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Relationship of Measures of Sleep Quantity and Quality with Performance Variables in NCAA Division I Female Soccer Players

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RELATIONSHIP OF MEASURES OF SLEEP QUANTITY AND QUALITY WITH
PERFORMANCE VARIABLES IN NCAA DIVISION I FEMALE SOCCER PLAYERS

By

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ABSTRACT

BACKGROUND: The growth in popularity of women’s soccer has led to an increased interest in the physical, physiological, and technical demands for these athletes. To meet these demands, optimal preparation and recovery are necessary. One growing area of interest in athletic performance is the role that sleep may have in preparation and recovery. However, details about sport-specific benefits of sleep are limited, particularly in female collegiate athletes. Athletes in the collegiate setting may suffer from lack of sleep due to the stresses of academics and athletics. Moreover, measurement of sleep in elite college soccer players using actigraphy does not exist in the literature. PURPOSE: To evaluate the relationship between sleep quantity and quality and soccer-specific performance variables in an elite group of female soccer players. METHODS: Eight NCAA college-aged competitive Division I women’s soccer players (18-23 yrs) participated in the study. Global Positioning Systems (GPS), heart rate monitoring and video analysis technologies were used during matches along with 24-hour actigraphy through the season. Actigraphy was also used to measure sleep quantity and quality. Data were collected for all 26 matches but only four competitive matches were included in the analysis as they met the following requirements: an evening match beginning at 1900 EST, time zones were not traveled across, goal differential was no more than two points (indicating a high level of competition) and for players’ data to be included they must have played at least 45 minutes of the 90-minute match. The night prior to the match was included for the data analyses of sleep quantity and quality. A multivariate analysis of variance (MANOVA) was utilized to determine whether the vectors of the means in groups of variables were significant. Paired t-tests were used to analyze if differences in variables of performance existed after the “best” and “worst” nights of sleep for quantity and quality. Significance was set at p<0.05. RESULTS: Mean sleep quantity and
quality for the “best” (575.0 ± 38.4 minutes, 91.9 ± 2.6% of time in bed spent sleeping) and “worst” (416 ± 57.6 minutes, 76.2 ± 12.1% of time in bed spent sleeping) nights were significantly different. The MANOVAs were not significantly different for the physiological and physical variables for quantity and quality of sleep. No differences in performance variables were observed after “best” and “worst” quantity sleep matches. However, differences existed between “best” and “worst” quality of sleep. Percent time spent exercising above 85% of the maximal heart rate (HRmax) was significantly lower after the “best” night of sleep (30.2 ± 13.5 vs. 47.9 ± 24.3%). Heart rate exertion was higher after the “best” night of sleep (518.5 ± 193.1 vs. 387.6 ± 148.9 AU) meaning the athletes were exercising at higher heart rates throughout the match without spending as much time in the anaerobic zone (>85%HRmax). High metabolic load distance (distance running at speeds greater than 19 km/hr and distance accelerating or decelerating quickly (>2 m/s²) was lower after the “best” quality night (11.8 ± 3.6 vs. 16.3 ± 6.0 yds/min) and the number of decelerations was higher after the “best” quality night (69.7 ± 28.1 vs. 50.6 ± 25.9) indicating less stress on the body. **CONCLUSION:** Quality of sleep is important for reducing the time spent exercising in the anaerobic zone (>85% HRmax). However the time spent exercising at high heart rates below the ventilatory threshold may be increased after a night of better sleep quality, indicating an increased aerobic capacity during a competitive women’s soccer match.
CHAPTER ONE

INTRODUCTION

Background

Soccer, one of the world’s most popular sports, requires “technical, tactical, and physical skills, all [of which] are important when evaluating performance differences in soccer” (Hoff, 2005). Interestingly, the physical demands of elite male soccer players are well documented in the literature, including match-specific variables (i.e. amount and characterization of the type of running performed, blood lactate levels, heart rate values and indicators of fatigue) (Bangsbo et al., 2006) and seasonal trends with respect to aerobic and anaerobic fitness, body composition and strength measurements (Kalapotharakos et al., 2011). However, with the well-known differences in hormones, injury patterns and body composition between males and females it cannot be expected to observe similar physiological responses in female athletes. Very little research has been conducted with female soccer players. Even a fairly comprehensive review of the physiological demands of soccer (Stolen et al., 2006) claimed that differences between sexes were non-existent but the review failed to include sufficient data on female athletes.

With the growth in popularity of soccer among females, the goal of many collegiate athletes is to play in professional leagues globally. Therefore there is a growing demand for the knowledge of specific physiological, technical and tactical demands of the sport in female athletes. There is a need to prepare females for their sport physically but up until this point there has been little research on the physical preparation needed for this population. With the wide breadth of current exercise physiology resources at the college level there still exists a lack of research in this population. These resources include access to experts in the fields of neurology, psychology and exercise science, performance laboratories, endurance and anaerobic testing
modalities, Global Positioning System (GPS) tracking, various fitness batteries, and specialized
strength and conditioning equipment and staff.

In addition to the requirements of competition, it is important to develop a more complete understanding of the events involved in preparation for these matches. To cope with the physical and psychological demands required, adequate preparation and recovery prior to competition is key. This includes injury prevention, nutritional intervention, strength, speed and power development, and psychological preparation. In addition, one area of particular interest that is often overlooked is the effect that sleep has on athletic performance (Davenne, 2009).

Researchers are attempting to understand the multifaceted benefits of sleep (Mah et al., 2008; Mah et al., 2011; Halston, 2013). Some studies have used actigraphy and sleep reports to demonstrate improved athletic performance, mood and vigor after a 2-hour extension from baseline of sleep in elite collegiate athletes (Mah et al., 2011). During the intervention period of one study, athletes had an increased mean sleep time of 110.0 ± 79.7 minutes (1.8 ± 1.3 hours). The increased sleep time was accompanied by improved free throw mean success rates from 7.9 ± 1.0 at baseline to 8.8 ± 1.0 (p<.001) and three-point field goal success (out of fifteen attempts) improved from 10.2 ± 2.1 to 11.6 ± 1.5 (p<.001). Time decreased over a 282 feet sprint from 16.2 ± 0.6 seconds to 15.5 ± 0.5 seconds (p<.001) while markers of reaction time, mood and well-being all significantly (p<.001) improved. However, what lies behind these improvements in performance is yet to be determined. That is, there is little research evaluating the specific physiological connections between sleep and athletic performance (Mah et al., 2011; Waterhouse et al., 2007). Anecdotal evidence suggests that it may be difficult for athletes to sleep due to stress prior to competition (Erlacher et al., 2011; Leeder et al., 2012; Juliff et al., 2014).
Therefore, interest is growing in the field of sleep and associated performance outcomes such as pass completion percentage, total distance covered, high velocity running and heart rate exertion.

Soccer is a particularly interesting sport to study with respect to sleep and these outcomes as the sport requires not only gross motor skills and coordination but at the elite level it requires high level thought processing and fine motor skills (Bangsbo et al., 2006). However studies evaluation the relationship between sleep and cognitive processing in elite soccer players are limited. In a small (n=8) group of trained soccer players, Reilly et al. (1983) demonstrated a deleterious effect on reaction time and neuromuscular coordination when sleep was rationed to 150 minutes (2.5 hours) per night for three successive nights. After just one night of only 150 minutes (2.5 hours) of sleep, subjects experienced slower reaction time performance on a two-choice visual reaction time assessment (p<0.05) and increased hand steadiness (p<0.05), which the authors suggest was indicative of a “decrease in spontaneous contractions in the arm musculature due to a reduced muscular tone.” Reilly et al. (1983) showed no decrements in anaerobic power during a stair run test, strength on an isometric grip test, expiratory lung function using a dry spirometer or endurance on an incremental treadmill test, respectively. Therefore the authors suggested that gross motor function may not be affected by acute sleep restriction but fine motor skills may decline.

In an attempt to apply this to the game of soccer, the complexity of a common skill in soccer, such as passing, can be observed. This skill requires spatial and temporal evaluation as well as fine motor involvement to elicit the precise biomechanical processes for the proper weight, flight and spin of the ball (Davids et al., 2000). If lack of sleep inhibits these fine motor skills then it would be likely that pass percentage, indicating primarily the accuracy of a kick, would be affected. With the observed outcomes in the aforementioned studies, this study aims at
evaluating the relationship between sleep quantity and quality and soccer-specific performance parameters in an elite group of female soccer players.

Therefore, the purpose of this study is to determine the acute effects of sleep quantity and quality on performance-specific and physiologic variables in division I female collegiate soccer players.

Specific Aims and Research Hypothesis

Specific Aim 1: To determine the extent to which sleep one night prior to a soccer match affects technical performance.

Hypothesis 1: A technical indicator of soccer performance, specifically percentage of passes completed, will be negatively affected by poor quality or quantity of sleep, one day before a match.

Specific Aim 2: To determine if sleep one night prior to a soccer match affects physical and physiological performance.

Hypothesis 2: Physical and physiological indicators of soccer performance will show decrements with poor sleep quality or quantity one night before a soccer match. Physical indicators of performance will be total distance covered per minute, high speed running per minute, high metabolic load distance per minute, accelerations, decelerations, and dynamic stress load. Physiological variables will be average heart rate, percentage of time spent exercising in the red zone and heart rate exertion.

The following assumptions for this study included:

1. All technology and research-associated equipment accurately recorded measurements over the course of the study. This includes the GPS units and software, the heart rate monitors, the actigraph watches and the video analysis components.
2. The athletes involved in the study wore the sleep monitors based on directions given. The watches were worn on the non-dominant wrist at all times, excluding training sessions and matches throughout the season.

**Delimitations**

The following delimitations for this study included:

1. Twenty-one active, healthy, pre-menopausal NCAA division I female soccer players between the ages of 18-24 years were recruited from the Florida State University soccer team.
2. Subjects were healthy and did not have any underlying diseases or medical conditions that prevented them from competing throughout the season.
3. Performance measure data were collected from four evening matches, meeting the following criteria: time zones were not traveled across, goal differential was no more than two (indicating a high level of competition) and for a player’s data to be included she must have played at least 45 minutes of the 90-minute match.

**Limitations**

The major limiting factors of this study included:

1. Diet and extra-curricular activities could not be controlled throughout the study.
2. Menstrual cycle timing was not recorded.
3. Actigraphy data were not validated using self-reported sleep logs. Due to technical error, some nights of sleep data were excluded from the final analysis.
4. The variables of Dynamic Stress Load and High Metabolic Load distance using the GPS data were based on proprietary algorithms.
**Definition of Terms**

**Dynamic Stress Load (DSL):** Measured in arbitrary units. DSL is a proprietary calculation that incorporates the total of weighted vertical and horizontal impacts and accelerations to the athlete. It is a representation of the mechanical stress of load placed on the body during activity. It may be considered an indicator of fatigue when this variable reaches significantly high values (when compared to a given subject’s normative values). This value should not be compared across players.

**Heart Rate Exertion (HRE):** Measured in arbitrary units (AU) and based on the work of Polar® (Kempele, Finland). It is calculated as the time spent in each “heart rate zone” multiplied by a weighing factor. Heart rate zones and weighing factors were 90-100% of the maximal heart rate ($HR_{max}$), 5; 80-89% $HR_{max}$, 4; 70-79% $HR_{max}$, 3; 60-69% $HR_{max}$, 2, 50-59% $HR_{max}$, 1. $HR_{max}$ values were determined during the Yo-Yo Intermittent Recovery Test (YYIRT) (Bangsbo et al. 2008).

**High Metabolic Load Distance (HML distance):** Measured in kilometers (km). The calculation combines distance running at speeds greater than 19 km·hr⁻¹ and distance accelerating or decelerating quickly ($>2m·s^{-2}$) (Oschnach et al., 2010; di Prampero et al., 2005; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004).

**Percentage of Passes Completed (Pass%):** This is the total number of passes attempted divided by the passes attempted, expressed as a percent.
**Sleep Debt**: Measured in hours. Accumulated sleep lost over the course of days or weeks, that must be “paid back” in order to avoid energy, mood and cognition deficits (Dement, 1999).

**Time in “Red Zone” (RZT)**: Measured in minutes. This is the time spent exercising at a heart rate greater than 85% of $HR_{max}$.

**Total Distance (TOT distance)**: Measured in meters. Determined from the GPS recordings using a proprietary interpolation algorithm that incorporate accelerometer data. This includes distance covered during match-time only, excluding warm-up and cool-down periods.

**Yo-Yo Intermittent Recovery Test 2 (YYIR2)**: Measured in distance covered (units). Compared to the Level 1 test (YYIR1), level 2 (YYIR2) starts at a faster speed and increases quicker. This modality involves specifically evaluating an individual’s anaerobic energy system contribution. It consists of 2 x 20 m shuttle runs, increasing in speed. Between each shuttle is a 10-second active recovery. Timing is controlled by recorded audio signals indicating when an individual should be starting the shuttle and when they should complete it. When an individual can no longer maintain the speed dictated, this indicates the end of the test. The YYIR2 test should last between 5 and 15 minutes. It is a valid measure for the ability to perform repeated intense exercise bouts, mirroring the requirements of a soccer match (Bangsbo et al. 2008).
CHAPTER TWO

LITERATURE REVIEW

Women and Soccer

Soccer is atop the world’s most admired pastimes and is played by males and females, children and adults, recreational and professional athletes (Sporis et al, 2009). However, with a high proportion of the population playing this sport, there is limited descriptive information aside from characteristics of elite male soccer players. The demands of the game are well described in males so it is important to review the relevant literature in this population. With the implementation of Title IX and women’s equality in athletics more women are playing sports now than ever before, especially in college (NCAA 2011). Therefore, there is a particular need for research in female athletes and the specific physiological demands of the sport in this group.

Physiologic Demands and Measurement

Soccer, an intermittent endurance sport, requires a multifaceted approach to preparation given that the sport consists of short bouts of intense exertion in the form of sprinting, jumping, sliding, diving, and tackling throughout a 90-minute competition (Stolen et al, 2005). During the 90-minute competition, elite male soccer players run approximately 10 km at an “intensity close to anaerobic threshold or 80-90% of maximal heart rate” (Hoff et al 2002). However there are breaks throughout the game where recovery may take place. Therefore aerobic capacity is vital to performance and maintenance of activity throughout the entire match (Stone and Kilding, 2009). Soccer is composed of three important components: maximal oxygen uptake (VO$_2$max), anaerobic threshold, and running/work economy (Hoff et al, 2002). VO$_2$max is the ‘ceiling’ of an athlete’s ability to exchange gases during exercise and is considered the measurable limit to aerobic capabilities. However the ability to maintain a high percentage of the VO$_2$max may be
more important for the success of intermittent athletes. The anaerobic threshold often lies between 80-90% of maximal values in elite intermittent athletes (Stølen et al. 2005; Alexandre et al., 2012). Specific methods of improving the lactate threshold in athletes vary. It has been proposed that implementation of a resistance training program may improve oxygen uptake and utilization values significantly by improving running and work economy (Saunders et al. 2004).

**Oxygen Consumption**

Due to difficulty of precise field testing in a sport like soccer, there are limited published studies on oxygen consumption during competitive soccer games. Literature suggests that elite male soccer players exercise at approximately 70-80% of VO$_2$ max (Bangsbo, 1994; Bangsbo, Mohr, & Krustrup, 2006), based on exercising heart rate and the relationship between this and VO$_2$. VO$_2$max values for elite male players range from 55-65 ml/kg/min (Davis, Brewer, & Atkin, 1992; Tonnessen, Hem, Leirstein, Haugen, & Seiler, 2013), suggesting an average exercising VO$_2$ of 35 to 50 ml/kg/min. Females typically exhibit lower maximal and exercising VO$_2$ values and a limited number of studies estimate these values to be approximately 55 ml/kg/min (Haugen et al., 2014; Vescovi et al., 2006).

**Heart Rate**

In addition to measures of VO$_2$, given the wide variety of physiological demands of match play, researchers monitor comprehensive individual demands by observing exercising heart rate. According to Alexandre et al. (2012), average heart rate values typically range between 80-90% of the HR$_{max}$ throughout the match, corresponding to values between 165 and 175 beats per minute (bpm) in females (Andersson et al., 2010; Barbero-Alvarez, Gomez-Lopez, Barbero-Alvarez, Granda, & Castagna, 2008; Krustrup et al., 2005). Heart rate values have been shown to oscillate throughout a match. Heart rate plateaus in the onset of the first half and
remains within the range of 165-175 bpm, significantly decreases during halftime and then rises again and reaches a plateau during the second half (Coehlo et al., 2010).

**Blood Lactate**

Soccer also requires “repeated high-intensity efforts and/or sprints for a couple of minutes,” (Bucheit et al 2012) indicating that the anaerobic system needs extensive development. Blood lactate is often observed to indicate markers of anaerobic capacity. Lactate values in males reach levels as high as 7 mmol/L during simulated soccer matches (Stølen et al 2005) indicating an advantage to have a developed anaerobic energy system. Other researchers have reported blood lactate values in males between 3-7 mmol/L (Krustrup et al., 2006; Aslan et al., 2012; Russell et al., 2014) during and immediately following competitions. No research on anaerobic capacity in elite female soccer players with the use of blood lactate values has been published.

**Physical Demands**

Similar to the physiological demands in females, much of what is known about the physical aspect of soccer competitions has been inferred from research on their male counterparts. Distance covered by field players varies depending on position, but the average in professional athletes lies between 9 and 13 kilometers per match, with midfielders covering considerably more than all other field positions (Andrzejewski et al., 2012; Andrzejewski et al., 2013; Bloomfield et al., 2007; Bradley et al., 2013; Di Salvo et al., 2013). Goalkeepers cover the least amount of distance, typically about 3-6 km. The single study conducted in college-age females with respect to math-specific distance data suggest that females cover less distance than males by approximately 2-4 km (Vescovi & Favero, 2014). Over the 8-9 km covered during the match, a larger percentage of the movements are lower intensity compared to males. However, until researchers begin to calculate running intensities (low, medium, high) as a percentage of an
individual’s maximal speed rather than absolute speed, the characterization of “high-speed”
running and the associated metabolic demands remain unclear. In one recent study “high-speed”
running was defined by running faster than 27 km/hr (Bradley et al., 2014), a speed that most
females may not even be able to reach during maximal effort, leading to little, if any, measured
high-speed running in a match. This is likely not the case. If competitive female matches mirror
those of their male counterparts, then according to recent research utilizing video analysis, most
distance covered is via jogging and walking. High intensity running and sprinting accounts for
about 12-13 minutes of the 90-minute match (Bradley, Di Mascio, Peart, Olsen, & Sheldon,
2010). In addition to linear running, the game is defined by a variety of unorthodox movements,
which can increase the caloric and metabolic cost compared to simply running. These include
running backwards and sideways, accelerating, decelerating, jumping, sliding, changing
directions, tackling and shooting (Bloomfield et al., 2007; Osgnach et al., 2010).

Technical Observations

With respect to the technical aspect of soccer, performance outcomes vary widely
depending on skill level of the player and of the opposing team, match conditions and officials
(referees). For male professional teams most average 5 shots “on goal” out of a total of 15 shots.
They gain possession 40-50 times, of which the ball is touched two to three times. For high level
players a success rate of 66-78% pass completion is expected of the 40-60 passes attempted
throughout the game (Carling & Dupont, 2011; Lago-Penas & Lago-Ballesteros, 2011;
Rampinini et al., 2009; Russell et al., 2013). A more recent study showed that a passing success
rate of about 86% was sustained in professional males throughout the duration of the match
(Harper et al., 2014). According to unpublished data from our research laboratory, elite female
collegiate soccer players demonstrate similar technical abilities as their male counterparts. The
meant percentage of completed passes over the course of a match was 80%, declining to approximately 70% during the last 15 min of the match.

**Sleep and the Athlete**

Sleep, which accounts for approximately a third of an athlete’s life, is often overlooked as a key to improving performance in this population. However, interest in the area of how sleep affects performance is growing as athletes search for the key to optimal preparation for, and recovery from, training and competition (Samuels, 2009).

**Sleep Physiology**

Sleep is defined as “a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment” (Carskadon & Dement, 2011). Although universally-required, the function of sleep is still not fully understood. One hypothesis for the purpose of sleep is that it is a time for repair and regeneration, indicated by growth hormone (GH) and other endocrine fluctuations spurred by sleep (Takahashi et al., 1968, Spiegel et al., 2004). Takahashi et al. demonstrated a surge in GH with the onset of “deep sleep” and when sleep was delayed by 3 hours, this peak was significantly smaller. This indicates that the importance of timing may also be a key in reaping the restorative benefits of sleep.

Although the reason for the need to sleep is unknown, components of sleep have been uncovered. Electroencephalogram (EEG), electromyogram (EMG) and electrooculogram (EOG) recordings have allowed researchers to discover the sleep cycles and stages occurring with a normal night of sleep. Sleep begins in non-rapid-eye-movement (NREM) Stage 1 and progresses through stages 2, 3 and 4 before entering into rapid-eye-movement (REM). This progression represents one cycle of sleep and lasts between 70-120 minutes, with an average of 90 minutes (Carskadon & Dement, 2011).
Specific brain waveforms on the EEG accompany each stage of sleep. Upon entering a sleep episode the EEG shows a transition from alpha-waves (characteristic of wakefulness) to K-complexes, sleep spindles and low voltage, mixed frequency waves in NREM stages 1 and 2 (Carskadon & Dement, 2011). These waveforms are associated with memory consolidation (Gais et al., 2002). As deeper stages of NREM sleep are attained the EEG shows an accumulation of high voltage, slow-wave activity and arousal threshold peaks. The final stage in one sleep cycle is REM. REM is characterized by an EEG marked by low-voltage, mixed frequency waves, an EMG showing muscle atonia with occasional twitches, and an EOG with bursts of rapid eye movement, often visible through the eyelids (Carskadon & Dement, 2011). This last observation is what gives REM its name. With each progressive cycle of sleep, REM becomes longer, pointing to the importance of accumulating uninterrupted hours of sleep throughout the night (Carskadon & Dement, 2011).

The circadian rhythm, often referred to as the “body clock,” plays an important role in the regulation of sleep. It is generated by neural structures in the hypothalamus and further dictated by the light-dark cycle (but can operate in the absence of it when necessary) (Dunlap et al., 2004). The suprachiasmatic nuclei are the structures responsible for processing light and dark input from the retina (Colten et al., 2006). They regulate the circadian rhythm in all body organs by synchronizing the input received and subsequently resetting the rhythm-responsible genes to be in coordination with one another. A number of molecular pathways are thought to be responsible for this regulation of the 24-hour cyclic rhythm, affecting a whole multitude of physiologic responses; the rhythm coordinates the sleep-wake cycle and modulates body temperature, hormone release, hunger, satiety, heart rate, respiration and brain activity (Carskadon & Dement, 2011).
Sleep and Performance

Aside from the projected physiological benefits of sleep, there is evidence that extension of sleep from sub-optimal levels can have significant improvements on athletic performance (Mah et al., 2011; Waterhouse et al., 2007). With the limited number of sleep studies conducted in athletes much of what is known and practiced among the athletic population must be inferred from data collected from sedentary populations (Driver et al., 1994; Samuels, 2009; Leeder et al., 2012; Halson, 2014).

Anecdotal evidence and limited available research suggests that athletes playing a range of elite team and individual sports may suffer from difficulty sleeping prior to important competitions due to sleep interruptions (Erlacher et al., 2011; Leeder et al., 2012; Juliff et al., 2014). This may be due to the excitement and anxiety associated with competition, resulting in unwarranted arousal and delaying the onset of sleepiness (Shephard, 1984; Shapiro, 1981). The physiological explanation to this phenomenon begins with the fear of failure or the “socio-evaluative threat” associated with competitions (Suay et al., 1999). This stress can lead to an increased production and release of cortisol, the stress hormone, from the hypothalamic-anterior-pituitary (HPA) axis, leading to altered sleep patterns (Miller et al., 2002; Buckley et al., 2005). Research suggests that this potential restriction of sleep may lead to a variety of decrements in performance, particularly with respect to mood, cognitive performance, reaction time and coordination (Underwood, 2010; Blumpert et al., 2007). Interestingly, one study showed that despite self-reported sleep of athletes prior to competition being considered inadequate, objective measurement via actigraphy showed regular sleep patterns (Richmond et al., 2007).

Deprivation sleep studies, during which sleep is withheld from subjects, are conducted in an attempt to observe physiological, cognitive and psychological outcomes. They have provided
a few clear messages. A single night of sleep deprivation is associated with insulin resistance and continued accumulated sleep debt has shown a strong relationship with obesity, hypertension, diabetes, depression, myocardial infarction and stroke (Colten et al., 2006). There is strong evidence indicating that chronic restricted sleep, decreased as little as 7 hours per night can have a variety of deleterious effects on cognitive abilities, including attention, concentration and alertness (Belenky et al., 2003; Wesensten et al., 2005; Kendall et al., 2006; Van Dongen et al., 2003; Doran et al., 2001). It has also been suggested that lack of sleep can impact problem solving and decision-making (Linde et al., 1992, Harrison et al., 1999; Killgore et al., 2006; Linde et al., 1999). Cognitive performance decreases after one night of sleep deprivation and is similarly affected with continued partial sleep restriction (Van Dongen et al., 2003). This study observed the effect of restricted sleep on cognitive performance using psychomotor vigilance tasks (PVT). Nightly sleep was restricted to 8, 6, or 4 hrs for a total of 14 days, or was restricted completely for 3 days. For the 6- and 4-hr restriction conditions, PVT lapses were significantly greater than the 8-hr condition. The group with complete sleep restriction for three days experienced significantly increased numbers of lapses than in those three days relative to the 8-hr condition. Van Dongen et al. (2003) also found that 14 days of 4-hr sleep restriction resulted in similar PVT response times compared to 2 days of total sleep restriction.

There are few studies observing the association between sleep and performance in athletes (Halson, 2014); the studies that do exist are convincing (Driver et al., 1994; Samuels, 2009; Leeder, 2012). With respect to partial sleep deprivation, after two nights of decreased sleep time athletes seem to be unaffected when the exercise was a single bout of all-out effort but when multiple submaximal efforts were required, performance decreased significantly (Reilly et al., 1983). For example eight male subjects were allocated 3 hours of sleep per night for three
successive nights after a baseline night of normal sleep. Subjects were given submaximal and maximal weightlifting tasks (biceps curl, bench press, leg press and dead lift). There was no significant effect on maximal biceps curl but there were significant decreases ($p<.01$) in performance of all submaximal tasks performed after the second night of restricted sleep.

A subsequent study observed partially-reduced sleep and swimming performance, showing that there were no decrements in swim times, lung function or back/grip strength after 4 nights of sleep restricted to 150 minutes (2.5 hours) per night (Sinnerton & Reilly, 1992). Similar to other studies, Sinnerton and Reilly found that although performance was not directly affected during testing, the subjects suffered from altered mood states (tension, depression, confusion, anxiety, and fatigue). When motor skills and reaction time were tested during exercise on a treadmill following partial sleep deprivation, the investigators found that gross motor functioning remained intact but psychomotor skills significantly decreased after just one night of sleep deprivation (Reilly & Deykin, 1983). Thus, while major muscle function seems to be unaffected by sleep loss, there seems to be a different result for smaller, more precise and calculated movements and mood which may be important for soccer performance.

Observation of sleep in elite college soccer players using actigraphy does not exist in the literature. However limited data utilizing sleep journals and surveys do exist in the general college student population. According to one study, college students at a large private university exhibited a mean sleep time of approximately $421.0 \pm 69.0$ minutes ($7.0 \pm 1.1$ hours) but sleep patterns were erratic (Lund et al., 2010). Sleep in this student population was particularly restricted on weeknights with recovery sleep occurring on the weekends. Data were collected utilizing an online survey comprised of five published scales measuring stress, mood and sleep. In a study observing the sleep habits of elite athletes (mean age $22.2 \pm 3.0$ years), researchers
reported that team-sport athletes in the study accumulated approximately 420 ± 72 minutes (7.0 ± 1.2 hours) of sleep per night (Lastella et al., 2015).

Another study conducted at a large international university utilized 7-day sleep logs and showed that female college students had a mean sleep time of 419.0 ± 60.0 minutes (7.0 ± 1.0 hours) on weekdays and 466.0 ± 78.0 minutes (7.8 ± 1.3 hours) on weekends (p < .001) (Tsai et al., 2004). Based on reported sleep this cohort had a median value of 0.8 awakenings per night and spent 36.0 ± 22.7 minutes (0.6 ± 0.4 hours) napping on weekdays. Sleep efficiency, defined as [time asleep x 100/time in bed] was calculated to be 92.1 with a semi-interquartile range of 3.4 on weekdays whereas it was calculated to be 93.3 ± 3.8 on weekends (p < .01). Lund et al. (2010) and Tsai et al. (2004) suggested a variety of factors involved in the restricted sleep that college students experience including reduced adult supervision compared to early adolescence, access to controlled and uncontrolled substances and unstructured daily schedules. Although these concerns exist in the collegiate athlete population, there have been no studies to date observing this population.

Although sleep deprivation studies have been insightful with respect to physiologic response to lack of sleep, it cannot be assumed that the relationship between sleep and performance is linear from zero to twelve hours of sleep. Furthermore, although athletes may experience difficulty in sleeping, it is unlikely that sleep is completely withheld prior to competitions. Herein sleep extension studies can be useful. A group of researchers at a competitive private university on the west coast conducted the first sleep extension studies in athletes. The first was conducted with the men’s varsity division I basketball team (Mah et al., 2011). With an increase in mean sleep time of 110.0 ± 79.7 minutes (1.8 ± 1.3 hours), measured using actigraphy and sleep logs, athletic performance indices improved by about 9%, indicated
by free throws and three-point field goal percentages. Out of ten free throws, mean success rates improved from 7.9 ± 1.0 at baseline to 8.8 ± 1.0 following sleep extension (p < .001) and three-point field goal success (out of fifteen attempts) improved from 10.2 ± 2.1 to 11.6 ± 1.5 (p < .001). In addition, sport-specific sprint time decreased from 16.2 ± 0.6 seconds to 15.5 ± 0.5 seconds (p < .001) over a 282 feet sprint and markers of reaction time, mood and well-being improved, all significantly (p < .001). This same study also introduced the idea that many athletes underestimate the amount of sleep they get each night, leading to an accumulated sleep debt much greater than they may realize. Subjects underestimated actual sleep time by up to 116 minutes per night. For example, during the baseline testing period, mean sleep time measured using actigraphy was 400.7 ± 61.8 minutes (6.7 ± 1.0 hours) but subject sleep journals indicated estimations of 470.0 ± 65.9 minutes (7.8 ± 1.1 hours). In the sleep extension segment of the study, the same pattern was observed; a mean sleep time of 507.6 ± 78.6 minutes (8.46 ± 1.3 hours) was measured via actigraphy whereas subjective sleep time was estimated to be 624.2 ± 68.4 minutes (10.4 ± 1.14 hours).

The second study, conducted by the same group of researchers, observed sleep extension in collegiate swimmers. After extending sleep to approximately 9 hours per night, athletes showed improvements in 15-meter sprint time from 6.98 ± 0.99 to 6.47 ± 0.64 sec (p < .05), reaction time off the block from 0.88 ± 0.20 to 0.73 ± 0.13 sec (p < .05) and turn time from 1.10 ± 0.20 to 1.00 ± 0.22 sec (p < .05). The researchers also reported significant improvements (p < .05) of subjective markers of mood and sleepiness via the Profile of Mood States (POMS) and the Epworth Sleepiness Scale (ESS), respectively (Mah et al., 2008).
Physiologic, Technical and Tactical Measurements

In recent years, a number of technologies have been developed and utilized to measure physical, technical and tactical properties of soccer matches. The primary method of collecting these data is through video analysis (Amisco® and Prozone®). Players are “tagged” in a video recording of a match using identifying features and the video is submitted to be analyzed post-game by the company. Movements and technical skill (including passes completed, attempted, intercepted, shots on goal, etc.) are analyzed and returned to the team and/or staff for review. According to a number of researchers, this video analysis tool is reliable and valid when observing the team or average values for the desired variables (Barris & Button, 2008; Carling et al., 2008; Castellano et al., 2014; Edgecomb & Norton, 2006).

In addition to video analysis, GPS is in the spotlight as a potential new, more precise alternative to video analysis. The three main companies employing the new technology are Catapult®, STATSport®, and GPSport®. In addition to measuring player movements during the match via the GPS receiver, each device contains an accelerometer, magnetometer and gyroscope to evaluate 3-dimensional movements, speed and acceleration. With respect to the validity and reliability of GPS, studies indicate an error of less than 3% when observed speed and distance are compared to measured variables utilizing electronic timing gates or video analysis (Barbero-Alvarez, Coutts, Castagna, & Granda 2010; Coutts & Duffield, 2010; Rawstorn, Maddison, Ali, Foskett, & Grant, 2014). These studies were performed using subjects walking and/or running on linear and curvilinear tracks. As such, error may be introduced when lateral movements, such as those oftentimes observed in soccer and other field sports, are introduced. However, with the combined use of GPS (and the associated accelerometer, gyroscope, and magnetometer) and video analysis, a clearer picture of the physical and technical
demands of the game will certainly be elucidated. The combination of all of these technologies allow observation of a variety of performance metrics, including dynamic stress load, heart rate exertion, high metabolic load distance, number of passes attempted, number of passes completed, percentage of passes completed, time in “red zone”, and total distance covered.

**Measuring Sleep Quantity and Quality**

Polysomnography, the gold standard for measurement of sleep, includes the observation of brain activity, eye movements, muscle tone and heart rate (Carskadon & Dement, 2011; Halson 2014). Together these variables can be observed to accurately and precisely measure sleep quantity and quality. Due to the expense and invasive nature of requiring an individual to sleep in an unfamiliar setting, this is a difficult mode to utilize for measuring sleep in elite athletes.

One alternative to polysomnography is actigraphy. This technology involves wrist or ankle-worn devices that measure subject movements, via an accelerometer, corresponding to awake versus sleep periods. Although some researchers argue that this method inaccurately classifies many wake periods as sleep when the wearer is simply lying still in bed (Pollak et al., 2001; Paquet et al., 2007), it has been validated as an acceptable method to quantify sleep in non-sleep disordered populations (Littner et al., 2003; Morgenthaler et al., 2007). Certain varieties of the technology have a measured accuracy of up to 93% compared to polysomnography (Russell et al., In press), though most commercially available devices are closer to 83-85% accurate.

**Conclusion**

It is clear that success in the game of soccer is multifactorial. Success, defined by scoring more goals than the opponent, is a result of the cumulative effects of individual, team and environmental factors. This creates a complicated research environment. Trying to parse
preparation, fatigue, in-game factors and injury as possible indicators of success is difficult. However, a few observations are certain with respect to a competitive soccer match. The specific physiologic demands require the harmonious coordination of multiple organ systems. Carrying out the technical and physical demands of a competitive match requires fine and gross motor skills, high-level cognitive functioning and problem solving, psychological preparation and confidence. With the knowledge that sleep extension may significantly improve performance, many questions are left unanswered. It would seem that sleep trends and indices of performance collected from actual matches across a competitive season would be related, but which specific markers of soccer performance might be affected by sleep patterns? Are sleep patterns in a specific group of female collegiate soccer players at an elite program different from the normal college student? Can performance outcomes in a specific match be affected by deficits in sleep? Specifically, are sleep quantity and quality two days and one day prior to competition related to indices of soccer performance? With the limited number of studies examining sleep patterns in elite athletes, the purpose of this study is to describe these patterns and the association between measures of sleep and performance in elite female collegiate soccer players using retrospective data.
CHAPTER THREE
RESEARCH METHODS

Subjects

All of the twenty-one collegiate female soccer players (20.6 ± 1.4 years old) on the Florida State University women’s NCAA division I varsity team (100%) agreed to participate in this study. Height and weight were measured on a standard physician’s scale (SECA, Mexico) (Table 1). Approval for this research was granted by The Florida State University Institutional Review Board (Appendix A).

Design

A single case (soccer team) study over four matches was used in this project. Within the team, all players were measured on all variables. Performance measure data were collected from four evening matches, meeting the following criteria: time zones were not traveled across, goal differential was no more than two (indicating a high level of competition) and data were only included when the player was on the field for greater than 45 minutes of the 90-minute match. These criteria were established in attempt to control for accumulated fatigue, due to the condensed schedule of collegiate soccer, and circadian factors possibly affecting performance.

One technical variable (percentage of passes completed, six physical variables (total distance covered per minute, high speed running per minute, high metabolic load distance per minute, accelerations, decelerations, dynamic stress load) and three physiological variables (average heart rate, percentage of time spent exercising in the red zone and heart rate exertion) were measured for the four chosen matches. Sleep quantity and quality associated with one and two nights prior to the four matches were compared to each other and were then categorized as
“best” and “worst” night for the two sleep variables of quantity (total minutes of nightly sleep) and quality (percent time sleeping while in bed).

Instrumentation

The main variables of interest were sleep quantity and sleep quality and the technical, physical and physiological variables of performance during competitive Atlantic Coast Conference (ACC) soccer matches.

Sleep Quantity. Sleep quantity was measured using Readiband™ actigraph watches (Fatigue Science, Honolulu, HI, USA). Quantity was defined as the number of minutes of sleep during the night. Each band contained a 3D accelerometer that measured the precise timing and frequency of wrist movements 16 times per second (16 Hz), a storage chip and a 1.5V battery. This information was processed and converted to data showing periods of “sleep,” “wake,” and “off-wrist.” This particular actigraph technology is 93% accurate when compared to polysomnography (Russell et al., in press). Actigraphy data were scored by a validated proprietary algorithm through commercially available software (Fatigue Science™).

Sleep Quality. Sleep quality was measured as the percentage of time spent sleeping while in bed; specifically, sleep latency and wake episodes were combined to represent a percentage of time asleep of the total time in bed.

Physical Measures. STATSports Viper Pod® units were assigned to each subject. These units contained a Global Positioning System (GPS) module (10 Hz), a gyroscope (100 Hz), a tri-axial accelerometer (100 Hz), a magnetometer (100 Hz) and a 3-dimensional digital compass. The units were utilized for every match, training, and fitness session and/or testing. Specialized sport bras were created to hold the pods with a custom-sized pocket located between the subject’s two scapulae, just below cervical vertebrae. Specific variables were calculated or
observed from the data collected via the GPS units (exact calculations are proprietary to STATSports) Total distance (TOT) was observed, defined as the distance covered by an individual during a match; High Metabolic Load distance (HML distance) was calculated, defined as the combination of distance running at speeds greater than 19 km/h and distance accelerating or decelerating quickly (>2 m/s²); Dynamic stress load, a proprietary calculation to STATSports, incorporating the total weighted vertical and horizontal impacts and accelerations which represented the mechanical stress of load placed on the body, was measured.

**Physiological Measures.** A Polar® heart rate monitor (Polar Team 2, Polar Electro, Kempele, Finland) was worn using a chest strap. Data were logged at 100 Hz. Heart rate variables observed included heart rate exertion (HRE) and time in red zone (RZT). HRE is calculated as the time spent in each heart rate “zone” multiplied by a weighing factor. The units for this variable are arbitrary units and may indicate total strain on the heart during a match. RZT is defined as the time (min) exercising at a heart rate greater than 85% of HRmax measured during the Yo-Yo Intermittent Recovery Test 2 (YYIR2).

**Technical Measures.** Video analysis was conducted by a third party (Prozone®, Leeds, UK) for all competitive matches throughout the season. Prior to the match, cameras were set up around the field to capture video. Players were tagged on a computer by position and physical characteristics (i.e. “long brown hair, pink shoes, yellow headband”). Following each match, individual match video and player descriptions were uploaded to the Prozone® website and within 24 hours match stats were returned to the coaching staff for review. This analysis provided the number of passes attempted, number of passes completed, and the percentage of passes completed.
Procedure

The researcher approached the head coach with the proposal of doing a research study utilizing the team members’ sleep and performance data. Once IRB permission was given the following procedures were taken:

Prior to participating a verbal explanation of the research was given. The purpose of the study was explained to the subjects so they could get a better understanding of how sleep and soccer performance were related. Informed consent was obtained from members of the team prior to initiation of the study (Appendix B). The data used in this study were collected beginning August 6th when the women reported for preseason training.

Actigraph watches were given to the subjects on August 6th. They were instructed to wear the watch at all times with the exception of training sessions and matches. Watches were collected every three weeks for download of actigraphy data using software installed on a single laptop computer in the soccer facility. The watches were then charged by the researchers on the provided charging dock. This time frame typically coincided with match-time and therefore watches were returned directly to the subjects following the match. Sleep tips were verbally given to members of the team the week prior to competition by the head coach with consultation from a sleep expert employed by Fatigue Science. These tips often varied in phrasing but content remained similar including the following: (1) try to get to sleep by 10:30 pm the night before the game, (2) on game day try to take a 30 min nap in the afternoon before the pre-game meal, and (3) after the evening game, try not to use electronics after 11pm (Phone, TV, computer, iPad).

During preseason all subjects performed the Yo-Yo Intermittent Recovery Test 2 (YYIR2). This fitness battery required each subject to run a measured 20-meter course out-and-back, with a 10-second rest between bouts. The pace increased with each successive level as set
by the CD recording (Nike Sparq®, Beaverton, Oregon) and failure to complete two shuttle runs resulted in termination of the test. The final level completed successfully was translated into the subject’s score. The highest heart rate attained during the test was also considered maximal heart rate.

Prior to every match and training session each subject put on a Polar® heart rate monitor so it fit snugly across their chest. The GPS pods were turned on and placed in the pockets by the strength and conditioning staff. Live data feed capability allowed the researchers to ensure data collection throughout the session. After each session, the investigators collected all heart rate straps and pods. Raw data were downloaded from the units.

One hour before every match three cameras were set up surrounding the field for collection of video to be sent to Prozone® for third-party technical analysis of each player. The cameras were placed behind each goal and above the press box. At the conclusion of the game, video from the three vantage-points was electronically submitted to Prozone® in addition to names and physical characteristics of players for analysis of technical performance. Passing percentage was calculated using the number of completed passes a player made divided by the total number attempted. A pass was considered completed when a member of the same team received the ball.

GPS and heart rate data collection continued through the competitive season until the National Championship game on December 7th, totaling 106 days of collection (26 matches and 80 training days). Prozone® data were collected on the 26 match days. Data were collected for all 26 matches but only four competitive conference matches met the criteria of having no more than a 2-point score differential. The quantity and the quality of sleep two nights prior to the four matches and the technical, physical and physiological data of the matches were included for the
Data analyses. These nights of sleep have been reported to be the most important in observation of acute effects of sleep deficit (Van Dongen et al., 2003).

**Data Analysis**

Descriptive data are presented as means ± standard deviations (SD). Measurements of sleep included sleep quantity (total minutes in bed) and quality (sleep latency and wake episodes). The variable for technical performance included percentage of passes completed (Pass%) and variables of physical performance included total distance covered per minute (TOT/min), high speed running per minute (HSR/min), high metabolic load distance per minute (HML/min), accelerations, decelerations, and dynamic stress load (DSL). Physiological variables included average heart rate (AvgHR), percentage of time spent exercising in the red zone (%RZT) and heart rate exertion (HRE). Actigraphy data for included subjects were visually inspected to categorize sleep quantity and quality as either “best” or “worst” night sleep of the nights preceding the four matches. The “best” or “worst” night sleep for quantity and quality may not have been associated with the same match for the subjects. A repeated measures multivariate analysis of variance (MANOVA) was used to test for differences in means between related groups of variables. The two groups were physical variables (TOT/min, HSR/min, HML/min, accelerations, decelerations and DSL) and physiological variables (Avg HR, %RZT, and HRE). The technical group (Pass %) was excluded from the MANOVA as it is a single variable. Sleep quantity and quality were analyzed for the subjects and technical, physical and physiological variables were compared between “best” and “worst” quantity and quality of sleep by paired t-tests. All significance was accepted at p≤ 0.05 and was described by Cohen’s d effect size coefficient.
CHAPTER 4

RESULTS

Subject Characteristics

Of the 21 players, eight college-aged competitive female soccer players were included in the final analysis since they met the criteria of having played at least 45 minutes of the four 90-minute matches observed. Subject characteristics are shown in Table 1.

Pre-season Testing

The average distance covered during the Yo-Yo test was 1430.0 ± 142.0 m and average maximal heart rate was 203.0 ± 8.0 bpm (Table 1). The VO$_{2\text{max}}$ estimated by the Yo-Yo test was 48.4 ± 4.4 ml/kg/min, a value calculated using a predictive equation (Bangsbo et al., 2008).

Table 1. Age, Anthropometric Characteristics and Preseason Performance on Fitness Battery in Collegiate Women Soccer Players (N=8)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>20.6</td>
<td>1.4</td>
<td>18.0-23.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.8</td>
<td>6.1</td>
<td>160.0-180.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.7</td>
<td>5.3</td>
<td>58.1-71.2</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>19.3</td>
<td>4.3</td>
<td>12.8-24.7</td>
</tr>
<tr>
<td>Yo-Yo (Level)</td>
<td>35.8</td>
<td>3.8</td>
<td>29.0-40.0</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>1430.0</td>
<td>142.1</td>
<td>1160.0-1600.0</td>
</tr>
<tr>
<td>Maximal HR (bpm)</td>
<td>203.0</td>
<td>8.0</td>
<td>196.0-219.0</td>
</tr>
<tr>
<td>Estimated VO2 Max (ml/kg/min)</td>
<td>48.4</td>
<td>4.4</td>
<td>46.1-49.8</td>
</tr>
</tbody>
</table>

Heart Rate (HR); Maximal Oxygen Consumption (VO2 Max)

Sleep Quantity and Quality

Mean sleep quantity and quality over the entire season were 480.1 ± 79.1 minutes per night (8.0 ± 1.3 hours) and 85.4 ± 8.1% efficiency, respectively. Sleep quantity prior to games ranged from 305.0 to 625.0 minutes per night, and quality ranged from 55.7% to 96.8%. A
secondary analysis was conducted to observe if differences existed between the two nights prior to match day for the observed “best” and “worst” nights of sleep (Table 2). Data points were missing for quantity and quality of sleep the second night prior to “best” night sleep for two subjects. Sleep quality was missing for two subjects the night prior to “worst” night sleep and for quantity for one subject. The mean of the “best” quantity night was 575.0 ± 38.4 minutes of sleep per night. When comparing quantity of sleep two nights prior to the match (533.0 ± 63.4 minutes) to the “best” quantity night sleep, although not statistically different, this value approached significance (p=0.051). There were no differences in quantity of sleep between the second night and “worst” night sleep (p=0.294), nor were there differences between the two nights prior to the matches analyzed for “best” and “worst” night of sleep for quality of sleep (p=0.21, p=0.17). With no differences existing between two nights prior to the match and the “best” and “worst” night sleep for quantity and quality, and evidence suggesting that performance deficits can be observed after just a single night of sleep deprivation (Van Dongen et al., 2003), the night sleep prior to each match was used in all analyses for sleep quantity and quality. Of the four nights the “best” quantity and “worst” quantity were selected and the matches following those nights for each subject were used for the analyses. The data analyzed for each subject may have been from different games of the four selected matches. The quantity of sleep between the best and worst nights was significantly different (“Best”: 575.0 ± 38.4 minutes vs. “worst”: 416 ± 57.6 minutes, p=.00). The same occurred for “best” and “worst” quality nights of sleep. Sleep quality prior to a match, defined as the percent of time asleep while in bed, differed significantly from the “best” and “worst” night sleep (“best”: 91.9 ± 2.6% vs. “worst”: 76.2 ± 12.1%, p=.01).
Table 2. Values for Sleep Quantity and Quality Between One and Two Nights Prior to Matches in Collegiate Women Soccer Players

<table>
<thead>
<tr>
<th>Variable</th>
<th>Night 1</th>
<th>Night 2</th>
<th>M diff</th>
<th>SD</th>
<th>Cohen’s d</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep Quantity (min)</td>
<td>575.00</td>
<td>38.41</td>
<td>533.00</td>
<td>63.40</td>
<td>42.00</td>
<td>45.77</td>
<td>0.82</td>
<td>2.43</td>
</tr>
<tr>
<td>Sleep Quality (%)</td>
<td>91.90</td>
<td>2.62</td>
<td>90.17</td>
<td>2.84</td>
<td>1.73</td>
<td>3.27</td>
<td>0.63</td>
<td>1.40</td>
</tr>
<tr>
<td>Worst</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep Quantity (min)</td>
<td>416.25</td>
<td>57.55</td>
<td>437.88</td>
<td>64.48</td>
<td>-21.63</td>
<td>53.97</td>
<td>0.35</td>
<td>-1.13</td>
</tr>
<tr>
<td>Sleep Quality (%)</td>
<td>76.21</td>
<td>12.06</td>
<td>85.67</td>
<td>4.89</td>
<td>-9.46</td>
<td>15.90</td>
<td>0.56</td>
<td>-1.57</td>
</tr>
</tbody>
</table>

Standard Deviation (SD); Mean of the difference (M diff); Effect size (Coden’s d); t-statistic (t); Degrees of freedom (df); p-value (p)

**Relationship between “Best” and “Worst” Night Sleep with Technical, Physical and Physiological Measures**

Prior to conducting the paired t-tests, MANOVAs were conducted to test whether there were differences among means of the variables tested within each of the two groups of the physical and physiological measurements. For the physical and physiological variables and quality of sleep the differences were approaching significance, Wilk’s λ = .58, F(1,7)= 5.09, p< .06, η² = .42 and Wilk’s λ = .61, F(1,7)= 4.44, p< .08, η² = .39, respectively. No significant differences were found for sleep quantity and the associated physical (Wilk’s λ = .66, F(1,6)= 3.10, p< .13, η² = .34) and physiological (Wilk’s λ = .97, F(1,6)= .183, p< .68, η² = .03) variables.

Technical, physical and physiological variables between the “best” and “worst” nights of sleep quantity did not differ significantly (Table 3). Although there were no significant differences between the “best” and “worst” nights of sleep there were high effect sizes for some
of the variables ranging from .75 to .87. Variables with high effect sizes included %RZT, accelerations, and DSL.

Table 3. Values for “Best” and “Worst” Quantity Night Sleep for Technical, Physical and Physiological Variables in Collegiate Women Soccer Players (N=7)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best Night</th>
<th>Worst Night</th>
<th>Cohen's d</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Sleep Quantity</td>
<td>575.00</td>
<td>38.41</td>
<td>416.25</td>
<td>57.55</td>
<td>3.24</td>
</tr>
<tr>
<td>Pass% (%)</td>
<td>69.52</td>
<td>11.87</td>
<td>71.32</td>
<td>12.24</td>
<td>0.15</td>
</tr>
<tr>
<td>Avg HR (bpm)</td>
<td>153.39</td>
<td>13.21</td>
<td>163.29</td>
<td>22.94</td>
<td>0.55</td>
</tr>
<tr>
<td>%RZT (%)</td>
<td>26.89</td>
<td>21.33</td>
<td>45.76</td>
<td>28.46</td>
<td>0.76</td>
</tr>
<tr>
<td>HRE (AU)</td>
<td>406.94</td>
<td>154.96</td>
<td>343.72</td>
<td>119.23</td>
<td>0.46</td>
</tr>
<tr>
<td>Distance/min (yds/min)</td>
<td>96.41</td>
<td>29.22</td>
<td>107.51</td>
<td>34.89</td>
<td>0.35</td>
</tr>
<tr>
<td>HSR/min</td>
<td>3.22</td>
<td>1.89</td>
<td>3.31</td>
<td>1.93</td>
<td>0.05</td>
</tr>
<tr>
<td>HML dist/min (yds/min)</td>
<td>14.55</td>
<td>6.50</td>
<td>15.36</td>
<td>6.69</td>
<td>0.12</td>
</tr>
<tr>
<td>Accelerations (#)</td>
<td>39.86</td>
<td>15.36</td>
<td>29.00</td>
<td>11.86</td>
<td>0.80</td>
</tr>
<tr>
<td>Decelerations (#)</td>
<td>57.71</td>
<td>22.79</td>
<td>46.43</td>
<td>20.24</td>
<td>0.52</td>
</tr>
<tr>
<td>DSL (AU)</td>
<td>401.07</td>
<td>110.42</td>
<td>311.04</td>
<td>97.39</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Percentage of completed passes (Pass%); Average heart rate (Avg HR); Percent time spent at >85% Maximal Heart rate (%RZT); Heart rate exertion (HRE); High speed running (HSR); High metabolic load (HML); Dynamic stress load (DSL).

When observing sleep quality, the indicator chosen to represent the technical performance variable (passing percentage) was not different between the “best” and “worst” nights of sleep. However, a number of physiological and physical variables showed differences between the “best” and “worst” night of sleep. Results for variables after the “best” and “worst” quality night of sleep are presented in Table 4.

Percent of time spent working at 85% of the maximal heart rate (%RZT) was higher (47.9 ± 24.3%) after the “worst” quality night of sleep compared to after the “best” quality night of sleep (30.2 ± 13.5%)(p=.04). Heart rate exertion was higher after the “best” night of sleep (518.5 ± 193.1 AU vs. 387.6 ± 148.9 AU, respectively, P value) compare to following the “worst” night
of sleep. High metabolic load distance (HML) per minute of game time played was higher (16.3 ± 6.0 yds/min vs. 11.8 ± 3.6 yds/min, respectively, p value) after the “worst” quality night compared to after the “best” quality night of sleep. The number of decelerations was lower 50.6 ± 25.9 following the “worst” night compared to 69.7 ± 28.1 after the “best” night of sleep. Again although not significant there were high effect sizes for Avg HR (.76), Distance/min (.73), HSR (.76), and DSL (.79).

Table 4. Values for “Best” and “Worst” Quality Night Sleep for Technical, Physical and Physiological Variables in Collegiate Women Soccer Players (N=8)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best Night</th>
<th></th>
<th>Worst Night</th>
<th></th>
<th>Cohen's d</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep Quality</td>
<td>91.90</td>
<td>2.63</td>
<td>76.21</td>
<td>12.06</td>
<td>1.19</td>
<td>3.37</td>
<td>0.01</td>
</tr>
<tr>
<td>Pass% (%)</td>
<td>76.68</td>
<td>9.94</td>
<td>74.05</td>
<td>9.83</td>
<td>0.27</td>
<td>0.75</td>
<td>0.48</td>
</tr>
<tr>
<td>Avg HR (bpm)</td>
<td>153.24</td>
<td>12.17</td>
<td>166.80</td>
<td>11.52</td>
<td>0.76</td>
<td>-2.15</td>
<td>0.07</td>
</tr>
<tr>
<td>%RZT (%)</td>
<td>30.20</td>
<td>13.46</td>
<td>47.89</td>
<td>24.34</td>
<td>0.87</td>
<td>-2.45</td>
<td>0.04</td>
</tr>
<tr>
<td>HRE (AU)</td>
<td>518.51</td>
<td>193.15</td>
<td>387.59</td>
<td>148.92</td>
<td>0.85</td>
<td>2.42</td>
<td>0.05</td>
</tr>
<tr>
<td>Distance/min (yds/min)</td>
<td>90.42</td>
<td>20.96</td>
<td>111.81</td>
<td>22.54</td>
<td>0.73</td>
<td>-2.06</td>
<td>0.08</td>
</tr>
<tr>
<td>HSR/min</td>
<td>2.10</td>
<td>0.91</td>
<td>3.41</td>
<td>1.78</td>
<td>0.76</td>
<td>-2.17</td>
<td>0.07</td>
</tr>
<tr>
<td>HML dist/min (yds/min)</td>
<td>11.84</td>
<td>3.59</td>
<td>16.28</td>
<td>5.97</td>
<td>0.87</td>
<td>-2.46</td>
<td>0.04</td>
</tr>
<tr>
<td>Accelerations (#)</td>
<td>44.88</td>
<td>21.17</td>
<td>34.13</td>
<td>16.88</td>
<td>0.68</td>
<td>1.93</td>
<td>0.09</td>
</tr>
<tr>
<td>Decelerations (#)</td>
<td>69.75</td>
<td>28.14</td>
<td>50.63</td>
<td>25.87</td>
<td>1.06</td>
<td>2.99</td>
<td>0.02</td>
</tr>
<tr>
<td>DSL (AU)</td>
<td>410.43</td>
<td>137.05</td>
<td>305.70</td>
<td>90.82</td>
<td>0.79</td>
<td>2.25</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Percentage of completed passes (Pass%); Average heart rate (Avg HR); Percent time spent at >85% Maximal Heart rate (%RZT); Heart rate exertion (HRE); High speed running (HSR); High metabolic load (HML); Dynamic stress load (DSL).
CHAPTER 5

DISCUSSION

Acute and chronic sleep deprivation have been shown to affect a variety of technical, physical and psychological variables in many settings. These observations are limited in athletes and particularly in elite soccer players. The current study aimed to observe differences between quantity and quality of sleep prior to match day and the variables associated with performance in respective matches following those nights of sleep. Technical performance as indicated by passing percentage completed was not affected by sleep quantity or quality and our first hypothesis was rejected. However, certain physical and physiological indices of performance such as time in the red zone and high metabolic load distance were improved significantly when sleep quality was increased. Although other variables were not significantly different high effect sizes (> .70) were seen for AvgHR, Distance/min, HSR/min, accelerations and DSL. Therefore, it may be possible to affect physical or physiological performance outcomes by improving quality of sleep in athletes prior to match day.

Sleep Quantity and Quality Findings

Relative to the sleep patterns of normal college students (week days: 419.0 ± 60.0 minutes; Weekends: 466.0 ± 78.0 minutes)(Tsai et al., 2004), the athletes in the present study accumulated an in-season mean of 480.1 ± 79.1 minutes (8.0 ± 1.3 hours) of sleep per night. The “best” sleep quantity for these athletes (575.0 ± 38.4 minutes) was approximately 100 minutes longer than the average for college students. The subjects in the current study had an average of 85.4% of time sleeping while in bed (efficiency) through the season, whereas typical college students reported approximately 92.1% sleep efficiency (Tsai et al., 2004). Therefore, this population may be accumulating sleep debt at a greater rate than their non-athlete cohort. Our
findings are similar to Lastella et al. (2015) who reported mean sleep time of team-sport athletes to be approximately 420 ± 72 minutes (7.0 ± 1.2 hours) and mean sleep efficiency to be approximately 86.4 ± 4.8%.

Mechanisms can not be determined with the current study design, however the findings suggest that sleep quality prior to match day may have a greater effect on certain physical and physiological performance variables compared to sleep quantity. A possible explanation for differences in quantity and quality is that sleep quality is negatively influenced by the up-regulation of the sympathoadrenal response, often seen during brief awakenings during a night of sleep (Samuels et al., 2008). So even if athletes are spending more time asleep, if that sleep is consistently interrupted due to stress or the fear of failure or disappointment by family, friends, peers, teammates and coaches as discussed by Suay et al. (1999) then the restorative benefits of the deep-sleep stages may be compromised. This may ultimately lead to decrements in physical and physiological variables during a competitive soccer match.

Although sleep quantity is important, according to our results, it may be more important to begin measuring the quality component of sleep. Most of the research available measuring sleep in athletes uses sleep diaries but with the growth of accelerometer technology and widespread availability of various activity trackers, it is now possible to get a more accurate picture of sleep architecture in athletes. There is a need for more information about the sleep requirements of this group with the knowledge that sleep quality influences cardiovascular outcomes and may play a critical role in muscle regeneration and repair post-exercise (Takahashi et al., 1968; Spiegel et al., 2004). In a population engaging in intense exercise often throughout a condensed season, efficient muscle repair may not be achieved due to insufficient rest time. This observation suggests more research is needed to compare collegiate athletes with their non-
athlete student counterparts and develop a plan to assist student-athletes with improving sleep quality.

**Technical Findings**

In this study technical performance, measured as percentage of passes successfully completed, was unchanged following the “best” and “worst” nights of sleep. This is in contrast to the work of Mah et al. (2011) who showed improvements in sport-specific performance after sleep extension. It is certainly possible that passing percentage was not robust enough to show differences between the passing percentages for entire games. Also, in-game variables were used in the present study compared to a simplified post-practice shooting task used in previous work which excluded any complicating factors associated with game-specific performance (i.e. competition level, referee decision, field conditions). Additionally, it may be more effective to show pass percentages throughout the progression of the game versus overall pass percentage means. This is supported by unpublished data from our laboratory suggesting that pass percentage decreases significantly in the final 15 minutes of the match. By observing pass percentage during the last 15 minutes of the match it may be possible to observe differences in the rate of accumulating effects of fatigue and sleep deprivation after a night of poor sleep. This is particularly important in night games, when the body is accustomed to begin the process of preparing for sleep.

**Physical and Physiological Outcomes**

During team-sport competition, importance is placed on quick and precise decision-making. The physiological indications of sleep deprivation were apparent following the “worst” quality night of sleep. RZT was significantly increased, indicating that there may be a physiological mechanism creating strain on the heart after a night of poor sleep. One possible
explanation for RZT decrease versus HRE increase following the “best” quality night of sleep is that subjects with “best” quality of sleep were able to exercise at higher heart rates for longer without entering the red zone. In other words, following their “best” sleep, the athletes spent more time in the aerobic zone (<85% maxHR) without having to deplete anaerobic substrates at higher heart rates (>85% maxHR). This is in agreement with Mougin et al. (1989) who reported increases in heart rate during submaximal work in endurance athletes following moderately disturbed sleep one night prior to a submaximal exercise protocol at 75% of VO₂max. Although these results do not precisely mirror our findings of increased time above 85% HRmax, they support the notion that poor quality sleep may lead to increased heart rates. The authors suggested there may be an aerobic pathway impairment following poor sleep quality. Due to the nature of this research, this suggestion is purely speculative.

In agreement with Mougin et al. (1989) who demonstrated higher heart rate during submaximal activity in seven male endurance athletes after one night of 3 hours of partial sleep restriction, the current investigation showed a deleterious effect on aerobic performance and heart rate response when sleep quality was sub-optimal. However, unlike many studies observing sleep and performance this specific group of athletes demonstrated significant changes to certain cardiovascular variables measured. Total sleep deprivation one night prior to exercise has been shown to decrease endurance performance on repeated squats in a 50-minute protocol and reduced time to exhaustion on a submaximal ergometer cycle test (Thun et al., 2015) and the current study illustrates that deteriorated sleep quality, indicating a long sleep latency or numerous interruptions through the night also has a significant effect on performance.

Motivation, perceived exertion and psychological effects have often been cited as potential explanations for sleep-deprivation associated deficits in performance (Thun et al.,
The ability to maintain concentration and decision-making throughout a match is required at the elite level. Unfortunately research supporting this idea does not exist over the course of a competitive match due to the inherent difficulties of in-game assessment using subjective and objective methods. It is possible that the increased number of decelerations measured after the “best” night of sleep was an indicator of increased cognitive ability and thought-processing. That is, each deceleration requires coordinated motor unit contraction and the ability to make precise, calculated muscle movements. Although logical to conclude this is purely speculative. Additionally, higher HML distance in the match following the “worst” quality night of sleep may suggest that high speed movements are required to maintain appropriate positioning, win the ball, and keep possession. This is in contrast to thinking in advance and anticipating the positioning needed through the match. These findings may, indeed, support the idea that thought processing and cognitive abilities during competitive match play may be affected by sleep quality. Even though pass% was unaffected by sleep quantity or quality, other indirect indices of soccer performance were influenced including time in the red zone, average heart rate and high metabolic load distance.

**Limitations and Future Research**

One major limitation of the current study was the case-study nature of the research and no manipulation of the subjects could be done. Other limitations were that the subjects involved in the study were educated about sleep prior to having measurements taken, had different living and sleeping arrangements, did not document menstrual cycle timing or record in food logs prior to matches. However, the purpose of this research was to gain a better understanding of the sleep quantity and quality of these elite female athletes prior to competition and their subsequent
game-specific performance. The only way to truly measure game-time performance was to observe matches like the present study rather than in simulated testing environments.

Further investigation of sleep habits through the season and the architecture of sleep prior to matches are necessary in order to gain a better understanding of the sleep needs in this elite population. Specifically, it is important to know if the same results hold true in other collegiate soccer programs and competitive sport programs. If so, then it may be worthwhile for athletic teams to invest in educational programs for the athletes guiding them on how to improve sleep quality. It also may be useful to investigate interventions used for sleep difficulties in this population to prevent interrupted sleep prior to matches. It is also important to investigate the mechanisms behind the physiological responses of the cardiovascular system with poor quality of sleep, however care must be taken not to extrapolate data from controlled settings and expect similar results in a high-level competitive match.

**Conclusion**

Although one night of poor quantity sleep does not seem to have a significant effect on physical or physiological performance in this group of elite female soccer players quality of sleep is important for reducing their time spent exercising in the anaerobic zone (>85% HRmax). Further, large effect sizes for %RZT, accelerations and DSL indicate quantity of sleep may, indeed, affect physiological and physical performance. Furthermore the time spent exercising at high heart rates below the ventilatory threshold may be increased after a night of better sleep quality, indicating an increased aerobic capacity during a competitive women’s soccer match.
APPENDIX A

IRB PERMISSION

Office of the Vice President for Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

APPROVAL MEMORANDUM

Date: 09/01/2015
To: Marissa Abegg
Address:

Dept.: NUTRITION FOOD AND EXERCISE SCIENCES

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
Mattresses of Sleep Quality and Quantity Correlating with Performance in Division I Female Soccer Players

The application that you submitted to this office in regard to the use of human subjects in the proposal referenced above have been reviewed by the Secretary, the Chair, and two members of the Human Subjects Committee. Your project is determined to be Exempted per 45 CFR § 46.110(C) and has been approved by an expedited review process.

The Human Subjects Committee has not evaluated your proposal for scientific merit; except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 11/30/2015 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the chairman of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: Lyna Parenton <lpanton@admin.fsu.edu>, Advisor
HSC No. 2014.14096
APPENDIX B

INFORMED CONSENT

INFORMED CONSENT DOCUMENT

I give voluntary consent to be a participant in the research project “Sleep and Competition Performance in Division I Collegiate Women Soccer Players” conducted by Marisa Abegg, B.A., of the Department of Nutrition, Food & Exercise Sciences at The Florida State University.

The purpose of this project is to examine the correlation of sleep and performance metrics of female collegiate women soccer players during the competitive season. Data in this project will be used from Florida State University female soccer players between the ages of 18-23 years.

My participation in this project will involve performing in NCAA sanctioned colligate soccer matches while competing for Florida State University during the Fall 2014 season. My sleep will be measured by looking at the data collected on my FatigueScience® actigraph watch. My performance metrics will be collected with the Polar® heart rate straps and STATSports® GPS data. My technical statistics will be calculated from Prozone® analysis systems.

I understand there is a minimal level of risk if I agree for my biological and technical data to be collected and analyzed. However, there will be no additional risk to that of competing in a 90-minute soccer match.

Before each match I will put on a Polar® heart rate monitor and STATSports® GPS “pod” and will wear it during warm-up and throughout the entire period of play. I will be wearing the monitors throughout each game of the fall 2014 season. I will wear the FatigueScience® actigraph watch 24 hours per day every day, with the exception of games.

The possible benefits of my participation in this research project include observing how sleep quantity and quality one and two days before competition is correlated with performance.

Information obtained during the course of the study will remain confidential, to the extent allowed by the law. The results of this research project may be published but my name and/or identity will not be included in the publication. My name will not appear on any of the results. No individual responses will be reported. Only group findings will be reported in publications. Confidentiality will be maintained by assigning each participant a code number and recording all data by code numbers. The only record with the participant’s name and code number will be kept in a locked file in a locked office in the office of Marisa Abegg.


HSC # 2014.14096
Any questions I have concerning this research project or any aspect of my participation, before or after my consent, will be answered by the investigators or they will refer me to a knowledgeable source. I understand that I may contact Marisa Abegg or contact Lynn Panton at (850) 644-4685, email, lpanton@fsu.edu for answers to questions about this research project or my rights. Group results will be sent to me upon my request.

In case of injury, or if I have any questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I can contact the chair of the Human Subjects Committee, Institutional Review Board, through the Office of the Vice President for Research, at (850) 644-7900.

The nature, demands, benefits and risks of the project have been explained to me. I knowingly assume any risks involved. I have read the above informed consent document. I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefits to which I may otherwise be entitled. In signing this consent form, I am not waiving my legal claims, rights, or remedies. A copy of this consent form will be given to me.

______________________________  ___________________________  _________________
(Participant Name)  (Participant Signature)  (Date)

HSC # 2014.14096
REFERENCES


Marisa Abegg is currently in her 2nd year of study in the Department of Nutrition, Food & Exercise Sciences. She will graduate with her Master of Science in December 2015. Prior to her graduate studies, Marisa graduated with her BA in Human Biology with a concentration of Exercise Physiology and Human Nutrition from Stanford University. She also played soccer during her four years at Stanford University and continued to play professionally in the U.S. for three seasons.