THE EFFECT OF SLEEP QUALITY AND SLEEP QUANTITY ON CONCUSSION ASSESSMENT

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ABSTRACT

ERIC LENGAS: The Effect of Sleep Quality and Sleep Quantity on Concussion Assessment
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Proper concussion assessment is imperative for properly caring for athletes who sustain traumatic brain injuries. Decreased sleep quality and sleep quantity affect cognition and may threaten the validity of clinical measures often employed as a part of the concussion assessment. The purpose of this study was to determine if sleep quality or quantity affect performance on clinical measures of concussion and if changes in sleep quality or quantity are associated with changes in performance on clinical measures of concussion. We performed preseason baseline testing on 155 student-athletes; 56 were re-evaluated ten weeks later. Sleep quality and quantity data were collected during each testing session. Subjects with low sleep quantity at baseline reported a greater number of symptoms and more severe symptoms. Sleep quantity at baseline did not affect any concussion assessment measures. Also, there was no association between changes in sleep quality or quantity and changes in concussion assessment measures.

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CHAPTER I

INTRODUCTION

Concussion, a form of mild traumatic brain injury, is one of the most severe injuries an athlete of any level can sustain. It has been estimated that 1.6 to 3.8 million of these injuries occur each year during sports related activities, and it has been suggested that the number may actually be higher due to under reporting (Langlois, Rutland-Brown, & Wald, 2006; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Specifically at the collegiate level, concussions have been reported to constitute 6.2% of all injuries sustained by National Collegiate Athletic Association (NCAA) student athletes (Covassin, Swanik, & Sachs, 2003). The short-term effects of concussion are widely recognized in the medical community and include, but are not limited to, balance deficits, loss of concentration, memory and rapid visual processing, headache, nausea, sensitivity to light and sound, blurred vision and a feeling of being in a fog. Decreased cerebral function may be present for several days or weeks due to a series of ionic, metabolic, and physiologic events that occur immediately following a concussion (Giza & Hovda, 2001). In addition to the initial impairment, potentially life altering ramifications such as increased susceptibility to additional concussion, and late life cognitive impairment have also been discovered (Guskiewicz et al., 2005; Guskiewicz et al., 2003). There is also a risk of Second Impact Syndrome, which can result in major cognitive impairments and death when a patient sustains a second impact before symptoms associated with an initial injury have fully resolved (Cantu & Gean, 2010; Wetjen, Pichelmann, & Atkinson, 2010).

Combining the high prevalence of concussions and the potential severity of their implications to student athletes' health has resulted in an increased awareness and sensitivity towards the assessment and management of concussion. It is imperative that patients are returned to activity safely to minimize the risk of recurrence and the potential cumulative effects of concussion. For this reason, the National Athletic Trainers' Association and the National Academy of Neurophysiology recommend the use of pre-season baseline testing of the cognition, postural stability, and self-reported symptoms of concussion, to establish a patient-based standard to which these functions can be compared following concussion. However, the comparisons made between baseline test and follow up testing are only valid if the baseline test truly represents normal functioning for the athlete, and extraneous factors influencing the scores such as previous concussions, age, learning disabilities, attention deficit/hyperactivity disorder (ADHD), and previous neuropsychological testing are taken into account (Grindel, Lovell, & Collins, 2001).

Sleep quantity and quality may be one of many factors that affect the outcome of these concussion assessments. Decreases in sleep quantity have been shown to decrease cognitive function in several studies (Buboltz, Brown, & Soper, 2001; Deary & Tait, 1987; Jacques, Lynch, & Samkoff, 1990; Kelly, Kelly, & Clanton, 2001; Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002; Pilcher, Ginter, & Sadowsky, 1997; Robbins & Gottlieb, 1990; Trockel, Barnes, & Egget, 2000; Tsai & Li, 2004; Williamson & Feyer, 2000). Research focusing on medical residents, who often work in a sleep deprived state, showed that subjects performed worse on cognitive testing when they were sleep deprived than when they had received a normal night's sleep (Deary & Tait, 1987; Robbins & Gottlieb, 1990). Research performed during the "Hell Week" period of Navy SEAL training, when trainees may be sleep deprived for up to 72 hours, demonstrated that the cognitive test scores were significantly degraded after such sleep deprivation (Lieberman, et al., 2002). A similar study involving U.S. Army Rangers also found that when subjects were exposed to intense stressors of battle, including sleep deprivation, their level of cognitive performance was reduced significantly (Lieberman et al., 2005). The effects of insufficient sleep on levels of alertness and cognitive performance have also been demonstrated in airline pilots and truck drivers (Neri et al., 2002; Williamson & Feyer, 2000).

The negative effects of a decrease in sleep quantity on cognitive performance have also been demonstrated in college students. Seventy-three percent of college students reported at least occasional sleep disturbances (Buboltz, et al., 2001), and 71% expressed dissatisfaction with their sleep (Tsai & Li, 2004). It has also been demonstrated that college students who were sleep deprived for 24 hours performed significantly worse on complex cognitive tasks than non-deprived subjects (Pilcher, et al., 1997). Another study demonstrated that students who reported less sleep quantity had lower Grade Point Averages (GPA) than students with greater sleep quantity (Kelly, et al., 2001). Furthermore, overall poor sleep habits have also been shown to be related to lower GPA (Trockel, et al., 2000). Sleep deprivation has also been shown to negatively affect postural control (Fabbri, Martoni, Esposito, Brighetti, & Natale, 2006; Gribble & Hertel, 2004) and has been linked to increases in headache (Kelman & Rains, 2005).

While many of the previous studies focused on the effect of sleep quantity on cognitive function, overall sleep quality may have a greater influence on measures of overall health and well-being than just sleep quantity (Pilcher, et al., 1997). Furthermore, it has been demonstrated that subjects who had normal sleep quantity levels, but had a decreased sleep quality due to nocturnal asthma, had decreased cognitive performance in the day time (Fitzpatrick et al., 1991). Decreased cognitive performance has also been shown in cancer survivors who experience sleep quality deficits due to previous treatment (Clanton et al., 2011). This indicates that the effect of sleep quality on cognitive function needs to be examined along with the effect of sleep quantity.

If an athlete performs under his or her true normal cognitive level on baseline testing due to abnormal sleep, they may reach what is perceived to be a normal cognitive level before they have fully recovered from the injury. This will decrease the validity of the baseline testing and potential comparisons to follow-up tests if changes to sleep quantity and sleep quality are found during follow up testing.

If sleep quantity is found to affect the outcome of concussion assessments, clinicians need to instruct athletes to sleep his or her regular amount before baseline testing and any follow up testing. Sleep quantity is a single night measurement and athletes have control over when they go to bed and when they get up. This makes it possible for athletes to attempt to regulate sleep quantity before testing. Also, if an athlete reports to testing after receiving a short amount of sleep, it is possible to reschedule testing, and to instruct the athlete to receive a normal amount of sleep before the next session.

Sleep quality is measured over a longer period of time and includes factors the athlete may not be able to consciously control and, therefore, may be more difficult to change. If an athlete is found to have poor sleep quality at the time of testing it would be very impractical to instruct them to improve their sleep quality and report for testing the next month. However, if the athlete is found to have similar sleep quality deficits during follow up testing, the comparison of the follow up test to the baseline would still be considered valid. If a change in sleep quality was found then the comparison would not be valid and normative data may be a more valid baseline measure.

Currently, there is no research that examines the effect of sleep quality or previous night's sleep quantity on performance of the clinical tests commonly used in baseline and post-injury testing of the cognitive function in collegiate athletes. It is also unknown if the change in sleep quality/quantity affects the repeatability of these test scores. The findings of this study could help determine the need to account for quantity and quality of sleep when assessing athletes' cognitive function at baseline testing. Therefore, the purpose of this study is to determine if sleep quality over the previous month and the previous night's sleep quantity have an effect on concussion assessment measures in NCAA Division I athletes. The secondary purpose will be to determine if changes in sleep quality or quantity are associated with changes in concussion assessment measures in NCAA Division I athletes.

Research Questions

RQ_1: What is the effect of sleep quality, as measured by the Pittsburgh Sleep Quality Index (PSQI) (Appendix 1), on baseline concussion assessment outcomes in NCAA Division I athletes?

RQ_2: What is the effect of self-reported previous night's sleep quantity on baseline concussion assessment outcomes in NCAA Division I athletes?

RQ_3: Will a change in the previous month's sleep quality be associated with changes in concussion assessment outcomes in NCAA Division I athletes?

RQ_4: Will a change in the previous month's sleep quantity be associated with changes in concussion assessment outcomes in NCAA Division I athletes?

Independent Variables

- Sleep quality as measured using Pittsburgh Sleep Quality Index
    - High sleep quality
    - Low sleep quality
- Previous night's sleep quantity as a percentage of typical day sleep quantity
    - Greatest sleep quantity
    - Moderate sleep quantity
    - Least sleep quantity
- Change in sleep quality
    - Greatest change in sleep quality
    - Moderate change in sleep quality
    - Least change in sleep quality
- Change in sleep quantity
    - Greatest change in sleep quantity
    - Moderate change in sleep quantity
    - Least change in sleep quantity

Dependent Variables

- Outcome of baseline clinical measures of concussion assessment, and change in each measure between baseline and follow-up testing.
  - CNS Vital Signs
    - Composite Memory
    - Visual Memory
    - Verbal Memory
    - Psychomotor Speed
    - Reaction Time
    - Complex Attention
    - Cognitive Flexibility
    - Processing Speed
    - Executive Functioning
    - Reasoning
    - Neurocognitive Index
  - Sensory Organization Test
    - Composite score
  - Graded Symptom Checklist (GSC) (Appendix 2)
    - Somatic symptoms
      - Total Symptom Severity Score
      - Total number of symptoms endorsed
    - Cognitive symptoms
      - Total Symptom Severity Score

    - Total number of symptoms endorsed
  - Neurobehavioral symptoms
    - Total Symptom Severity Score
    - Total number of symptoms endorsed

Research Hypotheses

H_1: Subjects with a high sleep quality will have superior concussion assessment scores compared to subjects with a low sleep quality.

H_2: Subjects with a high sleep quantity will have superior concussion assessment scores compared to subjects with a medium sleep quantity, and subjects with a medium sleep quantity will have better concussion assessment scores compared to subjects with a low sleep quantity.

H_3: Decreases in subjects' sleep quality will be associated with a decrease in concussion assessment outcomes, while increases in sleep quality will be associated with an increase in concussion assessment outcomes, and no change in sleep quality will be associated with no change concussion assessment outcomes.

H_4: Decreases in subjects' sleep quantity will be associated with a decrease in concussion assessment outcomes, while increases in sleep quantity will be associated with an increase in concussion assessment outcomes, and no change in sleep quantity will be associated with no change concussion assessment outcomes.

Operational Definitions

- Sleep quality: Subjective feelings of depth of sleep, how well rested one feels after waking, and general satisfaction with sleep, measured with the Pittsburgh Sleep Quality Index, over the previous month (Pilcher, et al., 1997).

- High sleep quality: A score of five or less on the Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989).
- Low sleep quality: A score greater than five on the Pittsburgh Sleep Quality Index (Buysse, et al., 1989).
- Sleep quantity: The total number of hours spent sleeping the night prior to objective balance, cognitive, and symptom measures.
- Percentage of normal sleep quantity: The total number of hours of sleep for one night, divided by the normal hours of sleep indicated on the Pittsburgh Sleep Quality Index, multiplied by 100.
- Concussion Assessment: CNS Vital Signs, Sensory Organization Test, Graded Symptom Checklist.
- Athlete: A varsity student-athlete competing at the University of North Carolina-Chapel Hill.

Assumptions

- Athletes accurately self-reported the number of hours of sleep (sleep quantity).
- Athletes accurately completed the Pittsburgh Sleep Quality Index.
- The type of cognitive testing used accurately assessed cognitive function.
- All athletes performed the assessments to the best of their ability.
- The Pittsburgh Sleep Quality Index accurately assessed sleep quality.

Delimitations

- This study only included subjects from the ages of 18-19.
- Subjects were male and female.
- This study only included Division I athletes from the following selected sports:

    - Football
    - Men’s/Women’s basketball
    - Men’s/Women’s soccer
    - Baseball
    - Softball
    - Men’s/Women’s lacrosse
    - Gymnastics
    - Wrestling
    - Cheerleading
    - Swimming and Diving (Platform Divers)
    - Track and Field (Pole Vaulters)
    - Field hockey
- Subjects included only incoming freshman and transfer students.
- Subjects were excluded if they are currently taking prescription anti-depressants, attention deficit medication, or other forms of medication that may alter mental status.
- Any subject who was currently being treated for a concussion, or sustained one between the baseline and follow-up test sessions will be excluded from the study.

Limitations

- All sleep quality and quantity data were self-reported.
- The results may not be easily generalized to the general population because only Division I athletes were tested.

- The results may not be easily generalized to all athletes because only certain sports were included.
- A convenience sample was recruited during baseline testing. A random sample was selected from this initial sample to participate in the follow-up portion of the research study.

Significance of the Study

Accurate concussion assessment often relies on comparing post-concussion testing to baseline testing completed by the athlete when he or she has full cognitive function. Deficiencies in sleep quantity and sleep quality have been shown to negatively affect cognitive function. If these deficiencies exist during baseline testing, the validity of the baseline tests, and any comparisons made to the baseline test, would be threatened. This may lead to improper management of concussions, which could result in severe long term or deadly consequences. These consequences may be avoided by using normative data in the place of invalid tests, or by educating athletes on the importance of receiving a normal amount of sleep the night before testing.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The management of concussions is one of the most important clinical issues in Athletic Training and Sports Medicine. The incidence rate and potential long-term consequences of these injuries make it very important to make proper evaluation, treatment, and return to play decision (Guskiewicz, et al., 2005; Guskiewicz, et al., 2003). It is recommended that sports medicine clinicians assess the athletes' baseline symptoms, balance performance, and neurocognitive function prior to the sports participation, so that the change/recovery of these functions after sustaining a concussion can be used to assess the athlete's recovery and to make return to play decision. In order for the results from the preseason baseline testing to be used as a valid reference for the post-injury values, any extraneous factors that may influence the scores need to be identified and controlled for (Guskiewicz et al., 2004; Moser et al., 2007). Factors such as previous concussions, age, learning disabilities, ADHD, and previous neuropsychological testing experience, may influence neuropsychological test performance and needed to be accounted for when administering and interpreting these tests. (Grindel, et al., 2001).

Decreased amounts of sleep and lower levels of sleep quality have been shown to impair cognitive ability in numerous studies (Deary & Tait, 1987; Fitzpatrick, et al., 1991; Jacques, et al., 1990; Lieberman, et al., 2005; Lieberman, et al., 2002; Pilcher, et al., 1997; Robbins & Gottlieb, 1990; Williamson & Feyer, 2000). If baseline concussion assessment scores are compromised due to sleep impairments, they are not valid measurements. If baseline concussion assessment measures are not valid, neither are the comparisons made between baseline and follow up tests. Therefore the purpose of this study is to determine the effects of sleep quality and quantity on the results of concussion assessment.

In this literature review, the 1) short and long term consequences of concussion, 2) physiology of sleep, 3) effects of sleep quality and sleep quantity on cognitive functioning, and 4) methodological considerations for the clinical exams commonly used in baseline testing of symptoms, balance performance, and cognitive function, as well as the assessment of sleep quality/quantity will be discussed.

Concussion

Concussion has been defined as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (McCrory et al., 2009), which results in physical, psychological and cognitive deficits (Moser, et al., 2007). Concussion causes several physiological events that result in neural dysfunction in the brain. When the brain is injured, unregulated releases of neurotransmitters and ion fluxes occur, which results in a disruption of the neuronal membrane potential. As a result, sodium-potassium pumps are forced to work harder, increasing the need for adenosine triphosphate (ATP) and stimulating glucose metabolism. This causes a cellular energy crisis, and results in decreased cellular function (Giza & Hovda, 2001).

Loss of consciousness may occur following a concussive impact and typically resolves in 30 seconds (McCrea et al., 2003). Immediately following the injury, the individual may experience retrograde amnesia, loss of memory prior to the injury, lasting and average of 90 minutes, or anterograde amnesia, loss of memory after the injury, which typically resolves 120 minutes post injury (McCrea, et al., 2003). Short term signs and symptoms of concussion, which last an average of seven days (McCrea, et al., 2003), include headache, nausea, photophobia, phonophobia, blurred vision, a feeling of being in a fog, balance deficits, and a loss of concentration, memory and rapid visual processing (Guskiewicz, et al., 2004; Guskiewicz, Ross, & Marshall, 2001).

Potential life altering consequences can also occur as a result of concussion. Second impact syndrome occurs when the head or body is impacted while the brain is still recovering from the previous concussion (Cantu & Gean, 2010; Wetjen, et al., 2010). After a concussion, the brain loses some of its ability to auto-regulate its blood vessels (Wetjen, et al., 2010). When the head or body is impacted it results in a stress-induced release of catecholamine. These hormones cause heart rate and blood pressure to increase significantly, and since the brain is not able auto-regulate its blood flow, it begins to swell massively (Wetjen, et al., 2010). This can lead to severe neurocognitive impairment and, in some rare cases, immediate death (Cantu & Gean, 2010; Wetjen, et al., 2010).

While not all recurrent concussions will result in Second Impact Syndrome, there are still believed consequences to cumulative concussions (Cantu, 2003). A study of high school athletes suggested that recurrent concussions may result in more severe initial signs and symptoms. The study found that athletes with a history of three or more concussions were more likely to experience loss of consciousness, anterograde amnesia, and prolonged confusion after sustaining a subsequent concussion, than athletes sustaining a concussion with no previous history (Collins et al., 2002). A study using similar subjects also found that subjects who had sustained multiple concussions were more likely to experience post traumatic amnesia and more than five minutes of general mental disturbance (Iverson, Gaetz, Lovell, & Collins, 2004). Recurrent concussions were also shown to lower memory testing scores two days post injury, when compared to subject who had only received one concussion (Iverson, et al., 2004). A study including over 2500 retired professional football players also demonstrates the potentially severe long term consequences of recurrent concussions. The study indicated that sustaining repeated concussion is linked to memory loss later in life (Guskiewicz, et al., 2005). An athlete who sustains a concussion is likely to be vulnerable to the effects of recurrent concussion at some point because sustaining a concussion increases the likelihood of additional concussions (Guskiewicz, et al., 2003). A study that involved 2905 college football players over three seasons, found that concussion risk tripled in subjects who had sustained three or more concussions, compared to those who had no history of concussion (Guskiewicz, et al., 2003). Recovery time was also increased for subjects with a history of concussion (Guskiewicz, et al., 2003).

In order to account for all of the possible manifestations of concussion, a thorough assessment should include a graded symptom checklist, balance assessment, and a form of neurocognitive testing (Guskiewicz, et al., 2004). The importance of valid baseline testing cannot be overlooked when discussing the proper assessment of concussions. Each type of assessment must be conducted in each potential patient before they sustain a concussion to establish normal measure that post-concussion test values can be compared with (Guskiewicz, et al., 2004; Moser, et al., 2007). The importance of baseline testing has been recognized and is recommended by the National Academy of Neuropsychology and the National Athletic Trainers Association (Guskiewicz, et al., 2004; Moser, et al., 2007).

Sleep Physiology

Sleep is one of the most basic and essential functions of the human body, however the exact purpose of sleep is still largely unknown (Eidelman, 2002). Sleep is regulated largely by circadian rhythm, otherwise known as the sleep/wake cycle, which is controlled by the anterior hypothalamus in the suprachiasmatic nucleus (Stanley, 2005). The suprachiasmatic nucleus establishes the rhythm of sleep because it is sensitive to both light and body temperature. Sleepiness increases as core body temperature and light decrease, and arousal occurs as core body temperature and light increase in the morning (Stanley, 2005).

When an individual falls asleep, there is a progression through four stages of sleep. This progression, known as a sleep cycle, occurs three to four times during a normal night's sleep and each four-stage cycle lasts between 90 and 120 minutes. The four stages of the sleep cycle can be differentiated from each other through the recording of brainwaves. As a person falls asleep alpha (8-13 Hz) and beta (14-20 Hz) wave activity ceases and brain wave frequency progressively decreases through theta waves (4-7 Hz) in stages one and two, and then to delta waves (<3.5 Hz) in stages three and four. Muscle tone decreases but remains relatively high compared to a wakened state in stage one, and decreases with each following stage. (Stanley, 2005).

As the sleep cycle comes to an end, brain wave frequency increases and Rapid Eye Movement (REM) sleep occurs. The muscle tone is at its lowest point, and the most structured dreams occur during this stage. It is believed that the different levels of sleep serve different physiologic functions. Non-REM sleep is thought to contribute to physical rest and immune system maintenance, and REM sleep may be responsible for psychological rest and improving memory (Stanley, 2005). If these processes are disrupted as a result of poor sleep quantity or quality, there are potential negative consequences on the body in addition to cognitive difficulties. The endocrine system responds to sleep deprivation with an increase in evening cortisol, decreased thyrotropin activity, decreased glucose tolerance, changes in the timing of growth hormone secretion, and changes in the levels of appetite regulating hormones (Banks & Dinges, 2007). The immune system has been shown to decrease antibody production, and increases in markers of systemic inflammation following sleep deprivation may explain an increase in cardiovascular events and cardiovascular morbidity, which is also linked to sleep deprivation (Banks & Dinges, 2007).

Sleep Quantity

The effects of sleep loss have been studied in many different populations, including medical residents, airline pilots, truck drivers, the military, and college students (Buboltz, et al., 2001; Deary & Tait, 1987; Jacques, et al., 1990; Kelly, et al., 2001; Lieberman, et al., 2002; Pilcher, et al., 1997; Robbins & Gottlieb, 1990; Trockel, et al., 2000; Tsai & Li, 2004; Williamson & Feyer, 2000). When physicians are completing residency training, they are often required to work under sleep deprived conditions. The effects of lack of sleep on cognitive performance have been assessed by measuring cognitive performance after working an “on call” shift, which resulted in an average of 35 hours of sleep deprivation (Robbins & Gottlieb, 1990). Cognitive performance was assessed using a driving simulation to test attention span, hand-eye coordination, and reaction time and rapid number comparison to assess visual reaction time and accuracy, number discrimination and short-term memory. Additional tests were also done to assess concentration, and simple mathematical abilities. Each subject was baseline tested in a non-sleep deprived state and was then asked to retake the tests after completing an on call shift. The study demonstrated that there were significance differences between baseline and sleep deprived measures on all tests but the simple mathematic ability assessment (Robbins & Gottlieb, 1990).

Similar results were found in a study comparing the cognitive performance of residents after varying levels of sleep deprivation. Cognitive performance was tested after a night off duty, when subjects slept an average of 7 hours, a night on call, when they averaged 5 hours of sleep, and a night spent admitting new patients when the average sleep quantity was 1.5 hours. A total of five different tests were given to 12 medical residents to assess, memory, information processing, basic math skills, and concentration. A sixth test was given that is used to measure intelligence. After a night spent admitting new patients, short term memory was significantly impaired compared to a night spent off duty. The other tests, which were designed to mimic clinical diagnostic skills, were not significantly affected by the lack of sleep. The authors concluded that sleep loss may have a greater effect on basic psychological processes like memory, than on specific diagnostic skills (Deary & Tait, 1987).

Another study assessing the effect of sleep loss on the cognitive function of medical residents used the American Board of Family Practice In-Training Examination as the assessment tool. The test was administered to 353 residents and the results were correlated to self-reported sleep amounts the night before the test. The study demonstrated that there was a statistically significant relationship between declining amounts of sleep and decreased test scores (Jacques, et al., 1990).

Military personnel are often required to work while sleep deprived. During the most intense period of Navy SEAL training the trainees are sleep deprived of up to 72 hours, while being exposed to several other extreme physical and mental stressors. During this period of time, 68 trainees underwent four computerized tests to assess cognitive performance. The trainees were baseline tested prior to sleep deprivation. The study found that cognitive performance was significantly degraded after sleep deprivation (Lieberman, et al., 2002).

Data obtained from the study conducted on the Navy SEALS were also used in a second study that evaluated cognitive function of warfighters in high-intensity training operations (Lieberman, et al., 2005). Data were also collected from the U.S. Army Rangers during a particularly intense period of training. The same computer based test that were administered on the Navy SEALS, were completed by the Army Rangers after a similar 72 hour period of sleep deprivation and training. The cognitive function of both the Navy SEAL and Army Ranger groups had significantly decreased on every test after the training period compared to baseline measures (Lieberman, et al., 2005).

Truck drivers often work in a sleep deprived state that has the potential to hinder their cognitive performance (Williamson & Feyer, 2000). The effect of sleep deprivation on cognitive function was compared to the decreases in cognitive function due to alcohol consumption in a sample of 39 truck drivers (Williamson & Feyer, 2000). Subjects completed computerized tests to assess vigilance, reaction time, coordination, memory, perceptual coding, dual tasking, and logical reasoning, after up to 28 hours of sleep deprivation or prescribed doses of alcohol. Both sleep deprivation and alcohol consumption produced similar cognitive deficits and after 17-19 hours of sleep deprivation, the performance deficits were equal to those produced by illegal levels of alcohol consumption (Williamson & Feyer, 2000).

As for college students, the population that will be included in the current study, research shows a relationship between poor sleep habits and lower GPA scores (Kelly, et al., 2001). This was shown when students were divided into three groups based on self-reported sleep and asked to self-report their cumulative GPA. Subjects were defined as short sleepers if they reported receiving an average of less than 6 hours of sleep, average sleepers received 7-8 hours of sleep and those defined as long sleepers reported an average of 9 or more hours per night. When the cumulative grade point averages were compared between the three groups long sleepers reported significantly higher GPA's than short sleepers (Kelly, et al., 2001). Another study, which related several health related variables to GPA in first year college students found similar results. Two of the variables that were most significantly related to lower GPA scores were later weekday and weekend bedtimes (Trockel, et al., 2000).

Research has also been conducted on college students to directly measure cognitive performance changes as a result of decreases in sleep. Two groups of 44 total college students were compared, a sleep-deprived group (n=23) and a non-deprived group (n=21). The subjects were asked to sleep approximately 8 hours before the experiment began, and the next night the non-deprived group slept 8 hours again and the deprived group did not sleep at all during the same 24 hour time frame. After the prescribed sleep or lack of sleep was complete, each group underwent the Watson-Glaser Critical

Thinking Appraisal to measure cognitive performance. The results showed that the non-deprived group preformed significantly better than the sleep-deprived group on the cognitive performance measure (Pilcher, et al., 1997).

Decreases in sleep quantity have also been shown to affect balance. Postural sway measures taken using a force plate have been found to increase significantly following both 12 (Fabbri, et al., 2006) and 24 hours (Gribble & Hertel, 2004) of sleep deprivation. Sleep deficits have also been linked to increases in headaches, one of the most common symptoms of concussion (Kelman & Rains, 2005).

Sleep Quality

Although a lack of sleep quantity has been shown to negatively affect cognitive function, overall sleep quality may have a more significant effect than quantity of sleep. Sleep quality includes several aspects of an individual's sleep habits, including sleep quantity, sleep latency, sleep efficiency and sleep disturbances (Pilcher, et al., 1997). The study demonstrated that the sleep quality measured in college students using the Pittsburgh Sleep Quality Index (PSQI) had higher correlation to measures of health and well-being than sleep quantity alone. Decreased sleep quality was correlated to increased feelings of anxiety, depression, anger, fatigue, confusion, levels of day time sleepiness, and overall dissatisfaction with life. The results were similar when students were assessed during final exam week, and during a less stressful period of the semester. However, this study only examined the effects of sleep quality on overall health and well-being(Pilcher, et al., 1997).

Decreased levels of sleep quality have been specifically related to levels of cognitive function in asthma patients who experience disturbances due to nocturnal asthma (Fitzpatrick, et al., 1991). Subjects were asked to self-report several different sleep variables related to sleep quality including sleep efficiency (the percent of time in bed that is actually spent sleeping), sleep onset latency, time spent awake at night, and time awake after sleep onset. Subjects also underwent polysomnography to determine the amount of time spent in each stage of sleep. Subjects then completed a series of tests during the day to assess cognitive function. The subjects underwent tests to assess concentration and attention, coordination and mental flexibility, short term memory and an intelligence assessment. The study found that the subjects with nocturnal asthma had poorer sleep quality and lower cognitive performance than normal subjects. This suggests that sleep quality impairs cognitive function, however this study may be limited due to the fact that it did not use a standardized sleep quality scale, and the small sample size (12 with nocturnal asthma, and 12 controls) (Fitzpatrick, et al., 1991).

The sleep quality deficiencies that negatively affect cognitive performance have been shown to be very prevalent in college students, which is the population that will be examined in the current study. In a study of sleep patterns in college students, it was found that 48% of a sample of over 200 students had some form a sleep difficulty. The sleep difficulty was defined as waking more than once per night, sleep efficiency less than 85%, day time napping over one hour, and a self-reported sleep quality rating of less than 6 on a scale of 1 to 10, with a score of one being “extremely awful” sleep and ten being “extremely great” sleep. Although this study did not included a standardized sleep quality index, all of the factors used to define sleep difficulties, other than the subjective sleep quality rating, are factors considered in the Pittsburgh Sleep Quality Index, which will be used to assess sleep quality in the current study. This study also found that women had significantly poorer sleep patterns than men, indicating possible gender difference in sleep quality (Tsai & Li, 2004).

Sleep quality was also shown to affect cognition in cancer survivors who experienced sleep difficulties later in life. Individuals who were found to have poor sleep quality had increased problems with memory, attention, and processing speed (Clanton, et al., 2011).

A similar study found the prevalence of sleep difficulties to be even higher (Buboltz, et al., 2001). Subjects were asked to complete the Sleep Quality Index, which is a self-reported inventory similar to the Pittsburgh Sleep Quality Index. The study demonstrated that more than 15% of the subjects were classified as “poor sleepers” (Buboltz, et al., 2001), and that 73% of the 191 students reported at least occasional sleep problems on an aspect of the index, with women again reporting more difficulties than men.

Sleep quality is a combination of subjective and objective factors, including sleep quantity, that influence the effectiveness of an individual’s sleep. Like sleep quantity alone, studies suggest that sleep quality does have a significant impact on day time cognitive function. However, it has been indicated that the inclusion of the several factors that make up sleep quality makes it a more significant tool for assessing sleep.

Methodological Considerations

CNS Vital Signs

CNS Vital Signs (CNSVS) is a computerized neurocognitive test that was developed for use as a routine clinical evaluation tool. It consists of seven tests which include Visual Memory, Verbal Memory, Finger Tapping, Symbol Digit Coding, the

Stroop Test, the Shifting Attention Test and the Continuous Performance Test (CPT) (Gualtieri & Johnson, 2006). Test-retest reliability of the test was assessed in 99 subjects who completed CNSVS on two different occasions(Gualtieri & Johnson, 2006). The authors of this study computed r values to represent test, re-test reliability. No standard error or ICC values were given. The study stated that the r values of the domain scores of CNS Vital Signs ranged from 0.65 to 0.87. (Gualtieri & Johnson, 2006).

Immediate Post-Concussion and Cognitive Testing (ImPACT) is a computerized neuropsychological test battery similar to CNS Vital Signs and is widely used in a variety of different sports (Allen & Gfeller, 2011). ImPACT has been shown to have a high sensitivity (81.9%) and specificity (89.4%) when discriminating between concussed high school athletes and controls (Schatz, Pardini, Lovell, Collins, & Podell, 2006). ImPACT consists of six test modules, five of which compare closely to tests included in CNS Vital Signs (Allen & Gfeller, 2011). The Word Discrimination and Design Memory are similar to Verbal and Visual Memory of CNSVS, Symbol Matching and Color Matching are similar to Symbol Digit Coding and the Stroop Test, and the X and O test is similar to the Shifting Attention Test (Allen & Gfeller, 2011; Gualtieri & Johnson, 2006).

One significant difference between CNS Vital Signs and ImPACT is the presence of the Continuous Performance Test (CPT) in CNS Vital Signs. The CPT is a measure of vigilance or sustained attention over time (Gualtieri & Johnson, 2006). This is significant when determining the effect of sleep deficits on the test because sleep deprivation has been shown to significantly affect vigilance tasks like the CPT (Balkin et al., 2004).

Sensory Organization Test

The Sensory Organization Test (SOT) will be administered using the NeuroCom Smart Balance Master System (NeuroCom International, Inc, Clackamas, OR). This is a forceplate system that measures the body's center of gravity moving around a fixed base of support. The SOT creates disruptions in visual and somatosensory input by systematically eliminating visual input, and sway referencing the surrounding and the base of support (Guskiewicz, et al., 2001). This creates an environment which is challenges balance because visual and somatosensory input must be integrated to maintain equilibrium (Norre, 1993). The SOT has been found to have high sensitivity identifying patients with CNS dysfunction (90%) (Voorhees, 1990), and has also been shown to have a high specificity (95%) (Hamid, Hughes, & Kinney, 1991).

The SOT requires sophisticated equipment and may not be available to all clinicians who assess concussion. The Balance Error Scoring System (BESS) is an alternative method of assessing postural stability which requires the subject to maintain balance during three different stances completed on the ground and on a foam pad (Guskiewicz, et al., 2001). This method of assessing balance had been shown to be reliable (Riemann, Guskiewicz, & Shields, 1999) and has produced results related to the SOT (Guskiewicz, et al., 2001; Riemann, et al., 1999). However, when the BESS was administered repeatedly to high school athletes over a 30 a thirty day period, a practice effect was observed (Valovich, Perrin, & Gansneder, 2003).

Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality (PSQI) Index is a frequently used self-rating sleep questionnaire, which assesses sleep quality from the previous month. The 19 questions are derived from clinical intuition, experiences with sleep disorder patients, a review of previous sleep quality indexes published in the literature, and from 18 months of field testing (Buysse, et al., 1989).

The PSQI was originally published after being administered to 54 healthy control subjects with no complaints of sleep disturbance, and 62 patients in a psychiatric clinic who were being evaluated for a variety of sleep/wake complaints, and 34 patients with a major depressive disorder. All subjects completed the PSQI at least once and 91 subjects from each group completed the PSQI a second time (Buysse, et al., 1989). The results demonstrated that the seven component scores had a r value of 0.83. There were no significant differences between the first and second scores of the subjects who complete the index twice, indicating high test-retest reliability. The significant differences found between each group tested indicates that PSQI has high face validity (Buysse, et al., 1989).

Two other sleep assessment tools are the Stanford Sleepiness Scale and the Epworth Sleepiness Scale. The Epworth Sleepiness Scale is used to determine day time sleepiness. Subjects are asked to rate the likelihood that they would fall asleep during eight day time activities such as watching TV and sitting and talking to someone (Johns, 1991). The Stanford Sleepiness Scale is also used to assess subjects' current level of sleepiness. The subject is provided with seven descriptions of varying feelings of sleepiness. The descriptions are represented by the numbers one through seven with one being the most alert and seven being most sleepy (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973). Neither of these tools assesses characteristics of sleep as the PSQI does. In a study that used all three scales to assess college students it was found that sleep quality, as measured by the PSQI, was most significantly correlated to measures of health and well-being (Pilcher, et al., 1997).

CHAPTER III

METHODOLOGY

Study Design

This study was completed in two parts. The first portion of the study employed a cross-sectional design to assess the effect of sleep quality and sleep quantity on common preseason clinical measures of concussion. These data were collected between June 17th, 2011 and September 24th, 2011. For the second portion, a subset of the athletes completing preseason baseline testing were re-evaluated using a repeated measures design to determine if changes in sleep quality resulted in changes in concussion assessment scores.

Subjects

One hundred and sixty-one male and female freshman and transfer student athletes participated in the baseline testing portion of the study. One hundred and fifty-five subjects (57 females, 98 males; age = 18.8 ± 0.8 years; mass = 78.4 ± 19.6 kg; height = 177.4 ± 12.3 cm) met the inclusion criteria. Only student-athletes who compete in sports requiring concussion baseline testing before participation in sports were included in the study. Data from subjects who sustained a concussion during the past six months and/or reported having a vestibular, visual or balance disorder at the time of testing or were diagnosed with a psychiatric disorder at the time of testing were excluded from the analysis. Those who had previous experience completing the concussion assessment measures (e.g. "re-baselines") were also excluded. In addition, subjects who sustained a concussion between the primary testing session and retesting were excluded from the second part of the study.

Fifty-six subjects (21 females, 35 males; age = 18.7 ± 0.9 years; mass = 69.8 ± 14.8 kg; height = 171.6 ± 10.1 cm) who agreed to complete the concussion assessment measures a second time were included in the second portion of the study. Data collection for the second portion occurred between August 28th, 2011 and November 29th, 2011. Subjects followed up within three days before or after the date 10 weeks after the baseline testing session (mean = 1.31 ± 0.72 days within 10-week date). This allowed at least one full month to wash out the learning effect of the balance and computerized neurocognitive function tests, and allowed the PSQI to assess subject's sleep quality for the entire month leading up to the follow-up evaluation session without carry over from their baseline PSQI reporting. Fifty-five participants agreed to complete the assessment a second time and underwent a testing session identical to the baseline session. Subjects may have undergone the tests in a different order, and randomly generated components of CNS Vital Signs may also have been different.

Instrumentation

Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI) was used to assess the student athlete's sleep quality. The PSQI is a sleep questionnaire consisting of 19 self-rated questions pertaining to the individual's sleep habits during the previous month (Appendix 1). The self-rated questions were used to calculate seven sub-scores: 1) subjective sleep quality, 2) sleep latency, 3) sleep duration, 4) habitual sleep efficiency, 5) sleep disturbances, 6) use of sleeping medication, and 7) daytime dysfunction. Based on the responses to the questions, each sub-score will be calculated on a scale of 0 to 3, with a score of 0 indicating no presence of the habit and 3 indicating a high presence of the habit. All sub-scores are totaled forming a global score, which ranges from 0-21 (Buysse, et al., 1989). The PSQI has been shown to be reliable (Interclass correlation (r) = 0.87) between test and re-test sessions (Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002).

Graded Symptom Checklist

The graded symptom checklist (GSC) was used to assess the presence of 18 concussion related symptoms. The subject self-rated the severity of each symptom that they reported feeling at least three or more times per week on a 7 point Likert scale, ranging from 0 (asymptomatic) to 6 (severe). We specifically studied the total symptom severity score in addition to the total number of symptoms endorsed by the student-athlete for somatic, cognitive and neurobehavioral symptom groups (**Table 3.1)**.

Sensory Organization Test

The Sensory Organization Test (SOT) was administered using the NeuroCom Smart Balance Master System (NeuroCom International Inc.; Clackamas, OR), which is a force plate system that measures the body’s center of gravity moving within a fixed base of support. The SOT simultaneously disrupts the sensory selection process while measuring the subjects’ ability to maintain postural stability. The test consists of 18 trials (3 trials under 6 conditions), each 20 seconds long. During each trial, the subject is instructed to stand as still as possible with feet shoulder width apart. The six conditions consist of combinations of the three unique visual conditions (eyes open, eyes closed, sway-referenced visual surround) and two different surface types (fixed, sway referenced).

- Condition 1: fixed surface, eyes open
- Condition 2: fixed surface, eyes closed
- Condition 3: fixed surface, sway-referenced visual surround
- Condition 4: sway-referenced, eyes open
- Condition 5: sway-referenced, eyes closed
- Condition 6: sway-referenced, sway-referenced visual surround

Equilibrium scores are generated from each trial. A weighted average composite score is calculated from each individual score, with the results of conditions one and two being weighed less than conditions 3-6. Each equilibrium score is a percentage calculated by comparing the subjects' peak amplitude of A-P sway to the theoretical A-P limit of stability, which is based on the subjects' height and size of base of support. (Guskiewicz, et al., 2001).

CNS Vital Signs

CNS Vital Signs is a computerized neurocognitive assessment tool that is composed of a total of eight tests that have been shown to be reliable and valid (Gualtieri & Johnson, 2006). The eight tests include Visual Memory, Verbal Memory, Finger Tapping, Symbol Digit Coding, the Stroop Test, the Shifting Attention Test, Non-verbal Reasoning Test, and the Continuous Performance Test (CPT).

The Visual Memory Test measures recognition memory of 15 geometric shapes, which are presented one at a time for 2 seconds. Then similar to the Verbal Memory Test, the subject is asked to recall the shapes from a larger group of shapes. A delayed recognition trial takes place after the five remaining tests, and the Verbal Memory delayed recognition trial.

The Verbal Memory Test measures recognition memory for words. Fifteen words are presented, one at time, on the screen every two seconds. Immediately after, the subject is shown a longer string of words, which may or may have not have been included in the 15 words previously shown. The subject is asked to identify words that were previously shown. A delayed recognition trial takes place after the six other tests are administered.

The Finger Tapping Test requires the subject to press the Space Bar with their right index finger as many times as they can in 10 seconds. There is one practice trial, and then there are three test trials. The test is then repeated with the left hand.

Symbol Digit Coding Test consists of presentations of parallel rows of eight boxes. The top row of boxes contains symbols, and each symbol has a correlating number ranging from 2-9 in the bottom boxes. The participant types in the number that corresponds to the symbol that is highlighted, as fast and as accurate as possible.

The Stroop Test consists of three parts. First, the words red, yellow, blue and green are shown in black font. The subject is required to press the space bar as fast as possible when the word appears. During the next two trials the same words are shown in color. The subject is asked to press the space bar when the color matches the word, and then when the color does not match the word.

The Shifting Attention Test requires the subject to match colors and shapes. Two different color shapes are shown, and then a third is presented that is a duplicate of one of the shapes and is also the same color as one of the original shapes. The subject is asked to match the presented shape to one of the originals by either color or shape.

The Continuous Performance Test flashes single letters briefly on the screen for 5 minutes and requires the subject to press the space bar when the letter “B” is shown.

The Nonverbal Reasoning test asks subjects to predict the missing component of 15 matrices based on each individual pattern. The test measures the subject’s ability to understand relationships between abstract or visual information and reach a conclusion based on the relationship.

From these tests, 11 domain scores were derived by the program: 1) composite memory, 2) verbal memory, 3) visual memory, 4) psychomotor speed, 5) cognitive flexibility, 6) complex attention, 7) Processing speed, 8) executive functioning, 9) reaction time, 10) reasoning, and 11) Neurocognitive Index. (Gualtieri & Johnson, 2006). Subjects’ standard scores were used for each domain score of CNS Vital Signs. Standard scores are normalized raw scores, which CNS Vital Signs calculates based on normative data collected from healthy subjects over a wide range of ages. Standardized scores have a mean of 100 and a standardized deviation of 15, with a higher score always indicating better performance.

Procedure

Athletes reported to Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center at the University of North Carolina at Chapel Hill on the day designated for their team’s pre-participation examination. Before participation, all subjects signed the informed consent form approved by the university institutional review board and completed a form indicating if they were interested in participating in follow up testing for the study. Initial testing began in June 2011 and continued into September. As a part of the standard baseline testing procedures at the institution, each subject completed CNS Vital Signs, the SOT, and the graded symptom checklist. The PSQI was also completed electronically as an added module within the CNS Vital Signs. In addition, subjects self-reported previous night's quantity of sleep in hours.

Approximately four subjects were tested at one time. Two subjects completed CNS Vital signs, the Graded Symptom Checklist and the PSQI on desktop computers in a quiet room. This portion of our testing procedures lasted approximately 30 minutes. Dividers were placed in between the computers to minimize distractions, and subjects were instructed to read all directions carefully, not to talk to each other, and to complete the test battery's individual modules as quickly and as accurately as possible. The remaining subjects completed the Sensory Organization Test, one at a time. They were instructed to attempt to maintain their balance to the best of their abilities, and not to move more than necessary or talk to the test administrator during testing. Each subject required approximately 15 minutes to complete the test. Once the first tests were complete, the subjects switched and completed the remaining tests. Total testing time was approximately 60 to 90 minutes.

Subjects followed up within three days before or three days after the date 10 weeks after their baseline testing session. The time of day of the follow-up testing session was also matched within three hours before or after the original time of the baseline session. This allowed all subjects at least one full month of a wash-out period to minimize the learning effect of the balance and computerized neurocognitive function tests, and also allowed the PSQI to assess subject's sleep quality over an entire month after the baseline testing session. Approximately 100 subjects of those who expressed an interest in participating in the follow-up portion of the study were recruited to complete the assessment a second time. These subjects were contacted via email nine weeks after their original testing session and were asked to schedule a follow up session. Subjects who agreed to follow up underwent a testing session identical to the baseline session. Subjects may have underwent the tests in a different order, and randomly generated components of CNS Vital Signs such as word or shape lists may also have been different than the original test session. Subjects also followed up one at a time so no other subjects were present at the time of the retest.

Data Reduction

Previous night's sleep quantity was expressed as a percentage of the individual's normal sleep quantity reported by the subject in the PSQI. Sleep quantity data were divided into tertiles of greatest, least, and moderate sleep quantity.

Subjects sleep quality was measured by the PSQI and was categorized as high sleep quality if the PSQI global score was less than or equal to five, and was classified as low sleep quality if the PSQI global score was greater than five. Change scores for sleep quality were calculated relative to the baseline score and were divided into tertiles of greatest, least and moderate change in sleep quality.

Change scores for CNS Vital Signs domain scores, SOT composite score, number of symptoms and symptom severity score for somatic, cognitive and neurobehavioral symptom groups were calculated relative to baseline. The change scores were then divided into tertiles of greatest, least, and moderate change.

Statistical Analysis

Power Analysis

A priori power analyses were performed to determine sample sizes needed to sufficiently power the dependent variables CNS Vital Signs and the Sensory Organization Test. The power analysis for CNS Vital Signs was conducted for the Neurocognitive Index score. The effect size for the comparison of the neurocognitive index between the subjects with good, normal, and poor sleep quality/quantity was estimated at 0.76 based on the data from the previous study that compared the score between 100 depressed subjects and 100 control subjects (Iverson, Brooks, & Young, 2009). Based on this effect size, a total of 26 subjects in each group would be required to achieve a power of 0.80 at an alpha level of 0.05. The effect size for the comparison of the SOT composite score between the subjects with good, normal, and poor sleep quality/quantity was estimated at 0.59 based on the data from the previous study that compared SOT score between 19 healthy subjects and 13 subjects who were assessed one day post-concussion (Guskiewicz, et al., 2001). Based on this effect size, a total of 50 subjects per group would be required to produce a power of 0.80 at an alpha level of 0.05. Based on these analyses the first portion of this study would be sufficiently powered for both CNS Vital Signs and the SOT. With the effect sizes of 0.76 and 0.59 the second portion of the study to be sufficiently powered at 30-35 subjects per group.

Research Question 1: to study the effect of sleep quality on concussion assessment.

In order to determine the effects of sleep quality on CNS Vital Signs domain scores, SOT composite score, and graded symptom check list total symptom severity score and total number of symptoms endorsed for somatic, cognitive and neurobehavioral symptom categories, eighteen separate between-subjects one-way analyses of variance (ANOVA) were conducted. If any of the ANOVA analyses described produced a significant omnibus finding, a Tukey post hoc analysis was performed to identify any individual pairwise differences. All data were analyzed using SPSS 19.0 statistical software. The a priori alpha level was set at 0.05.

Research Question 2: to study the effect of sleep quantity on concussion assessment.

In order to determine the effects of sleep quantity on CNS Vital Signs domain scores, SOT composite score, and graded symptom check list total symptom severity score and total number of symptoms endorsed for somatic, cognitive and neurobehavioral symptom categories, eighteen separate between subjects, one way analyses of variance (ANOVA) were conducted. Tukey post hoc test was used to test the significance of each pairwise comparison. If any of the ANOVA analyses described produced a significant omnibus finding, a Tukey post hoc analysis was performed to identify any individual pairwise differences. All data were analyzed using SPSS 19.0 statistical software. The a priori alpha level was set at 0.05.

Research Question 3: to study the association between change in sleep quality and concussion assessment.

To determine if there was an association between change in sleep quality and change in CNS Vital Signs domain scores, SOT composite score, and graded symptom check list total symptom severity score and total number of symptoms endorsed for somatic, cognitive and neurobehavioral symptom categories, eighteen separate Chi Square analyses were conducted. All Chi Square analyses employed exact methods when expected cell counts were below 5. All data were analyzed using SPSS 19.0 statistical software. The a priori alpha level was set at 0.05.

Research Question 4: to study the association between change in sleep quantity and concussion assessment.

To determine if there was an association between change in sleep quantity and change in CNS Vital Signs domain scores, SOT composite score, and graded symptom check list total symptom severity score and total number of symptoms endorsed for somatic, cognitive and neurobehavioral symptom categories, eighteen separate Chi Square analyses were conducted. All Chi Square analyses employed exact methods when expected cell counts were below 5. All data were analyzed using SPSS 19.0 statistical software. The a priori alpha level was set at 0.05.

Table 3.2. Data Analysis Table

RQ	Description	Dependent Variables	Data Source	Method
1	Effect of sleep quality on concussion assessment	CNS VS 10 domain scores and NCI, SOT composite score, GSC, somatic, cognitive, and neurobehavioral number and severity of symptoms	Comparison of baseline concussion assessment scores between subjects with low and high PSQI scores	Eighteen one-way ANOVA’s
2	Effect of sleep quantity on concussion assessment	CNS VS 10 domain scores and NCI, SOT composite score, GSC somatic, cognitive, and neurobehavioral number and severity of symptoms	Comparison of baseline concussion assessment scores between subjects with greatest, moderate and least percentages of normal night’s sleep quantity	Eighteen one-way ANOVA’s
3	Association between change in sleep quality and change in concussion assessment	Change in CNS VS 10 domain scores and NCI, SOT composite score, GSC somatic, cognitive, and neurobehavioral number and severity of symptoms	Comparison of change in concussion assessment scores in subjects with greatest, moderate, and least change in PSQI scores.	Eighteen Chi-Square analyses
4	Association between change in sleep quantity and change in concussion assessment	Change in CNS VS 10 domain scores and NCI, SOT composite score, GSC somatic, cognitive, and neurobehavioral number and severity of symptoms	Comparison of change in concussion assessment scores in subjects with greatest, moderate, and least change in sleep quantity.	Eighteen Chi-Square analyses

CHAPTER IV

MANUSCRIPT

INTRODUCTION

Concussions effect an estimated 1.6 to 3.8 million athletes each year (Langlois, et al., 2006). The medical community widely recognizes the short-term symptoms, and cognitive and balance deficits, which typically follow a concussion (Giza & Hovda, 2001). In addition, potentially life-altering long term ramifications, such as increased susceptibility to additional concussion, and late life cognitive impairment have also been discovered (Guskiewicz, et al., 2005; Guskiewicz, et al., 2003). Of further concern is the catastrophic potential associated with sustaining a second impact before symptoms related to an initial injury have yet to fully heal. (Cantu & Gean, 2010; Wetjen, et al., 2010). These negative outcomes have informed conservative return-to-participation policies. Lending to this rationale, many clinicians and researchers have supported the use of pre-season baseline neurocognitive, postural stability, and symptom testing to establish a patient-specific standard to which these same domains can be compared following concussion (Grindel, et al., 2001). However, comparisons made between baseline tests and follow up testing are only valid if baseline testing truly represents normal functioning, and extraneous factors influencing the scores are taken into account (Grindel, et al., 2001).

Sleep quantity and quality may be factors that affect the outcome of concussion assessments. Decreases in sleep quantity have been shown to decrease cognitive function in several studies (Buboltz, et al., 2001; Deary & Tait, 1987; Jacques, et al., 1990; Kelly, et al., 2001; Lieberman, et al., 2002; Pilcher, et al., 1997; Robbins & Gottlieb, 1990; Trockel, et al., 2000; Tsai & Li, 2004; Williamson & Feyer, 2000). Decreases in sleep quality have also been shown to effect cognitive function and other aspects of health and well-being. (Buboltz, et al., 2001; Clanton, et al., 2011; Fitzpatrick, et al., 1991; Kelly, et al., 2001; Pilcher, et al., 1997; Trockel, et al., 2000; Tsai & Li, 2004). Sleep deprivation has also been shown to decrease postural control (Fabbri, et al., 2006; Gribble & Hertel, 2004) and has been linked to increases in headache (Kelman & Rains, 2005). If an athlete underperforms on baseline testing due to abnormal sleep, they may reach what is perceived to be a normal level before they have fully recovered from injury. This will decrease the validity of the baseline testing and potential comparisons to follow-up tests if changes to sleep quantity and sleep quality are found during follow up testing.

Currently, no research has examined the effect of sleep quality or previous night's sleep quantity on symptom reporting or on neurocognitive or postural stability performance, all of which are commonly evaluated in baseline and post-injury testing in collegiate athletes. The findings of this study could help inform clinicians of the potential need to account for quantity and quality of sleep when assessing athletes' cognitive function at baseline testing. The purpose of this study was to determine if sleep quality and sleep quantity have an effect on metrics commonly employed in the concussion evaluation of NCAA Division I student-athletes. The secondary purpose was to determine if changes in sleep quality or sleep quantity were associated with changes in clinical measures of concussion in healthy NCAA Division I student-athletes.

METHODS

Subjects

One hundred and fifty-five subjects (57 females, 98 males; age = 18.8 ± 0.8 years; mass = 78.4 ± 19.6 kg; height = 177.4 ± 12.3 cm), who were freshman or transfer student-athletes, met the inclusion criteria, and underwent preseason concussion baseline testing. Participants were excluded from our analyses if they had sustained a concussion during the six months prior to testing, or if they reported having an attention deficit disorder (ADD/ADHD), a vestibular, visual, balance, or psychiatric disorder. Those who had previous experience completing the concussion assessment measures were also excluded from our analyses. A total of 11 subjects were excluded from the baseline testing portion of the study. From this initial cohort, 56 subjects (21 females, 35 males; age = 18.7 ± 0.9 years; mass = 69.8 ± 14.8 kg; height = 171.6 ± 10.1 cm) completed testing a second time within three days before or after the date 10 weeks after the baseline testing session (mean = 1.31 ± 0.72 days within 10-week date). Subjects who sustained a concussion between the preseason testing session and the 10-week follow-up evaluations were excluded from the analyses addressing the second purpose of the study. Only one subject was excluded for this reason.

Instrumentation

Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality. The PSQI is a questionnaire consisting of 19 self-rated questions pertaining to the individual's sleep habits during the previous month (Buysse, et al., 1989). The PSQI has been shown to be reliable (Intraclass correlation (r) = 0.87) between test and re-test sessions (Backhaus, et al., 2002).

Graded Symptom Checklist

The graded symptom checklist (GSC) is a questionnaire used to assess the presence and severity of 18 concussion related symptoms. The subject self-rated the severity of each symptom that they reported feeling at least three or more times per week on a 7-point Likert scale, ranging from 0 (asymptomatic) to 1(mild) to 6 (severe). The outcome measure of the GSC was represented using the total symptom severity score in addition to the total number of symptoms endorsed by the student-athlete for somatic, cognitive and neurobehavioral symptom groups (**Table 3.1**).

Sensory Organization Test

The NeuroCom Smart Balance Master System (NeuroCom International Inc.; Clackamas, OR), a force plate system that measures the body's center of gravity moving within a fixed base of support, was used to administer the Sensory Organization Test (SOT). The SOT simultaneously disrupts the sensory selection process while measuring the subjects' ability to maintain postural stability. The test consists of 18 trials (3 trials under 6 conditions), each 20 seconds long. The six conditions consist of combinations of the three visual conditions (eyes open, eyes closed, sway-referenced visual surround) and two different surface types (fixed, sway referenced) (Guskiewicz, et al., 2001).

CNS Vital Signs

CNS Vital Signs is a computerized neurocognitive assessment tool that is composed of a total of eight tests that have been shown to be reliable and valid (Gualtieri & Johnson, 2006). The eight tests include Visual Memory, Verbal Memory, Finger

Tapping, Symbol Digit Coding, the Stroop Test, the Shifting Attention Test, Non-verbal Reasoning Test, and the Continuous Performance Test (CPT). The program then computes 10 domain scores in addition to an overall Neurocognitive Index (NCI) score (Gualtieri & Johnson, 2006). Subjects' standard scores were used for each domain score of CNS Vital Signs. Standard scores are normalized raw scores, which CNS Vital Signs calculates based on normative data collected from healthy subjects over a wide range of ages. Standardized scores have a mean of 100 and a standardized deviation of 15, with a higher score always indicating better performance.

Procedure

Subjects reported on the day designated for their team's pre-participation examination. Subjects signed the informed consent form approved by the university's institutional review board and completed a form indicating if they were interested in participating in testing 10 weeks following their initial visit. Each student-athlete completed CNS Vital Signs, the SOT, and the GSC. The PSQI was also completed electronically as an added module within the CNS Vital Signs. Our participants also self-reported their previous night's sleep quantity in hours.

CNS Vital Signs took approximately 30 minutes to complete on desktop computers in a quiet room. Dividers were placed in between the computers. Subjects were instructed to read all directions carefully, and to complete the test modules as quickly and accurately as possible. Subjects then completed the SOT. Subjects were instructed to maintain their balance, and not to move more than necessary or talk to the test administrator during testing. Each subject required approximately 10 minutes to complete the SOT. Total testing time was approximately 60 to 90 minutes for each subject.

Subjects followed up within three days before or three days after the date 10 weeks after the baseline testing session (mean = 1.31 ± 0.72 days). This allowed at least one full month to wash out the learning effect of the balance and computerized neurocognitive function tests, and allowed the PSQI to assess subject's sleep quality for the entire month leading up to the follow-up evaluation session without carry over from their baseline PSQI reporting. Fifty-five subjects volunteered to complete the assessment a second time and underwent a testing session identical to the baseline session. Subjects may have undergone the tests in a different order, and randomly generated components of CNS Vital Signs may also have been different.

Data Reduction

Previous night's sleep quantity was expressed as a percentage of the individual's normal sleep quantity reported by the subject in the PSQI. Sleep quantity data were divided into tertiles of greatest, moderate and least sleep quantity.

Our participants' sleep quality was measured by the PSQI and was categorized based on previously published criteria (Buysse, et al., 1989). Subjects were categorized as having high sleep quality if the PSQI global score was less than or equal to five, and were classified as having low sleep quality if the PSQI global score was greater than five. Change scores for sleep quality were calculated relative to the baseline score and were divided into tertiles of greatest, least and moderate change in sleep quality.

Change scores for CNS Vital Signs domain scores, SOT composite score, number of symptoms and symptom severity score somatic, cognitive and neurobehavioral symptoms categories were calculated relative to baseline. The change scores were then divided into tertiles of greatest, least, and moderate change.

Statistical Analysis

One-way between-subjects analyses of variance (ANOVA) were performed to study the effect of sleep quality for each of our clinical dependent measures. Similarly, one-way between-subjects ANOVA were performed to study the effect of sleep quantity for each of our clinical dependent measures. In the event of any significant omnibus findings, Tukey post hoc analyses were employed to identify significant pairwise differences. Chi-Square tests of association were employed to identify whether changes in sleep quality were associated with changes in clinical outcomes. Similar procedures were employed to determine whether changes in sleep quantity were associated with changes in clinical outcomes. Fisher's exact methods were employed when expected cell counts were less than five. All data were analyzed using SPSS 19.0 statistical software; with an a priori alpha level set to 0.05.

RESULTS

The mean PSQI global score was 4.44 ± 2.3. One hundred and five subjects had high sleep quality (score of less than 5) and 35 had low sleep quality (score of 5 or greater). Global PQSI scores categorized as high sleep quality ranged from 0-5 and had a mean of 3.4 ± 1.36. Those categorized as low sleep quality ranged from 6-12 with a mean of 7.57 ± 1.63. A summary of baseline Global PSQI score descriptive statistics can be found in **Table 4.1**.

Subjects found to have a low sleep quality reported a higher number of somatic ($F_{1,140}$ = 4.06; P = 0.046) and neurobehavioral symptoms ($F_{1,140}$ = 15.71; P = 0.00) and reported more severe neurobehavioral symptoms ($F_{1,140}$ = 21.62; P = 0.00) than those found to have high sleep quality. All other analyses were not statistically significant (P > 0.05). Descriptive and relevant statistical information for the effect of sleep quality are provided in **Table 4.2**.

The overall sleep quantity reported by our sample during baseline testing was 90.16% (±21.20%) of their normal night's sleep. Those with the greatest sleep quantity ranged from 163% to 100% with a mean of 110.21% (±16.85%). The moderate sleep quality group ranged from 100% to 83% with a mean of 90.97% (±6.46%). Those with the least sleep quantity averaged 68.75% (±12.7%) with a range of 83% to 33%. A summary of baseline percent of normal night's sleep descriptive statistics can be found in **Table 4.3**.

We observed a significance effect of sleep quantity on measures of visual memory ($F_{2,102}$ = 4.83; P = 0.01) and total number of somatic symptoms ($F_{2,102}$ = 3.96; P = 0.02). Post hoc analyses found moderate groups had lower visual memory scores than greatest (P = 0.02) and least groups (P = 0.02), and also reported more somatic symptoms than least groups (P = 0.02). Descriptive and relevant statistical information for the effect of sleep quantity are provided in **Table 4.4.**

We did not observe any associations between changes in sleep quality and changes in our clinical measures of concussion (P > 0.05 for all analyses). We did observe significant associations between changes in sleep quantity and changes in cognitive symptom severity ($F_{4,43}$ = 11.42; P = 0.006), number of neurobehavioral symptoms reported ($F_{4,43}$ = 9.75; P = 0.043), and severity of neurobehavioral symptoms ($F_{4,43}$ = 8.71; P = 0.05). All Chi Square analyses required the use of Fisher's Exact Test due to expected cell counts with expected values less than five. All relevant statistical information related to our Chi-Square tests of association is provided in **Table 4.5**.

DISCUSSION

We found that low sleep quality results in reporting a greater number of symptoms in somatic and neurobehavioral categories and greater neurobehavioral symptom severity, but does not appear to affect neurocognitive function as evaluated by CNS Vital Signs or balance performance as evaluated by the Sensory Organization Test in such a way that impacts the clinical interpretation of these measures. Those receiving moderate amounts of sleep the night prior to testing performed worse on visual memory testing, and reported more somatic symptoms than those who slept the most and those that slept the least. Differences in sleep quantity did not result in any other differences in neurocognitive function, balance performance, or symptom reporting. The study also found no association between changes in sleep quality and changes in neuropsychological testing, balance testing or symptom reporting. We did find an association between changes in sleep quantity and changes in severity of cognitive symptoms, and number and severity of neurobehavioral symptoms. Our results partially supported our research hypotheses in that sleep quality affected the number of symptoms and symptom severity, but did not appear to affect other clinical measures of concussion.

While studying the effect of sleep on college students, Pilcher et al. found that sleep quality was correlated to overall decreases in self-reported physical well-being. Specifically, greater feelings of anxiety, depression, anger, fatigue, confusion, and levels of daytime sleepiness were found with low sleep quality. Many of these symptoms are included in the GSC employed in our study, and our results are consistent with those of

Pilcher et al. Sleep disturbances have also been related to headaches, which is also included in the GSC and is one of the most common signs of concussion (Kelman & Rains, 2005). Collectively, every symptom in the GSC—except for vomiting—was endorsed by at least one student-athlete. Drowsiness, fatigue, and trouble falling asleep appeared to be the symptoms reported with the most frequency and with the most severity. These are all neurobehavioral symptoms of concussion, which can be easily associated with sleep. The significant effect of sleep quality on number and severity of neurobehavioral symptoms may be due to increases in symptoms that normally worsen with sleep deficiency. Furthermore the symptoms in the somatic category, which are more commonly associated with concussion, were also affected by sleep quality. This is a significant finding because clinicians often question about more common somatic symptoms such as headache, nausea, and dizziness during an initial concussion assessment. Frequency of symptom reporting in and severity reporting data can be found in **Table 4.6.**

The decreased performance on the visual memory test and increased somatic symptom reporting found among those subjects who were included in the moderate sleep quantity group disagreed with our hypotheses and previous research. This finding may have been due to out-lying data in each of these variables. Also the approximately 10-point difference between groups on the visual memory test and approximately one-half-point difference in symptom severity are notable, but lack clinical significance. For these reasons baseline sleep quality will be discussed as having no discernable effect on clinical measures of concussion.

The finding that decreased baseline sleep quantity did not have an effect on neuropsychological testing disagrees with current research regarding sleep deprivation and its effect on cognitive function. However, much of the research in this area involves subjects who undergo testing while in a completely sleep deprived stated, and the total sleep loss is much greater than that of the subjects in the current study. Subjects in previous studies with decreased cognition had been sleep deprived from 17-72 hours (Deary & Tait, 1987; Jacques, et al., 1990; Lieberman, et al., 2005; Lieberman, et al., 2002; Robbins & Gottlieb, 1990; Williamson & Feyer, 2000). These studies found decreased sleep quantity to have an effect on several different cognitive domains. Most commonly memory, concentration, reaction time and vigilance tasks were affected. None of these domains as measured by CNS Vital Signs were affected by deceased sleep quantity in our study.

Previous studies tested subjects who often work in a sleep deprived state such as truck drivers (Williamson & Feyer, 2000), military personnel (Lieberman, et al., 2005; Lieberman, et al., 2002), and medical residents (Deary & Tait, 1987; Robbins & Gottlieb, 1990). College students may intentionally deprive themselves of sleep in order to meet an academic deadline, study for an exam, or socialize with friends. This is contrary to truck drivers, military personnel, and medical residents who feel a sense of occupational pressure to consistently perform in a sleep-deprived state (Pilcher, et al., 1997). None of the student-athletes in our study limited his or her sleep to the same level consistently reported by the occupational professionals previously mentioned. Student-athletes who slept the least still averaged 68.75% (±12.7%) of their normal night's sleep. In the previous research, subjects experiencing a decreased level of sleep did not receive any sleep the night before testing. It could be said that these subjects slept 0% of their normal night's sleep (Jacques, et al., 1990; Lieberman, et al., 2005; Lieberman, et al., 2002; Robbins & Gottlieb, 1990; Williamson & Feyer, 2000). One previous study did test subjects who received some sleep before testing (Deary & Tait, 1987). Short-term memory was significantly degraded when subjects slept an average of 21.4% percent of their normal night's sleep (Deary & Tait, 1987). None of our student-athletes slept less than 33% of their normal night's sleep. Deary & Tait found no cognitive changes in their moderate sleep loss group (average of 71.42%), which was comparable to the average of the subjects who slept the least in our current study.

Based on previous research, it would appear that our subjects reporting the least sleep quantity experienced sufficient sleep to overcome sleep deprivation deficits observed in other studies. However, it is important to point out that student-athletes, including those in our study, are commonly instructed to sleep well the night before testing by their clinical athletic trainers. Subjects were not instructed to get a good night's sleep before testing by our research team, but the results of our study suggest that athletes are generally conscious of sleeping an appropriate amount before mandatory baseline testing.

The finding of associations between changes in sleep quantity and changes in cognitive symptom severity and the number and severity of neurobehavioral symptoms may have been caused by changes in sleep quantity that were larger than the differences between sleep quantity groups at baseline. The symptoms included in these categories are recognized as symptoms of concussion, but are also common symptoms of receiving decreased sleep.

Poor sleep quality also had no effect on neurocognitive or balance measures. This is in disagreement with previously reported data that observed poor sleep quality decreased cognitive ability (Clanton, et al., 2011; Fitzpatrick, et al., 1991). However, Fitzpatrick et al. only questioned subjects about several components of sleep quality, and did not employ a standardized sleep quality scale as we employed in our study. Clanton et al. employed the PSQI (as we did) to differentiate between good and poor sleep quality, but failed to report information regarding the actual global scores. Also, subjects in each of these studies were suffering from medical conditions that severely impacted their sleep, and although no specific data were reported, these subjects may have had more severely degraded sleep quality. Subjects categorized as having poor sleep quality in our study had an average global PSQI score of 7.57 (±1.63), with no subject reporting a score worse than 12. A global score of 5 or more is considered poor sleep quality, with 21 being the worst score. Although college students report frequent sleep difficulties (Buboltz, et al., 2001), generally healthy college students do not suffer from the same sleep deficiencies as cancer patients (Clanton, et al., 2011) or patients with nocturnal asthma(Fitzpatrick, et al., 1991).

We likely did not observe an association between changes in sleep quality and changes in concussion assessment outcomes or changes in sleep quantity and changes in measures of cognition and balance because our participants reported receiving with sleep quality scores that were not degraded severely enough. This resulted in relatively small change scores. The average change of sleep quality relative to baseline was 0.86 (±0.30) points and the average change in sleep quantity was 0.95 (±0.30) hours.

Based on our study results, recording sleep quality may be beneficial when trying to clinically interpret the number of symptoms reported by student-athletes and their respective severities. Although no association was found between change in sleep quality and change in GSC scores, it is reasonable to think that if there is a change in long-term sleep quality we may expect a change in the normal amount and severity of symptoms a person experiences. This may justify a reassessment of sleep quality every 1-2 months and reassessing baseline GSC if a change in sleep quality is observed. This would ensure that clinicians are fully aware of any changes in baseline symptoms before a symptom assessment would be employed as part of a multi-faceted concussion management plan. Since sleep quality did not affect neurocognitive function or balance performance no changes to these aspects of the baseline testing procedures appear warranted even if a subject displayed poor sleep quality.

Based on comparisons to previous research the subjects in our study who had the least amount of sleep quantity the night before testing only had a moderate loss of sleep. Thus, the results of our study suggest that moderate sleep loss does not need to be considered when assessing the validity of a student-athlete's baseline concussion assessment. However, based on previous research, student-athletes reporting to baseline testing after receiving no sleep the night before he or she should be asked to reschedule and sleep as close to normal as possible the night before testing.

Limitations

This study was limited by the fact that all sleep quality and quantity data was self-reported. Subjects were unaware that they would be reporting sleep data, which may have led to potential recall inaccuracies. Accuracy of self-reported sleep data may have been increased by asking subjects to record bed times, wake times and sleep habits during the month before testing to increase awareness of their own sleep habits. A convenience sample of generally health collegiate student-athletes was recruited during baseline testing, which resulted in a general lack of including specific patient populations that experience major sleep difficulties on a regular basis. Also, all Chi Square analyses required the use of Fisher's Exact Test due expected cell counts less than five.

Recommendations for Future Research

Future research in this line of research could involve a completely sleep deprived group, or intervention groups with modified amounts of sleep. This may create a potent effect between groups that would be more easily compared to previous research, and provide us with evidence that complete sleep deprivation also affects the specific tests used for concussion assessment in student-athletes. Also, a sleep journal may be beneficial to help subjects become more aware of their sleeping habits, which may help lower the possibility of self-reporting inaccuracies with respect to the sleep quality index used in our study.

Since the body performs neurocognitive and physical maintenance during sleep, we speculate that ensuring adequate sleep may have a potent effect on recovery following concussion. Future research could examine the effect that varying levels of sleep has on recovery time after concussions. This could provide important insight with respect to sleeping habits that may optimize a rapid and complete recovery.

The cumulative effect of moderately decreased sleep may also have an effect on concussion assessment measures. This type of sleep loss may occur over the course of a few days due to short-term changes in lifestyle. This represents a form of sleeping difficulty that might allow the clinician to distinguish between short-term previous night's sleep quantity and long-term sleep quality, both of which were measured in this study.

CONCLUSIONS

Poor sleep quality has a negative impact on general health and well-being and can produce signs and symptoms associated with concussions. Sleep quality should be measured at baseline in conjunction with a symptom assessment, and can be reassessed up to every month to evaluate changes, which could result in changes in baseline symptom scores. The relatively moderate sleep deficits experienced by subjects in this study did not affect performance on neurocognitive testing or balance testing. However, previous research has established that total sleep deprivation negatively affects neurocognitive testing performance and athletes who report to baseline testing completely sleep deprived should be rescheduled and told to report after a normal night's sleep.

Table 3.1: Graded Symptom Checklist (GSC) Symptom Categories

Somatic		Cognitive	Neurobehavioral
Headache	Sensitivity to noise	Difficulty concentrating	Trouble falling asleep
Nausea	Ringing in the ear	Feeling “in a fog”	Drowsiness
Vomiting	Sensitivity to light	Difficulty remembering	Fatigue
Dizziness	Blurred vision		Sadness
Poor balance	Neck pain		Irritability

Table 4.1. PSQI global score descriptive statistics.

Group	N	Mean	SD
High	105	3.4	1.36
Low	35	7.57	1.63

Table 4.2. The effect of sleep quality on CNS Vital Signs domain scores, composite SOT score, and number and severity of symptoms reported.

Clinical Measure	Domain	High Sleep Quality (N=105)		Low Sleep Quality (N=35)		F	*P*
		Mean	SD	Mean	SD		
CNS Vital Signs	Composite Memory	97.17	18.18	99.06	22.81	0.245	0.62
	Psychomotor Speed	103.02	15.32	105.94	10.65	1.07	0.30
	Reaction Time	98.47	14.77	99.66	13.44	0.18	0.68
	Complex Attention	95.07	31.68	91.06	51.39	0.30	0.59
	Cognitive Flexibility	96.90	18.42	95.89	18.3	0.08	0.78
	Processing Speed	101.66	14.65	101.43	16.36	0.01	0.94
	Executive Functioning	97.39	17.28	96.63	17.48	0.05	0.82
	Verbal Memory	95.70	19.55	98.00	22.94	0.33	0.57
	Visual Memory	99.99	15.42	100.34	17.864	0.01	0.91
	Reasoning	94.95	15.99	98.57	14.41	1.41	0.24
	NCI	97.99	14.10	99.06	17.01	0.13	0.72
SOT	Composite	76.31	7.75	75.95	8.35	0.05	0.82
GSC	Somatic (number)	0.65	1.21	1.17	1.65	4.06	0.046*
	Somatic (severity)	0.86	1.78	1.62	2.58	3.06	0.06
	Cognitive (number)	0.41	0.83	0.66	0.94	2.19	0.14
	Cognitive (severity)	0.70	1.93	1.20	2.21	1.61	0.21
	Neurobehavioral (number)	0.73	1.09	1.62	1.35	15.71	0.00‡
	Neurobehavioral (severity)	1.01	1.57	2.65	2.41	21.62	0.00†

* Low sleep quality group experience a greater number of somatic symptoms than the high sleep quality group.

‡Low sleep quality group experiences a greater number of neurobehavioral symptoms than the high sleep quality group.

† Low sleep quality group experiences a greater severity of neurobehavioral symptoms than the high sleep quality group.

Table 4.3. Baseline percent of normal sleep quantity descriptive statistics

Group	N	Mean	SD
Greatest	31	110.21%	16.85%
Moderate	31	90.97%	6.46%
Least	32	68.75%	12.7%

Table 4.4. The association between sleep quantity and CNS Vital Signs domain scores, composite SOT score, and number and severity of symptoms reported.

Clinical Measure	Domain	Least Sleep Quantity (N=31)		Moderate Sleep Quantity (N=26)		Greatest Sleep Quantity (N=45)		F	*P*
		Mean	SD	Mean	SD	Mean	SD		
CNS Vital Signs	Composite Memory	99.74	23.01	92.54	14.52	100.89	18.44	1.68	0.19
	Psychomotor Speed	103.77	18.20	99.88	10.80	105.49	12.44	1.31	0.27
	Reaction Time	99.10	13.81	95.92	18.07	99.62	13.03	0.56	0.58
	Complex Attention	95.26	44.73	98.88	15.01	99.29	89.44	0.14	0.87
	Cognitive Flexibility	95.00	20.53	96.92	12.21	99.24	15.50	0.62	0.54
	Processing Speed	100.23	10.88	96.77	13.29	102.62	20.01	1.10	0.34
	Executive Functioning	95.45	19.60	97.85	11.37	99.42	15.05	0.58	0.56
	Verbal Memory	96.48	25.56	98.08	17.28	100.33	15.92	0.36	0.70
	Visual Memory	102.65	16.82	91.31	13.28	102.33	16.40	4.83	0.01*
	Reasoning	97.77	16.40	89.96	14.47	96.91	14.24	2.33	0.10
	NCI	99.27	16.63	96.31	11.55	101.07	12.75	0.99	0.38
SOT	Composite	76.72	8.01	76.22	7.61	76.39	8.39	0.03	0.97
GSC	Somatic (number)	0.48	0.88	1.33	1.69	0.81	1.37	3.96	0.02†
	Somatic (severity)	0.58	1.09	2.17	3.05	1.05	2.00	1.70	0.19
	Cognitive (number)	0.32	0.65	0.71	1.04	0.38	0.79	2.73	0.07
	Cognitive (severity)	0.45	0.96	1.50	3.04	0.54	1.31	2.27	0.11
	Neurobehavioral (number)	0.87	1.18	1.29	1.30	0.95	1.27	0.85	0.43
	Neurobehavioral (severity)	1.19	1.89	2.04	2.24	1.10	1.46	2.79	0.07

*Post hoc testing found differences between least and moderate groups (*P* = 0.02) and moderate and greatest groups (*P* = 0.02)

† Post hoc testing found differences between least and moderate groups (*P* = 0.02).

Table 4.5. The associations between changes in sleep quality and sleep quantity and change in CNS Vital Signs domain scores, composite SOT score, and number and severity of symptoms reported.

Clinical Measure	Domain	Sleep Quality		Sleep Quantity	
		χ^2	***P***	χ^2	***P***
CNS Vital Signs	Composite Memory	4.63	0.33	1.49	0.89
	Psychomotor Speed	3.24	0.56	3.45	0.51
	Reaction Time	4.40	0.35	4.69	0.34
	Complex Attention	6.09	0.19	4.27	0.39
	Cognitive Flexibility	2.05	0.77	1.63	0.88
	Processing Speed	5.04	0.29	3.68	0.48
	Executive Functioning	2.37	0.70	2.56	0.67
	Verbal Memory	6.79	0.15	1.87	0.82
	Visual Memory	1.01	0.95	1.27	0.93
	Reasoning	4.68	0.32	0.81	0.99
	NCI	1.98	0.76	0.38	1.00
SOT	Composite	5.50	0.24	5.29	0.26
GSC	Somatic (number)	1.10	0.95	4.72	0.33
	Somatic (severity)	2.29	0.69	4.19	0.40
	Cognitive (number)	2.72	0.65	5.70	0.16
	Cognitive (severity)	2.46	0.69	11.42	0.006*
	Neurobehavioral (number)	1.44	0.88	9.75	0.043*
	Neurobehavioral (severity)	1.76	0.80	8.71	0.05*

*****Indicates significant association

Table 4.6. Baseline Graded Symptom Checklist frequency of reported symptoms and total cumulative severity for each symptom across all study participants.

Symptom	Frequency Reported	Symptom Severity
Headache	17	23
Nausea	10	11
Vomiting	0	0
Dizziness	10	17
Poor Balance	12	18
Sensitivity to Sound	8	9
Ringing in the Ears	11	10
Sensitivity to Light	10	10
Blurry Vision	8	9
Neck Pain	11	13
Difficulty Concentrating	24	35
Mentally Foggy	14	16
Difficulty Remembering	21	23
Trouble Falling Asleep	33	40
Drowsiness	26	41
Fatigue	29	39
Sadness	12	9
Irritability	15	13

Appendix 1

Subject's Initials________________ID#__________________Date_______________Time_____ AM/PM

PITTSBURGH SLEEP QUALITY INDEX

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

1. During the past month, what time have you usually gone to bed at night?

   BED TIME ___________

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

   NUMBER OF MINUTES ___________

3. During the past month, what time have you usually gotten up in the morning?

   GETTING UP TIME ___________

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

   HOURS OF SLEEP PER NIGHT ___________

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

b) Wake up in the middle of the night or early morning

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

c) Have to get up to use the bathroom

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

d) Cannot breathe comfortably

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

e) Cough or snore loudly

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

f) Feel too cold

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

g) Feel too hot

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

h) Had bad dreams

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

i) Have pain

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

j) Other reason(s), please describe____

____

How often during the past month have you had trouble sleeping because of this?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?

Very good ___________

Fairly good ___________

Fairly bad ___________

Very bad ___________

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all ___________

Only a very slight problem ___________

Somewhat of a problem ___________

A very big problem ___________

10. Do you have a bed partner or room mate?

No bed partner or room mate ___________

Partner/room mate in other room ___________

Partner in same room, but not same bed ___________

Partner in same bed ___________

If you have a room mate or bed partner, ask him/her how often in the past month you have had . . .

a) Loud snoring

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

b) Long pauses between breaths while asleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

c) Legs twitching or jerking while you sleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

d) Episodes of disorientation or confusion during sleep

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

e) Other restlessness while you sleep; please describe________________________________

____

Not during the past month_____	Less than once a week_____	Once or twice a week_____	Three or more times a week_____

Scoring Instructions for the Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI) contains 19 self-rated questions and 5 questions rated by the bed partner or roommate (if one is available). Only self-rated questions are included in the scoring. The 19 self-rated items are combined to form seven "component" scores, each of which has a range of 0-3 points. In all cases, a score of "0" indicates no difficulty, while a score of "3" indicates severe difficulty. The seven component scores are then added to yield one "global" score, with a range of 0-21 points, "0" indicating no difficulty and "21" indicating severe difficulties in all areas.

Scoring proceeds as follows:

Component 1: Subjective sleep quality

Examine question #6, and assign scores as follows:

Response	Component 1 score
"Very good"	0
"Fairly good"	1
"Fairly bad"	2
"Very bad"	3

Component 1 score: ______

Component 2: Sleep latency

1. Examine question #2, and assign scores as follows:

Response	Score
≤ 15 minutes	0
16-30 minutes	1
31-60 minutes	2
> 60 minutes	3

Question #2 score: ______

2. Examine question #5a, and assign scores as follows:

Response	Score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Question #5a score: ______

3. Add #2 score and #5a score

Sum of #2 and #5a: ______

4. Assign component 2 score as follows:

Sum of #2 and #5a	Component 2 score
0	0
1-2	1
3-4	2
5-6	3

Component 2 score: ______

Component 3: Sleep duration

Examine question #4, and assign scores as follows:

Response	Component 3 score
> 7 hours	0
6-7 hours	1
5-6 hours	2
< 5 hours	3

Component 3 score: ______

Component 4: Habitual sleep efficiency

(1) Write the number of hours slept (question # 4) here: _______

(2) Calculate the number of hours spent in bed:

Getting up time (question # 3): _______

− Bedtime (question # 1): _______

Number of hours spent in bed: _______

(3) Calculate habitual sleep efficiency as follows:

(Number of hours slept/Number of hours spent in bed) × 100 = Habitual sleep efficiency (%)

(_______/_______) × 100 = _________%

(4) Assign component 4 score as follows:

Habitual sleep efficiency %	Component 4 score
> 85%	0
75-84%	1
65-74%	2
< 65%	3

Component 4 score: _______

Component 5: Sleep disturbances

(1) Examine questions # 5b-5j, and assign scores for *each* question as follows:

Response	Score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

#5b score _______
c score _______
d score _______
e score _______
f score _______
g score _______
h score _______
i score _______
j score _______

(2) Add the scores for questions # 5b-5j:

Sum of # 5b-5j: _______

(3) Assign component 5 score as follows:

Sum of # 5b-5j	Component 5 score
0	0
1-9	1
10-18	2
19-27	3

Component 5 score: _______

Component 6: Use of sleeping medication

Examine question # 7 and assign scores as follows:

Response	Component 6 score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Component 6 score: _______

Component 7: Daytime dysfunction

(1) Examine question # 8, and assign scores as follows:

Response	Score
Never	0
Once or twice	1
Once or twice each week	2
Three or more times each week	3

Question # 8 score: ______

(2) Examine question # 9, and assign scores as follows:

Response	Score
No problem at all	0
Only a very slight problem	1
Somewhat of a problem	2
A very big problem	3

Question # 9 score: ______

(3) Add the scores for question # 8 and # 9:

Sum of #8 and #9: ______

(4) Assign component 7 score as follows:

Sum of # 8 and #9	Component 7 score
0	0
1-2	1
3-4	2
5-6	3

Component 7 score: ______

Global PSQI Score

Add the seven component scores together:

Global PSQI Score: ______

Appendix 2

Graded Symptom Checklist (GSC)

Symptom	Time of injury	2-3 Hours postinjury	24 Hours postinjury	48 Hours postinjury	72 Hours postinjury
Blurred vision					
Dizziness					
Drowsiness					
Excess sleep					
Easily distracted					
Fatigue					
Feel "in a fog"					
Feel "slowed down"					
Headache					
Inappropriate emotions					
Irritability					
Loss of consciousness					
Loss or orientation					
Memory problems					
Nausea					
Nervousness					
Personality change					
Poor balance/coordination					
Poor concentration					
Ringing in ears					
Sadness					
Seeing stars					
Sensitivity to light					
Sensitivity to noise					
Sleep disturbance					
Vacant stare/glassy eyed					
Vomiting					

NOTE: The GSC should be used not only for the initial evaluation but for each subsequent follow-up assessment until all signs and symptoms have cleared at rest and during physical exertion. In lieu of simply checking each symptom present, the ATC can ask the athlete to grade or score the severity of the symptom on a scale of 0-6, where 0=not present, 1=mild, 3=moderate, and 6=most severe.

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