The Effects of Concussion on Quantity of Sleep and Quality of Sleep

Taren Asheton Bone

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APPROVAL OF THESIS

We, the faculty supervising the work of Taren Asheton Bone, affirm that the thesis, The Effects of Concussion on the Quality of Sleep and Quality of Sleep, meets the high academic standards for original scholarship and creative work established by the Master of Science in Exercise Science and the College of Health Professions. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

Dr. Suzanne Kozlowski, Department of Biomechanics Committee Chairperson 2/9/2021

Dr. William Garrett, Department of Athletic Training Committee Member 2/9/2021

Dr. Charles Gilliland, J. C. Edwards School of Medicine Committee Member 2/9/2021
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ABSTRACT

This study observed how a concussion's effects change the quantity and quality of sleep in collegiate athletes. There is a lack of research pertaining to this topic, explicitly involving collegiate athletes and the changes in sleep outcomes during concussion recovery from a concussion. The study design is a convenient cohort in the field involving athletes from two local universities. Participants wore a Readiband™ device for seven to ten days or throughout their concussion recovery. There were differences in total minutes in bed and calculated minutes in bed between concussed and non-concussed participants. This study indicates that concussion affects the quantity of sleep, with concussed athletes spending less time in bed and fewer minutes asleep. Understanding that sleep changes occur post-concussion may delay their recovery time as sleep is essential for recovery and performance. This research can formulate new standards of care for athletes through the duration of concussion and recovery.
CHAPTER 1
INTRODUCTION

Sleep is a process that nearly every organism on Earth experiences at one point or another in a lifetime. Sleep is essential for humans because their bodily processes rely on a period of rest to maintain a smooth and adequately functioning balance (Luyster et al., 2012). The American Sleep Association reports that 50-70 million people in the United States have a sleep disorder, ranging from sleep apnea to general sleep deprivation (Colten et al., 2006). With a reported number of 50-70 million people of the US population having a sleep disorder, according to Colten, many aspects of the health and wellness of those sleep-disordered individuals are compromised due to their abnormal sleep patterns (Demirel, 2016). Individuals with abnormal sleep patterns may have increased risks of weight gain, depression, hypertension, decreased immune function, impaired performance, and increased risk of injury (Watson et al., 2015).

Four theories exist as to why experiencing healthy sleep is vital in maintaining homeostasis (Porkka-Heiskanen et al., 2013). The first theory described by Benington and Heller (1995), the energy hypothesis theory, claims that during sleep, a decrease (10%) in the use of energy and the restoration of cellular metabolites required for energy throughout periods of wakefulness occurs (Kong et al., 2002; Porkka-Heiskanen et al., 2013; Scharf et al., 2008). A second theory, the repair and restoration theory, suggests that adequate sleep helps the body's immune response, including the ability to fight off infection by revitalizing and restoring the body's physiology, so the mind and body are healthy and adequately functioning (Brinkman et al., 2020; Cohen et al., 2009; Porkka-Heiskanen et al., 2013).

The inactivity theory, based on the concept that creatures are less likely to die from attacks and injury at night due to decreased activity, creates a benefit for a period of nightly
inactivity (Brinkman et al., 2020). The final theory, and perhaps the most important for this research, is the brain plasticity theory. Brain plasticity theory explains how the brain forms a foundation of learning, memory, and behavior during sleep (Diekelmann & Born, 2010; Lo et al., 2012; Porkka-Heiskanen et al., 2013).

Considerations are needed when reviewing the sleep theories since the theories were developed and applied to the general population. How do sleep theories apply to an athletic population, specifically collegiate athletes? For athletes, the brain's plasticity when properly functioning is essential for cognitive function and physical ability for sports performance (Atkinson & Reilly, 1996; Mah et al., 2018; Reilly & Edwards, 2007). Recovery and repair are essential for performance and recovery from injury by allowing proper immune and endocrine function (Cohen et al., 2009; Kripke et al., 2002; Malhotra, 2017; Walker & Stickgold, 2005).

Collegiate student-athletes experience increased amounts of stress that can cause an increase in abnormal sleep patterns, specifically with early waking and increased difficulty falling asleep and staying asleep (Demirel, 2016).

Not only do collegiate student-athletes have stress from classwork and schedules, but also a concern of injuries, specifically brain injuries. Concussion is currently a hot topic in the sports medicine world. The complexity and the high prevalence of concussion continues to be one of the most common issues that medical professionals and collegiate athletes face throughout their careers (Broglio et al., 2014; Taylor et al., 2017).

Concussion disrupts the physiological function of the brain. From this disruption, signs and symptoms emerge, with the classic and well-known being headache, dizziness, light sensitivity, noise sensitivity, and balance issues (Norton, 2018). Although this understanding of
the classic signs and symptoms is positive, more complex issues arise from symptoms that are not as well understood, such as disruption of sleep or changes in sleep.

**Statement of the Problem**

Approximately 36%-70% of patients diagnosed with a concussion report a disruption or change in their sleep after a concussive episode (Keshavan et al., 1981; McLean et al., 1984; Rao & Rollings, 2002). Castriotta et al. (2007) reported that approximately three months after traumatic brain injury (TBI), 46% of patients still had sleep disturbances. However, most current research focuses on the return to play and recovery following concussion in athletics. A lack of research exists on the effects of sleep disruption or sleep changes in athletes who have experienced a concussion.

**Purpose**

The purpose of this study was to investigate the changes in sleep patterns and sleep quality of concussed collegiate football players through Readiband™.

**Research Question**

Does concussion cause a change in sleep quality and sleep quantity in collegiate football players?

**Hypothesis 1**

**Null Hypothesis.**

There will be no difference between the sleep quality between the non-concussed and concussed athletes, as assessed by Readiband™ actigraphy.
**Alternative Hypothesis.**

There will be a difference between the sleep quality of the non-concussed and concussed athletes as assessed by Readiband™ actigraphy.

**Hypothesis 2**

**Null Hypothesis.**

There will be no difference between the quantity of sleep in non-concussed and concussed athletes, as assessed by Readiband™ actigraphy.

**Alternative Hypothesis.**

There will be a difference between the quantity of sleep in non-concussed and concussed athletes as assessed by Readiband™ actigraphy.

**Limitations**

Limitations of this study included:

1. The interpretation of the concussion evaluation varied between physicians and athletic trainers.
2. The interpretation of the data from the Readiband™ is based on the understanding of the presenting data.
3. The sample size was small.
4. The number of subjects from each university was limited and not equal.
5. Subjects may not have been honest when completing surveys.
6. Subjects may not have been honest when reporting concussive symptoms.

**Delimitations**

Delimitations of this study included:
1. Subjects were current college football players from an NCAA D-I university and an NAIA college.

2. All subjects were male.

3. Readiband™ devices were used for actigraphy assessment.

4. There was a comparison between non-concussed and concussed athletes.

5. The Pittsburgh Sleep Quality Index Questionnaire was used to assess the self-perception of the subject’s sleep.

6. The symptom score was used to assess the overall burden of concussion symptoms that the subject is experiencing.

Assumptions

Assumptions of this study included:

1. All concussions occurred from athletic activity.

2. Non-concussed athletes were honest and reported any concussive event.

3. Concussed athletes were indeed concussed.

4. The subjects answered all questionnaires truthfully.

5. The subjects had a sincere interest in participating in this study.

6. All subjects were compliant with wearing the Readiband™

7. Readiband™ is a reliable and valid means of measuring sleep.

Operational Definitions

*Awakenings per Hour* - The total estimated awakenings are divided by sleep quantity hours (Nejait, 2021).

*Concussed Collegiate Football Players* - Collegiate football players diagnosed with a concussion.
Non-concussed Collegiate Football Players - Collegiate football players who do not have a concussion.

Pittsburgh Sleep Quality Index Questionnaire – is a self-rated questionnaire on sleep quality and sleep disturbances (Buysse et al., 1989).

Sleep Efficiency - The percentage of time in bed sleeping (Nejait, 2021).

Sleep Quality - The number of awakenings per hour and minutes of sleep lost to awakenings, rated on a scale of 1-10 (Nejait, 2021).

Sleep Quantity - The estimated time of the longest sleep periods, naps excluded (Nejait, 2021).

Total Awakenings - The estimated number of awakenings longer than 5 minutes (Nejait, 2021).

Wake After Sleep Onset - The estimated awake minutes between sleep onset and wake time (Nejait, 2021).

Wake Time - Amount of waking time from major sleep and naps are excluded (Nejait, 2021).
CHAPTER 2
LITERATURE REVIEW

The Centers for Disease Control and Prevention reports that there were approximately 2.8 million TBI within the United States in 2013, with the most common mechanism of injury being falls (Taylor et al., 2017). Due to the surprising number of TBIs occurring for one year, the concern is significant for the athletic population. The rise in concussive incidents raises not only public awareness but also practical questions in the medical field. Researching concussion effects will provide insight into the full burden the patient experiences. The increase of available research could lead to more effective treatment algorithms for concussions. Further research will also aid in recognizing less frequently apparent symptoms following a concussion diagnosis.

For the study, the researchers analyzed mild traumatic brain injury (mTBI) in collegiate football players and issues that arose from the diagnosis; precisely, how does the quality of sleep and quantity of sleep change when a subject is concussed. Concussion and mTBI were used interchangeably for this research. From the sleep data collected, concussed athletes were compared to their non-concussed counterparts, hypothesizing that the concussion population will decrease sleep quality and sleep quantity compared to their non-concussed counterparts. Within this research, multiple aspects were involved in the data collection that were considered, including the brain's anatomy, mechanism of injury, signs, symptoms, diagnostic criteria, actigraphy, healthy sleep, and sleep disruption following brain injury, along with the possible effects of recovery.

Reviewing current published literature did not give practitioners or patients insight into concussion and sleep in the athletic population. A knowledge base was built on concussion and
how it presents itself through a review of anatomy, mechanisms of injury for concussions, signs, and symptoms of a concussion, and diagnostic criteria for a concussion. Looking deeper into the current information about sleep studies via actigraphy, the patterns of healthy sleep, the base knowledge of sleep, and how it can be measured outside of a hospital was gained. Information on sleep in traumatic brain injury patients exists but could the information be applied to mild traumatic brain injury or concussion? This point had yet to be consistently validated.

**Anatomy**

Anatomy involved with a concussion pertains to the brain and its functions. The anatomical structures discussed in this review pertain to the specific structures directly affected by concussions that result in the subject having changes in sleeping patterns. The researchers first looked at the head and the makeup of the bony and soft tissue structures involved. The skull protects the brain, comprised of meninges (Norton, 2018). Even though bony structures help preserve the brain, the brain is free-floating within the cerebrospinal fluid and prone to movement within the cavity according to Norton. Various portions of the brain are responsible for the different functions occurring throughout the body. To understand the effects of an mTBI, the researcher examined the functions most commonly affected by an mTBI.

The cerebrum is responsible for motor input signals (Tortora & Derrickson, 2014). The increased signal from the cerebrum also accounts for the more complex symptoms that the subject may experience, such as memory issues, balance issues, and even verbal difficulties (Barkhoudarian et al., 2011; Norton, 2018). The number of symptoms a patient experiences can also be based on the sex of the patient, with females tending to have a higher number of symptoms than males (Thomas et al., 2018). The difference in the burden of symptoms is due to the anatomical makeup of the brains of males and females (Solomito et al., 2019). The
significant difference between male and female brains for discussion on concussion is the amount of gray matter, with males having a greater amount of grey matter according to Solomito. However, Solomito also determined that females make more use of both hemispheres of the brain. Due to this information from Solomito, this could be why females take longer to recover from a concussion or mTBI than their male counterparts. However, only male subjects were be used in this research.

**Mechanism of Injury**

Although the CDC reports that the most common cause of TBI in 2013 were falls and forces associated with falling (Taylor et al., 2017), acceleration, deceleration, or rotational forces can cause a TBI (Clay et al., 2013; Mullally, 2017; Norton, 2018; Voss et al., 2015). Research still needs to be completed validating the argument that force alone causes an mTBI. The most common cause of a TBI or mTBI can vary when assessing a specific population. The most common mechanism of mTBI in football is player-to-player contact according to Mullally. When considering that information and the review of anatomy, it is clear to see why incidents would occur the most in football, according to Clay. Players collide with one another as part of the play during a football game. The skull's anatomy allows the brain to move within the cavity at different acceleration and deceleration rates, resulting in an impulse to the brain from striking the skull (Kerr et al., 2015; Kirk et al., 2018). Houck et al. (2016) found the environment and type of play can alter the mechanism and incident of concussive injury, with full padded practice having the highest incidence of concussions (69.9%) due to the rate of contact a player experiences. The player's position may also alter the incident and mechanism of concussive injury due to the frequency of concussive forces a player will experience throughout practices or games (Buckley, 1988; Guskiewicz et al., 2000, & Guskiewicz et al., 2003).
Signs and Symptoms

Classic symptoms of an mTBI exhibited by a subject could include headache, nausea, confusion, trouble with memory, balance difficulties, and other nonspecific incidents such as increased light and noise sensitivity (Clay et al., 2013; Mullally, 2017; Norton, 2018). By noting the symptoms that a subject reports and the signs they exhibit, a concussion (mTBI) can be suspected. When assessing symptoms, it is essential to note all forms of symptoms that are being presented, including physical, emotional, and cognitive symptoms (Guskiewcz et al., 2000; Kelly & Rosenberg, 1997; Mullally, 2017). Physical symptoms may be presented through slurred speech, vomiting, appearing disoriented, and delayed response to questions or other stimuli (Guskiewcz et al., 2000; Kelly & Rosenberg, 1997; Kirk et al., 2018). Another symptom and the primary symptom(s) of concern for this research is sleep and how it is affected during a concussed state.

Concussion research has typically included the commonality of symptoms reported by concussed patients. However, the symptoms that were of most interest to this study are sleep disturbances along with changes in activity during sleep, quality of sleep, and quantity of sleep; which all can impede neurocognitive performance leading to a continuation of symptom burden (Dinges et al., 1997; Mihalik et al., 2013; Stocker et al., 2017).

Normal Sleep

Sleep is an essential process for many aspects of health and wellness, including healing to aid the body's immune response for proper functioning (Besedovsky et al., 2012; Brinkman et al., 2020; Demirel, 2016; Cohen et al., 2009; Porkka-Heiskanen et al., 2013). Sleep is measured in cycles, those being non-rapid eye movement (NREM) and rapid eye movement (REM) (Fuller
et al., 2006). During NREM, there are a total of four stages that a person will go through with a varying level of consciousness they experience according to Fuller.

Occasionally coinciding with NREM sleep, REM sleep allows a person to go into an 'active' state of sleep accompanied by rapid eye movements and only accounts for a small amount of overall sleep humans experience (Aserinsky & Kleitman, 1953; Fuller et al., 2006; Peever & Fuller, 2017). The purpose of REM sleep is hypothesized to have an impact on brain development and maturation (Marks et al., 1995). According to McGaugh (2004), another important function of REM sleep is sleep-dependent emotional processing.

The cycles and timing of sleep that a human experiences are based on a specific interaction between the time of day and the amount of time someone is awake commonly referred to as the circadian rhythm (Borbély, 1982; Brown et al., 2012). This cycle is mediated by neurons located in the hypothalamus and brainstem, allowing periods of sleep and wakefulness (Fuller et al., 2006).

**Sleep after TBI**

A common symptom from an acute concussion is the reported disruption or difficulty sleeping (Allan et al., 2017; Jaffée et al., 2015). Changes in sleep after TBI can present themselves in different forms, such as drowsiness, lethargy, difficulty sleeping, or increased sleeping (Allan et al., 2017). Due to sleep changes, patients who experienced a TBI could also have their function and performance affected, including cognitive function and immunity (Kripke, 2002; Malhotra, 2017). Patients diagnosed with a traumatic brain injury (46%) had abnormal sleep studies (Castriotta et al., 2007).

Human sleep is a mechanism that relies on single cells in the brain to maintain a clock mechanism (Barshikar & Bell, 2017) and is broken into two categories: REM and non-REM
Due to brain alteration during TBI (Sandsmark et al., 2017), a change in sleep after the injury is common. From the changes in sleep patterns, the symptoms seen could increase, or the development of new symptoms due to the lack of sleep can result in psychological and cognitive function changes (Fogelberg et al., 2012).

Sleep assessment is not always completed or considered when patients are diagnosed with TBI (Mani et al., 2015). Since abnormal sleep can cause psychological and cognitive function decreases (Fogelberg et al., 2012; Mani et al., 2015), more research is needed to understand the effects of the changes in sleep from TBI. Mani et al. (2015) claimed that no instrumentation was specific for measuring sleep in TBI patients. However, actigraphy can be used to study the movements that happen during sleep, creating measurements to assess the quality of sleep (Allan et al., 2017; Raikes & Schaefer, 2016).

Sleep is an essential tool for recovery due to injury (Cohen et al., 2009; Malhotra, 2017). However, the changes in sleep that patients report could increase or prolong symptoms and recovery (Fogelberg et al., 2012; Mani et al., 2015). Due to the consequences of changing sleep patterns and the treatment of rest after a concussion, currently, there are no sleep recommendations specifically for concussion recovery (Moser et al., 2012; Sufrinko et al., 2018).

Acute phase concussive patients with sleep difficulties are comparable to patients with chronic sleep difficulties (Raikes & Schaefer, 2016). The increase in sleep difficulty complaints for early concussion patients leads to an increased need for sleep within the first 24-hours of the injury according to Raikes and Schaefer. With a lack of sleep present during the acute phases of concussion, there can be a decrease in cognitive testing performance, leading to a delay in recovery and return to sport (Mihalik et al., 2013; Murdaugh et al., 2018).
The increasing number of concussions reported and the increased knowledge about concussions gives rise to the need for more research on the topic of sleep and concussion. The free-floating organ that is the brain can be injured through various mechanisms, resulting in an injury that causes many well-known symptoms and changes. One change that is common but not highly researched is the alterations in the quality of sleep and quantity a concussion patient experiences. Based on clinical knowledge and experience with concussion and recovery, there seems to be a decrease in sleep aspects, leading to the belief that concussions result in decreased sleep quality and quantity.

**Diagnostic Criteria**

The methods for classifying and diagnosing a head injury can vary from the injury being opened or closed, as well as the neurocognitive function of the patient (Norton, 2018). The Glasgow Coma Scale is used to assess brain injury severity (Kruse et al., 2018; Norton, 2018). The Glasgow Coma Scale is graded based on a patient's consciousness, alertness, and memory, with mTBI scoring between 13-15 (Blyth & Bazarian, 2010; Friedland, 2013; Levin & Diaz-Arrastia, 2015). Norton states that once Glasgow Coma Scale has been assessed, further investigation into the patient's neurocognitive and physical function can be assessed with a battery of tests to determine the severity of their symptoms, which may vary from typical symptoms, such as headaches, to more subtle symptoms like difficulty concentrating.

Cognitive functioning refers to the ability to process thoughts and emotions, while physical functioning refers to balance or physical signs, including vomiting (Kirk et al., 2018; McCrory et al., 2017; Norton, 2018). The Sport Concussion Assessment Tool (Echemendia, et al., 2017) provides a sideline screening that assesses a patient's consciousness, neurological functioning, cognitive function, alertness, and current symptoms (Downey et al., 2018; Kruse et
Within the SCAT5, two components important for assessment are symptom scoring and balance assessment according to Kruse. Concussion symptom scoring is used not only as a diagnostic assessment measure but also to track the patient's progression throughout their recovery from a concussive event (Kruse et al., 2018; Notebaert & Guskiewicz, 2005, Echemendia et al.).

Medical imaging does detect changes within the brain caused by an mTBI and is used in long-term cases or cases that are taking an extended time to recover (Giza & Hovda, 2014; McCrory et al., 2013). For acute concussions, further assessment after the initial diagnosis and throughout the recovery should be continued to monitor symptoms and function (Kruse et al., 2018; Notebaert & Guskiewicz, 2005). The SCAT can be administered throughout recovery and post-concussion recovery to determine how the patient's scores change (Downey et al., 2018) as well as other cognitive tests such as Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is a six-module computer test that scores verbal memory, reaction time, visual speed, and visual memory (Broglio et al., 2006). The sideline test, King-Devick, can measure visual-motor speed since visual-motor speed delay is a highly reported sign of mild traumatic brain injuries (Dessy et al., 2017). Research indicates that ImPACT and King-Devick testing strongly correlate with similar results with patients who have experienced an mTBI (Dessy et al., 2017; Tjarks et al., 2013). From the ImPACT test results, a determination can be made to assess the patient for a concussion through scores that determine deficits in visual-motor speed, visual memory, and reaction time (Tjarks et al., 2013). The ImPACT test can be useful in the diagnosis process because the exam results can reflect an interruption of the anatomy of the brain and the neural
pathways that cause axonal damage from the mechanism of injury experienced (Dessy et al., 2017; Tjarks et al., 2013). The King-Devick test will not be included in the methods for this research.

Once a concussion is suspected, the patient is given a battery of tests to check the patient's neurological ability. Through sideline evaluations or more in-depth testing, such as the ImPACT testing and symptom scoring, a better understanding of the current cognitive function determines if a patient is concussed or not. The standard of care for concussion diagnosis is to have initial baseline tests on the athletes so that if a concussion is suspected, there can be a comparison between baseline and suspect testing.

Symptom Scoring

When evaluating an athlete for concussion, the typical setting is on the sideline of practice or competition. However, doing a sideline evaluation often includes tests and questions that may not fully represent the athlete's concussion. In general, many athletes may have symptoms without a concussive episode occurring, so that would make relying on the symptom score alone a misrepresentation (Shehata et al., 2009). The symptoms that the athlete reports may be related to existing comorbidities. The recommendation is that the symptom score of the patient as well as other assessments, such as balance testing and ImPACT testing, occur to gain a comprehensive evaluation of the athlete's current cognitive function (Putukian, 2017; Sufrinko et al., 2017).

ImPACT Testing

Immediate Post-Concussion Assessment and Cognitive Testing is a battery of tests used to measure an athlete's neurocognitive function when suspected of a concussion (Schatz et al., 2006). Verbal and visual memory testing, visual speed, and reaction time measurements,
combined with the athlete's symptom score, occur during the test according to Schatz. The reported sensitivity of the ImPACT test is 81.9%, while specificity is reported at 89.4%; however, there are issues with the test, such as with verbal memory could increase in performance if the test is taken multiple times (Schatz, 2010; Schatz et al., 2006). The long-term use of ImPACT for baseline testing has been shown to have consistent data when used across two years, with only 0-6% having changes in composite scores and 5-10% having changes in symptom scores (Schatz, 2010).

Pre-existing factors can affect changes in ImPACT testing results, including biological sex, psychiatric conditions, and attention deficit hyperactivity disorder (Cottle et al., 2017; Solomon GS, Haase RF, 2008). However, the pre-existing factors are not a concern for this research since the inclusion and exclusion criteria take into account those factors and how they may alter the ImPACT test results. The overall evaluation for a concussion includes ImPACT testing and the comprehensive evaluation when diagnosing a concussion completed by the physician or athletic trainer.

**Pittsburgh Sleep Quality Index Questionnaire (PSQI)**

The Pittsburgh Sleep Quality Index is a self-completed questionnaire to assess sleep quality and sleep quantity (Buysse et al., 1989). Byusse states that, first developed in 1989, there are several goals of the PSQI: valid measurement of sleep quality, discrimination between ‘good’ and ‘poor’ sleepers, easy interpretations for clinicians and researchers, and brief clinical assessment of sleep disturbances. Nineteen questions are to be completed by the patient, with an additional five questions to be completed by roommate or bedmate as part of the PSQI; however, the last five questions are not considered in the PSQI score according to Buysse.
The PSQI has an 89.6% sensitivity and 86.5% specificity when distinguishing between ‘good’ and ‘poor’ sleepers as stated by Buysse. When individually assessing patients after they have sustained a traumatic brain injury, the PSQI has a sensitivity of 93% and specificity of 100% for diagnosing insomnia when the overall global score is above 8, according to results of Fichtenberg et al. (2001).

**Actigraphy**

Wrist actigraphy has been used in the medical field since the 1950s but was not used to measure body movement through wearable wrist devices (Martin & Hakim, 2011). Through the development and advances in technology, actigraphy devices are now small in size and lightweight as stated by Martin and Hakim, allowing the devices to be carried by various populations across settings. Data is collected and recorded using the devices for the degree of limb movement over a given time (Smith et al., 2018). Actigraphy is recommended and used to study adult patients known to have sleep-wake disorders to assess the amount of time the patient is sleeping and is awake according to Smith. Smith also states that total sleep time and wake time can be established using the sleep time measurements to determine the overall quality and quantity of sleep the patient is getting.

When using actigraphy to study a patient's sleep, a sleep diary is used in conjunction with the actigraphy data (Allan et al., 2017; Raikes & Schaefer, 2016). Allan et al. (2017) studied 48 university subjects using actigraphy on their non-dominant wrist for 14 days to measure their sleep after reporting sleep and mTBI in a survey finding that the subjects with an mTBI did have more disturbed sleep and more periods of sleeping during the day. Raikes and Schaefer (2016) studied 17 young adults determined concussed individuals trended toward an increase of variability of total sleep time over 24 hours but were within four days of their initial injury and
were not restricted in any manner, minus sport-related activity. The data within these two studies show that the athletic population in this study will follow the trend that concussion or mTBI will cause a change in sleep for the affected subjects.

**Readiband™**

For this research, the actigraphy device used is the Readiband™ by Fatigue Science from Vancouver, British Columbia, Canada. Compared to the gold standard of sleep studying, the polysomnography, the Readiband™, is reported to be 93% accurate compared to polysomnography (Russell et al., 2011). The USDA has approved Readiband™ for monitoring sleep (Driller et al., 2016). The inter-device reliability reported and tested for the Readiband™ is 95% of agreement between two different Readiband™ devices worn simultaneously as stated by Driller.

A common symptom after an acute concussion is sleep aberrancy (Allan et al., 2017). Recent research has indicated that sleep changes after sustaining a traumatic brain injury show decreased quality and quantity (Gosselin et al., 2009; Khoury et al., 2013; Ouellet et al., 2006; William et al., 2008). Although this information is useful for the overall view of TBI, there has been little research on acute concussion and its effects on sleep. Using this information, actigraphy can be applied to patients with concussion or mTBI to measure their sleep quality and quantity after injury.
CHAPTER 3
METHODS

Research Design

The study was a prospective cohort study.

The dependent variables for this study were

- sleep quality, sleep quantity,
- awakenings per hour,
- total awakenings,
- wake after sleep onset
- sleep efficiency, and,
- wake time.

The independent variables for this study were

- non-concussed collegiate football players, and
- concussed collegiate football players.

Participants

Participants for this study were collegiate football players who consented to be included in the study. Participants were current college football players from two local universities who had met the inclusion criteria and had met none of the exclusion criteria. The baseline athletes, including non-concussed collegiate football players that had been asked and agreed to participate, were screened for inclusion or exclusion from the study. Once this screening was completed, the athlete read and signed a written informed consent stating that they understood the purpose of the study.
Once an athlete was diagnosed with a concussion by their athletic trainer or team physician, they were presented with the opportunity to participate in the study. If the athlete agreed to participate, a verbal consent was read to the concussed athlete (See Appendix C) by the athletic trainer with a witness present. The athlete gave verbal consent to participate. The informed consent and verbal consent reading allowed enrollment into the study. Once the concussed athlete was cleared from the concussion protocol, they were required to read and sign a written informed consent (See Appendix B).

If at any point the subjects in this study did not wish to participate or did not correctly complete the consenting process, they were withdrawn from the study, and their data was not included in the analysis.

**Inclusion Criteria:** a current collegiate football player, aged 18-25, male, non-concussed for baseline sleep analysis, and concussed for sleep analysis.

**Exclusion Criteria:** currently concussed, any psychological disorders, such as anxiety or depression, that could affect sleep, history of sleeping disorders, such as apnea, visited areas with different or multiple time zones within the last six weeks, or taking any medication that may induce sleep.

This project has been approved by the Marshall University Institutional Review Board (See Appendix A).

**Instrumentation**

Diagnostic tools that were used were determined by a certified athletic trainer or team physician, including symptom scoring, ImPACT testing (ImPACT Applications, Inc., Pittsburgh, PA), or SCAT 5 (Concussion in Sport Group, 5th International Consensus Conference on Concussion in Sport, Berlin, Germany). ImPACT testing has a reported 81.9% sensitivity and
89.4% specificity (Schatz, 2010; Schatz et al., 2006). Patient symptom scores were performed on concussed patients as they progressed through recovery. Readibands™ (Fatigue Science, Blaine, WA) were placed on the subject's wrist for sleep analysis. Readibands™ (Fatigue Science, Blaine, WA) has been testing and compared to polysomnography and reports a 93% accuracy (Russell et al., 2011) and a ±95% agreement between Readiband™ and polysomnography (Driller et al., 2016). All subjects completed a Pittsburgh Sleep Quality Index Questionnaire to assess their sleep perception. When used to differentiate between good and poor sleepers, the PSQIQ has a sensitivity of 89.6% and specificity of 86.5% (Buysse et al., 1989). When used with patients that have sustained a traumatic brain injury, there is a reported sensitivity of 83% and specificity of 100% for insomnia when scoring a PSQIQ Global score of 8 or above (Fichtenberg et al., 2001).

Protocol

After completing the consent process, subjects were given a Readiband™ device and instructed on its usage. Subjects wore a Readiband™ device on their dominant wrist for five to ten days. Once the subject returned the Readiband™ device, they completed a Pittsburgh Sleep Quality Index Questionnaire. After the Pittsburgh Sleep Quality Index Questionnaire was completed, the baseline subject was finished with their contribution to the study.

Concussed subjects wore a Readiband™ device on their dominant wrist for their concussion duration. The timeline began as soon as the subject was diagnosed with a concussion and was completed when the subject was cleared for return to play. Throughout their concussion, concussed subjects wore a Readiband™ device. Subjects filled out a concussion symptom score sheet daily with the athletic trainer. Subjects completed a single Pittsburgh Sleep Quality Index
Questionnaire at the return of the Readiband™ device. After the Pittsburgh Sleep Quality Index Questionnaire was completed, the subject was finished with its contribution to the study.

**Procedures**

During the Spring 2019 football season, baseline sleep data were collected from collegiate football players of two local universities. Each subject voluntarily signed informed consent (Appendix B) and was given a Readiband™ device to wear for 5-10 days on the dominant hand's wrist. Sleep quality and sleep quantity (awakenings per hour, total awakenings, wake after sleep onset, sleep efficiency, and wake time) were collected from the Readiband™ device's cloud-based data storage and entered into an Excel spreadsheet. The sleep quality and sleep quantity were visible through the Fatigue Science website or the Readiband™ application on an iPad. No participant had their personal information displayed on the Fatigue Science website or Readiband™ application. The information from the Pittsburgh Sleep Quality Index Questionnaire (Appendix D) and the concussion symptom score (Appendix E) were entered in an Excel Spreadsheet.

During the 2019-2020 football season, beginning on the first day of practice in August 2019, data was collected from athletes as they were diagnosed with a concussion by their athletic trainer or team physician from the same universities. All concussions were evaluated by a team athletic trainer and physician when a concussion was suspected. The athletic trainer and physician used concussion symptom scoring and neuropsychological testing to measure memory, reaction time, visual difficulties, sleep difficulties, and symptom burden. Once a diagnosis was made and the inclusion/exclusion criteria were reviewed, the athlete was eligible for inclusion in the study.
A verbal consent (Appendix C) was read to the participant in the presence of a witness, and the verbal consent was signed by the participant if they agreed to participate. Once this occurred, the participant was given a Readiband™ for data to be collected on an iPad via the Readiband™ application, with no personal information being given.

Every day, the concussed athlete was seen in the Athletic Training Clinic. There was a concussion symptom score completed personally by the athlete. These symptom scores were used to compare the changes in symptoms burden with the changes in sleep. When the athlete had been released to return to play, they read and signed a written informed consent; their data were excluded if they did not consent. The athlete completed a Pittsburgh Score Index Questionnaire as well as additional demographics, including age, height, weight, and position they play on the football team.

Data Analysis

The PSQI and concussion symptom scores were analyzed using non-parametric tests. Significance was set at the .05 level. A paired T-test was used to compare initial and final actigraphy measurements. One-way ANOVA was used to compare the concussed group to the non-concussed groups. A case-cohort was completed with similar non-parametric tests to compare initial and final measurements and compare concussed and non-concussed groups.

The dependent variables for this study were

- sleep quality,
- sleep quantity,
- awakenings per hour,
- total awakenings,
- wake after sleep onset,
• sleep efficiency,

• wake time, and

• player schedules.

The independent variables for this study were

• non-concussed collegiate football players, and

• concussed collegiate football players.
CHAPTER 4

RESULTS

Descriptive

The results for this research included 27 participants (20 non-concussed and 7 concussed) from two different universities (Table 1). All subjects were male collegiate football players (19.93 ± 1.14 years old, 1.82 ± 0.08m, and 96.42 ± 21.26 kg). Each class level of a 4-year university was represented within the study. The height of each participant is similar, with a difference of 0.29 meters between the minimum and maximum. The shortest participant was 1.64 meters, and the tallest being 1.93 meters. The participants' weight had greater variability due to the different position expectation in football and the difference in physical demands present at the two university programs. The minimum weight of the participants was 68.5 kilograms, and the maximum was 151.9 kilograms.

Table 1

Means and Standard Deviations for Participant Demographic Variables.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Statistic</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>1.41</td>
<td>0.096</td>
</tr>
<tr>
<td>Age</td>
<td>19.93</td>
<td>0.22</td>
</tr>
<tr>
<td>Class</td>
<td>2.04</td>
<td>0.18</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.82</td>
<td>0.01</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>96.42</td>
<td>4.09</td>
</tr>
<tr>
<td>Concussion status</td>
<td>1.26</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Note: n = 27 Standard Deviation is abbreviated Std. Dev.

A variety of measurements were taken to investigate how sleep parameters changed while the participant wore a Readiband device. When comparing the initial and final day of measurement, the device was worn, parameters increased, and decreased with no apparent trends.
Most notably, there was an increase in wake episodes and a reduction in total minutes in bed and total minutes asleep (Table 2). The parameters were taken contrary to the concussion status of the participant.

Table 2.

Means and Standard Deviations for Initial vs. Final Measurement Variables for all Participants.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial measurement</th>
<th>Final measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wake episodes</td>
<td>3.93 ± 2.88</td>
<td>3.89 ± 3.15</td>
</tr>
<tr>
<td>Average wake episodes</td>
<td>8.51 ± 5.63</td>
<td>9.70 ± 6.42</td>
</tr>
<tr>
<td>Wake after sleep onset (minutes)</td>
<td>39.7 ± 33.43</td>
<td>41.85 ± 40.004</td>
</tr>
<tr>
<td>Number of awakenings/hours</td>
<td>0.66 ± 0.44</td>
<td>0.64 ± 0.52</td>
</tr>
<tr>
<td>Readiband™ sleep quality</td>
<td>5.7 ± 2.85</td>
<td>4.89 ± 3.04</td>
</tr>
<tr>
<td>Total minutes in bed*</td>
<td>440.85 ± 130.53</td>
<td>399.78 ± 187.29</td>
</tr>
<tr>
<td>Total minutes asleep</td>
<td>358.48±107.97</td>
<td>325.44 ± 148.87</td>
</tr>
<tr>
<td>Calculated minutes in bed</td>
<td>411.74 ± 117.26</td>
<td>378.81 ± 176.67</td>
</tr>
<tr>
<td>Calculated time awake (minutes)</td>
<td>53.26 ± 45.14</td>
<td>53.37 ± 43.80</td>
</tr>
<tr>
<td>Average wake time (minutes)</td>
<td>12.38 ± 10.76</td>
<td>13.36 ± 8.42</td>
</tr>
<tr>
<td>Efficiency</td>
<td>81.39±8.68</td>
<td>73.25 ±27.59</td>
</tr>
<tr>
<td>Sleep onset group</td>
<td>3.19 ± 0.62</td>
<td>2.96±1.22</td>
</tr>
<tr>
<td>Wake group</td>
<td>2.07±0.73</td>
<td>1.81±0.96</td>
</tr>
<tr>
<td>Hours asleep last 7 days</td>
<td>13.20 ±19.37</td>
<td>27.87 ±20.90</td>
</tr>
</tbody>
</table>

Note: n = 27. *Total minutes in bed includes minutes not asleep and asleep.

Concussed vs. non-concussed comparison

The participants were compared using paired t-tests to determine the significance between the paired variables of interest for the entire dataset. The hours asleep over the last 7 days (df(26) = -2.989, p = .006) was significant when comparing the initial measurement (13.20 ± 19.37 hours) to the final (27.87 ± 20.90 hours) and was the only sleep parameter that provided a significant difference between the two groups.

The independent samples t-tests of the 20 non-concussed (mean & std. dev of age (19.57 ± 1.81), height (1.84 ± 0.08), and weight (90.52 ± 19.43) and 7 concussed (mean & std. dev of
age 20.05 ± 0.83), height (1.82 ± 0.076), and weight (98.49 ± 21.95) (Table 3) provided significant results. The analysis indicated a difference between the total minutes in bed at the initial measurement ($df = 11.839, p = .037$) between the concussed (353.29 ± 110.48 minutes) and non-concussed (471.5 ± 125.09 minutes) groups. There was also a difference between the total minutes asleep at the initial measurement ($df = 12.662, p = .032$) between the concussed (286.43 ± 86.73) and non-concussed groups (383.7 ± 104.86). The last measurement that also indicated a difference in the quantity of sleep was the calculated minutes in bed at the initial measurement ($df = 11.916, p = .023$) between the concussed (326.4 ± 97.01) and non-concussed groups (441.60±110.55).

**Table 3.**

**Means and Standard Deviations for Demographic Variables for Non-concussed and Concussed Groups.**

<table>
<thead>
<tr>
<th></th>
<th>Non-concussed</th>
<th>Concussed</th>
</tr>
</thead>
<tbody>
<tr>
<td>School</td>
<td>1.45 ± 0.51</td>
<td>1.29 ± 0.49</td>
</tr>
<tr>
<td>Age</td>
<td>20.05 ± 0.83</td>
<td>19.57 ± 1.81</td>
</tr>
<tr>
<td>Class</td>
<td>2.2 ± 0.89</td>
<td>1.57 ± 0.976</td>
</tr>
<tr>
<td>Hgt (m)</td>
<td>1.82 ± 0.076</td>
<td>1.84 ± 0.08</td>
</tr>
<tr>
<td>Wgt (kg)</td>
<td>98.49 ± 21.95</td>
<td>90.52 ± 19.43</td>
</tr>
</tbody>
</table>

Note: Non-concussed (n=20); Concussed (n=7)
Table 4.

*Means and Standard Deviations for Group Variables for Non-concussed and Concussed Groups*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-concussed</th>
<th>Concussed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>5.29 ± 1.92</td>
<td>4.67 ± 2.87</td>
</tr>
<tr>
<td>Average Alertness Initial</td>
<td>67.61 ± 35.44</td>
<td>50.54 ± 35.21</td>
</tr>
<tr>
<td>Average Alertness Final</td>
<td>66.48 ± 35.21</td>
<td>59.14 ± 41.53</td>
</tr>
<tr>
<td>Latency Initial</td>
<td>26.80 ± 36.02</td>
<td>26.86 ± 26.28</td>
</tr>
<tr>
<td>Latency Final</td>
<td>21.75 ± 27.93</td>
<td>18.71 ± 21.15</td>
</tr>
<tr>
<td>Number of Wake Episodes Initial</td>
<td>4.30 ± 2.87</td>
<td>2.86 ± 2.85</td>
</tr>
<tr>
<td>Number of Wake Episodes Final</td>
<td>3.95 ± 3.24</td>
<td>3.71 ± 3.15</td>
</tr>
<tr>
<td>Average Wake Episodes Initial</td>
<td>8.83 ± 4.44</td>
<td>7.59 ± 8.57</td>
</tr>
<tr>
<td>Average Wake Episodes Final</td>
<td>9.10 ± 6.13</td>
<td>11.37 ± 7.43</td>
</tr>
<tr>
<td>Wake After Sleep Onset Initial</td>
<td>42 ± 33.10</td>
<td>30.71 ± 35.52</td>
</tr>
<tr>
<td>Wake After Sleep Onset Final</td>
<td>41.50 ± 43.68</td>
<td>42.86 ± 29.84</td>
</tr>
<tr>
<td>Number of Awakenings/Hour Initial</td>
<td>0.70 ± 0.43</td>
<td>0.56 ± 0.50</td>
</tr>
<tr>
<td>Number of Awakenings/Hour Final</td>
<td>0.64 ± 0.50</td>
<td>0.67 ± 0.61</td>
</tr>
<tr>
<td>Readiband™ Sleep Quality Score Initial</td>
<td>5.50 ± 2.67</td>
<td>6.29 ± 3.50</td>
</tr>
<tr>
<td>Readiband™ Sleep Quality Score Final</td>
<td>5 ± 3.044</td>
<td>4.57 ± 3.26</td>
</tr>
<tr>
<td>Total Minutes in Bed Initial</td>
<td>471.5 ± 125.09</td>
<td>353.29 ± 110.48</td>
</tr>
<tr>
<td>Total Minutes in Bed Final</td>
<td>409.60 ± 180.94</td>
<td>371.71 ± 217.02</td>
</tr>
<tr>
<td>Total Minutes Asleep Initial</td>
<td>383.70 ± 104.86</td>
<td>286.43 ± 86.73</td>
</tr>
<tr>
<td>Total Minutes Asleep Final</td>
<td>332.50 ± 141.42</td>
<td>305.29 ± 179.08</td>
</tr>
<tr>
<td>Calculated Minutes in Bed Initial</td>
<td>441.60 ± 110.55</td>
<td>326.43 ± 97.01</td>
</tr>
<tr>
<td>Calculated Minutes in Bed Final</td>
<td>387.85 ± 169.91</td>
<td>353 ± 206.85</td>
</tr>
<tr>
<td>Calculated Time Awake Initial</td>
<td>57.90 ± 48.22</td>
<td>40 ± 34.51</td>
</tr>
<tr>
<td>Calculated Time Awake Final</td>
<td>55.35 ± 47.74</td>
<td>47.71 ± 32.36</td>
</tr>
<tr>
<td>Average Wake Time Initial</td>
<td>13.19 ± 11.194</td>
<td>10.08 ± 8.62</td>
</tr>
<tr>
<td>Average Wake Time Final</td>
<td>13.37 ± 8.62</td>
<td>13.35 ± 8.49</td>
</tr>
<tr>
<td>Sleep Onset Group Initial</td>
<td>3.15 ± 0.58</td>
<td>3.29 ± 0.75</td>
</tr>
<tr>
<td>Sleep Onset Group Final</td>
<td>3.20 ± 1.196</td>
<td>2.29 ± 1.11</td>
</tr>
<tr>
<td>Wake Group initial</td>
<td>2.30 ± 0.66</td>
<td>1.43 ± 0.55</td>
</tr>
<tr>
<td>Wake Group Final</td>
<td>1.90 ± 0.99</td>
<td>1.57 ± 0.98</td>
</tr>
<tr>
<td>Hours Asleep last 7 days Initial</td>
<td>14.13 ± 20.13</td>
<td>10.57 ± 18.19</td>
</tr>
<tr>
<td>Hours Asleep last 7 days Final</td>
<td>26.74 ± 20.97</td>
<td>31.13 ± 21.98</td>
</tr>
<tr>
<td>PSQIQ Score</td>
<td>5.30 ± 2.60</td>
<td>10.57 ± 6.43</td>
</tr>
</tbody>
</table>
The Mann-Whitney U analysis for PSQIQ (6.67±4.47) (Table 5) provided a score of 32.5 and a z-score of -2.09. There was a significant difference between the concussed and non-concussed groups ($p = .036$)

**Table 5.**

*Mann-Whitney U Analysis Results for the PSQIQ Scores of Concussed and Non-concussed Groups.*

<table>
<thead>
<tr>
<th>Concussion Status</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-concussed</td>
<td>20</td>
<td>12.13</td>
<td>242.5</td>
</tr>
<tr>
<td>PSQIQ Concussed</td>
<td>7</td>
<td>19.36</td>
<td>135.5</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.**

*PSQIQ Mean and Standard Deviation Scores of Concussed and Non-concussed Groups.*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSQIQ</td>
<td>6.67</td>
<td>4.47</td>
</tr>
</tbody>
</table>

**Table 7.**

*Z-score Results for the PSQIQ Scores of Concussed and Non-concussed Groups.*

<table>
<thead>
<tr>
<th>PSQIQ Score</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>32.5</td>
</tr>
<tr>
<td>Z</td>
<td>-2.09</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>0.36*</td>
</tr>
</tbody>
</table>

Note: * = significant comparison

**Case Series**

Nine of the subjects were reviewed as a case series to compare high and low PSQIQ scores of the non-concussed and concussed subjects. Although the case series did not produce significant evidence of changes in sleep, there was a similar significance for the hours asleep in
the last seven days ($df = 8, p = 0.008$) between the initial measurement (7.22 ± 14.34) and the final measurement (32.67 ± 19.46) (Table 7). When seeing the sign of change in hours asleep, there was a further investigation that led to finding there to be a difference in the amount of time spent in bed ($df = 6.776, p = 0.038$) between the initial (393.44 ± 124.12) and final measurements (307.78 ± 186.75) (Table 7). There was also a change indicated for wake time ($df = 5, p = 0.025$) between the initial (28.33 ± 9.12) and final measurements (22.75 ± 7.38) (Table 7). The results of these changes did have a variation on the PSQIQ ($df = 2.397, p = 0.044$) score reported by the participants producing a significant difference between the high (16.33 ± 5.51) and low scoring PSQIQ (3.33 ± 2.42).
Table 8.

Means and Standard Deviations for Initial vs. Final Measurement Variables of the Case-Cohort Analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial Measurement</th>
<th>Final Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wake episodes</td>
<td>3.78 ±3.23</td>
<td>4.44±3.13</td>
</tr>
<tr>
<td>Average wake episodes</td>
<td>9.31±7.89</td>
<td>11.18±6.50</td>
</tr>
<tr>
<td>Wake after sleep onset</td>
<td>46.70±43.80</td>
<td>56.11±51.71</td>
</tr>
<tr>
<td>Number of awakenings/hour</td>
<td>0.70±0.54</td>
<td>0.79±0.58</td>
</tr>
<tr>
<td>Readiband™ sleep quality</td>
<td>5.44±3.61</td>
<td>4±2.92</td>
</tr>
<tr>
<td>Total minutes in bed</td>
<td>393.44±124.12</td>
<td>307.78±186.75</td>
</tr>
<tr>
<td>Total minutes asleep</td>
<td>307.78±90.45</td>
<td>305.78±138.22</td>
</tr>
<tr>
<td>Calculated minutes in bed</td>
<td>367.89±118.7</td>
<td>370.33±172.89</td>
</tr>
<tr>
<td>Calculated time awake (minutes)</td>
<td>60.11±48.99</td>
<td>64.56±55.73</td>
</tr>
<tr>
<td>Average wake time (minutes)</td>
<td>28.33±9.12</td>
<td>22.75±7.38</td>
</tr>
<tr>
<td>Efficiency</td>
<td>78.94±9.28</td>
<td>70.12±27.37</td>
</tr>
<tr>
<td>Sleep onset group</td>
<td>3.22±0.67</td>
<td>2.44±1.01</td>
</tr>
<tr>
<td>Wake group</td>
<td>1.56±0.53</td>
<td>1.44±0.73</td>
</tr>
<tr>
<td>Hours asleep last 7 days</td>
<td>7.22±14.34</td>
<td>32.67±19.46</td>
</tr>
<tr>
<td>PSQIQ Score</td>
<td>7.67±7.31</td>
<td></td>
</tr>
</tbody>
</table>

*Note: N=9, non-concussed=3, concussed=6
Table 9

Means and Standard Deviations for Group Variables of Non-concussed and Concussed

Groups for the Cohort Study

<table>
<thead>
<tr>
<th></th>
<th>Non-concussed</th>
<th>Concussed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake Episode Initial</td>
<td>4.33±3.14</td>
<td>4±4</td>
</tr>
<tr>
<td>Wake Episode Final</td>
<td>4±2.53</td>
<td>5.33±3.51</td>
</tr>
<tr>
<td>Mean Wake Episodes Initial</td>
<td>9.83±5.04</td>
<td>5.2±5.30</td>
</tr>
<tr>
<td>Mean Wake Episodes Final</td>
<td>9.90±6.37</td>
<td>13.46±5.71</td>
</tr>
<tr>
<td>WASO Initial</td>
<td>53.33±42.97</td>
<td>35±44.44</td>
</tr>
<tr>
<td>WASO Final</td>
<td>51.67±63.85</td>
<td>60±22.91</td>
</tr>
<tr>
<td>Awakenings per Hour Initial</td>
<td>0.69±0.53</td>
<td>0.68±0.61</td>
</tr>
<tr>
<td>Awakenings per Hour Final</td>
<td>0.68±0.42</td>
<td>0.83±0.49</td>
</tr>
<tr>
<td>Quality Initial</td>
<td>5.50±3.33</td>
<td>5.67±4.04</td>
</tr>
<tr>
<td>Quality Final</td>
<td>5.50±2.58</td>
<td>4.67±2.51</td>
</tr>
<tr>
<td>Minutes in Bed Initial</td>
<td>477.17±75.60</td>
<td>365±172.83</td>
</tr>
<tr>
<td>Minutes in Bed Final</td>
<td>431.33±118.41</td>
<td>475.67±82.58</td>
</tr>
<tr>
<td>Minutes Asleep Initial</td>
<td>386.50±37.81</td>
<td>290±110</td>
</tr>
<tr>
<td>Minutes Asleep Final</td>
<td>346.67±74.00</td>
<td>371.67±40.72</td>
</tr>
<tr>
<td>Viable Minutes in Bed Initial</td>
<td>466.67±76.40</td>
<td>335±147.63</td>
</tr>
<tr>
<td>Viable Minutes in Bed Final</td>
<td>412.33±111.05</td>
<td>438.33±63.67</td>
</tr>
<tr>
<td>Calculated Time Awake Initial</td>
<td>80.17±62.90</td>
<td>45±40.78</td>
</tr>
<tr>
<td>Calculated Time Awake Final</td>
<td>65.67±65.99</td>
<td>66.67±26.35</td>
</tr>
<tr>
<td>Average Wake Time Initial</td>
<td>15.03±8.24</td>
<td>5.83±5.75</td>
</tr>
<tr>
<td>Average Wake Time Final</td>
<td>13.85±5.52</td>
<td>14.99±6.53</td>
</tr>
<tr>
<td>Efficiency Initial</td>
<td>82.13±11.22</td>
<td>81.63±8.59</td>
</tr>
<tr>
<td>Efficiency Final</td>
<td>82.13±10.66</td>
<td>78.77±6.014</td>
</tr>
<tr>
<td>Sleep Onset Group Initial</td>
<td>2.83±0.41</td>
<td>3±1</td>
</tr>
<tr>
<td>Sleep Onset Group Final</td>
<td>3.17±0.41</td>
<td>2.67±0.58</td>
</tr>
<tr>
<td>Wake Group Initial</td>
<td>2.33±0.52</td>
<td>1.33±0.58</td>
</tr>
<tr>
<td>Wake Group Final</td>
<td>2±0.89</td>
<td>2±0</td>
</tr>
<tr>
<td>Onset Variance Initial</td>
<td>11.67±88.24</td>
<td>29.97±41.93</td>
</tr>
<tr>
<td>Onset Variance Final</td>
<td>(-)55.33±140.2</td>
<td>(-)17±13.23</td>
</tr>
<tr>
<td>Wake Variance Initial</td>
<td>53.83±79.48</td>
<td>(-)133.67±155.93</td>
</tr>
<tr>
<td>Wake Variance Final</td>
<td>(-)54.67±139.43</td>
<td>(-)73.67±55.00</td>
</tr>
<tr>
<td>Hours Asleep Last 7 Days Initial</td>
<td>5.30±12.98</td>
<td>11.07±19.17</td>
</tr>
<tr>
<td>Hours Asleep Last 7 Days Final</td>
<td>34.08±17.707</td>
<td>44.03±7.61</td>
</tr>
</tbody>
</table>

32
The Mann-Whitney U analysis for PSQIQ (7.67 ± 7.31) low and high groups (Table 10) provided a score of 0, $z$-score = -2.34, and significance between high-low groups ($p = .019$).

**Table 10**

*Mann-Whitney U Results for the PSQIQ Low and High Group Measurement.*

<table>
<thead>
<tr>
<th></th>
<th>High-Low PSQIQ</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concussed</td>
<td>3</td>
<td>8</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Non-concussed</td>
<td>6</td>
<td>3.5</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 11**

*Means and Standard Deviation for PSQIQ Low and High Group Measurement*

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSQIQ</td>
<td>6.89 ± 7.66</td>
</tr>
</tbody>
</table>

**Table 12**

*Z-score for PSQIQ Low and High Group Measurement*

<table>
<thead>
<tr>
<th></th>
<th>PSQIQ Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>0</td>
</tr>
<tr>
<td>Z</td>
<td>-2.374</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>0.018</td>
</tr>
</tbody>
</table>
CHAPTER 5
DISCUSSION

The purpose of this research was to investigate the changes in sleep patterns and sleep quality of concussed collegiate football players. Due to the lack of research on this topic, the effects of concussion on sleep are not well known. Despite the lack of concussion history or present concussion, the baseline participants experienced an increase in wake episodes and a decrease in minutes in bed as well as time spent asleep. The subjects’ poor sleep leads to the assumption that outside factors could change sleep patterns in student-athletes, which was not a factor that was considered. Including player class and athletic schedules in future research could improve the understanding of how lifestyle changes can affect student-athletes' sleep patterns.

Investigating all participants (n=27) non-concussed and concussed, there was a significant difference in hours slept over the last seven days at initial and final measurements (df = -2.989, p = 0.006). Concussed participants slept less and were waking more with self-reported lower sleep quality. Tham et al. (2019) had similar results, with participants having variability of changes within sleeping patterns. Castriotta et al. (2007) also determined that approximately 46% of patients diagnosed with TBI had abnormal sleep studies. The result does support the alternative hypothesis for Hypothesis 2 that there will be a difference in sleep quantity between the non-concussed and concussed athletes. The decrease in the concussed participants' sleep quantity could be from continuing symptoms, increased wake after sleep onset, or difficulty falling asleep, causing concussed participants to have a decreased quantity of sleep. Raikes & Schaefer (2016) found similar variability in sleep patterns to this result in day-to-day sleep changes and persisted for 1-month post-concussion. A decrease in sleep can also affect the
athletes’ performance, ability to make decisions and form memories, or recover from an injury such as a concussion (Malhotra, 2017).

The change in sleep over the last seven days may have been an important measurement to have and leads to the question of why there was this change. Further investigation into all participants did also show that there were also differences in total minutes in bed ($df = 11.839$, $p = 0.037$), total minutes asleep ($df = 12.662$, $p = 0.032$), and calculated minutes in bed ($df = 11.916$, $p = 0.023$), with all of these parameters having an increase at the final measurement. These results are also similar to Raikes & Schaefer (2016) and Chung et al. (2019) with respect to the variability in multiple sleep parameters within a week. These increases could result from the athlete being accommodated to their schedules, concussion symptoms resolving, or an increased need for sleep due to the demanding schedule of academics and athletics requirements. The results of this study support the alternative Hypothesis 1 that there will be changes in sleep quality in concussed athletes compared to non-concussed.

Overall, all results that show a change of sleep quality and sleep quantity are supported by research that was completed by Gosselin et al. (2009), who determined that sleep issues are related to wakefulness. However, since there was a small subject pool for the current study and did not have any apparent trends, a case-series study was completed. Nine subjects were reviewed to compare the high and low PSQIQ scores of the non-concussed and concussed subjects. In the case study, there were no apparent trends in the results.

The hours asleep in the last seven days did significantly differ between the initial and final measurements ($df = 8$, $p = 0.008$), with an increase in sleep in the final measurement, these results are similar to Hoffman et al. (2020) with there being less sleep measured between initial and final points in recovery. These results are similar to the results when comparing all study
participants (n = 27). The amount of time spent in bed ($df = 6.776, p = 0.038$), change in wake time ($df = 5, p = 0.025$), as well as a difference in the PSQIQ scores ($df = 2.397, p = 0.044$) were found when comparing the initial and final measurements of the nine participants within the case study.

The case-series study results support the alternative hypothesis for Hypothesis 2; however, no evidence would support Hypothesis 1. The hypothesis one was rejected since no evidence of a change in the quality of sleep between the non-concussed and concussed players were found for the case series.

Although there were significant changes in several sleep parameters in the overall comparison and the case-series study, some questions have arisen from those results. Changes that were measured could have been from the recovery of a concussion, or they could have been from acclimation to rigorous schedules with the academic or athletic requirement. More research should be performed to see how practice and class schedules affect the sleep cycle of colligate football players to clarify this issue.
CONCLUSION

Participants who sustained a concussion had a significant difference in the quantity of sleep when compared to non-concussed players. However, it did not produce any statistically significant results that would support a change in sleep quality. Several clinically significant findings in this research could lead to how and when the treatment for sleep changes during a concussion begins to occur, with rest being the best being the current best practice (Broglio et al., 2014).

Improvements for future research would include using a device(s) that also measure heart rate and respiratory rate for a more accurate reading of when the participants are asleep or awake. Other improvements could also include research into changes in the participant's sleep when their practice, work out, travel, or school schedules change. The sex of the participant could also be a factor, so researching how female athletes react to all of the above scenarios, including concussion, could affect sleep. These could factor in the participants’ ability to restful sleep and are possible research parameters into this topic for future studies.
REFERENCES


doi:10.1016/j.emc.2010.03.003


http://doi:10.1146/annurev.neuro.27.070203.144157

https://doi.org/10.1227/00006123-198404000-00001

http://doi:10.1097/JSM.0b013e318295a834


http://doi:10.1016/j.apmr.2018.01.005


https://doi.org/10.1093/sleep/zsx044


http://doi:10.1016/j.pneurobio.2008.08.003


APPENDIX A

Office of Research Integrity
Institutional Review Board
One John Marshall Drive
Huntington, WV 25755

February 26, 2019

Mark Timmons, PhD
Marshall University, School of Kinesiology

RE: IRBNet ID# 1399603-1
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title: [1399603-1] The Effects of Concussion on the Quantity and Quality of Sleep

Site Location: MU
Submission Type: New Project
Review Type: Expedited Review

In accordance with 45CFR46.110(a)(4)(7), the above study was granted Expedited approval today by the Marshall University Institutional Review Board #1 (Medical) Chair. An annual update will be required on February 26, 2020 for administrative review and approval. The update must include the Annual Update Form and current educational certificates for all investigators involved in the study. All amendments must be submitted for approval by the IRB Chair prior to implementation and a closure request is required upon completion of the study. The Waiver of Alteration to the Informed Consent was also approved.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

Sincerely,

Bruce F. Day, ThD, CIP
Director, Office of Research Integrity
Marshall University
Informed Consent to Participate in a Research Study
The Effects of Concussion on the Quantity and Quality of Sleep

You are being invited to take part in a research study about how a concussion effects how well you sleep. You will be asked to wear a sleep monitoring device around your wrist. This device is similar to a watch or Fitbit. You will need to wear the device for 1 week, only remove the device to shower or swim. The data that the device collects will be downloaded to an IPad device by the researchers at the end of the 1 week. You will also be asked to complete a survey following at the end of the week.

By doing this study, we hope to learn more about how concussions effect the quality and amount of sleep following a concussion. Your participation in this research will last about 3 days.

The purpose of this research is to determine if a concussion prevents an individual from achieving a full night’s sleep and possibility effecting the recovery from the concussion.

There is no direct benefit to you for participating in this study this information might help Doctors treat people with concussion in the future. There is no known risk to your participation. You will be asked to complete the study questionnaire and report to the Athletic Trainer in order to download the data. For a complete description of risks, refer to the Detailed Consent.

You do not have to participate in this study; if you do not participate, your treatment will not be affected. For a complete description of alternate treatment/procedures, refer to the Detailed Consent. If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any services, benefits or rights you would normally have if you choose not to volunteer.

For questions about the study or in the event of a research-related injury, contact the study investigator, Mark Timmons at (304) 696-2925. You should also call the investigator if you have a concern or complaint about the research. For questions about your rights as a research participant, contact the Marshall University Office of Research Integrity at (304) 696-4303.

You will be given a signed and dated copy of this consent form.

SIGNATURES
You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form, you are not giving up any legal rights to which you are entitled.

Subject Name (Printed)

Subject Signature Date

Person Obtaining Consent (Printed)

Person Obtaining Consent Signature Date

Rev 1/30/19

Subject’s Initials _______
DETAILED CONSENT:

Are There Reasons Why You Would Not Qualify for This Study?

You would not be able to participate in the study if you have a history of concussion prior to the current concussion. You are younger than 18 years old. You have any known sleep disorders or you if you take medications that might affect your sleep patterns. You must be a college football player to in this study.

How Many People Will Take Part In The Study?

About 40 people will take part in this study, 60 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

You will be asked to wear a sleep monitoring device around your wrist. This device is similar to a watch or Fitbit. You will need to wear the device for 3 days, only remove the device to shower or swim. The data that the device collects will be downloaded to an iPad device at the end of the 3 days. You will also be asked to complete a survey following at the end of the 3 days.

How Long Will You Be In The Study?

You will be in the study for about 3 days; the treatment for your concussion could last much longer and will be determined by your doctor.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the study investigator or study staff as soon as possible.

The study investigator may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

There are no known risks to those who take part in this study.

There may also be other side effects that we cannot predict. You should tell the researchers if any of these risks bother or worry you.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: improved understanding how a concussion effects a person's sleep.

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law says we must keep your study records private. Nevertheless, under unforeseen and rare circumstances, we may be required by law to allow certain agencies to view your records. Those agencies would include the Marshall University IRB, Office of Research Integrity (ORI) and the federal Office of Human Research Protection (OHRP). This is to make sure that we are protecting your rights.
and your safety. If we publish the information, we learn from this study, you will not be identified by name or in any other way.

**What Are The Costs Of Taking Part In This Study?**

There are no costs to you for taking part in this study. All the study costs, including any study tests, supplies and procedures related directly to the study, will be paid for by the study. Cost associated with the treat of your concussion but not related to the study will not be covered by the researchers.

**Will You Be Paid For Participating?**

You will receive no payment or other compensation for taking part in this study.

**Who Is Sponsoring This Study?**

The Marshall Sports Medicine Institute is sponsoring this study. The sponsor is providing money or other support to help conduct this study. The researchers do not; hold a direct financial interest in the sponsor or the product being studied.

**What Are Your Rights As A Research Study Participant?**

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first.
APPENDIX C

Verbal Consent to Participate in Research

The Effects of Concussion on the Quantity and Quality of Sleep
Mark K Timmons Ph.D. ATC, Principal Investigator

You are being asked to participate in a research study. At this time, you are providing verbal consent to participate. When your concussion clears up, you will be asked to provide written consent to your participation in the study. If at any time you do not wish to participate, you may stop your participation at any time.

Research must read the following:

The purpose of this research is to determine if a concussion prevents an individual from achieving a full 'night's sleep. The loss of sleep could have possibly affected a person's recovery from a concussion. During the study, you will wear a wristwatch like device on your arm for 1 week. There is no direct benefit to you for participating in this study. This information might help Doctors treat people with concussion in the future. You do not have to participate in this study. There is no known risk to your participation.

If you agree to participate, you must state aloud that you agree to participate. You will be given a signed and dated copy this document.

You may contact the researcher, Mark Timmons phone number 304 696 2925 any time if you have questions about the research.

You may contact the Institutional Review Board (IRB) Chair Dr. Henry Driscoll or at (304) 696-7320 if you have questions about your rights as a research subject or what to do if you are injured.

Your participation in this research is voluntary, and you will not be penalized or lose benefits if you refuse to participate or decide to stop.

_________________________________________
Name of Participant

_________________________________________
Name of Witness

_________________________________________  ______________________
Signature of Witness          Date

_________________________________________
Name of Oral Presenter

_________________________________________  ______________________
Signature of Oral Presenter    Date
**APPENDIX D**

**Athlete ___________________________**  
**Date _____________________**

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Rate 0 - 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td></td>
</tr>
<tr>
<td>Nausea</td>
<td></td>
</tr>
<tr>
<td>Vomiting</td>
<td></td>
</tr>
<tr>
<td>Balance Problems</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td></td>
</tr>
<tr>
<td>Lightheadedness</td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
</tr>
<tr>
<td>Trouble Falling Asleep</td>
<td></td>
</tr>
<tr>
<td>Sleeping more than usual</td>
<td></td>
</tr>
<tr>
<td>Sleeping less than usual</td>
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</tr>
<tr>
<td>Drowsiness</td>
<td></td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td></td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td></td>
</tr>
<tr>
<td>Irritability</td>
<td></td>
</tr>
<tr>
<td>Sadness</td>
<td></td>
</tr>
<tr>
<td>Nervous/Anxious</td>
<td></td>
</tr>
<tr>
<td>Feeling more emotional</td>
<td></td>
</tr>
<tr>
<td>Numbness/Tingling</td>
<td></td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td></td>
</tr>
<tr>
<td>Feeling &quot;in a fog&quot;</td>
<td></td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td></td>
</tr>
<tr>
<td>Difficulty remembering</td>
<td></td>
</tr>
<tr>
<td>Visual problems</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL PSQI**

The following questions related to your usual sleep habits during the past month only. Please answer all questions accurately.

1. When have you usually gone to bed?___________
2. How long (minutes) has it taken you to fall asleep each night?________
3. When have you usually gotten up in the morning?_______
4. How many hours of actual sleep do you get a night? (different than the # of hours in bed)____________
5. During the past month how often have you had trouble sleeping because you
   a. Cannot get to sleep within 30 min
   b. Wake up in the middle of the night or early morning
   c. Have to get up to use the bathroom
   d. Cannot breathe comfortably
   e. Cough or snore loudly
   f. Feel too cold
   g. Feel too hot
   h. Have bad dreams
   i. Have pain
   j. Other, please describe
6. How often have you taken medicine to help you sleep?
7. How often have you had trouble staying awake?
   While driving, eating or engaging in social activity
8. How much of a problem has it been for you to keep up enthusiasm to get things done?

Hou would you rate your sleep quality?
Very good (0)  
Fairly good (1)  
Fairly bad (2)  
Very bad (3)  

Component 1 #9 score…………………………………………………………………
Component 2 #2 score (≤15 min=0, 16 - 30 min=1, 31 - 60 min =2, >60 min =3) + #5a Score.(IF sum is equal 0=0; 1 - 2=1; 3 - 4=2; 5 - 6=3…………………)
Component 3 #4 Score(>7=0; 6 - 7=1; 5 - 6=2; >5=3)………………………
Component 4 (total # of hours asleep)/total # of hours in bed) x 100 >85% = 0, 75% - 84% =1, 65% - 74% = 2, <65%= 3…………………………………………...
Component 5 Sum of scores #5b to #5j 0=0; 1 - 9=1; 10 - 18=2; 19 - 27=3…
Component 6 #6 score……………………………………………………………………………………………….C6____
Component 7 #7 score + #8 score (0=0; 1 - 2=1; 3 - 4=2; 5 - 6=3)………………………………………C7_____

Add the seven component scores together__________
Global PSQI Score______
## APPENDIX E

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Rate 0-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td></td>
</tr>
<tr>
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<td></td>
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<tr>
<td>Vomiting</td>
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<td></td>
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<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td>Trouble Falling Asleep</td>
<td></td>
</tr>
<tr>
<td>Sleeping more than usual</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Drowsiness</td>
<td></td>
</tr>
<tr>
<td>Sensitivity to light</td>
<td></td>
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<tr>
<td>Sensitivity to noise</td>
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<td>Visual problems</td>
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<tr>
<td><strong>TOTAL</strong></td>
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