestion, cold exposure, and degree of heat acclimatization.

Fluid and Electrolyte Needs

Optimal hydration of an athlete reflects a physical state of normal body water and electrolytes, changes in seasonal environments can create distinctive challenges especially for track and field athletes participating in the hot weather during summer events (Casa et al., 2019). These environmental conditions can be highly variable depending on ambient are temperature, humidity, wind velocity, and sun exposure (Periard et al., 2021). The type of clothing and equipment worn also significantly effects sweat rates and the body's ability to maintain core body temperatures and dissipate excess heat (Sawka et al., 2007). The wide variety in these factors results in a large discrepancy in sweating rates among track and field athletes, which can range from 0.5L – 3.0L per hour (Baker et al., 2016). Typical track and field training sessions can increase daily fluid needs by 1-6L/day from sweat loss, as well as electrolyte (sodium and potassium) losses of 1g/L (Baker et al., 2016). Additional research conducted by Watson et al. (2005) analyzed sweat volume losses in simulated sprint sessions and found that BW reductions averaged from 0.8 – 1.3kg over a 2-hour period. These reductions in BW were equivalent to approximately 1 -1.5% of the athletes' body mass (Watson et al., 2005). These reductions require track and field athletes to replenish body water and electrolyte losses on a daily basis and failure to do so will lead to dehydration, poor training, and negative outcomes in competition (Casa et al., 2019).

Fluid Intake

The goal of consuming fluids prior to the start exercise allows an individual to achieve a euhydrated state with normal plasma electrolyte levels (Sawka et al., 2007). One research study has indicated that prior to the start of exercise activities individuals should slowly drink fluids throughout the day, with pre-exercise hydration recommendations including the consumption of 6mL of water per kg of body mass every 2-3 hours, as well as drinking this amount 2-3 hours prior to the start of training or competition (Racinais et al., 2015). However, the research surrounding the sources of pre-practice fluid recommendations are somewhat unclear and additional research needs confirm the efficacy of these recommendations. Further research focusing on the consumption of sodium with small meals and salty snacks has also been indicated to help to retain fluids and stimulate thirst (Sawka et al., 2007).

Consuming fluids while exercising helps to avoid excessive dehydration >2% BW and substantial changes in electrolyte balance to mitigate reductions in exercise performance (Sawka et al., 2007). During exercise sessions lasting longer than an hour athletes should aim to consume a fluid solution containing 0.5-0.7 g/L of sodium (Casa et al., 1999). Individuals experiencing muscle cramping should increase the electrolyte solution content to 1.5 g/L of sodium (Bergeron et al., 2003). Athletes participating in exercise lasting longer than an hour should also consume 30-60g/h of carbohydrates (CHO) within a fluid solution (Van Duvillard et al., 2004). For exercise activities lasting longer than 2.5 hours individuals should consume up to 90g/h of CHO from fluid solutions (Burke et al., 2011). Total volume of fluid intake during exercise should be ingested at a rate of 0.5-2L/hour to prevent hypohydration (International Society of Sports Nutrition [ISSN], 2010).

Following exercise, the objective is to completely restore any losses in fluids and/or electrolytes, for quick recovery from dehydration individuals should aim to consume 1.5L per kg of BW lost (Sawka et at., 2007). Further rehydration strategies should include consumption of sodium, CHO, and protein following exercise (Racinais et al., 2015). In addition, the consumption of fluids and snacks containing sodium will help to accelerate rehydration (Sawka et al., 2007). The application of these strategies allows athletes to maintain a euhydrated state and enhance performance, euhydrated states can be defined by <1% changes in body mass, plasma osmolality <290 mmol/kg, and USG of ≤1.020. (Racinais et al., 2015).

Hydration and Performance Measures

Body water and electrolyte balance disturbances are prevalent when performing demanding physical work and especially during exposure to environments of extreme heat (Sawka et al., 1996). There is a wealth of knowledge and studies regarding the negative effect of hypohydration on performance as well as the adverse effects on health (Casa et al., 2005; Institute of Medicine, 2005). Current literature indicates athletic performance begins to be negatively impacted when BW loss due to sweating reaches 2% (Bardis et al., 2013). However, the literature in regard to the effects of hypohydration on maximal muscle strength and power is less consistent (Bowtell et al., 2013). Even less focus has been diverted to the effects of fluid loss on muscle performance (Minshull & James, 2013). Studies examining the impact of dehydration on anaerobic performance are limited (Kraft et al., 2012). Strength and power are important factors for the anaerobic performance of muscle (Naharudin & Yusof, 2013). However, the relationship between hypohydration and performance within anaerobic based sports which require short duration high velocity movements is less understood (Naharudin & Yusof, 2013). Research conducted by Savoie et al. (2015) showed that hypohydration causes reductions in strength and anaerobic power, these were both significantly impaired at body water losses of 3-4%. Hypohydration was found to significantly reduce maximal force production of the knee extensor by 8.5% in maximal torque when 2.6% of BW was reduced from body water loss (Hayes & Morse, 2010). It was also indicated that these suboptimal levels of hydration cause reductions in anaerobic performance (Cheuvront et al., 2010; Jones et al., 2008). However, previous studies have also reported the contrary, that anerobic performance measures are not influenced by hypohydration (Cheuvront et al., 2006; Judelson et al., 2007). These inconsistencies in findings have prompted further investigations examining the impact of hypohydration on athletic performance.

Subsequent work by Cheuvront et al. (2010) sought to determine the effect of VJH and its relationship to strength to mass ratio in respect to gravitational resistance. Increases in the strength to mass ratio are believed to improve performance within TAF events that are heavily reliant upon explosive movements, dependent on body mass (Cheuvront et al., 2010). This research concluded that reductions in BW, as a result of hypohydration, have a negative effect upon athletic performance within these sporting events. This would be of particular interest to TAF athletes competing in high jump, long jump, triple jump, and pole vault events because of the reliance upon explosive body mass-dependent movements required by the sport (Viitasalo et al., 1987). Hypohydration has been shown to reduce anaerobic performance with loss of 3% body mass (Kraft et al., 2012). Hypohydration has also shown to have a negative effect on muscular strength and muscular power (Schoffstall et al., 2001; Kraft et al., 2011). Ratings of perceived exertion (RPE) have also been shown to be negatively affected by moderate dehydration of 3% (Gann et al., 2016). The assessment of muscular strength through 1RM testing for bench press showed to be significantly reduced when hypohydrated (Gann et al., 2020). The researchers of this study concluded that dehydration may have a negative impact on both muscular strength and perceptual feelings of exertion and recovery (Gann et al., 2020). Research conducted by Minshull and James (2013) indicated that losses of 2.1% body mass was associated with a 7.8% decrease in volitional static peak force (PF_v) Additionally, it was determined that 24-hour fluid restriction was associated with significant losses in knee extensor strength, which may affect performance in strength related exercise activities (Mihshull & James, 2013). Further research demonstrated that dehydration induced exercise caused decreases in knee extensor isometric torque by 16%, illustrating impaired maximal strength production on exercise knee extensor muscles (Rodrigues et al., 2014). The results of research conducted by Judelson et al. (2007) also suggest that hypohydrated individuals completing isotonic, multiple-repetition, multiple-set, intermittent resistance exercise tasks will likely experience impaired performance. Hypohydration and factors connected to the dehydration process, are coupled with statistically significant decreases in muscle endurance, strength, and anaerobic power (Savioe et al., 2015). Body fluid losses of 3-4% BW reduces muscular strength, power, and high-intensity endurance by 2, 3, and 10% respectively (Judelson et al., 2007). A further systematic review conducted by Savioe et al. (2015) showed results that indicated hypohydration or variables coupled with dehydration are associated with significant decreases in muscular endurance, strength, and anaerobic power. This study also demonstrated that active hypohydration (i.e., induced by exercise) elevates the performance reductions in muscle endurance, strength, and anaerobic power and capacity ~2.3-fold compared to passive dehydration (Savioe et al., 2015). Isometric and isokinetic maximum eccentric force production are significantly impaired within conditions of hypohydration, the authors suggested diminished peripheral contractility underpins the reductions in performance (Bowtell et al., 2013). The reductions in maximal force capacity within the hypohydrated state are likely due to excitation-contraction coupling failure (Bowtell et al., 2013). While there are an abundance of studies that have identified hypohydration as a detriment to athletic performance within endurance sports such as cycling and distance running (Goulet, 2011; Bardis et al., 2013), the effect of hypohydration on performance within anaerobically based sports such as TAF needs further investigation. Further research needs to be conducted on various TAF athletes such as jumpers, sprinter, and pole vaulters to better understand the role of hypohydration on athletic performance.

Metrics of Athletic Performance

There are a number of underlying factors may contribute to an athlete's performance (Suchomel et al., 2016). Currently, it is believed that high rates of force development (RFD) and external mechanical power are two of the most important characteristics in regard to sport performance (Stone et al., 2002). Marked differences in both RFD and power are routinely seen between starters and non-starters within athletics (Young et al., 2005). RFD has also been considered to be a primary factor in sports activities such as jumping and sprinting because of the sport's reliance upon rapid movements with a limited amount of time to produce the force (50-250ms) (Anderson et al., 2006).

The measure of impulse is also a performance metric commonly used and is defined as the product of force and the period of time in which the force is expressed, this measure is believed to be highly correlated to athletic performance (Garhammer & Gregor, 1992). Often, this measure is used to determine VJH and weightlifting performance, which is defined as the product of force and the period of time in which the force is expressed (Garhammer & Gregor, 1992).

Mechanical power is another metric routinely used because of its relation to performance characteristics for sports involving sprinting, jumping, changes of direction (COD), and throwing velocity (McEvoy & Newton, 1998). It has also been theorized that enhanced force-time characteristics should transfer to the ability in performing general sport skills (Suchomel et al., 2016). For this reason, the impact of muscular strength on jumping and sprinting should not be disregarded. The overwhelming evidence of performance measure research indicates that when individuals are stronger, they tend to jump higher compared to weaker individuals (Krasha et al., 2009). Regarding sprint performance, prior research has revealed that elite level athletes produce greater speeds over shorter distances when compared to non-elite athletes (Cometti et al., 2001). It has also been shown that faster runners possess characteristics such as greater force application, shorter ground contact time, and greater stride length (Weyand et al., 2000). It has also been indicated that individuals who are stronger end up producing faster sprinting performances when compared to those individuals who are weaker (Wisloff et al., 2004).

Muscular Strength

Previous studies support that muscular strength is one of the underlying determinants of strength-power performance (Suchomel et al., 2016). Studies comparing the differences between stronger and weaker athletes has provided very strong support that stronger athletes within relatively equal level of skill, perform better when compared with weaker athletes (Meckel et al., 1995). In addition, research suggests there is a transfer of lower-body strength training to sprint performance, which is shown by a very substantial correlation between sprint performance and squat strength (Seitz et al., 2014). Investigations have also revealed that an individual's overall sprint performance or capacity to express higher sprint velocities is affected by their ability to express high peak ground reaction force (pGRF), and impulse (Hunter et al., 2005). Further studies have been conducted testing isometric strength as a performance measure, these include isometric mid-thigh pull, isometric squat, and isometric half-squat (Suchomel et al., 2016). Within these measures a maximal load is not being lifted but prior research has determined a relationship between isometric strength tests and dynamic strength performance (Bazyler et al., 2015; McGuigan et al., 2008). Isometric strength is frequently evaluated because of its usefulness in controlling adaptive alterations in training and in meeting desired demands (Guillet et al., 2017). While dynamic strength has long been valued for its importance for stability and movement within sports activity (Hahn et al., 1999).

Often the one repetition max (1RM) test is used to assess strength, however its application within certain sports can be difficult. One practical alternative to 1RM measurements is the set-rep best method using set loads for training for a specific number of repetitions (Stone & O'Bryant, 1987). Overall, greater muscular strength shows to improve the force-time characteristics (external mechanical power and RFD) for an individual, this can then be applied to athletic performance. Muscular strength is also strongly correlated with superior jumping, sprinting, COD movements, and sport-specific performance (Suchomel et al., 2016). Additionally, stronger athletes tend to demonstrate superior RFD and external mechanical power, and consequently jump higher, run faster, perform COD tasks faster, as well as potentiate earlier and are less likely to get injured (Suchomel et al., 2016). The improvements in sprint performance resulting from resistance training are of practical significance for athletes and coaches in sport activities requiring high levels of speed, especially over short or medium distances (<30 meters) (Seitz et al., 2014).

Sport Specific Training Adaptations

Physiological and metabolic adaptations from training function to maintain homeostasis for a given exercise intensity, which in turn delay the onset of fatigue (Hearris et al., 2018). Within the context of sports competition, the delaying of fatigue has potential to enhance athletic performance. Research by Egan and Zierath (2013) demonstrated that training adaptations also play a significant role in energy utilization and hydration requirements of the athlete. The relative intensity and duration of a training session influences the contributions of both CHO and lipids, as well as the amount of circulating extramuscular and intramuscular fuel sources used in energy production (Egan & Zierath, 2013). Adaptations seen within athletes participating in both aerobic and anaerobic training include increases in mitochondrial biogenesis, capillary density, and upregulation of specific enzyme functions depending on the mode of training experienced by the athlete for their particular sport (Hearris et al., 2018). The most impactful of these changes is the occurrence of mitochondrial biogenesis (Bartlett et al., 2014). This remodeling causes increases in both mitochondrial number and volume, as well as changes in the composition of organelles (Howald et al., 1985). These alterations includes both an increase in size and number of mitochondria located within the trained skeletal muscles, these adaptations enable higher absolute exercise intensities and workloads to be met (Egan & Zierath, 2013).

Energy Metabolism

Energy production within the body occurs predominately from the breakdown of CHO and fats as well as to a lesser extent with protein (Dohm, 1986). The relative amounts of CHO and fats being utilized during exercise is dependent upon both intensity and duration of the exercise as well as the training status of the individual (Egan & Zierath, 2013). Research has also indicated that at low to moderate exercise training intensities the primary source of fuel for the skeletal muscles are glucose and free fatty acids (FFA) released from adipose tissues through lipolysis (Egan & Zierath, 2013). Additionally, as exercise intensity increases muscle utilization of FFA declines and the use of glucose for energy production increases up to maximal intensities (Van Loon et al., 2001). Whereas exercise completed for a prolonged period of time (>60 min) at a submaximal level, lipid oxidation becomes a larger contribution of energy production (Egan & Zierath, 2013). Athletic performance in sport is highly dependent upon the bioavailability of CHO within the body and subsequent research has also indicated that the two most important substrates for muscle contractions used in sport are muscle glycogen and blood glucose (Romijn et al., 1992). Further research has explored the relationship between fatigue during prolonged exercise and its association with reductions muscle glycogen, blood glucose, and resultant fluid loss, which illustrate the importance of pre-exercise concentrations for exercise performance (Jeukendrup, 2004).

Energy production within the body during exercise activities are heavily reliant upon stored CHO within the athlete, these stored amounts of CHO are predominately found within skeletal muscle (400g) and the liver (100g) as glycogen, and to a lesser extent CHO are also stored and carried within the blood (5g) (Hearris et al., 2018). The ingestion of CHO prior, during, and after competition has been a well-established strategy to enhance performance in sport with high daily training volumes and intensity levels (Burke et al., 2011). These same recommendations for daily CHO intake are also included within the International Olympic Committee's (IOC) dietary guidelines (Potgieter et al., 2013). The evidence supporting the necessity of optimal CHO bioavailability during competition for peak performance is overwhelming and the ergogenic effect seen with optimal levels of CHO bioavailability occur through the enhanced availability of blood glucose for energy production within the active muscles (Coggan & Coyle, 1991).

Dietary Needs of Athletes

The importance of attaining appropriate dietary needs on a daily basis cannot be overstated for individuals participating in athletics. Attaining these dietary needs is considered the single most complementary factor to any physically active individual or elite athlete (Potgieter, 2013). All types of athletes can benefit from implementing specific dietary strategies prior, during and following training and competition to help maximize physical performance (IOC, 2011). Follow dietary guidelines on the amount, composition, and timing of food intake have been recognized to help athletes perform and train more effectively (IOC, 2011). A review article conducted by Kreider et al. (2010) demonstrated that adequate diets for athletes should be well balanced providing sufficient energy in order to maintain energy balance with the added requirements of physical activity.

Daily energy requirements for athletes can range from 50-200kcal/kg of BW depending on the volume and intensity of training (Kreider et al., 2010). The daily CHO recommendations for athletes can range from 3-5g/kg of BW for low intensity, skill-based sports up to 8-12g/kg of BW for high intensity endurance-based sports (IOC, 2011). Adequate amounts of CHO (1-2g/kg) of BW should be consumed 3-4 hours prior to the start of training or competition (IOC, 2011).

These CHO should be easily digestible with low fiber and fat content (IOC, 2011). Further consumption of CHO during exercise should occur within training sessions exceeding 45-minutes in duration when sustained high intensity is required. The recommended amount of CHO required during exercise can vary from small sips of a sports drink containing a CHO solution to as much as 30-60g/h for aerobic based sports (IOC, 2011). Post exercise CHO ingestion should occur within 30 minutes of the end of the training session or competition aiming for 1-1.2g/kg of BW per hour for the first four hours following activity (IOC, 2011).

Daily dietary requirements of protein for athletes also vary across differing sports; general guidelines for athletes are 1.3-1.8g/kg of BW (IOC, 2011). Elevated amounts of protein (1.6-1.7g/kg) of BW are recommended for individuals participating within strength-training sports (IOC, 2011; Slater & Phillips, 2011). The consumption of sufficient amounts of protein helps to support muscle protein synthesis, reduces muscle protein breakdown, and repairs muscle damage (Phillips et al., 2011). Additionally, the ingestion of 20 grams of protein with CHO within 30-minutes post exercise is recommended and shows beneficial effects (IOC, 2011; ISSN, 2010; ACSM, 2009). Some of these effects include an improved performance both during exercise and during recovery prior to subsequent exercise tests (Betts & Williams, 2010).

Daily intake of fats for athletes should include no less than 15-20% of total caloric intake (IOC, 2011). Intake of proper amounts of dietary fats ensures optimal health, energy balance maintenance, adequate amounts of essential fatty acids and fat-soluble vitamins, as well as replenishing intramuscular triacylglycerol stores (Kreider et al., 2008). In addition, adequate fluid and electrolyte intakes should limit hypohydration to <2% losses in body mass and maintain athletic performance (IOC, 2011).

Dietary Assessment Methods

The dietary needs of a particular athlete are highly variable and reliant upon the energy demands required by the sport in which they participate. Dietary assessments can help provide information regarding daily nutrient intake to help match energy intake with energy needs. The attempt to record what people consume is not an easy task, even when the best possible methods are selected some measurement errors are introduced and need to be accounted for in the analysis of results (Freedman et al., 2011). There are two main classifications of assessment methods: short and long-term instrumentation (Bailey, 2021). Short-term dietary methods are aimed to obtain a thorough reporting of all the foods and beverages consumed by an individual over a short period of time (Kirkpatrick et al., 2019). Whereas long-term dietary evaluations aim to capture dietary information over an interval of weeks up to a year (Bailey, 2021). Self-reported dietary intakes are also routinely used and can be grouped into real-time recording (food diaries and duplicate food method) and methods of recall (dietary histories, food frequency questionnaires (FFQs), and 24-hour dietary recalls (Naska et al., 2022). Within food diaries individuals are asked to record every food or beverage they consume in real time; it also requires the recording of actual quantities consumed, whereas within the duplicate portion method pairs of daily portions are used, with one being consumed by the individual and the second being chemically analyzed for content (Naska et al., 2022). Additionally, there are a range of well-established self-reported dietary assessments methods of recall used, these include 24-hour dietary recalls, diet histories, FFQs, and food records (Burrows et al., 2019). The application of 24-hour dietary recalls and food records are often useful because they capture multidimensionality with foods and beverages being consumed over a fixed number of days (Thompson et al., 2017). The Automated Multiple-Pass Method (AMPM) has also been shown to be a valid measure and tool administered when capturing foods and beverages consumed over multiple days (Moshfegh et al., 2008). However, accurately measuring dietary exposures through self-report are notoriously difficult to measure accurately and reliably (Bailey, 2021). These approaches can be very useful, but they are known to mis-report, which is frequently classified as over- or under-reporting (Harrison et al., 2000). Further image-based dietary assessment (IBDAs) methods have been developed and require participants to capture digital images of foods and beverages prior to and following consumption, similar to the traditional food record (Rollo et al., 2016). Mis-reporting from this assessment method occur due to reactively bias in which acknowledging one must take an image of the foods to be eaten may influence the person's choice in food (Gemming et al., 2015). This evaluation tool when used as a primary dietary record, provides a valid assessment result of energy intake (EI) and macronutrient intake as traditional methods like 24-hour recalls, but not doubly labeled water (DLW) (Ho et al., 2020).

The use of objective dietary assessment tools are also used and are necessary to measure the validity of the assessment techniques chosen for nutrient intake records (Burrows et al., 2019). The DLW assessment is an objective method of evaluating total energy expenditure (TEE), often used as a reference measure for gauging the validity of self-reported EI within individuals who are relatively weight stable (Burrows et al., 2010). For example, research conducted by Eldridge et al. 2018) found that IBDAs along with other traditional methods show to have measurement errors significantly under-estimating EI when compared to DLW. A review conducted by Trabulski et al. (2001) determined that EI is consistently under-reported when compared to DLW with the majority of the assessment tools being used were food record or diaries. Further research has shown that assessment tools measuring EI most often underestimate actual amounts, with a range of 11-41% for food records, 1.3-47% for diet histories, and 4.6-42% for FFQs (Burrows et al., 2019). Whereas 24-hour recalls have been shown to have the lowest total amount and lowest level of variation, with under-estimates of EI in range of 8-30% (Burrows et al., 2019). EI was also shown to be under-estimated by 20% ranging all the way to 37% in some assessments (Ho et al., 2020). Certain characteristics have also been identified to be associated with under-reporting, these include dietary restraint, socioeconomic status, and gender (Hill & Davies, 2001).

CHAPTER III: METHODODOLGY

RESEARCH DESIGN

The purpose of this research study was to examine if a specific fluid recommendations for TAF athletes, based upon USG classification cutoffs, helps to improve performance in practice or competition. This research will also analyze the influence of BW on the amount of fluid and/or electrolyte supplements an athlete needs to consume in order to attain an euhydrated state prior to practice or competition.

Sampling Technique

Subjects were comprised of NCAA collegiate division I TAF athletes attending the University of Mississippi. Each of the voluntary participants had received medical clearance to participate within this study through completion of pre-participation exams (PPE) prior to the start of this study, therefore all were deemed physically fit and healthy. On the initial day of the study participants reported to the laboratory to have anthropometric measurements of height, weight, and body composition, as well as estimation of resting metabolic rate (RMR).

Body composition (BW, lean body mass (LBM), fat mass) was examined using a BODPOD (air displacement plethysmography, COSMED; USA) measurement. The two-compartment model was used to establish fat-free and fat mass utilizing the Siri equation; [(% body fat = (495/Body Density) – 450]. The COSMED equipment and computer system then determined each participant's resting metabolic rate (RMR), using the abbreviated Weir equation; [3.9 (VO_2) + 1.1 (VCO_2)] x 1.44. This value was then used for a calculation of daily total caloric needs.

Participants were then instructed of the study protocol to follow throughout the duration of the 5-week study. On the preliminary day of data collection, athletes met at the field house located at University of Mississippi's track and field facility. Measurements of daily temperature, relative humidity, and cloud cover were record for both morning and practice times. Each of the participants provided their initial urine samples in the mornings 2-3 hours prior to the start of daily training sessions. The USG measurements were then used to assess HS established on the following cutoff points: well hydrated (USG $\leq$ 1.010), euhydrated (USG = 1.011-1.020), significant hypohydration (USG = 1.021-1.029), and severe hypohydration (USG $\geq$ 1.030). The USG was then analyzed using a hand-held refractometer (PAL-10S, ATAGO; Bellevue, Washington). The refractometer was calibrated with 2-3 teaspoons of water prior to the assessment of each urine sample. Each of the participant urine samples were collected and evaluated within 30 minutes from the time of initial fluid excretion. Following the determined USG reading, a fluid recommendation was prescribed to the participant based upon the group they were randomly assigned. This included two different groups, one group receiving recommendations from USG classification cut off values (control), as seen in Table 2. The second group received fluid recommendations based relative to BW (experimental). Participants within the experimental group would follow the same fluid recommendations but the quantity of fluid volume prescribed was dependent on each individual's BW and determined by the following formula: = (7.5g/kg BW). The participants were then supplied with their own water bottle to be used throughout the study to consume the daily fluid intake recommended by each protocol. After the initial USG measurement of the first urine sample was recorded, fluid recommendations were determined, and one of four hydration protocols would be given to the individuals within the control group (Table 2). The volume of recommended fluids would then be distributed into the participants' water bottle to be consumed throughout the 2–3-hour period. The subjects again report to the field house at the track and field facility to give their second urine sample ≤30 minutes prior to the start of their daily training session. Once the sample was collected USG measurements were taken and recorded. These daily study protocols were followed Monday through Friday for 5-weeks.

Additionally, subjects in this experiment also completed a performance measure of VJH throughout the 5-week interval of this research study. Each participant reported to the Gillom Center or Indoor Practice Facility (IPF) weight rooms once weekly to perform a vertical jump test, occurring within 30 minutes of their 2nd daily USG measurement. The participants entered the weight room and were instructed to step onto the force mat in an athletic position and jump with maximal effort. The jump measurements were recorded and repeated for a total of 3 repetitions attempting for the highest vertical jump possible. Each participant completed a total of 15 VJH measurements over the duration of this investigation.

Sample Size

The sample size was be based upon the amount of available and willing athletes on the University of Mississippi's current TAF roster.

USG Measurement

USG measurements within this study were analyzed using a validated hand-held refractometer (PAL-10S, ATAGO; Bellevue, Washington). Measurements were collected twice daily before practice for the entirety of this 5-week investigation.

Vertical Jump Assessment

Estimated VJH was measured once weekly for five weeks with each participants throughout the duration of the study. Each participant was instructed to stand on the jump mat (Probotics Inc; Huntsville, AL) in an athletic position and complete a total of three separate jumps at maximal effort for an estimation of VJH; the three measurement were then averaged for each participate.

Data Analysis Methods

All collected data was encoded and analyzed through SPSS 26.0 statistical software package (SPSS Inc. Chicago, IL). Statistical significance will be set to $p \leq 0.05$. A split-plot analysis of variance (SPANOVA) was conducted between hydration groups across pretest and posttest measures of VJH. Assumptions for normality, homogeneity of covariances, and homogeneity of variances were met. A SPANOVA analysis was ran to determine VJH among participants within this study. A Pearson's correlation analysis was conducted to establish the effect of VJH on athletic performance metrics.

Ethical Considerations

Procedures to protect subjects' privacy occurred in a manner in which names, phone numbers, and e-mail addresses, were recorded and stored in a locked filing cabinet. All participants were be given an ID number unrelated to personal record identifiers and this ID was used to link the participant's personal information with their data collected during the study. Thus, all data and personal information was locked in separate filing cabinets, and any information stored electronically was saved on password protected computers that were only accessible by faculty and fellow graduate students. All participants' related material will be kept for at least 5 years.

CHAPTER IV: MANUSCRIPT I

The Influence of Body Weight on Fluid Intake Needs for Euhydrated Status in Athletes

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Abstract: Maintenance of hydration levels are often a key focus when trying to sustain athletic performance in sport. The amount of fluid intake needed to reach appropriate hydration levels varies widely from a multitude of factors. This ideal hydration level (euhydration) is characterized by an optimal total intracellular and extracellular body water content, which is the ultimate goal of fluid intake protocols within athletics. The aim of this research was to investigate if a specific fluid recommendations for track and field (TAF) athletes, based upon urine specific gravity (USG) classification cutoffs, helps to improve athletic performance. This study also analyzed the influence of body weight (BW) on the amount of fluid and/or electrolyte supplements an athlete needs to consume in order to attain an euhydrated state prior to practice or competition. A total of 35 subjects participated in the study, who were then divided into two groups: a control and experimental each receiving different hydration protocols. Fluid intake needs were assessed using anthropometric tests and air displacement plethysmography. Urine samples were taken to determine hydration status (HS) and were analyzed through USG measurements. The results indicated that HS was increased in both groups upon engagement of the hydration recommendation protocol routine. However, the analysis of HS showed that there was not a statistically significant interaction between the hydration protocol groups. The application of hydration protocols based on BW are not indicated to be necessary to achieve a euhydration state when TAF athletes follow specific fluid recommendations based upon USG classification cutoffs.

Keywords: euhydration, track and field, urine specific gravity, body weight, anthropometric, air displacement plethysmography

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1. **Introduction**

The components influencing human physical performance are multifactorial and determined by a range of environmental (physical training, nutrition, and technological aids) and genetic factors [1]. In the field of nutrition, HS has long been studied for its significant role influencing health and well-being, as well as physical capacity [2]. Research has also demonstrated that HS is greatly effected by fluid intake, exercise intensity, and environmental factors which are essential for performance [3]. This has led to further development of hydration strategies to improve athletic performance across a variety of sporting domains. The analysis of HS can be measured through a variety of techniques, which provide valuable information guiding the development of appropriate hydration protocols to optimize athletic performance.

During physical activity thermoregulation of the body is dependent upon several factors including the environment, (i.e., ambient air temperatures, humidity, wind velocity, and solar radiation), task dependent parameters of heat exchange, (i.e., metabolic rate of heat production and clothing), and personal parameters (i.e., age, sex, body mass, body surface area, and aerobic fitness) [4]. Each of these factors needs to be considered when designing hydration protocols in order to maintain appropriate HS. The evaluation of HS can be characterized by a few common terms; euhydration (i.e., a state of optimal total intracellular and extracellular body water (TBW) content, hypohydration (i.e., a state of water deficit with insufficient replacement of fluids caused by acute or chronic dehydration), and dehydration (i.e., the process of losing water from the body through sweating during exercise) [5,6].

The measurement and analysis of HS is conducted through five main techniques: plasma osmolality (Posm), urine osmolality (Uosm), USG, urine color (UC), and body weight (BW) [7]. USG measurements are often used because it is a simple, accurate, and valid indicator of whether an athlete is hypohydrated before exercise [8]. The National Athletic Trainer's Association (NATA) classify hydration states into four categories: well hydrated (USG ≤ 1.010), euhydrated (USG =1.011-1.020), significant hypohydration (USG =1.021-1.029), and severe hypohydration (USG ≥ 1.030) [9]. These standard classifications for HS are used across a multitude of sports in a variety of different athletes. Further tailoring these recommendations based upon one's relative BW may provide additional accuracy in providing adequate fluid needs to maintain euhydration and improve athletic performance.

Importantly, in order to determine the actual relationship between athletic performance and USG cutoffs, the influence of BW on the amount of fluid and/or electrolyte supplements necessary achieve optimal TBW content must first be assessed. The majority of previous research on HS has focused on endurance sports such as cycling and distance running [10,11]. The results of these studies have indicated that proper hydration maintenance while competing in endurance activities is essential to athletic performance, which is greatly dependent upon the body's ability to match energy production requirements of the sport [12]. Additionally, previous research analyzing the effect of hot ambient temperatures and hypohydration on anerobic performance has been less studied and somewhat less clear [13,14]. Therefore, it can be hypothesized that specific fluid recommendations protocols from USG cutoffs based upon one's relative BW will better maintain optimal HS than those athletes following the standard USG fluid recommendation protocol. The aim of this study was two-fold: to assess specific fluid recommendations upon USG cutoffs and to determine if BW influences the amount of fluid and/or electrolyte supplements an athlete needs to consume to achieve an optimal TBW content.

2. Materials and Methods

2.1 *Participants*

Participants were comprised of NCAA collegiate division I TAF athletes attending the University of Mississippi. Data was collected from the participants for a duration of 5-weeks during the 2021 fall semester. Each of the voluntary participants had received medical clearance to participate within this study through completion of pre participation exams (PPE) prior to the start of the study, thus all were considered physically fit, healthy, and able to take part within the study. Subjects were recruited and randomly assigned into two groups. In Group 1, participants followed fluid recommendations based on USG hydration cutoffs [9]. Within Group 2, participants received fluid recommendations based on BW. All research procedures were conducted in accordance with the principles set by the University of Mississippi Institutional Review Board (IRB).

2.2 *Assessment of Anthropometry*

Participant anthropometric measurements of height, weight, and body composition were collected. Body composition (BW, lean body mass [LBM], fat mass) was analyzed using a

BODPOD (air displacement plethysmography, COSMED; USA) measurement. The two-compartment model was used to determine fat-free and fat mass utilizing the Siri equation; [(% body fat = (495/Body Density) – 450]. Participants measures of height and body mass were recorded and then used with the assessment of body composition through air displacement plethysmography. This analysis further provides the measures of lean body mass and body fat percentage, as well as calculated estimates of resting metabolic rate (RMR) and total energy expenditure (TEE).

2.3 Assessment of Resting Metabolic Rate & Caloric Needs

A measurement of resting metabolic rate (RMR) was taken using the COSMED apparatus and computer system which then determined each participant's RMR, using the abbreviated Weir equation; [3.9 (VO_2) + 1.1 (VCO_2)] x 1.44. This value was then used for a calculation of daily total caloric needs. Through this calculation a TEE for each participant was computed accounting for additional caloric needs based upon physical activity levels.

2.4 Assessment of Hydration Status & USG Measurements

Daily urine samples were collected from each participant and provided their initial urine samples in the mornings 2-3 hours prior to the start of each training session. USG measurements were then used to assess HS based on the following cutoff points: well hydrated (USG $\leq$ 1.010), euhydrated (USG =1.011-1.020), significant hypohydration (USG =1.021-1.029), and severe hypohydration (USG $\geq$ 1.030). USG was then analyzed using a hand-held refractometer (PAL-10S, ATAGO; Bellevue, Washington). The refractometer was calibrated with 2-3 teaspoons of water prior to the assessment of each urine sample. All participant urine samples were collected and analyzed within 30 minutes from the time of initial fluid excretion. The participants would once again report to the field house at the track and field facility to give their second daily urine sample within 30 minutes prior to the start of their training session. Once the sample was collected USG measurements were taken and recorded. These daily research protocols were followed Monday through Friday for a total of 5-weeks.

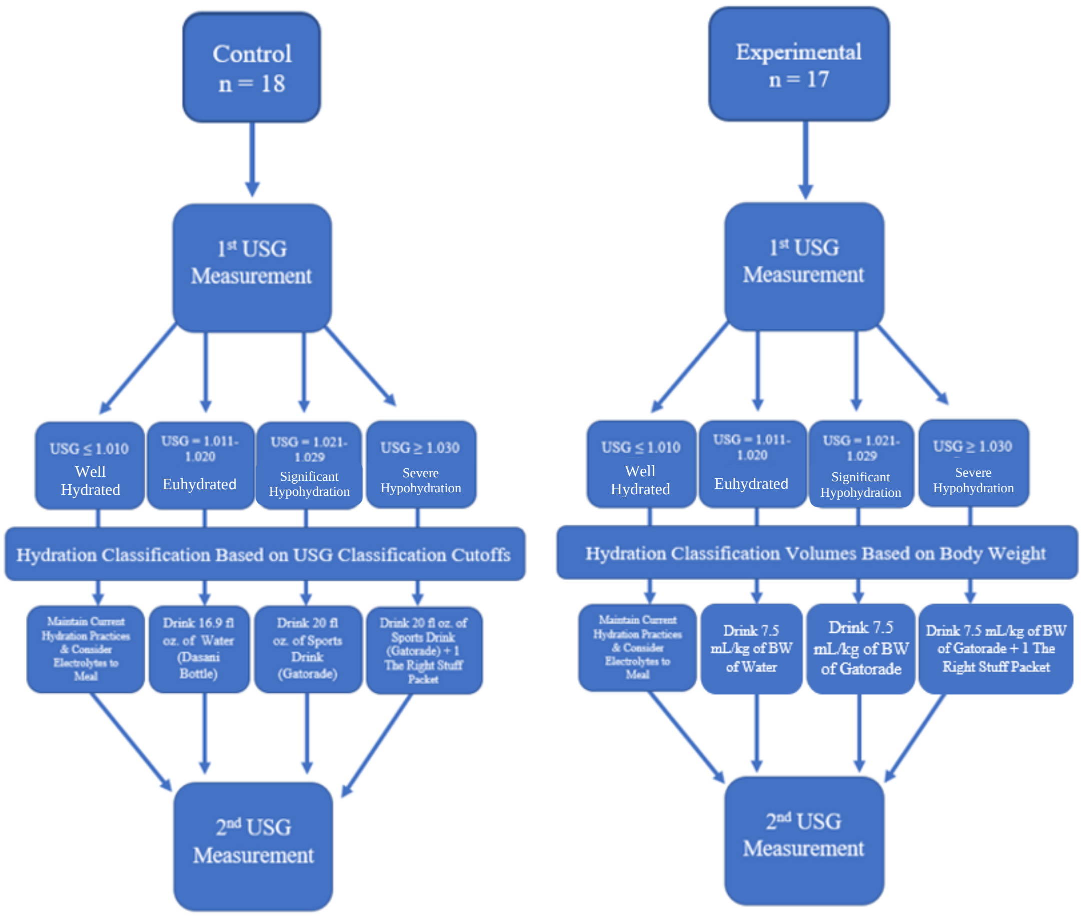

Figure 1. Intervention and control group procedures of the study in accordance to the research protocol. Overall, there were a total of 35 subjects participating in the investigation with (n=18) athletes within group 1 (control) and (n=17) athletes within group 2 (experimental). A total of 88 first and second USG measurements were taken for group 1 and 92 first and second USG measurements were taken for group 2.

2.5 Assessment of Fluid Prescription

Following the measured USG reading, a fluid recommendation was prescribed to the athletes based upon the group they were randomly assigned. This included two groups, one group with recommendations from the standard USG classification cut off values (control), as seen in Table 1. The second group with fluid recommendations based relative to BW (experimental). The subjects were then provided with their own water bottle to be used throughout the duration of the study to consume the daily fluid intake recommended by each protocol. After the initial USG measurement of the first urine sample was recorded, fluid recommendations were determined, and one of four hydration protocols would be given to the individuals within the control group; USG ≤ 1.010 (maintain current hydration practice & consider adding electrolytes to meals, no fluids were provided), USG = 1.011-1.020 (drink 16.9 fluid ounces of water, USG = 1.021-1.030 (drink 20 fluid ounces of Gatorade®), USG > 1.030 [drink 20 fluid ounces of Gatorade® + 1 packet of The Right Stuff® (electrolyte liquid drink additive)]. Subjects within the experimental group would follow the same fluid recommendations however the quantity of fluid volume prescribed was dependent on each individual's BW and determined by the following formula: = (7.5g/kg BW). The volume of prescribed fluids would then be dispensed into the participants water bottle to be consumed entirely throughout the 2–3-hour period.

Table 2. USG Classification/Categories & Fluid Intake Recommendations.

Hydration Category	USG	Fluid Intake Recommendation Protocol
Well Hydrated	≤1.010	Maintain current hydration practice & consider adding electrolytes to meals
Euhydrated	1.011-1.020	Drink 16.9 fl oz. of water (Dasani bottle)
Significant Hypohydration **	1.021-1.030	Drink 20 fl oz. of sports drink (Gatorade)
Severe Hypohydration **	>1.030	Drink 20 fl oz of sports drink (Gatorade) + 1 packet of The Right Stuff (electrolyte liquid drink additive)

*USG cutoffs based on Casa, 2000 **If athlete is still in this category after 2nd pre-practice USG, he/she will be marked as high risk and protocol will be adjusted or individualized to add more electrolytes.

2.6 Assessment of Weather Parameters (Temperature, Relative Humidity, and Cloud Cover)

Measurements of daily temperature, relative humidity, and cloud cover were recorded for both morning and practice times daily for the 5-week duration of the study.

2.7 Statistical Analysis

A split-plot analysis of variance (SPANOVA) was conducted between hydration groups across pretest and posttest measures of HS. An alpha level of .05 was utilized. Assumptions for normality, homogeneity of covariances, and homogeneity of variances were met. A SPANOVA analysis was ran to determine HS among participants within this study. All data was encoded and analyzed with SPSS 27.0 statistical software package (SPSS Inc. Chicago, IL). Statistical significance was set at $p \leq 0.05$.

3. Results

The anthropometrics measurements taken for each of the participants are shown below (Table 1). These participants were involved in a hydration recommendation protocol to examine the statistical significance between two differing hydration protocols allowing participants to reach a euhydrated HS.

Table 1. Subjects Demographics and Anthropometric Measures

	Male (n = 19)	Female (n=16)	Total (n=35)
Age (y)	20.39± 1.29	20.84± 0.98	20.57 ± 1.18
Height (cm)	181.05± 6.22	169.34± 6.35	176.17 ± 8.52
Body Mass (kg)	74.75± 5.94	62.88± 6.02	69.43 ± 8.68
BMI (kg/m²)	22.99± 1.82	20.78± 2.01	23.28 ± 2.91
Fat Free Mass	67.44± 5.49	52.52± 5.57	61.22 ± 9.24
Body Fat %	9.68± 4.48	15.26± 3.81	12.00 ± 5.00
Resting Metabolic Rate (RMR) (kcal/day)	1769.61± 139.60	1393.20± 143.44	1612.77 ± 234.07
Total Energy Expenditure (TEE) (kcal/day)	3079.14± 242.84	2424.20± 249.64	2806.25 ± 407.26

Subject demographics are expressed mean ± SD

A group of 35 subjects (16 females, 19 males; ages 18-23) participated and were randomly assigned into two groups. Group 1 (18 participants), subjects followed fluid recommendations based on USG hydration cutoffs [9]. In Group 2 (17 participants), subjects received fluid recommendations based on BW. A sensitivity test was conducted to determine the statistical power from the sample. Given the total sample size of 180 data points, it had a statistical power large enough to detect a small effect size of $\eta^2 = .011$.

The split-plot analysis of variance (SPANOVA) conducted between hydration groups determined that there was not a statistically significant interaction between the hydration protocol groups, $F(1, 178) = 1.21$, $p = .272$ (see Figure 1). Thus, results are generalizable across testing periods and hydration groups. However, there was a statistically significant difference between pretest and posttest HS, $F(1, 178) = 410.45$, $p < .001$, $\eta_p^2 = .70$ indicative of a very large effect size. Hydration was increased in both groups upon engagement of the hydration recommendation protocol routine (Table 3).

Table 3. Descriptive Statistics of Hydration Groups Across Testing Periods.

	Hydration Protocol	Mean	SD	N
Pretest	Control	1.019	0.005	88
	BW	1.014	0.006	92
	Total	1.017	0.006	180
Posttest				
	Control	1.008	0.006	88
	BW	1.005	0.004	92
	Total	1.007	0.006	180

*p < 0.05

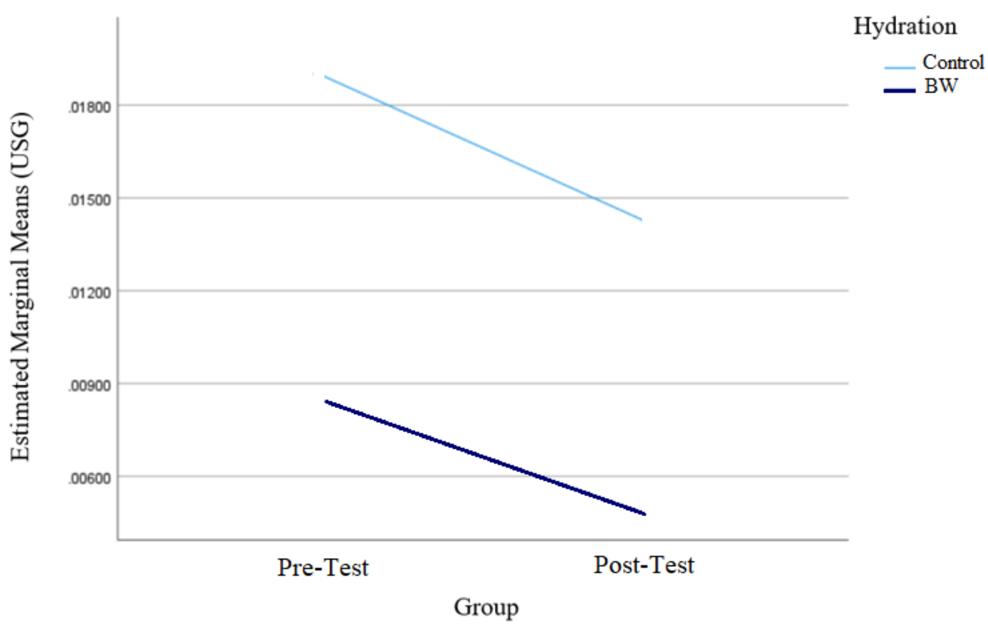

Figure 2. Plot of hydration levels pre- and post-test for fluid recommendation protocols for experimental and control groups.

4. Discussion

In the present study a population of division I collegiate TAF athletes' daily measurements analyzing HS were administered to provide further insight into the role of hydration on overall health and its effect on athletic performance. The findings from our study suggest that an individual's BW does not influence the amount of fluid and/or electrolyte supplements needed to consume to achieve a state of euhydration following the USG classification cutoffs [9]. However, it was evident when analyzing the collected data that both hydration protocols used within this study significantly improved HS from initial USG measurements to the second USG measurements within a 2–3-hour period. Each hydration protocol facilitated hydration levels towards optimal levels ≤ 30 minutes prior to the start of training sessions.

The findings of this study suggest that fluid intake recommendations from USG classification cutoffs adequately improve HS to optimal levels independent of the individual's BW. Previous research has used differing protocols to analyze HS prior to the start of exercise, some applying a standard (~500 mL) [15,9, 31,29] and others providing ranges (5-10 mL/kg·BW)[27,26,28]. Within the fluid recommendation based on BW the following equation was used to determine each quantity of volume to be distributed (7.5mL/kg· BW). Further analysis of the differing recommendation protocols suggests there may be a threshold in which we would expect a divergence in HS following the protocols. The 500 mL water and 592 mL Gatorade® recommendations for fluids are a standard volume which is capable of providing adequate hydration to those within the range in which it provides. Overall, these guidelines for hydration appear to be efficacious for the large majority of individuals. However, within the realm of sports this protocol has potential to provide inadequate fluids and electrolytes for individuals having a larger BW. For this reason, the use of BW in the calculation of fluid needs adds a degree of specificity to the protocol and a larger volume to the individual.

The TAF athletes taking part in this study participate in a variety disciplines within the events of jumping, sprinting, and pole vaulting. The use of this distinct group of athletes for this research enabled a unique ability to gather data within the environment of athletics. The protocols used within this study provided important insights on both the overall effectiveness and practical use of hydration recommendations and their utility in sport.

The findings of this study provide additional validation for the efficacy of USG recommendation cutoffs for hydration protocols which are able to hydrate an athlete to ideal levels for performance within a period of 2-3 hours. Larger individuals could benefit from consuming larger volumes of fluids meeting their hydration needs (5-10 mL/kg·BW)[27,26,28] This occurrence helps to illustrate the resiliency of the human body, and its ability to maintain total body water within such a narrow range and time frame to homeostasis[5]. Our data revealed that BW did not significantly impact the ability of the participant to reach improved HS and attain optimal fluid and electrolyte levels. Additional results from this research observed was the frequency in which participants were found to be "significantly" hypohydrated at their initial morning USG measurements[9]. This research utilized a refractometer to collect USG measurements of HS from participants which has been validated in previous studies[21,22,8]. These participants routinely had USG readings ranging from (1.021-1.029). The results indicated for these subjects' adherence to the fluid prescription recommendations showed to adequately rehydrate these individuals within the 2-3 hours and reached a state of euhydration within 30 minutes of daily training sessions. This clearly illustrated the efficacy of the hydration protocol because these athletes were considered to be "significantly" or even those considered less hydrated, within the “severely” hypohydrated USG classification of (≥ 1.030) were still able to reach an optimal HS following the hydration protocol. However, it is important to consider that these individuals classified into the two highest USG categories of hypohydration would experience increased cardiovascular stress[16] and compromised thermoregulation [17] if they were to perform a training session in that state of hypohydration. Measurements of USG ranging from (1.021-1.030) correlate to a ~3 to ~5% loss in BW from water loss[8]. Indicated by previous research, hypohydration to this extent would no doubt lead to detriments in athletic performance in a variety of performance metrics[11,19,20,21,22] Throughout the duration of this study, it become more evident that many of the participants were chronically hypohydrated during the initial morning USG measurements. An analysis of the data pertaining to the prevalence and magnitude of the hypohydration of the initial USG measurements revealed that 24.6% of participants arriving every morning during the week had a USG reading of (≥1.021) classifying these athletes as significantly hypohydrated and considered to be “high risk” by the hydration recommendation protocol to participate in training[8]. The presence of chronic hypohydration within a number of participants highlights the need for daily self-assessment tools for HS. Fortunately, some researchers have developed a self-evaluation tool of day-to-day hydration status, the (WUT) symptoms, the authors created it to simplify hydration status monitoring for athletes and ensure optimal hydration status for training and competition[9]. The hydration assessment tool focuses on three parameters or signs of hypohydration: weight loss, urine color, and thirst. In the presence of two parameters hypohydration is likely, possessing all three markers, hypohydration is very likely[24]. The authors suggest that parameters of hypohydration should be assessed each morning upon waking up and greater attentions should be focused upon 24-hour fluid and electrolyte intake.

The data revealed that fluid recommendation protocols based on BW was not any more effective or efficacious in rehydrating the experimental group of participants to optimal HS than the standard USG classification protocols. The intention of this research was to analyze the efficacy of USG classification cutoffs fluid recommendations for athletes varying in body size, circumference, and weight, as well as the type of sport in which they compete. The large discrepancies in anthropometric measures between TAF athletes competing in different events (sprinting, jumping, and pole vaulting) help to illustrate the possible variability in daily fluid intake requirements. The differing types of training required to compete in these TAF events effects several factors influencing thermoregulation [3,4,11,18], which should be considered in the proper maintenance of HS. Further research should analyze daily fluid intake habits in athletes and how they are affected by receiving information and education of the role hydration has on overall health and performance.

There were several limitations found within the present study. One of the major constraints of this investigation was participant compliance throughout the duration of this investigation. This could be attributed to numerous factors, (e.g., athletics/team obligations, school responsibilities, or social commitments). Also, the fluid recommendation protocols for this study required the subjects to only consume the fluids provided in each of their water bottles between USG measurement. However, the actual amount of compliance to those instructions for each athlete was highly variable, thus introducing possible confounding variables in the 2nd daily USG measurements,

5. Conclusions

In conclusion, the present study demonstrated that BW did not significantly affect the fluid recommendations needed to attain a state of euhydration prior to the start of training sessions. Hydration protocols based upon USG cutoffs maintained HS regardless of an individual's BW.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data supporting reported results are available upon reasonable request and in accordance with the ethical principles.

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CHAPTER V: MANUSCRIPT II

The Effect of Hydration Status on Performance in Collegiate Track and Field Athletes

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Abstract

Hogg JS, Kostelnik SB, Andre TL, Joung Hyun-Woo (David), Bomba AK, Jo Jangwoo (JJ), Valliant, MW. The effect of hydration status (HS) on athletic performance metrics in collegiate track and field (TAF) athletes. *J Strength Cond Res*. The role of hypohydration on aerobic performance has long been studied however for less is known about its effect on anaerobic performance. The purpose of this study was to evaluate the effects of HS on the athletic performance measure of vertical jump height (VJH). Using a between subject design, 35 subjects performed weekly VJH assessments following a HS analysis through urine specific gravity (USG) measurements. These daily measurements were assessed to determine HS through specific guidelines for USG classification cutoffs for hydration status. Both daily USG and weekly VJH assessments were collected for the duration of the 5-week study. The results of this investigation were evaluated through a Pearson's correlation analysis examining the relationship between HS and VJH measures. The analysis of the data concluded there was not a statistically

significant relationship between the HS and VJH within the research study. There was no significant correlation between the two variables (r =-0.24, p = 0.301). These findings indicate HS is not associated with significant changes in VJH among TAF athletes.

Key Words: hydration status, vertical jump height, urine specific gravity, track and field

Introduction

Within recent years, numerous studies have explored the role of HS and its effects on thermoregulation (11,42,13,17,22). The findings of these investigations have contributed greatly to further our understanding of the physiological demands placed upon athletes while participating in the heat and its resultant effect on performance. The capacity of the body to maintain thermoregulation is dependent upon several parameters of the environment, (i.e., ambient air temperatures, humidity, wind velocity, and solar radiation) (38). In the presence of these warm and muggy conditions the human body's most effective means to dissipate heat is through evaporative heat loss into the environment (30). The major variables impacting total sweat loss include body size, exercise intensity, exercise duration, environment, and choice in clothing, these factors make up greater than 90% of the variability in sweat loss amounts seen among athletes (14). Within temperate or warmer environments, dissipation of heat through sweating can account for more than 50% of heat loss, which can nearly approach 100% in very hot environments (6). Previous research as indicated that a rise in humidity in the presence of hot temperatures elevates physiological strain through a reduction in evaporative capacity to the environment (35). This impact of humidity on thermoregulation and circulatory stress has been indicated to decrease capacity to perform and complete exercises requiring all out efforts or intensities (33). Additionally, the participation of exercise within these intense and muggy environments can greatly influence hydration needs which may pose severe challenges to the human regulatory systems (19), which has also been revealed to hinder endurance performance resulting from the development of hyperthermia (36). For this reason, the importance of maintaining proper HS while exercising cannot be overstated. Research conducted by The National Athletic Trainers' Association (NATA) provides evidence-based recommendations that promote optimized fluid maintenance practices for physically active populations and those participating in sport, these fluid replacement protocols maintain optimal HS which aides in sustaining athletic performance, increases metabolic heat transfer, and supports recovery from exercise (30). However, proper daily fluid intakes may not occur, thus causing hypohydration which is defined as body water content deficits >2% beyond normal daily fluctuations (42). This state of suboptimal hydration within humans can be induced through water restriction, prolonged exercise, heat stress, and administration of diuretics (1,48). Research focusing on HS of elite level athletes observed the majority of athletes arrived to daily workouts hypohydrated (37,50,39). The occurrence of hypohydration in athletes may also be the result of improper fluid intakes during recovery following training sessions.

Evidence demonstrating the negative effect of hypohydration on aerobic performance is overwhelming when total body water loss > 2% (38,43,42,28,4,9,12). However, the overall influence of HS on athletic performance within anerobic sports is somewhat limited and less studied (34,7). Studies including TAF athletes of either elite or collegiate level focus on a relatively limited number of disciplines and often exclude the anerobic based events (jumping, sprinting, and pole vaulting). The majority of these studies analyzing performance and HS focus upon aerobic events of cross country and distance running (6). As a result, there appears to be gaps within the literature regarding HS and its effect on performance within these shorter duration TAF events. However, the studies that have been conducted often reveal conflicting results and regarding the actual effect of hypohydration on athletic performance. One such study analyzing anerobic performance with moderate levels of hypohydration (1.7-3.6% loss in BW) determined no significant impact on performance measures (7). Additional research focusing on (~4% loss in BW) concluded that there is no net effect of hypohydration on VJH because of offsetting reductions in vertical ground reaction impulse and body mass. (8). However, the authors suggest that the difficult to perceive reductions in strength to mass ratio seen in hypohydration may negatively impact performance in sports (8). A further study analyzing (1-4% loss in BW) revealed that a deterioration in motor skill performance was initiated and progressively became more significant as additional loss in body mass was incurred (2). A review focusing on the effects of hypohydration (>1% loss in BW) on specific anaerobic parameters of performance determined that muscle endurance, strength, and anerobic power are all significantly reduced in a hypohydrated state (42). The authors suggested that dehydration impairs non-BW-dependent muscular performance in a functional related manner and hypohydration of (~3%) may actually enhance BW-dependent tasks such as VJH (42). These studies indicate that while there does appear to be degrees of reduction in some parameters of performance there is still a high degree of variability and conflicting evidence as to the effect of hypohydration and the resultant effect on athletic performance. These inconsistencies reveal the necessity to further investigate how athletic performance is effected by the presence of hypohydration

The purpose of this study was to determine the role of HS on athletic performance measures in TAF athletes. Previous research exploring the role of hypohydration on athletic performance have used differing methods and protocols to analyze metrics of anerobic performance. Specifically, the aim of this research was to assess HS and VJH to further expand on the findings of previous investigations and built upon the knowledge of this topic. Additionally, the protocol used in this study was developed to facilitate accurate comparisons between results in previous studies analyzing these two variables. Previous research was limited analyzing the role of hypohydration on metrics of anerobic power. However, we hypothesized that as hypohydration incrementally rises it will cause reductions in VJH among participants of this study.

Methods

Experimental Approach to the Problem

The investigators used a between-subjects research design to assess the effect of HS on athletic performance. This investigation had participants complete a series of anthropometric measurements and were instructed upon the procedures of the research protocol. Participants would then provide daily urine sample to be collected and USG measurements were then analyzed for the assessment of HS of each subject. Following the USG measurements HS was determined through the USG classification cutoffs. The assessment of athletic performance was conducted through the measurement of VJH. Protocols assessing VJH were conducted weekly through a series of three vertical jump measurements of maximal effort. The subject were instructed to stand on the jump mat in an athletic position and complete three jumps of maximal effort. Recorded measurements are then used to calculate estimations of vertical jump height. Daily USG measurements and weekly VJH assessments were taken for the duration of the 5-week study.

Subjects

Participants were comprised of NCAA collegiate division I TAF athletes attending the University of Mississippi. Data was collected from the participants for a duration of 5-weeks during the 2021 fall semester. Each of the voluntary participants had received medical clearance to participate within this study through completion of pre-participation exams (PPE) prior to the start of this study, thus all were considered physically fit, healthy, and able to take part within the study. Subjects were recruited from the active TAF roster. Each participant reporting to the university's outdoor track facility provide daily urine samples to be measured for an assessment of HS. All urine samples were administered $\leq$ 30 minutes prior to the start of daily training sessions. Research procedures were conducted in accordance with the principles set by the University of Mississippi Institutional Review Board (IRB).

Procedures

On the participant's initial visit to the university indoor practice facility anthropometric measurements of height, weight, and body composition were collected. Body composition (BW, lean body mass [LBM], fat mass) was analyzed using a BODPOD (air displacement plethysmography, COSMED; USA) measurement. The two-compartment model was used to determine fat-free and fat mass utilizing the Siri equation; (% body fat = [495/Body Density] – 450). A measurement of resting metabolic rate (RMR) was taken using the COSMED apparatus and computer system which then determined each participant's RMR, using the abbreviated Weir equation; $[3.9\ (VO_2) + 1.1\ (VCO_2)]x\ 1.44$. This value was then used for a calculation of daily total caloric needs. Following the completion of anthropometric measurements, the subjects were then informed of the research protocol and given instructions to meet at the outdoor track facility the following week. Participants were directed to meet at the facility for daily USG measurements to assess HS. Subjects then arrived at the facility for collection of USG measurements which were then used to assess HS based on the following cutoff points: well hydrated (USG ≤ 1.010), euhydrated (USG =1.011-1.020), significant hypohydration (USG =1.021-1.029), and severe hypohydration (USG ≥ 1.030) (see Figure 1). USG was then analyzed using a hand-held refractometer (PAL-10S, ATAGO; Bellevue, Washington). The refractometer was calibrated with 2-3 teaspoons of water prior to the assessment of each urine sample.

All participant samples were collected and analyzed within 30 minutes from the time of initial administration. The participants would once again report to the field house at the track and field facility to provide daily samples for USG measurements within 30 minutes prior to the start of their training session. Once the sample was collected USG measurements were taken and recorded. These daily research protocols were followed Monday through Friday for a total of 5-weeks. Additional, measurements of daily temperature, relative humidity, and cloud cover were recorded for both morning and practice times daily for the 5-week duration of the study.

Estimated vertical jump height (VJH) was measured once weekly for 5-weeks with each participants throughout the duration of the study. The subject reported to athletic facility weight rooms once weekly to perform a vertical jump test, occurring within 30 minutes of their daily USG measurement. The subjects were instructed to stand on the jump mat (Probotics Inc; Huntsville, AL) in an athletic position and jump with maximal effort for a total of three separate jumps to estimate VJH; the three measurement were then averaged for each participate. Each participant completed a total of 15 VJH measurements over the duration of this investigation.

Anthropometric Data Collection

Upon the start of data collection for this research study subjects provided information regarding their age and participated in several anthropometric measures as part of data collection for this investigation. Measures of height and body mass were recorded and then applied to the assessment of body composition through air displacement plethysmography.

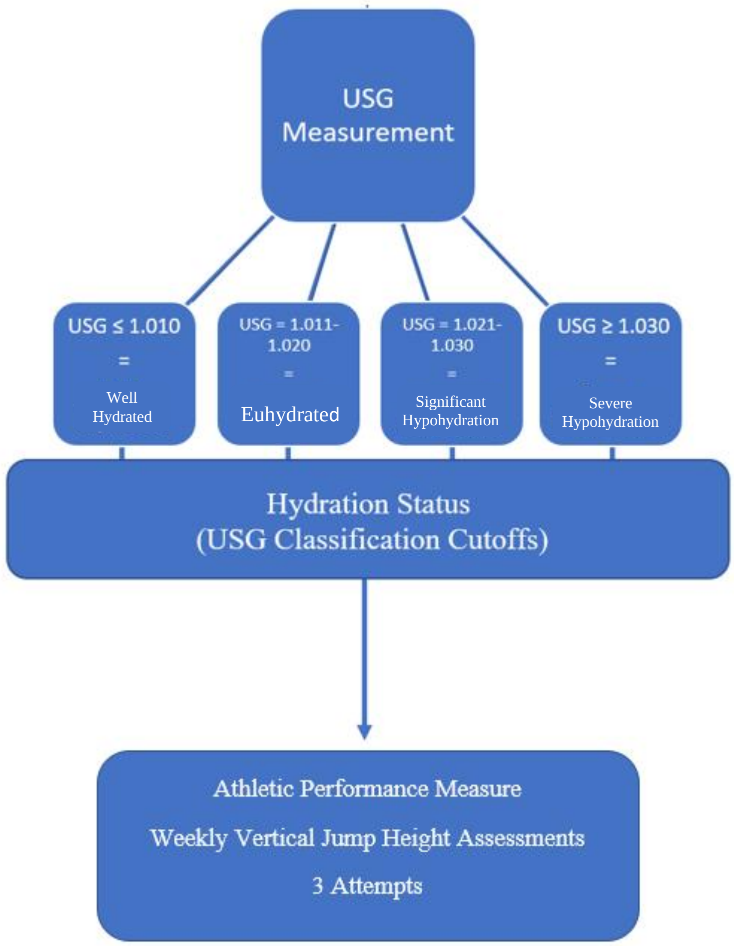

Figure 1. Daily USG measurements occurring ≤ 30 minutes prior to the start of training sessions then compared to corresponding VJH measurements on days in which they were recorded (once weekly).

Statistical Analysis

An alpha level of .05 was utilized within the statistical analysis of this study. Assumptions for normality, homogeneity of covariances, and homogeneity of variances were met. A Pearson's correlation analysis was conducted to establish the effect of HS on athletic performance through measurement of VJH. Data collected within this study was encoded and analyzed with SPSS 27.0 statistical software package (SPSS Inc. Chicago, IL).

Results

Table 1. Participant Anthropometric Values

	Male (n = 19)	Female (n=16)	Total (n=35)
Age (y)	20.39± 1.29	20.84± 0.98	20.57 ± 1.18
Height (cm)	181.05± 6.22	169.34± 6.35	176.17 ± 8.52
Body Mass (kg)	74.75± 5.94	62.88± 6.02	69.43 ± 8.68
BMI (kg/m^2)	22.99± 1.82	20.78± 2.01	23.28 ± 2.91

Athletic Performance Measures

A Pearson correlation analysis was computed to assess the relationship between HS and VJH. There was no statistically significant correlation between the two variables, r(19) = (-0.24), p = (0.301). The correlation analysis results are shown in (Table 3.)

Table 3.

Correlation analysis between hydration status (HS) and vertical jump height (VJH).

	VJH
HS	-0.24

df	p-value	Pearson Correlation	95% Confidence Interval for Difference Lower Bound	Upper Bound
19	0.301	-0.237	-0.607	0.217

* p < 0.05

Discussion

Previous research exploring the effect hypohydration of ~3% reductions in body mass have been shown to reduce anaerobic metrics of performance (39,28). Additionally, it was indicated that in the presence of hypohydration reductions in muscular power occurred (27).The current study found that hypohydration did not have a significant effect on VJH. These findings are consistent with the overwhelming majority of previous investigations exploring the influence of hypohydration on jumping performance (8,36,20,21,26,49) with the exception of two studies. Each of these two studies showed to have improvements in VJH while in a hypohydrated state. The first of these studies analyzed the effect of rapid weight reduction on force production and vertical jumping height (47). The remaining investigation showed to have improvements in VJH within female mixed martial artists within a hypohydrated state while completing a weight cycling program (16). A more recent investigation was conducted on hypohydration but failed to influence vertical jump height (25). The authors suggested that if hypohydration fails to reduce muscle force or power, then vertical jump height should increase as total body water decreases because the jumper becomes light and must move less mass. Additionally, a meta-analysis determined that hypohydration is associated with statistically significant reductions in muscular endurance, strength, and anerobic power (39).

Through the use of the jump mat an estimation of VJH was calculated for each of the participant's three attempts during the weekly performance measurements. These assessments were recorded a total of five times during the duration of this research study. The findings of this study suggest that there is no meaningful influence of HS on VJH. The analysis of data indicated there was essentially no relationship between hypohydration and VJH with a negative correlation of ($r = -.24$). There were a total of ten previous original research studies focusing on HS and its effect VJH. It was indicated that two studies reported increases in VJH (48,16), while the remaining eight reported no significant effect VJH (8,23,20,15,21,26,49.25). The findings from this investigation agree with the majority of other studies conducting similar research. Investigators proposed though the consensus within the results of these studies clearly shows there is no significant impact of hypohydration on VJH, this may only indicate that the loss in body mass could mask the reduction in VJH and anerobic power because of the decrease load required to move off of the ground (25). However, additional research attempted to reveal the reduction in anaerobic power that is normally offset or negated by a reduction in BW (8). The use of a weighted vest worn while conducting the VJH assessment was able to remove the advantage of a reduction in BW when performing a VJH test. The authors then suggest that the impairments in VJH seen while wearing the vest may then indicate that hypohydration is detrimental to performance even though it may be difficult to detect in a practical real-world setting.

The vertical jump assessment is a reliable and valid assessment to measure lower limb muscle strength and power (18), which is often used in the athletic population (24). The decision to use this metric of anaerobic power to assess athletic performance for this population of athletes made both practical and logical sense. These participants would be very familiar with the protocol and this assessment would cause minimal disruption to the athletes training schedule and would minimize issues with data collecting with these TAF athletes.

Additionally, within this present study numerous other measures of anaerobic performance would have been utilized within the research design if it would have been feasible. The potential exercises of choice to measure athletic performance would have been those measuring isometric strength because of its strong relationship to dynamic strength performance; examples include isometric mid-thigh pull, squat, and half-squat (3,32,31). Additional research has shown these types of exercises can be manipulated in order to provide added positional specificity; these movements closely align with sport specific movements allowing these exercise tests to have greater relevance to performance (45). The application of dynamic strength exercise testing would also have been useful because they are commonly performed and are familiar exercises which include back squat, front, squat, half squat, power clean, hang clean and leg press (46). Most likely the application of using one of these exercises would be utilizing the set-rep best method which estimates training loads and repetitions to estimate 1RM, minimizing the risk of unnecessary potential injuries (46). The use of a box squat or other lift the TAF athletes commonly use throughout training would also be an option and advantageous because it would help reduce the likelihood of injury. Force plates would have been preferred to using the jump mat however it was not available for the use of this study. The practicality of performing any sort of additional exercise outside of their normal lifting routine would have been nearly impossible with the time constraints each of the teams and coaches had moving from outdoor practices to indoor lift groups. Integrating a lift used as a part of their training program and tracking progressive overload for each athlete would have been most ideal. It was also attempted to use each of the athlete's resistance training logs to calculate an estimated 1-RM, however the differing resistance training routines made it impossible to compare estimated 1-RM for different exercises. The workout routines were not progressive, so there would not have been any relevant changes in strength.

The present research study contained several limitations, the most notable of investigation was subject compliance during the study. In the initial and final week of this research, subject participation was less than expected. This could have been associated with a multitude of variables (e.g., social commitments, athletics/team obligations, or school responsibilities,). Additionally, the performance measure of VJH was not an ideal metric. I Exercises providing movement through multiple planes and joints; include isometric mid-thigh pull, squat, and half-squat (32) would have been preferred. However, considering the time constrains the athletes had and the resources available for data collection, the decision to use the vertical jump test within the present study was made because its reliable and validated assessment measuring lower limb muscle strength and power (18). The test was used because of its practical application to the subject population and viability of conducting with minimal disturbances to the coaches, trainers, and athletes.

Practical Application

The group of subjects that participated in the research project were a unique group of individuals that not often get studied in research. The TAF athletes had a very diverse set of athletic abilities developed within their specified events in which they compete (jumping, sprints, or pole vaulting). It was a unique experience with these athletes' gathering data that may potentially elaborate on the foundation of current knowledge in regard to fluid recommendation protocols to maintain optimal levels of athletic performance. Also, developing a better understanding of the relationship between levels or degrees of hypohydration and the resultant impact on parameters of athletic performance through a variety of sport domains. One of the most applicable findings within this study was the frequency in which athletes would arrive to the initial morning USG measurements chronically dehydrated. It was more prevalent than expected, coaches, trainers, and sports dietitians could benefit from understanding that more than likely some of their athletes are not as hydrated as they should be and an added focus could be applied to hydration needs in the mornings (especially in summer months during conditioning sessions), coaches could also consider making this a priority by emphasizing to athletes the importance of consuming fluids in the mornings prior to workout sessions or pushing timeslots around to allow for more time hydrate before and following practice. Additionally, athletic trainers could put this knowledge to practical use and recognize the athletes that are not adequately hydrated for the workout session. An emphasis on the importance of proper hydration before, during, and after training sessions would allow athletes to perform at their best and avoid any health-related complications resulting from suboptimal hydration status.

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