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Effects Of Nutrition, Hydration, Exertion, And Sleep On Injury And Illness In Female Collegiate Soccer Players

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EFFECTS OF NUTRITION, HYDRATION, EXERTION AND SLEEP ON INJURY AND ILLNESS IN FEMALE COLLEGIATE SOCCER PLAYERS

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ABSTRACT

Injury and illness rates in collegiate athletics continue to rise. Women's soccer tends to have high numbers of injuries because it is a contact sport. Research has shown that there are several contributing factors to injury and illness rate in collegiate athletics. This study will provide an in depth look at female athletes, more specifically female collegiate soccer players and several factors – including dietary intake, hydration status, exertion and sleep that may attribute to injury and illness in this population. Researchers utilized weekly 3-day diet records, daily urine specific gravity, training load and self-reported sleep quantity to establish a relationship with injury and illness. Twenty-four NCAA Division I college soccer players were recruited to provide data throughout the course of pre- and competition season. Statistical analysis showed a statistically significant effect of hydration and sleep on injury and illness. A statistically significant effect was not found between training load and injury and illness. Data from the 3-day diet records showed a statistical imbalance and violated assumptions, therefore no relationship was found between caloric intake and injury and illness. Based on the results of this study, it is concluded that hydration and sleep play a significant contributing role in the occurrence of injury and illness in female collegiate soccer players. Based on this finding it is recommended that athletes sleep a minimum of 8 hours per night and properly hydrate before, during and after competition.

DEDICATION

I would like to dedicate this dissertation to my wife Caroline, my son Channing and my daughter Henley. They gave me the inspiration to further my education and the strength to finish this process. Without their love and support I would not be where I am today and would not have been able to complete this project. To Caroline, thank you for the encouragement and support. Without you taking care of our family and being there for us, none of this would have been possible. To Channing, dream big and remember no matter the challenge you can achieve anything with hard work and dedication. Be determined and follow through on your goals! To Henley, you are so young and bright. I hope that you will see this one-day and know that no matter what stands in front of you big things are possible. Never let anyone tell you there is anything you cannot achieve.

LIST OF ABBREVIATIONS AND SYMBOLS

ACL	Anterior Cruciate Ligament
CMP	Coach Me Plus
EA	Energy Availability
GPS	Global Positioning System
HIPAA	Health Insurance Portability and Accountability Act
LEA	Low Energy Availability
MAI	Medical Attention Injury/Illness
NCAA	National Collegiate Athletic Association
NDS-R	Nutrient Data System for Research
RED-S	Relative Energy Deficiency in Sport
RMR	Resting Metabolic Rate
TEE	Total Energy Expenditure
TL	Training Load
TLI	Time Loss Injury/Illness

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CHAPTER I

INTRODUCTION

Injuries in athletics continue to rise as the physical demand placed on athlete's increases. Soccer, in particular, is a contact sport in which the chances of injury and illness are common. In the United States alone, more than 200,000 soccer-related injuries are reported annually, with approximately 80% of those injuries occurring among players younger than 25 years (Esquivel, Bruder, Ratkowiak & Lemos, 2015). According to Drew and Finch (2016), there is emerging evidence for a relationship between training load (exertion) and risk of injury and illness. Additionally, soccer players who exhibited a higher preseason weekly training load were found to be at significantly higher risk of injury (Malone et. al, 2017). Fortunately, athletes' training data can be used to quantify the risk of injury and or illness and sports medicine professionals should monitor this data for trends and acute spikes in loads in order to potentially avoid risk of injury or illness.

Hausswirth and Mujika (2013) reported that a reduction in sleep quality and quantity could result in an autonomic nervous system imbalance which can simulate the symptoms of overtraining syndrome. Athletes who sleep less than eight hours a night are at 1.7 times greater risk of sustaining an injury than those who sleep eight hours or more a night (Milewski, et al., 2014). Conversely, sufficient sleep can help to increase perceptual and motor learning as these processes continue into and throughout a sufficient night's sleep. Although Rosen et al. (2016), reported a high percentage of sleep deprivation and irregular sleep patterns in adolescent, non-athletes, few have investigated sleep deprivation in adolescent athletes and to what extent it affects the risk of sustaining injuries.

According to Meyer et al. (2009), appropriate dietary intake, rather than use of supplements, is recommended to ensure young athletes participate fully and safely in athletics. Although nutrition likely affects their overall health, as well as their ability to recover and perform at high levels, it is uncertain as to what degree athletes follow appropriate dietary guidelines. Athletic participation increases total energy expenditure and some findings suggest that low energy availability may be linked to associated health risks (Ackerman et al., 2018; Heikura, et al., 2018; Meyer, et al., 2009). Many athletes, particularly those at the collegiate level, struggle to find the time or effort to plan out their daily meals and snacks. This inability to properly plan their meals can lead to improper fueling and low energy availability. According to Ackerman et. al, (2018) low energy availability may cause decreases in training response and endurance, compromised decision making, and reduced coordination and concentration, irritability, and depression. The decrease in concentration or performance may then be attributed to potential injury risk in collegiate athletics.

As with energy intake, collegiate athletes in particular seem to have a difficult time maintaining adequate hydration. Hypohydration appears to have several effects on both the performance of athletes as well as their overall well-being. Hypohydration status may have physiological effects on the cardiovascular system, and well as muscle function and endurance (Judelson, et. al, 2007). Altered physiology due to dehydration may attribute to injuries and illness in athletics as well as decreases in performance.

Injury and illness rates continue to rise in athletics. While there has been a focus on injury rates in traditionally male sports like American football and other high profile sports such as Australian Rules football and Rugby, there has been little data presented on female athletes (Cross, Williams, Trewartha, Kemp, & Stokes, 2016; Drew & Finch, 2016; Kerr, et al., 2019). While the characteristics of female competition are slightly different than their male counterparts, it has been shown that training loads and relative workload are very similar between Division I collegiate male and female soccer players (McFadden, Walker, Bozzini, Sanders, & Arent, 2020). The following summarizes the current literature with regard to effects of low energy availability, hypohydration, over exertion, and sleep deprivation in athletics. This study aims to provide an in depth look at female athletes, more specifically female collegiate soccer players and several factors including dietary intake, hydration status, exertion and sleep that may attribute to injury and illness in this population.

CHAPTER II

REVIEW OF LITERATURE

Background on Injury and Illness in Athletics

Athletics is widely regarded across all cultures throughout the world. Money and time are continually invested in understanding sport and gaining an advantage over the competition. However, injury rates in athletics continue to rise (Burt & Overpeck, 2001). According to the National Collegiate Athletic Association (NCAA), the overall injury rate in NCAA women's soccer is 7.3 per 1,000 athlete exposures (Powell, 2017). Of these injuries, 34% resulted in an average of 3-6 missed days of sport related activity. Scandinavian studies have shown that sports injuries account for roughly 10-19% of all acute emergency room visits each year (Bahr & Holme, 2003). These studies also indicate that anterior cruciate ligament (ACL) tears are 3-5 times higher in female athletes than males. While these studies document a higher rate of injury incidence with female athletes, they do not provide insights on the underlying causes. Several links to long-term health risks have been evaluated due to the number of injuries in professional soccer (Drawer & Fuller, 2002); these long-term health consequences may be avoided or diminished if research findings can suggest ways to decrease the overall injury rate in athletics.

Defining Sports-related Injuries and Illness

Injuries have been extensively researched in the literature with little to no congruity in the definition of an injury. In order to further evaluate sports injuries and their prevention and intervention, studies must understand what a sports injury is and how to distinguish between them (Finch, 1997; Junge & Divorak, 2000). In deciding what is classified as a sports injury, it is clear that the injury should be directly related to the sport, yet there is some debate as to what ailments should be included (Junge, Dvorak, Graf-Baumann, & Peterson, 2004). Fuller et. al (2006) labeled an injury as any physical complaint that results from a training session or competition regardless of the need for medical attention or time away from sport activity. They also determined that it is best to distinguish between injuries by listing them as a medical attention injury (MAI) or time loss injury (TLI). Hagglund, Walden, Bahr & Ekstrand (2005) state that a time loss injury definition is practical for all playing levels of soccer. These definitions of injury may very well go beyond soccer to all athletics, and distinguishing between MAI and TLI injuries should help researchers better understand the data being presented. In order to properly report injury data, research must move toward a consistent definition of what an injury is and how it will be reported. This investigation will utilize the consensus agreement presented by Fuller et al. (2006) as described above.

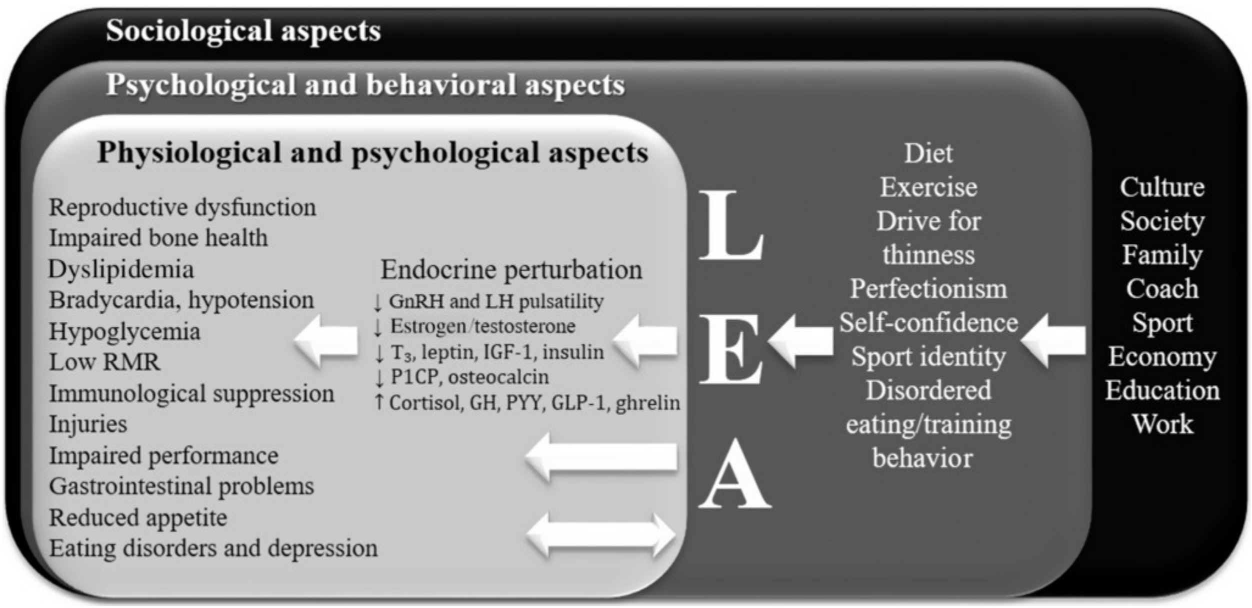
Illnesses can be sport related in the same way as injuries. While illness may not be the direct result of sport, they may be indirectly caused by athletic participation. Intense bouts of exercise have been related to suppressed immune system for up to 72 hours post exercise (Nimmo & Ekblam, 2007). This indicates that while the body is recovering from intense exercise and experiencing a suppressed immune system it is far more receptive to germs and infections, which could result in exertional related illness.

While Matthews, et al. (2002) linked increased inflammatory response and illness to the immunosuppressant effect of extreme training, there have been studies that document moderate exercise has an immune boosting capability as it may stimulate stress reducing responses of the body (Matthews, et al., 2002; Nieman, 1994; Fondell, et al., 2011). According to Walsh (2019) infections were the second most common reason for athletes to seek medical attention. This data shows that the occurrence of illness must be addressed when looking at prevention of time loss or medical attention in sports.

It is essential for athletes to understand the risk involved in their sports and properly describe and assess this risk, but this is only a single step in the process. Teams must also utilize risk assessment to properly identify the risk and apply appropriate measures to decrease the likelihood of these events (Fuller & Drawer, 2004). In order to better understand injuries in female athletes, researchers must look at several contributing factors. The relationships between nutrition, hydration, exertion and sleep and injury or illness must be considered. Once these measures have been addressed teams may be able to utilize risk assessment and the relationship between these measures and injury and illness to properly reduce their occurrence in female athletics.

Nutrition

Relative energy deficiency in sport (RED-S) is a phenomenon linked to energy deficiency that can impair physiological function (Mountjoy, et al., 2015). RED-S is a result of low energy availability (LEA). An individual is considered to have LEA when caloric intake does not meet the need for physiological function once sport activity and exercise are taken in to account (Mountjoy, et al., 2015). Adequate energy is necessary to meet the needs for growth, heath and overall well-being, yet LEA is becoming more common and has been shown to have several risk factors (Meyer, O'Connor & Shirreffs, 2009). According to Melin, Heikura, Tenforde & Mountjoy (2019), LEA may result in adverse health outcomes, soft tissue and stress injuries as well as impaired athletic performance. This indicates that if collegiate athletes continue to deprioritize nutrition and energy intake, they will be at risk of injury and illness as well as long-term health consequences. Low energy availability may be the result of several factors including but not limited to: Lack of knowledge, intent to meet sport specific physique, lack of food or food insecurity, and poor planning of daily meals (Burke, Loucks, & Broad, 2006; Burke, Lundy, Fahrenholtz, & Melin, 2018). The graphic below describes the factors leading to low energy availability and the physiological and psychological responses that LEA may elicit.



(Melin, Heikura, Tenforde, & Mountjoy, 2019, pg. 153)

Low energy availability is common in female athletes. One study has shown that 51% of female endurance athletes have LEA (Melin, Heikura, Tenforde, & Mountjoy, 2019). Female athletes with LEA are at a greater risk of performance related injuries, and thus are more likely to suffer a TLI, which can decrease performance due to time away from training (Drew, et al., 2017). Melin, Heikura, Tenforde and Mountjoy (2019) have shown that LEA is prevalent in sports in which athletes feel they must manipulate their weight in order to compete at a high level. Although LEA is most common in individual sporting events, it is also seen in team sporting events as well. Female athletes with LEA may show decreases in bone mass. This decrease in bone mass at peak bone building phases in life may lead to decreases in long-term bone mass and possibly osteoporosis or osteopenia later in life (Meyer, O'Connor & Shirreffs, 2009; Barrack, Loan, Rauh, & Nichols, 2010). Some female athletes have shown a willingness to forgo future athletic success and health for immediate gratification. The immediate impact of lower body fat or overall mass may lead to success, but will eventually lead to low energy stores, fatigue, interruption of body physiology and injury.

Low energy availability will affect performance in the athletic population. If athletes do not meet their energy needs, they may see decreases in training response, coordination concentration and endurance (Ackerman, et al., 2018). This is important for athletes to understand the need for fueling for performance. It is important to note that while Ackerman et al. (2018) found no difference in injury statistics between individuals with LEA and adequate energy availability several other studies have shown that LEA can lead to long term health risk and decreased performance which in turn may lead to greater risk of injury (Griffin, Knight, Bass, & Valliant, 2017; Melin, Heikura, Tenforde, & Mountjoy, 2019; Sale & Elliot-Sale, 2019; Smith & Jeukendrup, 2013). Furthermore, this study used a questionnaire that included self-reported injuries. This self-reporting could have potentially led to an underreporting of injuries by the participants.

Proper nutritional intake can affect both recovery and injury prevention. According to Burke and Mujika (2014), recovery may have two separate goals—to restore body losses that occurred during sport activity or to assist the body in adapting to the physiological changes of exercise and gradually allow the body to become better equipped for performance. Sufficient caloric, macronutrient and micronutrient intakes can help to restore nutrients lost during exercise or used to regenerate the body post exercise.

The nutritional needs of soccer players vary widely based on level of participation, portion of season and position of play (Burke, Loucks, & Broad, 2006). Athletes should maintain a macronutrient and caloric intake sufficient to sustain their current level of activity. Their intake however may need to adjust rapidly as the competitive season changes; according to Reed, De Souza, and Williams (2013) the energy needs of soccer players adjust throughout the season and as practice volume increases or decreases so does energy expenditure. If caloric intake does not increase as the number of competitions or training sessions increase, athletes are at risk of becoming energy deficient, and not recovering between training sessions or competition. While female soccer players are not considered "at risk" for low energy availability it has been linked to this demographic, and further study is needed to address their energy needs (Reed, De Souza, & Williams, 2013).

After bouts of intense training or competition, athletes must ingest carbohydrate and protein to aid in muscle glycogen synthesis in order to ensure proper recovery (Beelen, Burke, Gibala, & van Loon, 2010). A study by Brito, et al. (2012) shows that decreased muscle glycogen later in matches causes muscle fatigue and decreased postural stability in athletes post-match. Decreases in energy levels post-match may cause athletes to begin the next training session or match in a caloric deficit. Failure to properly restore muscle glycogen, by ingesting proper carbohydrate and protein ratios will hinder recovery and possibly lead to injury or illness in athletes.

The use of nutrients to restore energy stores may also be useful in preventing illnesses such as upper respiratory infections. The immune system's ability to properly fight infection or clear viruses is dependent upon an adequate supply of fuel sources (Walsh, 2019). If caloric, micronutrient and macronutrient intake are not sufficient the immune system may be unable to fight off infection. According to Castell, Nieman, Bermon and Peeling (2019) the body undergoes several changes during the exercise-induced immunosuppressant phase and it is possible that immunonutrition may help to combat this suppression of the immune system. Glucose, amino acids and fatty acids all have a role in energy generation for immune cells and enable the cells to proliferate. This shows that the immunosuppressant effect of intense exercise can be combatted by proper nutrition. Nutrition as a means of recovery and prevention is vitally important to an athlete's overall wellbeing and proper nutrient intake can have a direct effect on an athlete's recovery and health.

Hydration

Severe dehydration or hypohydration has been shown to have vast effects on performance across all levels of athletics including elite female soccer players (Andersson, et al., 2008; Maughan & Shirreffs, 2010). While moderate dehydration may not impact athletic performance, many athletes begin activity in mild hypohydration and do not replace fluids throughout competition, increasing dehydration as competition advances (Maughan & Shirrefs, 2010). Hypohydration is more likely to affect endurance athletes and team sports than strength or power athletes (Maughan & Shirrefs, 2010). According to Burke (2001), the maintenance of fluid balance is a key issue in health and performance for athletes. Hypohydration has damaging effect on exercise outcomes and impairs performance during prolonged aerobic activity. When exercising in the heat it is of upmost importance to maintain hydration. As the duration increases, athletes must be aware of hydration status as sweat loss during sustained aerobic activity in high heat conditions can be roughly 2-3 liters per hour (Marriott, 1993; Rehrer, 2001; Sawka, Wenger, & Pandolf, 2011). Fluid intake during activity may not be enough to combat fluid loss, and most athletes can expect to end training sessions under a dehydrated state. This suggests that athletes must have a rehydration plan in order to intake enough fluids to return to euhydration. The following table describes a proper hydration regiment during activity to ensure that athletes maintain hydration.

Table 5. Summary of hydration guidelines

When	How Much to Consume	Comment
Preexercise	12-20 oz water or sport drink, 8 oz just prior to event	Consider small salty snack for fluid retention
During exercise	6-12 oz of water or sport drink every 15-30 minutes	No energy drinks. Consider sodium replacement in endurance events
Postexercise	16-24 oz of fluid for every pound lost	May obtain sodium and electrolyte replacement from a wide variety of foods

(Bytomski, 2017, pg. 52)

If an athlete does not replace fluid losses from training or competition and remains in a dehydrated state, they will begin to show a deficit of hydration, which could lead to a decrease in performance and mental status. Mcgregor, Nicholas, Lakomy, and Williams (1999) performed an experiment in which nine semi-professional soccer players completed a shuttle test in two groups. One group was given water during testing and the other group was not; before and after the test each group performed soccer specific drills as well as a mental concentration test. The group who was not given fluids declined in performance by nearly 5%. The dehydrated group also had a collectively higher heart rate and more difficulty completing the tasks. While this study was limited in number of participants, the findings suggest that dehydration during the course of training or competition can result in mental and physical fatigue, which can diminish athletic performance. A study by Baker, Dougherty, Chow, and Kenney (2007), found that dehydration of 1-4% of an athlete's body weight can significantly inhibit basketball performance. It has been shown that failure to replace sweat and fluid losses leads to inefficiency and exhaustion (Barr, 1999). This inefficiency and exhaustion may be further explained by decreases in physiological function and increases in core body temperature.

Dehydration can affect the function of the cardiovascular system as shown in the study by Mcgregor, Nicholas, Lakomy, & Williams (1999). The dehydrated athletes exhibited higher heart rates and increased physical and cardiovascular strain. This strain is due to increased blood viscosity, reduced cardiac filling and stroke volume (Sawka, Cheuvront, & Kenefick, 2012; Stöhr, et al., 2011). This reduction in cardiac efficiency will cause a decrease in athletic performance. As the heart begins to work harder, and output is reduced, athletes will be unable to sustain high aerobic output over long periods of time, causing fatigue and decreased athletic performance.

This decrease in cardiac output and increase in blood viscosity can be linked to limited oxygenation of the muscles and muscular fatigue. It has been shown that under a hypohydrated state, the muscles tend to fatigue at a faster rate. While muscles fatigue quicker there is little to no effect on muscular strength (Montain et al., 1998). This observed decrease in muscular endurance led researchers to estimate that dehydration can cause a decrease in athletic performance. While research outcomes of muscular strength reduction during hypohydration have been mixed, a study by Minshull & James (2012) showed that volitional static peak force was reduced by 7.8% following hypohydration (Judelson, et al., 2007a, Judelson, et al., 2007b). Therefore, peak athletic performance under dehydration will be significantly shortened in duration, if attainable at all. However, it is unlikely that a dehydrated athlete would be able to achieve peak athletic performance at all due to lack of muscular endurance and decreased neuromuscular activation.

As previously discussed, dehydration effects several aspects of human physiology and performance. These decreases in anaerobic & muscular endurance, cardiovascular function and neuromuscular activation as well as increases in core temperature and heart rate may lend to increases in injury and illness in collegiate athletes. As the body begins to break down due to dehydration and fatigue, injury to the musculoskeletal system could potentially follow. In exercise the body utilizes neuromuscular awareness and proprioception to know where its limbs are in space. Researchers have observed that under fatigue, the body's awareness and proprioception have shown decreases (Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004), and speculate that decreased proprioception due to dehydration and muscular fatigue can lead to severe injuries in contact sports. Further studies are needed to assess the potential injury rates due to dehydration in collegiate athletics.

Exertion

Athletes continuously push themselves to train harder, exceed their current limits and improve performance. Unfortunately, many athletes do not understand the importance of rest and recovery needs or the amount of rest needed and thus are more likely to subject themselves to overtraining. Also known as "overreaching", overtraining is the practice of increasing loads while decreasing rest periods has below recommended amounts. One study described overtraining as a stimulus and stated that one outcome of overtraining may be decreased athletic performance, while another study showed that overreaching in athletics will lead to decreased performance and altered mood states (Callister, Callister, Fleck, & Dudley, 1990; Coutts, Reaburn, Piva, & Roswell, 2007; Winsley & Matos, 2010). This decrease in performance and physical breakdown of the body physically may increase injury and illness in athletes.

Increased training volumes over a short duration and increased spikes in training and internal loads have been linked to increases in injury and illness in athletes. Soccer players, in particular, are subjected to extremely high training loads due to the short recovery periods between matches and the high intensity of competition (Curtis, Huggins, Benjamin, Sekiguchi, Adams, et al., 2019a; McFadden, et al., 2020). There is a risk of doing too much too quickly without acclimatization of the body, and this can cause physiological breakdown. This breakdown may lead to time loss and can have negative effects on performance (Drew & Finch, 2016). Acute to chronic work ratios should be monitored closely in soccer. A study by Malone, et al. (2017) showed that 75 time-loss injuries were reported during the course of one season—an average of 1.6 time loss injuries per player—due to over training and poor acute to chronic workload management. Overtraining and increased training loads over the course of a season are problematic for recovery and regeneration of soccer player and predispose them to increases in injury and illness.

There are many important reasons for monitoring training load in athletes (Curtis, Huggins, Benjamin, Sekiguchi, M. Arent, et al., 2019b). Evidence shows that unmonitored high loads or overtraining may lead to injury, illness, decreases in performance and time loss. Inappropriate training loads and overtraining effects may impact the risk of injury and illness in athletes for up to one month (Drew & Finch, 2016). This lingering effect of over exertion makes it even more important for coaches and athletes to encourage appropriate training regiments and monitoring of external and internal loads. According to Kellmann, at al. (2018), athletes and coaches are taking a more scientific approach to training and competition. They are beginning to look at the overall season and designing programs based around periodization and competition schedules. By monitoring loads and planning training in advance, the coaches and athletes may be able to properly assess an athlete's response to training, and properly prescribe recovery (Curtis, et al., 2019b).

There are currently several options for monitoring exertion and training load during training and competitions. One common practice of monitoring training load is the use of heart rate based global positioning systems (GPS). Heart rate based GPS systems provide coaches and athletes with a measure of the internal load of training and competition (Kellman, et al., 2018). The use of heart rate monitors for training load assesses the load placed on each individual athlete. This form of monitoring allows coaches and athletes to see the exact internal load of the external training stimulus (Casamichana, Castellano, Calleja-Gonzalez, Román, & Castagna, 2013). Individualized monitoring of internal loads and exertion allows coaches to tailor training and external stimulus to each player. This also allows athletes to base their recovery on individualized data shown by the heart rate monitor. This information will ensure that the athletes are not over- or undertraining, and developing the correct work recovery ratios.

Sleep

There is little research that provides information on sleep with regards to athletic performance or injury. Although little data has been provided, sleep has been identified as an adjustable risk factor to athletic injury. While chronic lack of sleep has been linked to a greater risk of musculoskeletal injury in adolescents, there is not enough data to determine a relationship between acute sleep deprivation and injury at this time (Gao, Dwivedi, Milewski, & Cruz, 2019). Lack of sleep may impair psychomotor function in adults, as well as lessen reaction times and cognitive function (Milewski, et al., 2014). Lack of cognitive function and slower reaction time may lead to injury in contact sports such as soccer. In athletics, the participant must be aware of their surroundings, and must react quickly to the opposing team players. Any inhibition in reaction time may place the athlete at a physical disadvantage.

Sleep disturbances will alter the ability to perform at peak level. Lack of sleep may impair an individual's endurance and physical capacity as sleep deprivation has been shown to decrease VO_2 max in some athletes (Chennaoui, Arnal, Sauvet & Leger, 2015). This decrease in aerobic capacity will limit the athlete's ability to compete at an optimal performance level. This shows that adequate sleep is necessary for athletes to not only increase their performance but also to maintain performance. Sleep is critically important to the recovery and regeneration of physical function of athletes.

It is important to understand both the physiological and psychological results of sleep on the athletic population. Chronic sleep deprivation will inhibit athletes from advancing their abilities and limit growth both physically and emotionally. Sleep provides both psychological and physiological roles in recovery. A study by Mah, Mah, Kezirian, & Dement (2011) showed that basketball players who increased their sleep to at least ten hours a night improved both physical performance and scores on tests of emotional well-being.

There are many causes of sleep disturbances or sleep deprivation in athletes. Frequent travel and irregular match schedules resulted in interrupted sleep routines in elite soccer players (Nédélec, Halson, Abaidia, Ahmaidi, & Dupont, 2015). Collegiate athletes must incorporate studying, tutors and social lives into their schedule as well. This routine may leave little time for sleep. Late night games may create an arousal in athletes causing delayed bed time or little sleep prior to the next day's academic and physical training sessions. Athletes face many challenges to properly time for adequate amounts of sleep. However, it is important that athletes and teams prioritize sleep as a valuable component to their training and competition regiment.

Gaps in the Literature

Injury and illness have long been studied in athletes, however there is little research in the prevention of injuries. While studies have linked health related outcomes to certain causes, they have not connected the gaps between these causes and their solutions. Many studies separate injury and illness, but by taking a holistic approach and including both injury and illness in the projected study one will be able to see the effects of both and interpret how much time is really being lost in athletics. There is little data on pre-elite athletics and their link between nutrition intervention or prevention strategies for injury and illness; this remains an area in which data collection can be useful (Smyth, Newman, Waddington, Weissensteiner, & Drew, 2019).

Research on relative energy deficiency in sports is well studied in individual sports such as track and field events, endurance racing and swim and dive (Mountjoy et al., 2018), but understudied in team sports. There are various psychological factors that may lead to increased cases of LEA in team sport athletes such as playing time, the fear of being "too big" or even the stress and balancing athletics, school and personal lives. The study of these factors as they pertain to team sports would provide more information on LEA in a less researched area of sports nutrition. There is a surplus of information connecting LEA in female athletes and bone health, however little information exists on overall injury and illness prevalence. While LEA leads to possible bone loss and hard tissue injuries, there may be more association to soft tissue injury and illnesses that have not been properly addressed.

Hydration has been well studied in male athletes as well as the military (Marriott, 1993; Rehrer, 2001; Sawka, Wenger, & Pandolf, 2011). However there is less information in female athletes. Many of the studies contained in the review of literature had few subjects over a short period of time or intermittently for different stages of the season. This limited data shows a gap in the literature that needs to be addressed. Taking hydration over the entire course of a competitive season may lend to new discoveries about hydration and its effects on injury and illness.

Many studies on exertion and injury have been done in male sports but little has been done for female athletes. While we have been able to draw conclusions or infer data from male athletes to female athletes it would do more justice to show a direct study for females. Female athletes have proven to be as athletic and powerful in their own right, however their physiology is much different than that of their male counterparts. By tracking the training load and seasonal exertion of a women's soccer team, the researchers may be able to identify the mechanisms that lead to injury and illness in the female athletics population.

Sleep deprivation has been linked to factors of risk and injury in many areas of our lives. Lack of sleep may lead to lack of focus and neurological response to activity. This lack of focus has been linked to athletic injury in few studies. By looking at the entire competition season's sleep for each athlete we may be able to statistically show the direct effects of sleep deprivation on injury and illness in athletes.

Purpose of the study

Injury and illness rates continue to rise in athletics. While there has been a focus on injury rates in revenue generating male sports, there has been little data presented on female athletes. This study aims to provide an in depth look at female athletes, more specifically female collegiate soccer players and several factors – including dietary intake, hydration status, exertion and sleep that may attribute to injury and illness in this population. Researchers will aim to identify correlations as well as solutions for female athletes.

Hypothesis

H_{01a}: Caloric intake will have no effect on injury and illness rates in female collegiate soccer players.

H_{A1a}: Caloric intake will have a direct effect on injury and illness rates in female collegiate soccer players.

H_{01b}: Hypohydration will have no effect on injury and illness rates in female collegiate soccer players.

H_{A1b}: Hypohydration will have a direct effect on injury and illness rates in female collegiate soccer players.

H_{02}: High exertional training loads will have no effect on injury and illness rates in female collegiate soccer players.

H_{A2}: High exertional training loads will have a direct effect on injury and illness rates in female collegiate soccer players.

H_{03}: Amount of sleep will have a no effect on injury and illness rates in female collegiate soccer players.

H_{A3}: Amount of sleep will have a direct effect on injury and illness rates in female collegiate soccer players.

CHAPTER III

METHODS

Study Design

This quantitative study assessed the relationship of athletes' nutritional intake, hydration status, physical exertion or training load, and sleep in regards to health status.

Recruitment and Data Collection Procedures

All participants were current members of the women's soccer team at the University of Mississippi and 18 years of age or older. Information collected on each athlete was protected as a part of the student athletes' personal medical record. Data was kept in a locked office and on a HIPAA compliant encrypted and password protected computer provided by the University of Mississippi Athletics Department. Once data was collected it was de-identified for all research purposes. Data collection occurred during the preseason and competition season of collegiate soccer. Informed consent approved from the University of Mississippi Institutional Review Board was obtained as well as support from the University of Mississippi Athletics Department.

Variables and Measurement

Dietary Intake

Dietary intake was assessed on each athlete throughout the data collection process. Each participant filled out a weekly 3-day diet record. The diet records were dispersed and collected by the primary investigator. Diet records were filled out on different days each week i.e. some weeks included a longer duration more strenuous practice, or shorter duration less strenuous practice; other weeks included game day, post game day recovery or an off day. This practice allowed the research team to assess several aspects of the participants' diet and ensure that the diet records represented normal dietary intake. Once diet logs were collected they were logged and analyzed by the team Dietitian and Athletic Trainer utilizing the Nutrient Data System for Research (NDS-R). The diet logs were analyzed for caloric intake with each athlete being prescribed a numeric value for meeting caloric needs (the number 1) or not meeting caloric needs (the number 0). Resting metabolic rate (RMR) was estimated for each participant based on the Nelson Equation, which includes lean body mass as a variable and thus has better likelihood of predictability. To further assess caloric intake the dietitian utilized an activity factor of 2.07 that correlates with very active individuals to multiply the RMR and receive each athlete's predicted total energy expenditure (TEE). This equation was confirmed by use of the Air plethysmography system (Cosmed, USA) calculations of each athlete's estimated RMR and TEE.

Hydration

Hydration was assessed each day of training or competition during the data collection period. Participants provided a urine sample that was assessed for urine specific gravity (USG). The participant was provided a sample cup that was filled and placed in a holding unit to be tested by the research staff. The research staff utilized an ATAGO digital pen refractometer to test the urine for USG. The research team recorded each USG based on the output of the pen refractometer. All USG was listed as a whole number. If the pen refractometer read 1.009 the research team recorded the participants USG as a 9 for that day. All readings were rounded to the nearest whole number. If the reading showed a 1.0095 the research team recorded a 10 for that day.

Exertion

Each participant wore a Polar Team Pro GPS heart rate monitor for all team-training sessions and games throughout the semester. The Polar heart rate monitor uses an algorithm designed to determine the difficulty of a single training session. This calculation of exertion is referred to as training load. The training load algorithm is based on the participants' heart rate throughout the session as well as the participants' age, sex, weight, and VO_2 max (Kangas, 2020). Training load is also roughly based on the TRIMP or training impulse method developed by E.W. Banister in 1991 that takes into account average heart rate throughout the session. This average heart rate keeps the unit from disproportionately giving an advantage to long duration low intensity sessions over high intensity short duration sessions ("Banisters TRIMP | Training Impulse," 2012). Training load can also be used as an estimation of the amount of macronutrients, such as protein and carbohydrate, utilized by the body during a training session. Once the data is recorded by the Polar heart rate monitor, the research team uploaded the data to the Polar Team Pro website and recorded each athletes' training load for all team training sessions and games into an excel spreadsheet.

Sleep

Each athlete self-reported the number of hours they slept the previous night as a part of a daily questionnaire they completed in the Coach me Plus (CMP) reporting system (Saathoff, 2019). This questionnaire was filled out each day and the athletes were continually encouraged to provide an accurate number of hours slept. The research team imported the data into a spreadsheet for the entire data collection period.

Injury and Illness Tracking

The Athletic Trainer tracked all injuries and illnesses throughout the data collection process. An injury was specified as a medical encounter with the Athletic Trainer in which the athlete received treatment and was monitored during any team training activity. All injury and illness was tracked in an excel spreadsheet, as well as the athletes' electronic medical record, and assigned a number based on the type of injury or illness the athlete sustained. Any athlete who was not receiving medical attention for an injury or illness on a given day was assigned a zero, meaning the athlete was healthy and injury or illness free. In the event that an athlete sustained an injury or illness that required medical attention, but she was not withheld from competition she was assigned the numeral one for a medical attention injury or illness (MAI). If an athlete was injured and withheld from training or competition, they were assigned the number two for a time-loss injury or illness (TLI). Injuries and illnesses were convertible from a MAI to a TLI or inversely (Fuller, et al., 2006). If an athlete initially had a time-loss injury or illness but was cleared to play while still receiving medical attention they were moved from a two to a one on the data collection sheet.

Statistical Analysis

Data was analyzed using IBM SPSS version 25. K-means clustering was used to assign groups between the subjects and an ANOVA and Tukey's post hoc analysis was run to assess the relationship between independent and dependent variable. A four-week rolling average of each participant's caloric intake, urine specific gravity, training load, and sleep was used to assess the ongoing relationship. The dichotomous dependent variable was assessed for strength of association based on the independent variable. Results are reported using descriptive statistics. While it is understood that we cannot draw direct conclusion or causation based on the relationship, it was the goal of the research team to draw associations between the variables based on reported statistics.

Chapter IV

Manuscript I

IMPACT OF CALORIC INTAKE AND HYDRATION ON INJURY AND ILLNESS IN DIVISION I FEMALE SOCCER PLAYERS

To be submitted to the International Journal of Sports Nutrition and Exercise Metabolism

INTRODUCTION

Caloric Intake & Relative Energy Deficiency in Sport

Relative energy deficiency in sport (RED-S) is a phenomenon linked to energy deficiency that can impair physiological function (Mountjoy, et al., 2015). RED-S is a result of low energy availability (LEA). An individual is considered to have LEA when caloric intake does not meet the need for physiological function once sport activity and exercise are taken in to account (Mountjoy, et al., 2015). Adequate energy is necessary to meet the needs for growth, heath and overall well-being, yet LEA is becoming more common and has been shown to have several risk factors (Meyer, O'Connor & Shirreffs, 2009). According to Melin, Heikura, Tenforde & Mountjoy (2019), LEA may result in adverse health outcomes, soft tissue and stress injuries as well as impaired athletic performance. This indicates that if collegiate athletes continue to deprioritize nutrition and energy intake, they may be at risk of injury and illness as well as long-term health consequences. Low energy availability in athletes could be attributed to several factors such as lack of knowledge, intent to meet sport specific physique, lack of food or food insecurity, and poor planning of daily meals (Burke, Loucks, & Broad, 2006; Burke, Lundy, Fahrenholtz, & Melin, 2018).

If athletes do not meet their energy needs, they may see decreases in training response, coordination concentration and endurance (Ackerman, et al., 2018). It is important for athletes to understand the need for fueling for performance. It is important to note that while Ackerman et al. (2018) found no difference in injury statistics between individuals with LEA and adequate energy availability several other studies have shown that LEA can lead to long term health risk and decreased performance which in turn may lead to greater risk of injury (Griffin, Knight, Bass, & Valliant, 2017; Melin, Heikura, Tenforde, & Mountjoy, 2019; Sale & Elliot-Sale, 2019; Smith & Jeukendrup, 2013).

Proper nutritional intake can affect both recovery and injury prevention. According to Burke & Mujika (2014), recovery may have two separate goals—to restore body losses that occurred during sport activity or to assist the body in adapting to the physiological changes of exercise and gradually allow the body to become better equipped for performance. Calorie and macronutrient intake can help to restore nutrients lost during exercise or used to regenerate the body post exercise.

The nutritional needs of soccer players vary widely based on level of participation, portion of season and position of play (Burke, Loucks, & Broad, 2006). Athletes should maintain a macronutrient and caloric intake sufficient to sustain their current level of activity. Their intake however may need to adjust rapidly as the competitive season changes; according to Reed, De Souza, and Williams (2013) the energy needs of soccer players adjust throughout the season and as practice volume increases or decreases so does energy expenditure. If caloric intake does not increase as the number of competitions or training sessions increase, athletes are at risk of becoming energy deficient, and not recovering between training sessions or competition. While female soccer players are not considered "at risk" for low energy availability it has been linked to this demographic, and further study is needed to address their energy needs (Reed, De Souza, & Williams, 2013).

After bouts of intense training or competition, athletes must ingest carbohydrate and protein to aid in muscle glycogen synthesis in order to ensure proper recovery (Beelen, Burke, Gibala, & van Loon, 2010). A study by Brito, et al. (2012) shows that decreased muscle glycogen later in matches causes muscle fatigue and decreased postural stability in athletes post-match. Decreases in energy levels post-match may cause athletes to begin the next training session or match in a caloric deficit. Failure to properly restore muscle glycogen, by ingesting proper carbohydrate and protein ratios will hinder recovery and possibly lead to injury or illness in athletes.

Hydration

Severe dehydration or hypohydration has been shown to have vast effects on performance across all levels of athletics including elite female soccer players (Andersson, et al., 2008; Maughan & Shirreffs, 2010). While moderate dehydration may not effect performance, many athletes begin activity in mild hypohydration and do not replace fluids throughout competition, increasing dehydration as competition advances (Maughan & Shirrefs, 2010). If an athlete does not replace fluid losses during training or competition and increases their dehydrated state the athlete may begin to show decreases in both performance and mental status. Mcgregor, Nicholas, Lakomy, and Williams (1999) performed an experiment in which nine semi-professional soccer players completed a shuttle test in two groups. One group was given water during testing and the other group was not; before and after the test each group performed soccer specific drills as well as a mental concentration test. The group who was not given fluids declined in performance by nearly 5%. The dehydrated group also showed to have higher heart rate and more difficulty completing the tasks.

Baker, Dougherty, Chow, and Kenney (2007), reported that dehydration of 1-4% of an athlete's body weight can significantly inhibit basketball performance. It has been shown that failure to replace sweat and fluid losses leads to inefficiency and exhaustion (Barr, 1999). This inefficiency and exhaustion may be further explained by decreases in physiological function and increases in core body temperature.

Dehydration can affect the function of the cardiovascular system as shown in the study by Mcgregor, Nicholas, Lakomy, and Williams (1999). Dehydrated athletes exhibited higher heart rates and increased physical and cardiovascular strain. This strain is due to increased blood viscosity, reduced cardiac filling and stroke volume (Sawka, Cheuvront, & Kenefick, 2012; Stöhr, et al., 2011). As the heart begins to work harder, and output is reduced, athletes will be unable to sustain high aerobic output over long periods of time, causing fatigue and decreased athletic performance.

A decrease in cardiac output and increase in blood viscosity can be linked to limited oxygenation of the muscles and muscular fatigue. It has been shown that under a hypohydrated state, the muscles tend to fatigue quicker. While muscles fatigue quicker there is little to no effect on muscular strength (Montain et al., 1998). This decrease in muscular endurance further emphasizes that dehydration can cause a decrease in athletic performance. While results in studies of muscular strength reduction during hypohydration have been contradicting, a study by Minshull and James (2012) has shown that volitional static peak force was reduced by 7.8% following hypohydration (Donahue, Wilson, Williams, Hill, Valliant & Garner, In Press; Judelson, et al., 2007a, Judelson, et al., 2007b). Thus peak athletic performance under dehydration will be significantly shortened in duration, if attainable at all. However it is unlikely that an athlete would be able to perform at their best under dehydration due to lack of muscular endurance and decreased neuromuscular activation.

As previously discussed, dehydration effects several aspects of human physiology and performance. These decreases in anaerobic and muscular endurance, cardiovascular function and neuromuscular activation as well as increases in core temperature and heart rate may lend to increases in injury and illness in collegiate athletes. As the body begins to break down due to dehydration and fatigue, injury to the musculoskeletal system could potentially follow. In exercise the body utilizes neuromuscular awareness and proprioception to know where its limbs are in space. Under fatigue the body's awareness and proprioception have shown decreases in certain studies (Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004). Decreased proprioception due to dehydration and muscular fatigue can lead to severe injuries in contact sports. Further studies are needed to assess the potential injury rates due to dehydration in collegiate athletics.

METHODS

Study Design

This quantitative study was designed to assess the relationship between sleep and injury and illness in collegiate athletics. More specifically between division 1 female soccer players caloric intake, urine specific gravity and injury and illness rates.

Participants

There were 24 participants in this study. All participants were current members of a Division I women's soccer team ages 18-22. Data collection occurred during the duration of the collegiate soccer season. Informed consent approved from the University Institutional Review Board.

Caloric Intake

Caloric intake was assessed on each athlete throughout the data collection process through weekly diet records submitted by each athlete. Diet records were filled out on different days each week i.e. some weeks included a longer duration more strenuous practice, or shorter duration less strenuous practice; other weeks included game day, post game day recovery or an off day. This practice allowed the research team to assess several aspects of the participants' diet and ensure that the diet records represented normal dietary intake. Once diet logs were collected they were logged and analyzed by the team Dietitian and Athletic Trainer utilizing the Nutrient Data System for Research (NDS-R). The diet logs were analyzed for caloric intake with each athlete being prescribed a numeric value for meeting caloric needs (the number 1) or not meeting caloric needs (the number 0). If an athlete did not fill out a diet log for a given week, they were assigned a one or zero based on their average caloric intake, as shown in NDS-R, throughout the season. Resting metabolic rate (RMR) was estimated for each participant based on the Nelson Equation, which includes lean body mass as a variable and thus has better likelihood of predictability. To further assess caloric need the dietitian utilized an activity factor of 2.07 that correlates with very active individuals to multiply the RMR and receive each athlete's predicted total energy expenditure (TEE). This equation was confirmed by use of the Air plethysmography (Cosmed, USA) calculations of each athlete's estimated RMR and TEE. This calculation of TEE was used to determine if the athlete's caloric intake that week was sufficient to meet caloric needs.

Hydration

Hydration was assessed each day of training or competition during the data collection period. Participants provided a urine sample that was assessed for urine specific gravity (USG). The participant was provided a sample cup that was filled and placed in a holding unit to be tested by the research staff. The research staff utilized an ATAGO digital pen refractometer to test the urine for USG. The research team recorded each USG based on the output of the pen refractometer. All USG was listed as a whole number. If the pen refractometer read 1.009 the research team recorded the participants USG as a 9 for that day. All readings were rounded to the nearest whole number. If the reading showed a 1.0095 the research team recorded a 10 for that day. This whole number was used to assess increases in injury or illness based on increases or decreases in hydration.

Injury and Illness Tracking

The Athletic Trainer tracked all injuries and illnesses throughout the data collection process. An injury was specified as a medical encounter with the Athletic Trainer in which the athlete received treatment and was monitored during any team training activity. All injury and illness was tracked in an excel spreadsheet, as well as the athletes' electronic medical record, and assigned a number based on the type of injury or illness the athlete sustained. Any athlete who was not receiving medical attention for an injury or illness on a given day was assigned a zero, meaning the athlete was healthy and injury or illness free. In the event that an athlete sustained an injury or illness that required medical attention, but she was not withheld from competition she was assigned the numeral one for a medical attention injury or illness (MAI). If an athlete was injured and withheld from training or competition they were assigned the number two for a time-loss injury or illness (TLI). Injuries and illnesses were convertible from a MAI to a TLI or inversely (Fuller, et al., 2006). If an athlete initially had a time-loss injury or illness but was cleared to play while still receiving medical attention they will move from a two to a one on the data collection sheet.

Statistical Analysis

Data was analyzed using IBM SPSS version 25. K-means clustering was used to assign groups between the subjects and a Welch's ANOVA and Tukey's post hoc analysis was run to assess the relationship between caloric intake, urine specific gravity and injury and illness. A four-week rolling average of each participant's urine specific gravity and caloric intake was used to assess the ongoing relationship. The dichotomous dependent variable was assessed for strength of association based on the independent variable.

RESULTS

Participants and *k*-means clustering

A total of 24 participants were included in the study. During the course of the 13 week season, participants totaled 69 days of training. Participants filled out dietary intake records for a 3-day period each week, while their hydration (USG) was measured and recorded. Each participant's number of days with no injury, MAI, or TLI was as shown in Table 1.

Based on the days of injury results, a *k*-means clustering analysis was performed to categorize participants. Clustering enabled to identify individuals' tendency to get injured, in turn to test the differences across the clusters. To determine the optimal number of groups (*k*), the elbow method was utilized (Bholowalia & Kumar, 2014). The within-cluster sum of square (*WSS*) was minimized when three clusters were extracted and did not notably improve when more clusters were considered. Thus, the participants were categorized in three groups: Injury/illness-free group (12 participants), mild to moderate injury/illness occurrence group (7 participants), and heavy injury/illness occurrence group (5 participants). Participants within the mild-moderate injury/illness occurrence group were listed as having an MAI or TLI for 22-68% of the training days, while those participants within the heavy injury/illness occurrence group were listed as having an MAI or TLI for 70% or more of the training days.

Analysis of Variance (ANOVA) and *Post-hoc* Tests

ANOVA tests were followed to assess the statistical differences in hydration, across the injury groups. Q-Q plots of residuals confirmed that each group was fairly normally distributed. Due to the lack of homogeneity of error variance in hydration (USG; Levene's $\text{Statistic}_{(2,1556)} = 8.447$, $p < .001$), Welch's ANOVA was utilized. Welch's ANOVA is a robust alternative of ANOVA that has been commonly employed when data violates the assumption of homogeneity of error variances (Moder, 2010). Welch's ANOVA suggested that hydration was statistically significantly different across the injury/illness groups. Small effect size was detected (hydration: $\eta^2 = .012$) (see table 2).

Tukey's *post-hoc* test was conducted to identify the statistically significant difference in hydration across injury/illness groups (see Table 3). This test found that in regard to hydration, the injury/illness-free group showed significantly lower urine specific gravity than other groups and small effect sizes were detected ($d_{12} = .205$, $p < .01$; $d_{13} = .228$, $p < .001$).

Caloric Intake

Of the 24 participants included in the study, only five participants met their caloric need at any point within the data collection period, for a total of 53 days of met caloric intake needs, compared to 1259 days of not meeting caloric intake needs. This data created a gross imbalance on nutritional intake. Due to this imbalance within the data, statistical analyses were not conducted on met vs. did not meet caloric intake requirements. These discrepancies violated all assumptions on statistical data and output was invalid. Due to this invalid output no statistical evidence is found to form a relationship between injury and illness and caloric intake at this time, and this has not been included in the results.

DISCUSSION

This study aimed to draw association between decreased hydration status or higher USG and decreased caloric intake or low energy availability in female collegiate soccer players and increases in occurrence of injury and illness. We used 24 participants' preseason and competition caloric intake and USG and statistically compared them to injury and illness rates. While several studies have aimed to look at comparisons of caloric intake and injury and others at hydration and performance and injury, few have followed one team throughout the course of the season and compared hydration status and caloric intake with injury and illness risks (Ackerman et al., 2018; Drew, et al., 2017; Heikura, et al., 2018; Judelson, et. al, 2007; Meyer, O'Connor & Shirrefs, 2009).

Throughout the season, all athletes showed habits of under fueling for sport participation. The overwhelming amount of under fueling across the team indicates that further data need to be collected regarding the nutritional habits and knowledge of female soccer players. Currently soccer players are not viewed to be at risk of RED-S or LEA (Reed, De Souza, & Williams, 2013). However considering the data collected throughout the entire season more information is warranted to see if RED-S or LEA should be linked with female collegiate soccer players or if there is simply a lack of knowledge and understanding of necessary fueling practices (Burke, Loucks, & Broad, 2006; Burke, Lundy, Fahrenholtz, & Melin, 2018).

The statistical results shown in table 2 and figure 3 provide further evidence that decreases in hydration can affect injury and illness rates in athletes. In accordance with studies by Wilkins, Valovich McLeod, Perrin, and Gansneder (2004), and Mcgregor, Nicholas, Lakomy, and Williams (1999), this data shows that decreases in hydration may affect the ability to perform at their athletic peak due to increased risk of injury or illness and decreases in physical capacity.

While this study showed limitations in the number of participants, it utilized an entire team of athletes for the duration of pre- and competition-season. Even though the participants were limited, they were exposed to 69 training sessions throughout the season. All participants were subject to the same pattern of training and conditioning. Athletes also filled out 3-day diet recalls on their own and may have underestimated fueling, or left out entire meals, leading to the imbalance of data presented and the under fueling represented by the majority of the team. Hydration status via urine specific gravity can potentially be manipulated by subjects through pushing fluids shortly before providing a sample or through providing a sample shortly after waking prior to consuming any fluids.

While there is statistical significance between lower USG scores and decreased injury rates, further information is needed to assess caloric intake and occurrence of injury and illness. It is unclear at this time whether this is due to underreporting of caloric intake on the diet logs, practitioner error on data input into NDS-R or true LEA in the entire team of athletes. Further research is warranted on RED-S and LEA in female collegiate soccer players as well as nutritional knowledge surveys and nutrition education.

PRACTICAL APPLICATION

Hydration was found to be statistically significant across all injury/illness groups (9.146, p < .001, η^2 = .012; d_{12} = .205, p < .01; d_{13} = .228, p < .001). Average USG for the injury-free group was 1.0156 (15.601) while the average USG for the mild-moderate & high injury/illness rate groups were 1.0172 (17.203) and 1.0174 (17.435) respectively (see table 3 & figure 2). With an association between lower USG scores and a lower incidence of injury and illness in this demographic, it is important to consider stricter standards for pre- and post-match hydration in collegiate soccer as well as increases in hydration breaks during practice. Sport staffs may consider alternate routes to encourage increased hydration outside of training and competition as well. This association between higher USG and increases in injury and illness warrants further investigation into the association between chronic hypohydration and injury/illness in collegiate athletics.

LIST OF REFERENCES

Ackerman, K. E., Holtzman, B., Cooper, K. M., Flynn, E. F., Bruinvels, G., Tenforde, A. S., …Parziale, A. L. (2018). Low energy availability surrogates correlate with health and performance consequences of relative energy deficiency in sport. *British Journal of Sports Medicine*, *53*(10), 628–633. doi: 10.1136/bjsports-2017-0989

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer. *Medicine & Science in Sports & Exercise*, *40*(2), 372–380. doi: 10.1249/mss.0b013e31815b8497

Baker, L. B., Dougherty, K. A., Chow, M., & Kenney, W. L. (2007). Progressive dehydration causes a progressive decline in basketball skill performance. *Medicine & Science in Sports & Exercise*, *39*(7), 1114–1123. doi: 10.1249/mss.0b013e3180574b02

Barr, S. I. (1999). Effects of dehydration on exercise performance. *Canadian Journal of Applied Physiology*, *24*(2), 164–172. doi: 10.1139/h99-014

Beelen, M., Burke, L. M., Gibala, M. J., & Loon, L. J. V. (2010). Nutritional strategies to promote postexercise recovery. *International Journal of Sport Nutrition and Exercise Metabolism*, *20*(6), 515–532. doi: 10.1123/ijsnem.20.6.515

Bholowalia, P., Kumar, A. (2014). EBK-Means: A clustering technique based on elbow method and K-means in WSN. *International Journal of Computer Applications*, 105(9), 17-24. doi: 10.5120/18405-9674

Brito, J., Fontes, I., Ribeiro, F., Raposo, A., Krustrup, P., & Rebelo, A. (2012). Postural stability decreases in elite young soccer players after a competitive soccer match. *Physical Therapy in Sport*, *13*(3), 175–179. doi: 10.1016/j.ptsp.2011.07.004

Burke, L. M., Loucks, A. B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*(7), 675–685. doi: 10.1080/02640410500482602

Burke, L. M., Lundy, B., Fahrenholtz, I. L., & Melin, A. K. (2018). Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 350–363. doi: 10.1123/ijsnem.2018-0142

Burke, L. M., & Mujika, I. (2014). Nutrition for recovery in aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(4), 425–436. doi: 10.1123/ijsnem.2014-0022

Donahue PT, Wilson SJ, Williams CC, Hill CM, Valliant M, Garner JC. Impact of hydration status on jump performance in recreationally trained males. *International Journal of Exercise Science.* (In Press)

Drew, M. K., Vlahovich, N., Hughes, D., Appaneal, R., Peterson, K., Burke, L., … Waddington, G. (2017). A multifactorial evaluation of illness risk factors in athletes preparing for the summer olympic games. *Journal of Science and Medicine in Sport*, *20*(8), 745–750. doi: 10.1016/j.jsams.2017.02.010

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., … Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine and Science in Sports*, *16*(2), 83–92. doi: 10.1111/j.1600-0838.2006.00528.x

Griffin, K. L., Knight, K. B., Bass, M. A. & Valliant, M. W. (2017). Predisposing risk factors and stress fractures in division I cross country cunners. *Journal of Strength and Conditioning Research*, Publish Ahead of Print, doi: 10.1519/JSC.0000000000002408.

Heikura, I. A., Uusitalo, A. L., Stellingwerff, T., Bergland, D., Mero, A. A., & Burke, L. M. (2018). Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 403–411. doi: 10.1123/ijsnem.2017-0313

Judelson, D. A., Maresh, C. M., Anderson, J. M., Armstrong, L. E., Casa, D. J., Kraemer, W. J., & Volek, J. S. (2007). Hydration and muscular performance. *Sports Medicine*, *37*(10), 907–921. doi: 10.2165/00007256-200737100-00006

Judelson, D. A., Maresh, C. M., Farrell, M. J., Yamamoto, L. M., Armstrong, L. E., Kraemer, W. J., … Anderson, J. M. (2007). Effect of hydration state on strength, power, and resistance exercise performance. *Medicine & Science in Sports & Exercise*, *39*(10), 1817–1824. doi: 10.1249/mss.0b013e3180de5f22

Maughan, R. J., & Shirreffs, S. M. (2010). Development of hydration strategies to optimize performance for athletes in high-intensity sports and in sports with repeated intense efforts. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 59–69. doi: 10.1111/j.1600-0838.2010.01191.x

Mcgregor, S., Nicholas, C., Lakomy, H., & Williams, C. (1999). The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. *Journal of Sports Sciences*, *17*(11), 895–903. doi: 10.1080/026404199365452

Melin, A. K., Heikura, I. A., Tenforde, A., & Mountjoy, M. (2019). Energy availability in athletics: health, performance, and physique. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 152–164. doi: 10.1123/ijsnem.2018-0201

Meyer, F., O’Connor, H., & Shirrefs, S.M. (2009). Nutrition for the young athlete. *Journal of Sports Science, 27*(6), 73-82.

Minshull, C., & James, L. (2013). The effects of hypohydration and fatigue on neuromuscular activation performance. *Applied Physiology, Nutrition, and Metabolism*, *38*(1), 21–26. https://doi.org/10.1139/apnm-2012-0189

Moder, K. (2010). Alternatives to F-Test in one way ANOVA in case of heterogeneity of variances (a simulation study). *Psychological Test and Assessment Modeling, 52*(4), 343-353.

Montain, S. J., Smith, S. A., Mattot, R. P., Zientara, G. P., Jolesz, F. A., & Sawka, M. N. (1998). Hypohydration effects on skeletal muscle performance and metabolism: A 31P-MRS study. *Journal of Applied Physiology*, *84*(6), 1889–1894. doi: 10.1152/jappl.1998.84.6.1889

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., … Ackerman, K. (2015). The IOC relative energy deficiency in sport clinical assessment tool (RED-S CAT). *British Journal of Sports Medicine*, *49*(21), 1354–1354. doi: 10.1136/bjsports-2015-094873

Reed, J. L., De Souza, M. J. D., & Williams, N. I. (2013). Changes in energy availability across the season in division I female soccer players. *Journal of Sports Sciences*, *31*(3), 314–324. doi: 10.1080/02640414.2012.733019

Sale, C., & Elliott-Sale, K. J. (2019). Nutrition and athlete bone health. *Sports Medicine*. doi: 10.1007/s40279-019-01161-2

Sawka, M. N., Cheuvront, S. N., & Kenefick, R. W. (2012). High skin temperature and hypohydration impair aerobic performance. *Experimental Physiology*. doi: 10.1113/expphysiol.2011.061026

Smith, J. W., & Jeukendrup, A. (2013). Performance nutrition for young athletes. *Nutrition and Enhanced Sports Performance*, 523–529. doi: 10.1016/b978-0-12-396454-0.00055-2

Stöhr, E. J., González-Alonso, J., Pearson, J., Low, D. A., Ali, L., Barker, H., & Shave, R. (2011). Dehydration reduces left ventricular filling at rest and during exercise independent of twist mechanics. *Journal of Applied Physiology*, *111*(3), 891–897. doi: 10.1152/japplphysiol.00528.2011

Wilkins, J. C., Valovich McLeod, T. C., Perrin, D. H., & Gansneder, B. M. (2004). Performance on the balance error scoring system decreases after fatigue. *Journal of Athletic Training*, *39*(2), 156–161.

APPENDIX

Table 1. Participants' days of injury/illness

Participant ID	Number of Days (days out of 69 training days)			Injury/illness Group
	No Injury/illness	MAI	TLI	
1	67	2	0	1
2	36	27	6	2
3	67	2	0	1
4	61	8	0	1
5	68	1	0	1
6	68	0	1	1
7	22	23	24	2
8	43	16	10	2
9	69	0	0	1
10	53	15	1	2
11	63	6	0	1
12	69	0	0	1
13	21	45	3	3
14	20	42	7	3
15	62	6	1	1
16	14	54	1	3
17	65	4	0	1
18	13	51	5	3
19	52	17	0	2
20	54	14	1	2
21	69	0	0	1
22	53	16	0	2
23	69	0	0	1
24	30	37	2	3

Note: * 1: Injury/illness-free group, 2: Mild to moderate injury/illness occurrence group, 3: Heavy injury/illness occurrence group.

Table 2. Welch's ANOVA Results

	Welch's Statistic	df_1	df_2	η^2
Hydration (USG)	9.146***	2	790.523	.012

Note: *** $p < .001$.

Table 3. Descriptive Statistics ($N = 24$)

	Hydration (USG)		
Injury/illness Group	*M*	*SD*	*N*
Injury/illness-free	15.601	8.051	791
Mild-injury/illness	17.203	7.340	444
Heavy-injury/illness	17.435	8.049	324

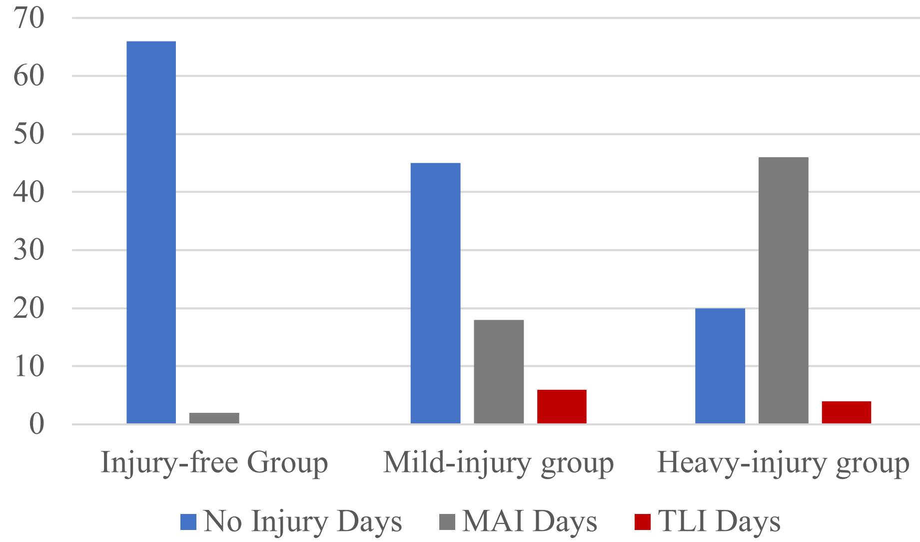


Figure 1. Final Cluster Centers

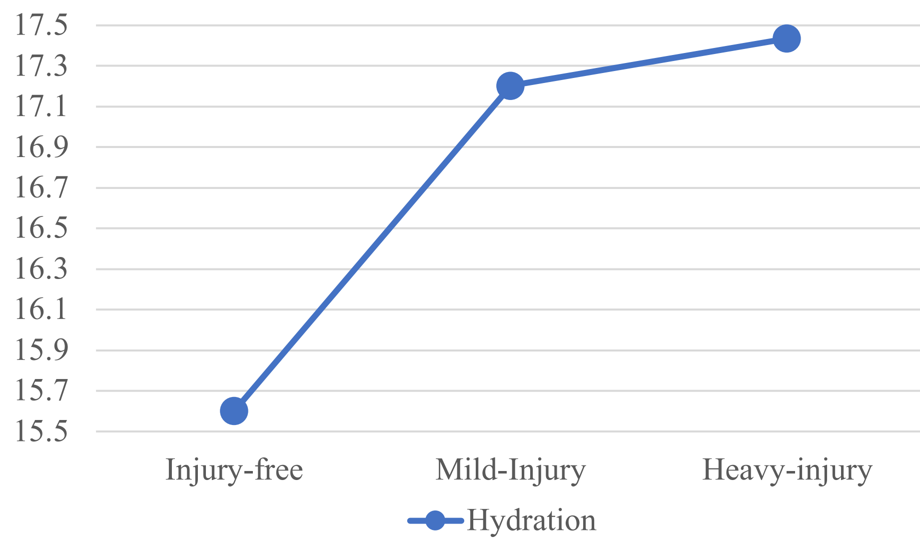


Figure 2. Hydration Plot

Chapter V

Manuscript II

EFFECTS OF TRAINING LOAD ON INJURY AND ILLNESS IN DIVISION I FEMALE SOCCER PLAYERS

To be submitted to the Journal of Strength and Conditioning Research

INTRODUCTION

Injury and illness rates continue to rise in athletics. There has been a focus on injury rates in traditionally male sports like American football and other high profile sports such as Australian Rules football and Rugby, however there has been less data presented on female sports (Cross, Williams, Trewartha, Kemp, & Stokes, 2016; Drew & Finch, 2016; Kerr, et al., 2019). Although the characteristics of female competition, such as sprint distance and high speed running, are slightly different than those of their male counterparts, it has been shown that training loads and relative workload are very similar between Division I collegiate male and female soccer players (McFadden, Walker, Bozzini, Sanders, & Arent, 2020).

According to Drew and Finch (2016), there is emerging evidence for a relationship between high volume training load (exertion) and risk of injury and illness in sport. Soccer players who exhibited a higher preseason weekly training load were found to be at significantly higher risk of injury (Malone et. al, 2017). Fortunately, athletes' training data can be used to quantify the risk of injury and or illness and sports medicine professionals should monitor this data for trends and acute spikes in loads in order to potentially avoid risk of injury or illness.

Training Load

Evidence shows that unmonitored high training loads can lead to injury, illness, decreases in performance and time loss. Inappropriate training loads and overtraining effects could impact the risk of injury and illness in athletes for up to one month. These training effects do not merely last through that specific day or week (Drew & Finch, 2016). Research shows that overtraining may lead to decreased athletic performance and altered mood states (Callister, Callister, Fleck, & Dudley, 1990; Coutts, Reaburn, Piva, & Roswell, 2007; Winsley & Matos, 2010). According to the American College of Sports Medicine, altered mood states have been linked to increases in injury and illness in athletic activity (Herring, et al., 2017).

Acute to chronic work ratios should be monitored closely in soccer. A study by Malone, et al. (2017) showed that 75 time loss injuries were reported during the course of one season—an average of 1.6 time loss injuries per player—due to over training and poor acute to chronic workload management. Overtraining and increased training loads over the course of a season are problematic for recovery and regeneration of soccer player and predispose them to increases in injury and illness.

Monitoring Training Load

There are currently several options for monitoring exertion and training load during training and competitions. One common practice of monitoring training load is the use of heart rate based global positioning systems (GPS). Heart rate based GPS systems provide coaches and athletes with a measure of the internal load of training and competition (Kellman, et al., 2018). Use of heart rate monitors for training load individualizes the load placed on each athlete. This form of monitoring allows coaches and athletes to see the exact internal load of the external training stimulus they have been placed under (Casamichana, Castellano, Calleja-Gonzalez, Román, & Castagna, 2013). Individualizing monitoring of internal loads and exertion allows coaches to tailor training and external stimulus to individual players. This also allows athletes to base their recovery on individualized data shown by the heart rate monitor (Curtis et al., 2019).

METHODS

Study Design

This quantitative study was designed to assess the relationship between training load and injury and illness in collegiate athletics. More specifically between division 1 female soccer players' previous 21 day average training load and injury and illness rates.

Participants

This study included 24 participants. All participants were current members of a NCAA Division I women's soccer team ages 18-22. Data collection occurred during the duration of the collegiate soccer season. This study was approved from the University Institutional Review Board.

Training Load

Each participant wore a Polar Team Pro GPS heart rate monitor for all team-training sessions and games throughout the semester. The Polar heart rate monitor uses an algorithm designed to determine the difficulty of a single training session. This calculation of exertion is referred to as training load. The training load algorithm is based on the participants' heart rate throughout the session as well as the participants' age, sex, weight, and VO_2 max (Kangas, 2020). Training load is also roughly based on the TRIMP or training impulse method developed by E.W. Banister in 1991 that takes into account average heart rate throughout the session. This average heart rate keeps the unit from disproportionately giving an advantage to long duration low intensity sessions over high intensity short duration sessions ("Banisters TRIMP | Training Impulse," 2012). Training load can also be used as an estimation of the amount of macronutrients, such as protein and carbohydrate, utilized by the body during a training session. Once the data is recorded by the Polar heart rate monitor, the research team uploaded the data to the Polar Team Pro website and recorded each athletes' training load for all team training sessions and games into an excel spreadsheet.

Injury and Illness Tracking

The Athletic Trainer tracked all injuries and illnesses throughout the data collection process. An injury was specified as a medical encounter with the Athletic Trainer in which the athlete received treatment and was monitored during any team training activity. All injury and illness was tracked in an excel spreadsheet, as well as the athletes' electronic medical record, and assigned a number based on the type of injury or illness the athlete sustained. Any athlete who was not receiving medical attention for an injury or illness on a given day was assigned a zero, meaning the athlete was healthy and injury or illness free. In the event that an athlete sustained an injury or illness that required medical attention, but she was not withheld from competition she was assigned the numeral one for a medical attention injury or illness (MAI). If an athlete was injured and withheld from training or competition they were assigned the number two for a time-loss injury or illness (TLI). Injuries and illnesses were convertible from a MAI to a TLI or inversely (Fuller, et al., 2006). If an athlete initially had a time-loss injury or illness but was cleared to play while still receiving medical attention they were moved from a two to a one on the data collection sheet.

Statistical Analysis

Data was analyzed using IBM SPSS version 25. K-means clustering was used to assign groups between the subjects and a Welch's ANOVA and Tukey's post hoc analysis was run to assess the relationship between training load and injury and illness. A 21-day rolling average of each participant's training load was used to assess the ongoing relationship. Statistics showed that the players averaged 21 training sessions per month, and according to Drew & Finch (2016) training load may effect players for up to one month. The dichotomous dependent variable was assessed for strength of association based on the independent variable.

RESULTS

Participants and *k*-means clustering

A total of 24 participants were included in the study. During the course of the 13 weeks season, participants totaled 69 days of training. Participants training load was measured and recorded by a Polar Team Pro GPS heart rate monitor worn for all team activity. Each participant's number of days with no injury, MAI, or TLI was as shown in Table 1.

Based on the days of injury/illness results, a *k*-means clustering analysis was performed to categorize participants. Clustering enabled to identify individuals' tendency to get injured or ill and in turn to test the differences across the clusters. To determine the optimal number of groups (*k*), the elbow method was utilized (Bholowalia & Kumar, 2014). The within-cluster sum of square (*WSS*) was minimized when three clusters were extracted and did not notably improve when more clusters were considered. Thus, the participants were categorized in three groups: Injury/illness-free group (12 participants), mild to moderate injury/illness occurrence group (7 participants), and heavy injury/illness occurrence group (5 participants). Participants within the mild-moderate injury/illness occurrence group were listed as having an MAI or TLI for 22-68%

of the training days, while those participants within the heavy injury occurrence group were listed as having an MAI or TLI for 70% or more of the training days.

Analysis of Variance (ANOVA) and *Post-hoc* Tests

ANOVA tests were followed to test the statistical differences in exertion across the injury groups. Q-Q plots of residuals confirmed that each group was fairly normally distributed. Welch's ANOVA suggested that training load did not show a statistically significant difference across the groups and a small effect size was detected ($\eta^2 = .004$) (see table 2). According to the ANOVA, there was no significant effect of training load on the injury and illness rates across groups. As seen in table 3, there is little difference between the average training loads of each injury group with averages of 118.854 for injury/illness free group, 129.906 for the mild to moderate occurrence injury/illness group and 133.522 for the high occurrence injury/illness group. While the training load did increase between groups this mean difference is not seen as significant (see table 2 & figure 2).

DISCUSSION

While training loads and adaptations are well studied in the literature, it was the aim of this study to draw an association between 21-day rolling average training load of 24 female collegiate soccer players and their rates of injury and illness (Callister, Callister, Fleck, & Dudley, 1990; Coutts, Reaburn, Piva, & Roswell, 2007; Winsley & Matos, 2010). To better understand the players overall response to their external and internal load demands on injury and illness research shows that you must look beyond a single training session (Drew & Finch, 2016). The research team did this by utilizing a 21-day rolling average. At each occurrence of injury or illness the average training load for the prior 21 days was correlated.

Upon interpreting the statistical analysis, this study shows that there is no statistical significance between training load and injury and illness rates. While a study by Malone et al. (2017) has shown that time loss injuries may be attributed to over training and poor acute to chronic (acute:chronic) workload management, this study shows that there is no relationship between increased training load and increases in injury and illness. Several other studies have linked over training or high exertional loads to decreases in physical performance, fatigue and altered mood states (Callister, Callister, Fleck, & Dudley, 1990; Coutts, Reaburn, Piva, & Roswell, 2007; Curtis, Huggins, Benjamin, Sekiguchi, M. Arent, et al., 2019b; Winsley & Matos, 2010).

There are a few limitations within this study. The study consisted of 24 participants all from the same organization. The athletes have all been subjected to a similar training regiment, thus the athletes have undergone similar training load averages. The study manifested over the course of the pre- and competition seasons providing ample amount of data to adjust for rolling average of training load. However, by looking at the rolling average of training load, researchers may have missed certain spikes within loads that could have elicited causation for injury but then were averaged out by decreases in periodization or adjustments in practice volume following these initial spikes in training load.

Future research should focus on the best way to quantify exertion or training for use in injury and illness data. The statistical analysis merits further analysis into whether individual training loads may correlate to injury and illness better than rolling averages. Additional investigation could also look into performance factors of sport as they relate to increases in training load and over exertion. In order to rule out the overall effect of training load on injury and illness occurrence more data may be needed.

PRACTICAL APPLICATION

The results of this study show that training load is not a strong predictor of injury and illness occurrence in women's collegiate soccer. This does not however show that exertion cannot be used in making rational decisions about periodization or practice and match planning in this demographic. Further studies are needed to understand what is the best used measure of exertion or acute:chronic work ratios to base periodization plans on. Assuring adequate work to rest ratios in athletics may be of some benefit but further research is needed at this time as to how training load can be used in this process.

LIST OF REFERENCES

Banisters TRIMP | Training Impulse. (2012). Retrieved April 2, 2020, from http://www.trainingimpulse.com/banisters-trimp-0

Bholowalia, P., & Kumar, A. (2014). EBK-Means: A clustering technique based on elbow method and K-means in WSN. *International Journal of Computer Applications*, *105*(9), 17-24. doi: 10.5120/18405-9674

Callister, R., Callister, R. J., Fleck, S. J., & Dudley, G. A. (1990). Physiological and performance responses to overtraining in elite judo athletes. *Medicine & Science in Sports & Exercise*, *22*(6), 816. doi: 10.1249/00005768-199012000-00014

Casamichana, D., Castellano, J., Calleja-Gonzalez, J., Román, J. S., & Castagna, C. (2013). Relationship between indicators of training load in soccer players. *Journal of Strength and Conditioning Research*, *27*(2), 369–374. doi: 10.1519/jsc.0b013e3182548af1

Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology*, *99*(3), 313–324. doi: 10.1007/s00421-006-0345-z

Cross, M. J., Williams, S., Trewartha, G., Kemp, S. P., & Stokes, K. A. (2016). The influence of in-season training loads on injury risk in professional rugby union. *International Journal of Sports Physiology and Performance*, *11*(3), 350–355. doi: 10.1123/ijspp.2015-0187

Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., Adams, W. M., Arent, S. M., … Casa, D. J. (2019). Contextual factors influencing external and internal training loads in collegiate men's soccer. *Journal of Strength and Conditioning Research*, *34*(2), 374-381. https://doi.org/10.1519/jsc.0000000000003361

Drew, M. K., & Finch, C. F. (2016). The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sports Medicine*, *46*(6), 861-883. doi:10.1007/s40279-015-0459-8

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., … Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine and Science in Sports*, *16*(2), 83–92. doi: 10.1111/j.1600-0838.2006.00528.x

Herring, S. A., Boyajian-O'neill, L. A., Coppel, D. B., Daniels, J. M., Gould, D., Grana, W., … Putukian, M. (2017). Psychological issues related to illness and injury in athletes and the team physician. *Medicine & Science in Sports & Exercise*, *49*(5), 1043–1054. doi: 10.1249/mss.0000000000001247

Kangas, N. (2020, April 2). Training Load. Retrieved from https://www.polar.com/blog/training-load-lets-talk-polar/.

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., … Beckmann, J. (2018). Recovery and performance in sport: Consensus statement. *International Journal of Sports Physiology and Performance*, *13*(2), 240–245. doi: 10.1123/ijspp.2017-0759

Kerr, Z. Y., Register-Mihalik, J. K., Pryor, R. R., Pierpoint, L. A., Scarneo, S. E., Adams, W. M., … Marshall, S. W. (2019). The association between mandated preseason heat acclimatization guidelines and exertional heat illness during preseason high school american football practices. *Environmental Health Perspectives*, *127*(4), 047003. doi: 10.1289/ehp4163

Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017). The acute:chonic workload ratio in relation to injury risk in professional soccer. *Journal of Science and Medicine in Sport*, *20*(6), 561-565. doi:10.1016/j.jsams.2016.10.014

McFadden, B. A., Walker, A. J., Bozzini, B. N., Sanders, D. J., & Arent, S. M. (2020). Comparison of internal and external training loads in male and female collegiate soccer players during practices vs. games. *Journal of Strength and Conditioning Research*, *34*(4), 969–974. https://doi.org/10.1519/jsc.0000000000003485

Winsley, R., & Matos, N. (2010). Overtraining and elite young athletes. *The Elite Young Athlete Medicine and Sport Science*, 97–105. doi: 10.1159/000320636

APPENDIX

Table 1. Participants' days of injury/illness

Participant ID	Number of Days (days out of 69 training days)			Injury/illness Group
	No Injury/illness	MAI	TLI	
1	67	2	0	1
2	36	27	6	2
3	67	2	0	1
4	61	8	0	1
5	68	1	0	1
6	68	0	1	1
7	22	23	24	2
8	43	16	10	2
9	69	0	0	1
10	53	15	1	2
11	63	6	0	1
12	69	0	0	1
13	21	45	3	3
14	20	42	7	3
15	62	6	1	1
16	14	54	1	3
17	65	4	0	1
18	13	51	5	3
19	52	17	0	2
20	54	14	1	2
21	69	0	0	1
22	53	16	0	2
23	69	0	0	1
24	30	37	2	3

Note: * 1: Injury/illness-free group, 2: Mild to moderate injury/illness occurrence group, 3: Heavy injury/illness occurrence group.

Table 2. Welch's ANOVA Results

	Welch's Statistic	df_1	df_2	η^2
Training Load	2.996	2	732.148	.004

Note: *** $p < .001$.

Table 3. Descriptive Statistics

	Training Load		
Injury/Illness Group	*M*	*SD*	*N*
Injury/illness-free (n = 12)	118.854	99.263	796
Mild-injury/illness (n = 7)	129.906	94.208	425
Heavy-injury/illness (n = 5)	133.522	112.280	314

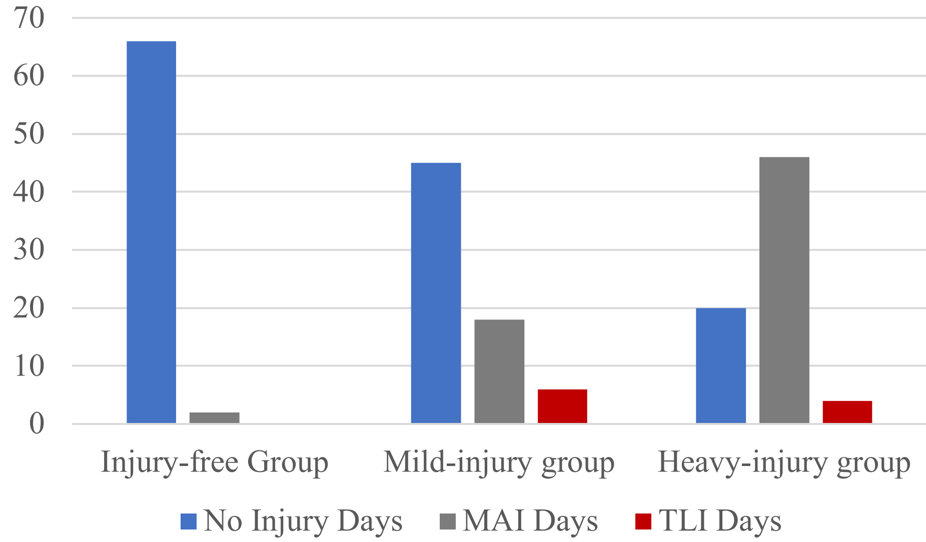


Figure 1. Final Cluster Centers

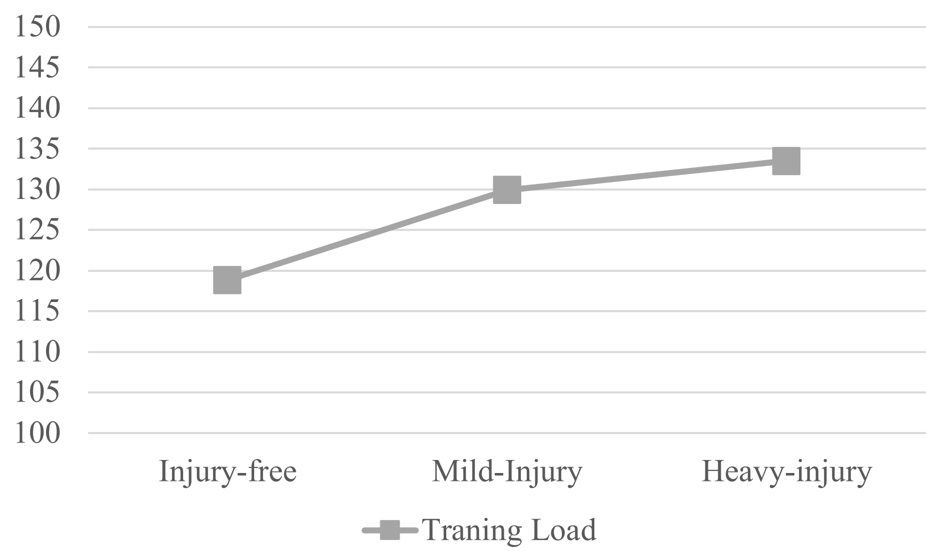


Figure 2. Training Load Plot

Chapter VI

Manuscript III

BENEFITS OF SLEEP ON REDUCTION OF INJURY AND ILLNESS IN DIVISION I FEMALE SOCCER PLAYERS

To be submitted to the Journal of Athletic Training

INTRODUCTION

Injuries in athletics continue to rise as the demand placed on athletes increases. Soccer is a contact sport in which the chances of injury and illness are common. According to the National Collegiate Athletic Association (NCAA), the overall injury rate in NCAA women's soccer is 7.3 per 1,000 athlete exposures (Powell, 2017). Of these injuries, 34% resulted in an average of 3-6 missed days of sport related activity. Hausswirth and Mujika (2013) reported that a reduction in sleep quality and quantity could result in an autonomic nervous system imbalance which can simulate the symptoms of overtraining syndrome. Athletes who sleep less than eight hours a night are at 1.7 times greater risk of sustaining an injury than those who sleep eight hours or more a night (Milewski, et al., 2014). Conversely, sufficient sleep can help to increase perceptual and motor learning as these processes continue into and throughout a sufficient night's sleep. Although, Rosen et al., (2016) reported a high percentage of sleep deprivation and irregular sleep patterns in adolescent, non-athletes, few researchers have investigated sleep deprivation in adolescent athletes and to what extent it affects the risk of sustaining injuries.

Sleep

Chronic lack of sleep has been linked to a greater risk of musculoskeletal injury in adolescents there is not enough data to determine a relationship between acute sleep deprivation and injury at this time (Gao, Dwivedi, Milewski, & Cruz, 2019). Lack of sleep may impair psychomotor function in adults, as well as lessen reaction times and cognitive function

(Milewski, et al., 2014). Lack of cognitive function and slower reaction time may lead to injury in contact sports such as soccer. In athletics, the participant must be aware of their surrounding, and must react to the opposing team players. Any inhibition in reaction time places the athlete at a disadvantage athletically.

Sleep disturbances will alter the ability to perform at peak level. Lack of sleep may impair an individual's endurance and physical capacity as sleep deprivation has been shown to decrease VO_2 max in some athletes (Chennaoui, Arnal, Sauvet & Leger, 2015). It is also important to understand that sleep provides a psychological role in recovery as well as the previously described physiological role. Chronic sleep deprivation will inhibit athletes from advancing their abilities and limit growth both physically and emotionally. A study by Mah, Mah, Kezirian, and Dement (2011) showed that basketball players who increased their sleep to at least ten hours a night increased not only physical performance, but also reported higher scores on emotional well-being. According to the American College of Sports Medicine, decreases in emotional well-being and increases in stress have been linked to increases in injury and illness in athletic activity (Herring, et al., 2017).

Defining Sports related Injury and Illness

In order to further evaluate sports injuries and their prevention and intervention, studies must understand what a sports injury is and how to distinguish between them (Finch, 1997; Junge & Divorak, 2000). In deciding what is included as a sports injury, it is clear that the injury should be directly related to the sport, yet there is some debate as to what ailments should be included (Junge, Dvorak, Graf-Baumann, & Peterson, 2004). Fuller et. al (2006) labeled an injury as any physical complaint that results from a training session or competition regardless of the need for medical attention or time away from sport activity. They also determined that it is best to distinguish between injuries by listing them as a medical attention injury (MAI) or time loss injury (TLI). Hagglund, Walden, Bahr & Ekstrand (2005) state that a time loss injury definition is practical for all playing levels of soccer. While illness may not be the direct result of sport, they may be indirectly caused by athletic participation. Intense bouts of exercise have been related to suppressed immune system for up to 72 hours post exercise (Nimmo & Ekblam, 2007). This indicates that while the body is recovering from intense exercise and experiencing a suppressed immune system it is far more receptive to germs and infections, which could result in exertional related illness.

METHODS

Study Design

This quantitative study was designed to assess the relationship between sleep and injury and illness in collegiate athletics. More specifically between division 1 female soccer players sleep quantity and injury and illness rate.

Participants

There were 24 participants included in this study. All participants were current members of a Division I women's soccer team ages 18-22 years. Data collection occurred during the duration of the collegiate soccer season. The University's Institutional Review Board approved this study.

Sleep

Each athlete self-reported the number of hours they slept the previous night as a part of a daily questionnaire they completed in the Coach me Plus (CMP) reporting system (Saathoff, 2019). This questionnaire was filled out each day and the athletes were continually encouraged to provide an accurate number of hours slept. The research team imported the data into a spreadsheet for the entire data collection period.

Injury and Illness Tracking

The Athletic Trainer tracked all injuries and illnesses throughout the data collection process. An injury was specified as a medical encounter with the Athletic Trainer in which the athlete received treatment and was monitored during any team training activity. All injury and illness was tracked in an excel spreadsheet, as well as the athletes' electronic medical record, and assigned a number based on the type of injury or illness the athlete sustained. Any athlete who was not receiving medical attention for an injury or illness on a given day was assigned a zero, meaning the athlete was healthy and injury or illness free. In the event that an athlete sustained an injury or illness that required medical attention, but she was not withheld from competition she was assigned the numeral one for a medical attention injury or illness (MAI). If an athlete was injured and withheld from training or competition they were assigned the number two for a time-loss injury or illness (TLI). Injuries and illnesses were convertible from a MAI to a TLI or inversely (Fuller, et al., 2006). If an athlete initially had a time-loss injury or illness but was cleared to play while still receiving medical attention they were moved from a two to a one on the data collection sheet.

Statistical Analysis

Data was analyzed using IBM SPSS version 25. K-means clustering was used to assign groups between the subjects and a Welch's ANOVA and Tukey's post hoc analysis was run to assess the relationship between sleep and injury and illness. A four-week rolling average of each participant's sleep was used to assess the ongoing relationship. The dichotomous dependent variable was assessed for strength of association based on the independent variable. While it is understood that we cannot draw direct conclusion or causation based on the relationship, it was the goal of the research team to draw associations between the variables based on reported statistics.

RESULTS

Participants and *k*-means clustering

A total of 24 participants were included in the study. During the course of the 13 weeks season, participants totaled 69 days of training. Participants filled out a survey each training day to include their total hours slept the previous night. Each participant's number of days with no injury, MAI, or TLI was as shown in Table 1.

Based on the days of injury results, a *k*-means clustering analysis was performed to categorize participants. Clustering enabled to identify individuals' tendency to get injured/ill, in turn to test the differences across the clusters. To determine the optimal number of groups (*k*), the elbow method was utilized (Bholowalia & Kumar, 2014). The within-cluster sum of square (*WSS*) was minimized when three clusters were extracted and did not notably improve when more clusters were considered. Thus, the participants were categorized in three groups: Injury/illness-free group (12 participants), mild to moderate injury/illness occurrence group (7 participants), and heavy injury/illness occurrence group (5 participants). Participants within the mild-moderate injury/illness occurrence group were listed as having an MAI or TLI for 22-68% of the training days, while those participants within the heavy injury/illness occurrence group were listed as having an MAI or TLI for 70% or more of the training days.

Analysis of Variance (ANOVA) and *Post-hoc* Tests

ANOVA tests were followed to test the statistical differences in sleep across the injury groups. Q-Q plots of residuals confirmed that each group was fairly normally distributed. Welch's ANOVA suggested that sleep was statistically significantly different across the injury groups. Small effect sizes were detected (sleep: $\eta^2 = .013$). Tukey's *post-hoc* tests were conducted to identify the statistically significant difference of sleep across injury groups (see Table 3). Sleep was statistically significantly lower in the heavy-injury group than other groups and small effect sizes were detected ($d_{31} = .282$, $p < .001$; $d_{32} = .278$, $p < .001$).

DISCUSSION

Chronic lack of sleep has been attributed to increases in musculoskeletal injuries in adolescents, but there is not enough information about acute lack of sleep or chronic lack of sleep in athletics (Gao, Dwivedi, Milewski, & Cruz, 2019). This study set out to show a relationship between sleep and injury and illness in collegiate athletes. Sleep has been associated with increased mood as well as athletic performance and physiological responses such as increased VO2 max (Chennaoui, Arnal, Sauvet & Leger, 2015; Mah, Mah, Kezirian, & Dement 2011).

In this study we used self-reported sleep to draw association between each athlete's 21-day rolling average of sleep and their likelihood of injury and illness. According to the results shown in table 3, participants who fell within the injury free group averaged 7.9 hours of sleep. As athletes get closer to 8 hours of sleep per night they will ultimately decrease their likelihood of injury and illness. These results can be further corroborated in a study by Gao, Dwivedi, Milewski, and Cruz (2019) in which adolescents showed a significantly increased likelihood of sports injury after chronically poor sleep.

Self-reporting of sleep within this study proves to be a significant limitation. However, throughout the research process subjects were continuously reminded of the importance of accurate and proper reporting of sleep. Further investigation into the usage and accuracy of wearable technology for purposes of sleep monitoring would be necessary to determine if it is a better suited method for monitoring actual sleep rather than use of self-reporting.

Further studies into the quality of sleep may prove useful within this demographic. According to Nédélec, Halson, Abaidia, Ahmaidi, and Dupont (2015), soccer players may be at a disadvantage for quality sleep due to travel, irregular match schedules and interrupted sleep routines. Sleep hygiene may also play a part in injury and illness among college athletes due to increased screen time and erratic schedules.

PRACTICAL APPLICATION

Statistically significant relationships were found between groups for averages in hours of accumulated sleep. Sleep appears to have a large effect on the occurrence of injury and illness in female collegiate soccer players. As seen in figure 2, as average hours of sleep accumulated gets farther below 8 hours of sleep per night the risk of injury and illness increases. This study shows that chronic sleep deprivation in athletics can reduce the ability of the body to remain injury and illness free.

LIST OF REFERENCES

Bholowalia, P., & Kumar, A. (2014). EBK-Means: A clustering technique based on elbow method and K-means in WSN. *International Journal of Computer Applications*, *105*(9), 17-24. doi: 10.5120/18405-9674

Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? *Sleep Medicine Reviews*, *20*, 59–72. doi: 10.1016/j.smrv.2014.06.008

Finch, C. F. (1997). An overview of some definitional issues for sports injury surveillance. *Sports Medicine*, *24*(3), 157–163. doi: 10.2165/00007256-199724030-00002

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., … Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine and Science in Sports*, *16*(2), 83–92. doi: 10.1111/j.1600-0838.2006.00528.x

Gao, B., Dwivedi, S., Milewski, M. D., & Cruz, A. I. (2019). Lack of sleep and sports injuries in adolescents. *Journal of Pediatric Orthopaedics*, *39*(5), 324–333. doi: 10.1097/bpo.0000000000001306

Hagglund, M., Walden, M., Bahr, R., & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Medicine*, *39*(6), 340–346. doi: 10.1136/bjsm.2005.018267

Hausswirth, C., & Mujika, I. (2013). Recovery for performance in sport. Champaign, IL: Human Kinetics.

Herring , S. A., Boyajian-O'neill, L. A., Coppel, D. B., Daniels, J. M., Gould, D., Grana, W., … Putukian, M. (2017). Psychological issues related to illness and injury in athletes and the team physician. *Medicine & Science in Sports & Exercise*, *49*(5), 1043–1054. doi: 10.1249/mss.0000000000001247

Nédélec, M., Halson, S., Abaidia, A.-E., Ahmaidi, S., & Dupont, G. (2015). Stress, sleep and recovery in elite soccer: A Critical Review of the Literature. *Sports Medicine*, *45*(10), 1387–1400. https://doi.org/10.1007/s40279-015-0358-z

Nimmo, M. A., & Ekblom, B. (2007). Fatigue and illness in athletes. *Journal of Sports Sciences*, *25*(sup1). doi: 10.1080/02640410701607379

Junge, A., & Dvorak, J. (2000). Influence of definition and data collection on the incidence of injuries in football. *The American Journal of Sports Medicine*, *28*(5_suppl), 40–46. doi: 10.1177/28.suppl_5.s-40

Junge, A., Dvorak, J., Graf-Baumann, T., & Peterson, L. (2004). Football injuries during FIFA tournaments and the Olympic games, 1998-2001. *The American Journal of Sports Medicine*, *32*(1_suppl), 80–89. doi: 10.1177/0363546503261245

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*, *34*(7), 943–950. doi: 10.5665/sleep.1132

Powell, R. (2017, June 1). Overuse injuries and periodization educational resources. Retrieved from http://www.ncaa.org/sport-science-institute/overuse-injuries-and-periodization-educational-resources.

Rosen, P. V., Frohm, A., Kottorp, A., Fridén, C., & Heijne, A. (2016). Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. *Scandinavian Journal of Medicine & Science in Sports*, *27*(11), 1364-1371. doi:10.1111/sms.12735

Saathoff, B. (2019, January 25). CoachMePlus Features - Applied Sports Science Suite of Tools. Retrieved from https://coachmeplus.com/features/.

APPENDIX

Table 1. Participants' days of injury/illness

Participant ID	Number of Days (days out of 69 training days)			Injury/illness Group
	No Injury/illness	MAI	TLI	
1	67	2	0	1
2	36	27	6	2
3	67	2	0	1
4	61	8	0	1
5	68	1	0	1
6	68	0	1	1
7	22	23	24	2
8	43	16	10	2
9	69	0	0	1
10	53	15	1	2
11	63	6	0	1
12	69	0	0	1
13	21	45	3	3
14	20	42	7	3
15	62	6	1	1
16	14	54	1	3
17	65	4	0	1
18	13	51	5	3
19	52	17	0	2
20	54	14	1	2
21	69	0	0	1
22	53	16	0	2
23	69	0	0	1
25	30	37	2	3

Note: * 1: Injury/illness-free group, 2: Mild to moderate injury/illness occurrence group, 3 : Heavy injury/illness occurrence group.

Table 2. Welch's ANOVA Results

	Welch's Statistic	df_1	df_2	η^2
Sleep	11.102***	2	852.367	.013

Note: *** $p < .001$.

Table 3. Descriptive Statistics

	Sleep (hours)		
Injury Group	*M*	*SD*	*N*
Injury/illness-free (*n* – 12)	7.931	1.333	822
Mild-injury/illness (*n* = 7)	7.918	1.305	478
Heavy-injury/illness (*n* = 5)	7.559	1.275	345

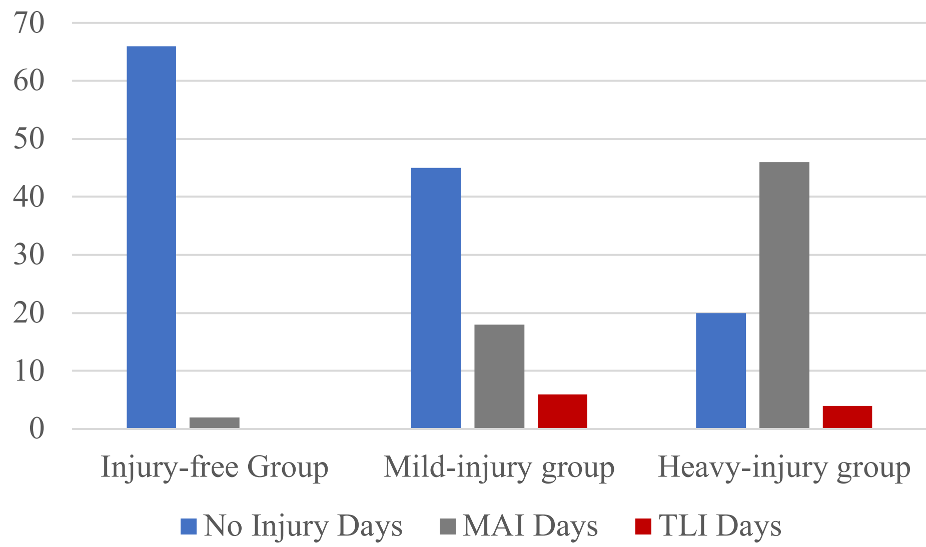


Figure 1. Final Cluster Centers

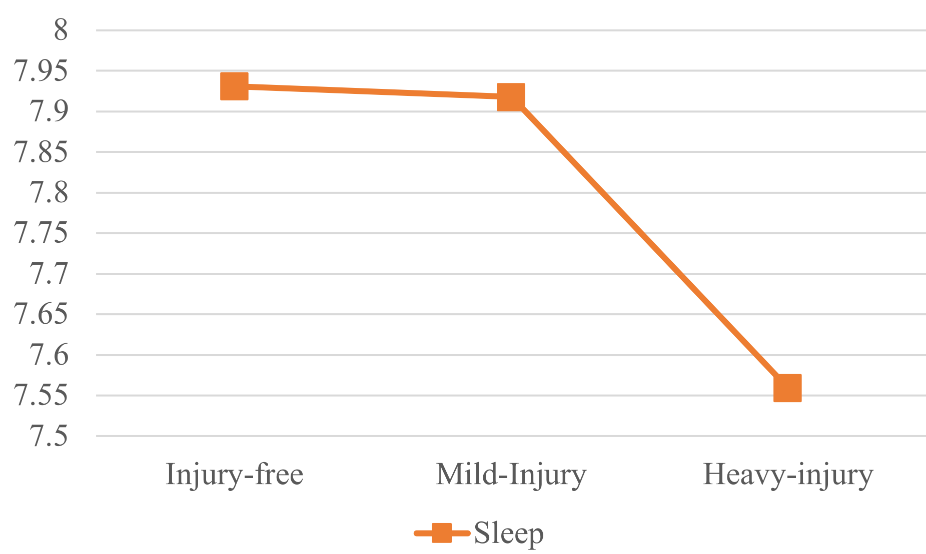


Figure 2. Sleep Plot

BIBLIOGRAPHY

Ackerman, K. E., Holtzman, B., Cooper, K. M., Flynn, E. F., Bruinvels, G., Tenforde, A. S., …Parziale, A. L. (2018). Low energy availability surrogates correlate with health and performance consequences of relative energy deficiency in sport. *British Journal of Sports Medicine*, *53*(10), 628–633. doi: 10.1136/bjsports-2017-098958

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer. *Medicine & Science in Sports & Exercise*, *40*(2), 372–380. doi: 10.1249/mss.0b013e31815b8497

Bahr, R., Holme, I. (2003). Risk factors for sports injuries -- a methodological approach. *British Journal of Sports Medicine*, *37*(5), 384–392. doi: 10.1136/bjsm.37.5.384

Baker, L. B., Dougherty, K. A., Chow, M., & Kenney, W. L. (2007). Progressive dehydration causes a progressive decline in basketball skill performance. *Medicine & Science in Sports & Exercise*, *39*(7), 1114–1123. doi: 10.1249/mss.0b013e3180574b02

Banisters TRIMP | Training Impulse. (2012). Retrieved April 2, 2020, from http://www.trainingimpulse.com/banisters-trimp-0

Barr, S. I. (1999). Effects of dehydration on exercise performance. *Canadian Journal of Applied Physiology*, *24*(2), 164–172. doi: 10.1139/h99-014

Barrack, M. T., Loan, M. D. V., Rauh, M. J., & Nichols, J. F. (2010). Physiologic and behavioral indicators of energy deficiency in female adolescent runners with elevated bone turnover. *The American Journal of Clinical Nutrition*, *92*(3), 652–659. doi: 10.3945/ajcn.2009.28926

Beelen, M., Burke, L. M., Gibala, M. J., & Loon, L. J. V. (2010). Nutritional strategies to promote postexercise recovery. *International Journal of Sport Nutrition and Exercise Metabolism*, *20*(6), 515–532. doi: 10.1123/ijsnem.20.6.515

Bholowalia, P., & Kumar, A. (2014). EBK-Means: A clustering technique based on elbow method and K-means in WSN. *International Journal of Computer Applications*, *105*(9), 17-24. doi: 10.5120/18405-9674

Brito, J., Fontes, I., Ribeiro, F., Raposo, A., Krustrup, P., & Rebelo, A. (2012). Postural stability decreases in elite young soccer players after a competitive soccer match. *Physical Therapy in Sport*, *13*(3), 175–179. doi: 10.1016/j.ptsp.2011.07.004

Burke, L. M. (2001). Nutritional needs for exercise in the heat. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *128*(4), 735–748. doi: 10.1016/s1095-6433(01)00279-3

Burke, L. M., Castell, L. M., Casa, D. J., Close, G. L., Costa, R. J. S., Desbrow, B., … Stellingwerff, T. (2019). International Association of Athletics Federations Consensus Statement 2019: Nutrition for Athletics. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 73–84. doi: 10.1123/ijsnem.2019-0065

Burke, L. M., Loucks, A. B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*(7), 675–685. doi: 10.1080/02640410500482602

Burke, L. M., Lundy, B., Fahrenholtz, I. L., & Melin, A. K. (2018). Pitfalls of conducting and interpreting estimates of energy availability in free-living athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 350–363. doi: 10.1123/ijsnem.2018-0142

Burke, L. M., & Mujika, I. (2014). Nutrition for recovery in aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(4), 425–436. doi: 10.1123/ijsnem.2014-0022

Burt, C. W., & Overpeck, M. D. (2001). Emergency visits for sports-related injuries. *Annals of Emergency Medicine*, *37*(3), 301–308. https://doi.org/10.1067/mem.2001.111707

Bytomski, J. R. (2017). Fueling for performance. *Sports Health: A Multidisciplinary Approach*, *10*(1), 47–53. doi: 10.1177/1941738117743913

Callister, R., Callister, R. J., Fleck, S. J., & Dudley, G. A. (1990). Physiological and performance responses to overtraining in elite judo athletes. *Medicine & Science in Sports & Exercise*, *22*(6), 816. doi: 10.1249/00005768-199012000-00014

Casamichana, D., Castellano, J., Calleja-Gonzalez, J., Román, J. S., & Castagna, C. (2013). Relationship between indicators of training load in soccer players. *Journal of Strength and Conditioning Research*, *27*(2), 369–374. doi: 10.1519/jsc.0b013e3182548af1

Castell, L. M., Nieman, D. C., Bermon, S., & Peeling, P. (2019). Exercise-induced illness and inflammation: can immunonutrition and iron help? *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 181–188. doi: 10.1123/ijsnem.2018-0288

Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? *Sleep Medicine Reviews*, *20*, 59–72. doi: 10.1016/j.smrv.2014.06.008

Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology*, *99*(3), 313–324. doi: 10.1007/s00421-006-0345-z

Cross, M. J., Williams, S., Trewartha, G., Kemp, S. P., & Stokes, K. A. (2016). The influence of in-season training loads on injury risk in professional rugby union. *International Journal of Sports Physiology and Performance*, *11*(3), 350–355. doi: 10.1123/ijspp.2015-0187

Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., Adams, W. M., Arent, S. M., … Casa, D. J. (2019). Contextual factors influencing external and internal training loads in collegiate men's soccer. *Journal of Strength and Conditioning Research*, *34*(2), 374-381. https://doi.org/10.1519/jsc.0000000000003361

Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., M. Arent, S., C. Armwald, B., … Casa, D. J. (2019). Seasonal accumulated workloads in collegiate men's soccer. *Journal of Strength and Conditioning Research*, Publish ahead of print, https://doi.org/10.1519/jsc.0000000000003257

Donahue PT, Wilson SJ, Williams CC, Hill CM, Valliant M, Garner JC. Impact of hydration status on jump performance in recreationally trained males. *International Journal of Exercise Science.* (In Press)

Drawer, S., & Fuller, C. W. (2002). Evaluating the level of injury in English professional football using a risk based assessment process. *British Journal of Sports Medicine*, *36*(6), 446–451. doi: 10.1136/bjsm.36.6.446

Drew, M. K., & Finch, C. F. (2016). The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sports Medicine*, *46*(6), 861-883. doi:10.1007/s40279-015-0459-8

Drew, M. K., Vlahovich, N., Hughes, D., Appaneal, R., Peterson, K., Burke, L., … Waddington, G. (2017). A multifactorial evaluation of illness risk factors in athletes preparing for the summer Olympic games. *Journal of Science and Medicine in Sport*, *20*(8), 745–750. doi: 10.1016/j.jsams.2017.02.010

Esquivel AO, Bruder A, Ratkowiak K, Lemos SE (2015). Soccer-related injuries in children and adults aged 5 to 49 years in US emergency departments From 2000 to 2012. *Sports Health*, *7*(4), 366-370. doi: 10.1177/1941738115579854

Finch, C. F. (1997). An overview of some definitional issues for sports injury surveillance. *Sports Medicine*, *24*(3), 157–163. doi: 10.2165/00007256-199724030-00002

Flack, K. D., Siders, W. A., Johnson, L., & Roemmich, J. N. (2016). Cross-validation of resting metabolic rate prediction equations. *Journal of the Academy of Nutrition and Dietetics*, *116*(9), 1413–1422. doi: 10.1016/j.jand.2016.03.018

Fondell, E., Lagerros, Y. T., Sundberg, C. J., Lekander, M., Bälter, O., Rothman, K. J., & Bälter, K. (2011). Physical activity, stress, and self-reported upper respiratory tract infection. *Medicine & Science in Sports & Exercise*, *43*(2), 272–279. doi: 10.1249/mss.0b013e3181edf108

Fuller, C., & Drawer, S. (2004). The application of risk management in sport. *Sports Medicine*, *34*(6), 349–356. doi: 10.2165/00007256-200434060-00001

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., … Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine and Science in Sports*, *16*(2), 83–92. doi: 10.1111/j.1600-0838.2006.00528.x

Gao, B., Dwivedi, S., Milewski, M. D., & Cruz, A. I. (2019). Lack of sleep and sports injuries in adolescents. *Journal of Pediatric Orthopaedics*, *39*(5), 324–333. doi: 10.1097/bpo.0000000000001306

Griffin, K. L., Knight, K. B., Bass, M. A. & Valliant, M. W. (2017). Predisposing risk factors and stress fractures in division I cross country runners. *Journal of Strength and Conditioning Research*, Publish Ahead of Print, doi: 10.1519/JSC.0000000000002408.

Hagglund, M., Walden, M., Bahr, R., & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Medicine*, *39*(6), 340–346. doi: 10.1136/bjsm.2005.018267

Hausswirth, C., & Mujika, I. (2013). Recovery for performance in sport. Champaign, IL: Human Kinetics.

Heikura, I. A., Uusitalo, A. L., Stellingwerff, T., Bergland, D., Mero, A. A., & Burke, L. M. (2018). Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(4), 403–411. doi: 10.1123/ijsnem.2017-0313

Herring , S. A., Boyajian-O'neill, L. A., Coppel, D. B., Daniels, J. M., Gould, D., Grana, W., … Putukian, M. (2017). Psychological issues related to illness and injury in athletes and the team physician. *Medicine & Science in Sports & Exercise*, *49*(5), 1043–1054. doi: 10.1249/mss.0000000000001247

Judelson, D. A., Maresh, C. M., Anderson, J. M., Armstrong, L. E., Casa, D. J., Kraemer, W. J., & Volek, J. S. (2007). Hydration and muscular performance. *Sports Medicine*, *37*(10), 907–921. doi: 10.2165/00007256-200737100-00006

Judelson, D. A., Maresh, C. M., Farrell, M. J., Yamamoto, L. M., Armstrong, L. E., Kraemer, W. J., … Anderson, J. M. (2007). Effect of hydration state on strength, power, and resistance exercise performance. *Medicine & Science in Sports & Exercise*, *39*(10), 1817–1824. doi: 10.1249/mss.0b013e3180de5f22

Junge, A., & Dvorak, J. (2000). Influence of definition and data collection on the incidence of injuries in football. *The American Journal of Sports Medicine*, *28*(5_suppl), 40–46. doi: 10.1177/28.suppl_5.s-40

Junge, A., Dvorak, J., Graf-Baumann, T., & Peterson, L. (2004). Football injuries during FIFA tournaments and the Olympic games, 1998-2001. *The American Journal of Sports Medicine*, *32*(1_suppl), 80–89. doi: 10.1177/0363546503261245

Kangas, N. (2020, April 2). Training Load. Retrieved from https://www.polar.com/blog/training-load-lets-talk-polar/.

Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., … Beckmann, J. (2018). Recovery and performance in sport: consensus statement. *International Journal of Sports Physiology and Performance*, *13*(2), 240–245. doi: 10.1123/ijspp.2017-0759

Kerr, Z. Y., Register-Mihalik, J. K., Pryor, R. R., Pierpoint, L. A., Scarneo, S. E., Adams, W. M., … Marshall, S. W. (2019). The association between mandated preseason heat acclimatization guidelines and exertional heat illness during preseason high school American football practices. *Environmental Health Perspectives*, *127*(4), 047003. doi: 10.1289/ehp4163

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*, *34*(7), 943–950. doi: 10.5665/sleep.1132

Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017). The acute:chonic workload ratio in relation to injury risk in professional soccer. *Journal of Science and Medicine in Sport*, *20*(6), 561-565. doi:10.1016/j.jsams.2016.10.014

Marriott BM, editor. Institute of Medicine (US) Committee on Military Nutrition Research; Nutritional needs in hot environments: applications for military personnel in field operations. Washington (DC): National Academies Press (US); 1993. 5, Water Requirements During Exercise in the Heat. Available from: https://www.ncbi.nlm.nih.gov/books/NBK236237/

Matthews, C. E., Ockene, I. S., Freedson, P. S., Rosal, M. C., Merriam, P. A., & Hebert, J. R. (2002). Moderate to vigorous physical activity and risk of upper-respiratory tract infection. *Medicine & Science in Sports & Exercise*, *34*(8), 1242–1248. doi: 10.1097/00005768-200208000-00003

Maughan, R. J., & Shirreffs, S. M. (2010). Development of hydration strategies to optimize performance for athletes in high-intensity sports and in sports with repeated intense efforts. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 59–69. doi: 10.1111/j.1600-0838.2010.01191.x

McFadden, B. A., Walker, A. J., Bozzini, B. N., Sanders, D. J., & Arent, S. M. (2020). Comparison of internal and external training loads in male and female collegiate soccer players during practices vs. games. *Journal of Strength and Conditioning Research*, *34*(4), 969–974. https://doi.org/10.1519/jsc.0000000000003485

Mcgregor, S., Nicholas, C., Lakomy, H., & Williams, C. (1999). The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. *Journal of Sports Sciences*, *17*(11), 895–903. doi: 10.1080/026404199365452

Melin, A. K., Heikura, I. A., Tenforde, A., & Mountjoy, M. (2019). Energy availability in athletics: health, performance, and physique. *International Journal of Sport Nutrition and Exercise Metabolism*, *29*(2), 152–164. doi: 10.1123/ijsnem.2018-0201

Meyer, F., O'Connor, H., & Shirrefs, S.M. (2009). Nutrition for the young athlete. *Journal of Sports Science, 27*(6), 73-82.

Milewski, M. D., Skaggs, D. L., Bishop, G. A., Pace, J. L., Ibrahim, D. A., Wren, T. A., & Barzdukas, A. (2014). Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *Journal of Pediatric Orthopaedics*, *34*(2), 129–133. doi: 10.1097/bpo.0000000000000151

Minshull, C., & James, L. (2013). The effects of hypohydration and fatigue on neuromuscular activation performance. *Applied Physiology, Nutrition, and Metabolism*, *38*(1), 21–26. https://doi.org/10.1139/apnm-2012-0189

Moder, K. (2010). Alternatives to F-Test in one way ANOVA in case of heterogeneity of variances (a simulation study). *Psychological Test and Assessment Modeling, 52*(4), 343-353.

Montain, S. J., Smith, S. A., Mattot, R. P., Zientara, G. P., Jolesz, F. A., & Sawka, M. N. (1998). Hypohydration effects on skeletal muscle performance and metabolism: A 31P-MRS study. *Journal of Applied Physiology*, *84*(6), 1889–1894. doi: 10.1152/jappl.1998.84.6.1889

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., … Ackerman, K. (2015). The IOC relative energy deficiency in sport clinical assessment tool (RED-S CAT). *British Journal of Sports Medicine*, *49*(21), 1354–1354. doi: 10.1136/bjsports-2015-094873

Nédélec, M., Halson, S., Abaidia, A.-E., Ahmaidi, S., & Dupont, G. (2015). Stress, sleep and recovery in elite soccer: A critical review of the literature. *Sports Medicine*, *45*(10), 1387–1400. https://doi.org/10.1007/s40279-015-0358-z

Nieman, D. C. (1994). Exercise, upper respiratory tract infection, and the immune system. *Medicine & Science in Sports & Exercise*, *26*(2), 128–139. doi: 10.1249/00005768-199402000-00002

Nimmo, M. A., & Ekblom, B. (2007). Fatigue and illness in athletes. *Journal of Sports Sciences*, *25*(sup1). doi: 10.1080/02640410701607379

Powell, R. (2017, June 1). Overuse injuries and periodization educational resources. Retrieved from http://www.ncaa.org/sport-science-institute/overuse-injuries-and-periodization-educational-resources.

Reed, J. L., De Souza, M. J. D., & Williams, N. I. (2013). Changes in energy availability across the season in division I female soccer players. *Journal of Sports Sciences*, *31*(3), 314–324. doi: 10.1080/02640414.2012.733019

Rosen, P. V., Frohm, A., Kottorp, A., Fridén, C., & Heijne, A. (2016). Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. *Scandinavian Journal of Medicine & Science in Sports*, *27*(11), 1364-1371. doi:10.1111/sms.12735

Rehrer, N. J. (2001). Fluid and electrolyte balance in ultra-endurance sport. *Sports Medicine*, *31*(10), 701–715. doi: 10.2165/00007256-200131100-00001

Saathoff, B. (2019, January 25). CoachMePlus Features - Applied Sports Science Suite of Tools. Retrieved from https://coachmeplus.com/features/.

Sale, C., & Elliott-Sale, K. J. (2019). Nutrition and athlete bone health. *Sports Medicine*. doi: 10.1007/s40279-019-01161-2

Sawka, M. N., Cheuvront, S. N., & Kenefick, R. W. (2012). High skin temperature and hypohydration impair aerobic performance. *Experimental Physiology*. doi: 10.1113/expphysiol.2011.061026

Sawka, M. N., Cheuvront, S. N., & Kenefick, R. W. (2015). Hypohydration and human performance: impact of environment and physiological mechanisms. *Sports Medicine*, *45*(S1), 51–60. doi: 10.1007/s40279-015-0395-7

Sawka, M. N., Wenger, C. B., & Pandolf, K. B. (2011). Thermoregulatory responses to acute exercise-heat stress and heat acclimation. *Comprehensive Physiology*. doi: 10.1002/cphy.cp040109

Smith, J. W., & Jeukendrup, A. (2013). Performance nutrition for young athletes. *Nutrition and Enhanced Sports Performance*, 523–529. doi: 10.1016/b978-0-12-396454-0.00055-2

Smyth, E. A., Newman, P., Waddington, G., Weissensteiner, J. R., & Drew, M. K. (2019). Injury prevention strategies specific to pre-elite athletes competing in Olympic and professional sports — A systematic review. *Journal of Science and Medicine in Sport*, *22*(8), 887–901. doi: 10.1016/j.jsams.2019.03.002

Stöhr, E. J., González-Alonso, J., Pearson, J., Low, D. A., Ali, L., Barker, H., & Shave, R. (2011). Dehydration reduces left ventricular filling at rest and during exercise independent of twist mechanics. *Journal of Applied Physiology*, *111*(3), 891–897. doi: 10.1152/japplphysiol.00528.2011

Walsh, N. P. (2019). Nutrition and athlete immune health: New perspectives on an old paradigm. *Sports Medicine*. doi: 10.1007/s40279-019-01160-3

Wilkins, J. C., Valovich McLeod, T. C., Perrin, D. H., & Gansneder, B. M. (2004). Performance on the balance error scoring system decreases after fatigue. *Journal of Athletic Training*, *39*(2), 156–161.

Winsley, R., & Matos, N. (2010). Overtraining and elite young athletes. *The Elite Young Athlete Medicine and Sport Science*, 97–105. doi: 10.1159/000320636

VITA

Ronald Corbit Franks Jr.

Experience

Assistant Athletic Trainer, Ole Miss Health and Sports Performance

July 2011 – Present

- Primary Athletic Trainer for the Women's Soccer Program (previously primary ATC for Men's & Women's Track and Field and Cross Country July 2011-July 2015)
- Supervise all student assistants in the Gillom Center Athletic Training Room
- Co-Supervise Internship program for students from CAATE Accredited programs
- Property Control & Inventory for University purchased equipment for all Athletic Training Rooms, Sports Nutrition and Sports Psychology
- Utilize Polar Wearable technology to Monitor loads placed on athletes during practices and games
- Communicate with all physicians, coaches and supervisors regarding health status of all athletes
- Movement Screening of all soccer athletes
- Disposal of expired medical records
- Assistant Manager for Gatorade Sports Summer Camps

Volunteer Intern Athletic Trainer, Ole Miss Health and Sports Performance

August 2010 – July 2011

- Assist Full time ATC's with Football and Track and Field and Cross Country in the daily management of the Athletic Training Room
- Assist with supervision of student assistants in Manning Center Athletic Training Room
- Assist with rehabilitation of athletic injuries
- Shadow physicians during clinic at Manning Center Athletic Training Room
- Other duties as assigned by Staff Athletic Trainers

Education

- University of Mississippi – Oxford, MS – PhD. in Sports Nutrition (Graduated May 2020) Dissertation—The Effects of Nutrition, Hydration, Exertion & Sleep on Injury and Illness in Female Collegiate Soccer Players
- University of Mississippi – Oxford, MS – MS in Nutrition (Graduated May 2013)
- Union University – Jackson, TN – BS in Athletic Training (CAATE Accredited Program)(Graduated May 2010)

Certifications

- Athletic Trainer NATA BOC (Certification #2000005439)
- MS State Board of Health (Licensure #AT0589)
- NPI Number 1710549795
- American Heart Association CPR/AED Certification
- NASM Corrective Exercise Specialist
- Selective Functional Movement Assessment Level I
- Functional Movement Screen Level I
- Graston Technique M1 Trained
- Mental Health First Aid
- Cosmed Bod Pod Certification
- Masters of Dry Needling Level I

Guest Lecture

- HP 303 Recovery and Therapeutic Technique Lecture Fall 2015
- HP 303 Recovery and Therapeutic Technique Lecture Spring 2016
- HP 303 Lower Body Mechanisms of Injury Fall 2016
- ES 391 Sports Nutrition & Injury Spring 2020
- NHM 719 NDSR Training Spring 2020

Presentations

- McCallum Place Eating Disorders in Sports Conference: Dietary Intake after Injury &/or Surgery: Where Athletes can Miss the Mark-Melinda Valliant, PhD., RD, Corbit Franks, MS, ATC, & Meredith Pendergast, MS, ATC
- Center for Health & Sports Performance Prevention Conference: Use of Technology in Player Reporting & Monitoring- Corbit Franks, MS, ATC, CES

Poster Presentations

- Morgan Delventhal, RD; Melinda W. Valliant, PhD, RD, CSSD; Kate Callaway MS, RDN, CSSD; Corbit Franks, MS, ATC, CES; Michaela Slatniske (2019). Comparison of ADP and ISAK Body Composition Assessment in D1 Collegiate Athletes. SCAN Symposium, Phoenix, AZ

Abstracts

- Frakes, Matthew; Valliant, Melinda W.; Crowther, Marshall; Michel, John; Callaway, Kate; Morgan, Becca; Franks, Corbit; Beyke, Andrew. (2019). **Collegiate Athletes That Consumed Adequate Energy Post-concussion Reported Fewer Days Of Concussion-related Symptoms.** Medicine & Science in Sports & Exercise: June 2019 - Volume 51 - Issue 6 - p 864–865.

Course Development

- Online Sports Nutrition- Upper Level Elective
- Assisted in development of MSAT program at University of Mississippi—approval granted by Mississippi Institute of Higher Learning Board of Trustees March 2020

References

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