Is Concussion-Related Sleep Disturbance Present After Return to Play in College Athletes?

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Is Concussion-Related Sleep Disturbance Present After Return to Play in College Athletes?

Alex Gallaer

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Does Concussion-Related Sleep Disturbance Linger After Other Symptoms Subside?

Abstract

As one of the most commonly experienced symptoms, the ramifications of sleep disruption as a result of concussion are potentially great, yet widely unexplored. Particularly troublesome is murky data regarding the length of sleep disruption following a concussion. By analyzing self-reported sleep data via the Pittsburgh Sleep Quality Index, this study seeks to investigate potential differences in sleep quality between injured college athletes 40 days after they have been cleared to play and matched controls. Data was analyzed using ANOVA analysis as well as Pearson correlation. No significant differences were found in sleep quality between groups, nor was there a relationship between GPA and sleep quality. Future study may wish to focus on alternate populations, or more closely control sleep variables.
Literature Review

Sleep disruption is an established symptom of concussion (Junn et al., 2015; Ponsford et al., 2013; Parcell et al., 2006). What is not established, however, is if the disruption of sleep ends concurrently when neurocognitive and motor symptoms subside. In order to examine this question, one must first start at a baseline understanding of what is already known. This literature review will attempt to confirm that concussion in sport is not a niche problem and affects a wide multitude of people, will define concussion as it is currently known as well as known side effects, and specifically explain the effect of a concussion on sleep and how one can measure this.

Participation in Sport

In the United States, participation levels in organized sport are extremely high. According to the National Federation of State High School Associations (NFHS), high school athletics participation has grown for 28 straight years (NFHS, 2017). As of 2017, there are 7,963,535 high school students that participate in school-sanctioned athletics, including over 3.3 million who participate in collision sports, where forceful contact is necessary for play, or contact sports, where collisions routinely occur but is less forceful in nature (Rice, 2008). At the collegiate level, 491,930 athletes compete in the NCAA, with over 200,000 competing in collision or contact sports (NCAA, 2017). Since not all high school and college athletes compete in the NFHS or the NCAA, these numbers should be considered low compared to the true numbers of high school and college athletes.

Injury Epidemiology

While injuries are often regarded as an inherent risk in sports, not all injuries occur at the same rate. Comstock, Currie, and Pierpoint (2015) surveyed high school athletes across the
United States in order to track injury rates. Ankle and knee injuries made up 15.1% and 13.7% of all injuries, respectively. These injuries are primarily to the ligaments in each joint. Hip/thigh injuries made up 9% of all injuries, and were the only category of injury that was more prevalent in practice (11.5%) relative to games (7.5%). The only other categories of injury that made up more than 4% of the total pool were hand/wrist and shoulder injuries, each accounting for 7%, and head/face injuries, accounting for the largest portion of the total injuries at 27.4% (Comstock, Currie, and Pierpoint, 2015).

Comstock, Currie, and Pierpoint (2015) also indicated injury rates by sport in their study. The only collision sport studied, Football, saw an overall injury rate of 3.73/1000 exposures, with the rate jumping to 11.97/1000 exposures in competitions. Comparatively, the average overall injury rate for contact sports is 1.81/1000 and non-contact sports is 1.03/1000. Of these, no injury rate is higher than 2.6/1000 exposures (girls soccer) (Comstock, Currie, and Pierpoint, 2015). This demonstrates that, in terms of hierarchy of injury potential, the order is collision sports > contact sports > non-contact sports.

Lastly, there is variation in terms of the composition of injuries by sport, as well. For example, while the most common injury in girls soccer is to the head/face (36%), the most common injury in girls volleyball is to the ankle (37.7%) and head/face only makes up 26.1% of injury. Interestingly, head/face injuries made up 25.2% of all injuries in football, despite being the only sport studied with protection provided by a helmet (Comstock, Currie, and Pierpoint, 2015). While other sports often list facial contusions, lacerations, and fractures as part of their overall percentage, these are unlikely in football. While Comstock, Currie, and Pierpoint do not differentiate between concussion and other head injury, multiple studies have found the
concussion rate in football to be higher than other sports at the high school level, potentially contributing to the high percentage reported (Rosenthal et al., 2014; Marshall et al., 2015).

A study by Kerr et al. (2015) analyzed NCAA injury data from 2009 through 2014. In this study, it was determined that 45.45% of injuries were strains/sprains, 12.8% were contusions, 10.4% were inflammatory conditions, 6.4% were fractures/dislocation/subluxations, 5.4% were concussions, and 19.5% were classified as “other” (Kerr et al. 2015). Kerr et. al (2015) also found that injuries were significantly more likely to happen in competition relative to practice, with football, men’s hockey, wrestling, and soccer, and women’s soccer displaying especially high disparities. The increase in injury rate is likely due to a combination of longer sustained periods of exertion, higher risk tolerance, and a less controlled environment in games relative to practice.

**Defining Concussion**

Concussion has been defined as a brain injury that is “a complex pathophysiological process affecting the brain, induced by biomechanical forces” (McCroy et al., 2013, pp. 251). The forces that cause the injury do not need to be directly applied to the head, as studies have shown that the fluid wave caused by a whiplash-like motion can also induce concussion or mild traumatic brain injury (mTBI) (Laurer and Mcintosh, 1999; Povlishock and Christman, 1995).

The damage from a concussion is often associated with the direct impact of the brain with the inside of the skull, as well as from shearing forces as different areas of the brain moving at different speeds. These forces can directly damage nerves, and brain function continues to be impaired due to the ion and chemical imbalances caused by concussion, as well as reduced blood flow to the site of the injury (Johnson et al. 2013). While some of this nerve damage is recoverable, some function may be permanently lost.
The symptoms associated with concussions can include, but are not limited to, headaches, dizziness, fatigue, impaired focus, and an increased sensitivity to light and sound (Ling et al. 2015). Most of these symptoms are usually resolved within a few weeks, though some individuals may experience symptoms for months or even years (Ling et al. 2015). A reduction in activity, both mental and physical, is necessary in order to properly recover from a concussion. A second concussion that occurs before the full resolution of symptoms from a first concussion can lead to brain swelling, permanent impairment, and, rarely, death (Ling et al. 2015).

**Concussion Incidence in Sports**

Concussions in sports are a problem at all levels of play, particularly in collision and contact sports (Langlois et al. 2006). An epidemiologic study by Zuckerman et al. in 2015 found that concussions account for 6.2% of all injuries to NCAA athletes. Notably, football, men’s wrestling, and men’s ice hockey accounted for higher injury rates than any other sports, leading to 6.71, 10.92, and 7.91 concussion per 10,000 athlete exposures, respectively. Despite this, women’s sports were found to have a higher overall concussion rate, 3.94 per 10,000 exposures, than men’s sports, which had a rate of 3.23. Across both genders, competition injury rates were significantly higher than practice rates, matching the result of Kerr et al. (2015) (Zuckerman et al. 2015). These numbers highlight both the overall prevalence of concussion, which can affect over 26,000 athletes in a given year (Kerr et al. 2015), as well as the significantly higher numbers of concussion in collision and contact sports such as football.

A study of high school athletes by Lincoln et al. (2011) found a similar rate for boys, 3.4 concussions per 10,000 exposures as in the Zuckerman et al. study (2015), but a reduced rate for girls, 1.3 per 10,000 exposures. While this rate difference is found to be significant, girls were actually found to have a nearly twofold risk for concussion in similar sports (basketball, soccer,
baseball/softball), indicating that concussions suffered in boy’s contact sports that do not have a girls equivalent may be to blame for the difference in overall concussion rates (Lincoln et al. 2011).

In a cohort study, 25 American College Football Teams were studied in 1999, 2000, and 2001 by Guskiewicz et al. (2003) in an effort to measure concussion occurrence and trends. Of patients analyzed, there were a greater number of participants with a previous history of head injury compared to those suffering first-time concussions. This is indicative of two possibilities: that certain individuals are predisposed to suffering head injury, or that previous head injury is a risk factor for suffering another one. Since this study, there has been support for predisposition to concussions resulting from both a genetic basis, where severity of and recovery from concussion linked to certain allele variation of the NMDA NR2A subunits (McDevitt et al. 2014), as well as recurrent head injury, where individuals with a previous history of concussion are more likely to suffer another (Zemper 2003).

Lastly, Langlois et al. (2006) estimates that between 1.6 and 3.4 million sports-related concussions occur in a given year. Due to the high occurrence of concussions in athletes at all levels, particularly those in collegiate athletics, it is clear that concussions are not a small-scale problem but a growing public health issue.

**Physiological Effects of Concussion**

As concussions in sport have been established as commonplace, the symptoms associated with them are equally well documented. Common symptoms of concussion, according to Junn et al. (2015), include headache, neck pain, postural instability/dizziness, vision changes, memory impairment, fatigue, depression, anxiety, and disruption of normal sleep. While the absence of
these symptoms do not mean a concussion has not occurred, 80-100% of patients will present with at least one of these symptoms (Junn et al. 2015).

**Headache.** Headache is one of the most common symptoms experienced after a concussion (Faux et al. 2008). It has an initial prevalence of 30-50%, with up to 15.34% reporting headaches after three months as a result of minor head injury (Faux et al. 2008) Mild TBI (mTBI) has a similar initial prevalence, though it often has a delayed onset, with up to 62% of patients reporting headache at three months post-injury, 69% at six months, and 58% of at 1 year mTBI (Lucas et al. 2013). Treatment for headache in a typical concussion is mostly trial and error, though symptoms are expected to resolve with the resolution of other concussion symptoms, typically between a week and three months (Faux et al. 2008). In more severe head injury, headache may persist well beyond this time frame, indicating that full healing has not yet occurred. As the most common symptom of concussion, a report of a headache should be used as a warning sign for follow up testing to determine the presence of a concussion.

**Neck Pain.** Neck pain can occur in concussion with or without the presence of a comorbid headache, and occurs in roughly 28% of patients (Lahz and Bryant, 1996). In the absence of cervical pathology, this pain will often resolve within 10 days and can be relieved with the use of NSAIDs to directly minimize pain, muscle relaxers to prevent spasms, and a minimization of neck extension and flexion until pain has subsided (Lucas, 2011). Lucas (2011) claims that neck pain is often the result of the impact or motion that caused a concussion and not necessarily a symptom of brain injury in and of itself. Neck pain may also originate due to nerve compression, particularly of the occipital nerve, though this is less common than traditional pain and stiffness that resolves itself within two weeks (Gawel and Rothbart, 1992).
Postural Instability/Dizziness. Dizziness and postural instability frequently occur as a result of concussion, with 18-27% of patients experiencing these symptoms (Dikmen et al. 2010). These symptoms can be caused by either central nervous dysfunction that occurs within the CNS, or by peripheral nervous dysfunction in the inner ear, which is often linked to nausea (Junn et al., 2015). Caution should be exercised if this is observed, as this symptom is likely to be very disruptive to everyday life, as balance and motor function disruptions not only interfere with most everyday actions but can potentially lead to further injury in case of a fall or similar incident. These symptoms are most likely to resolve in 3-10 days (McCrea et al., 2003).

Vision Changes. Blurred vision occurs in 16-21% of individuals afflicted with a concussion (Dikmen et al. 2010), though this symptom sees a wide variety of prevalence based on the criteria used to define vision changes, and has been estimated to be as high as in 80% of all concussions (Kapoor and Ciuffreda, 2011). These changes most often occur due to a decrease in accuracy of small movements of the eyes, as well as increased time between movements, leading to a lesser ability to focus an image (Heitger et al, 2002). As is the case with CNS dysfunction, blurred vision is potentially dangerous and disruptive to daily life and those injured should be advised to exercise caution if exhibiting this symptom. Blurred vision that persists longer than a few days could be indicative of permanent change and should be assessed by a doctor (Heitger et al., 2002).

Memory Impairment. Memory impairment is one of the most common subjective symptoms following concussion, and is experienced by 26-44% of patients (Dikman et al., 2010). Memory impairment most often seems to affect processing speed and the working memory, which functions to temporarily store and manipulate relevant information for cognitive processes during a task. The working memory is closely related to frontal lobe and executive
functioning (Baddeley, 2004; Cicerone, 2002). In students, memory impairment is especially worrisome due to the inherent reliance of school on a functioning memory. It is often debated how long memory impairment lasts during concussion, as, in the absence of baseline, subjective dialogue is often the most sensitive measure, despite inherent inaccuracies (Bell et al., 2008).

**Fatigue.** Fatigue is often experienced by individuals afflicted with a concussion due to the disruption of sleep that often occurs, though this does not fully explain the “pathological” or mental fatigue that is not alleviated by rest (Mollayeva et al., 2014). Fatigue is often one of the slower symptoms to resolve, with up to 28% of patients reporting fatigue lasting up to 3 months after their initial injury (Mollayeva et al., 2014). It is not well understood how this mental fatigue is caused, though fatigue can negatively impact daily function and is potentially dangerous in situations where attention and alertness are needed, such as driving an automobile.

**Depression and Anxiety.** In the year following moderate to severe traumatic brain injury, up to 53% of patients will meet the criteria for a major depressive episode (Bombardier et al., 2010). In mild traumatic brain injury and concussion, however, the prevalence is usually much lower, around 15% (Roiger et al., 2015). Though all symptoms of concussion can have negative impacts on day to day life, depression can especially reduce an individuals’ quality of life and may actually slow down the healing process (Renner and Erfurt-Berge, 2017). This could potentially delay the healing of brain injury, as well. Since the onset of depression and anxiety is often delayed in those that do experience it, it is important to monitor for these factors even after other symptoms subside (Silver, 2014).

**Disruption of Normal Sleep.** In addition to the previously mentioned symptoms, disruptions in normal sleep occur in approximately 24-26% of concussions (Junn et al. 2015). In a 2013 study comparing patients with mild traumatic brain injury to matched controls, Ponsford
et al. found that those who had suffered a brain injury had lower sleep quality, higher daytime sleepiness, longer sleep onset latency, poorer sleep efficiency, longer sleep duration, and more frequent daytime napping. Additionally, those with more severe brain injuries were found to need to sleep for a longer duration, though sleep efficiency remained poor when compared to matched controls. A study in Switzerland by Parcell et al. (2006) had very similar results to Ponsford et al. (2013), finding via the Pittsburgh Sleep Quality Index (PSQI) that those with traumatic brain injury had poorer sleep quality. Additionally, injured participants were found to have reduced rapid eye movement and more often awoke during the night (Parcell et al., 2006).

The PSQI was created by DJ Buysse et al. in 1988, and is a self-rated questionnaire designed to measure sleep quality and disturbances (Buysse et al., 1988). There are seven components that are measured: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Scoring is set up for each component and the scores are summed to create a global score, which is compared to established norms to determine sleep quality. In 2015, an empirical study in Spain was done by de la Vega et al. to determine the efficacy of the PSQI on individuals between the ages of 14 and 24. While the sleep medication component was found to perform poorly and subsequently removed for testing, the rest of the questionnaire was found to be internally consistent and to be a valid measure of sleep quality in this age group.

**Importance of Sleep**

Sleep in humans is a phenomena that is poorly understood, yet universally required in order to sustain life. In a review article by Jerome Siegel (2005), he suggests that sleep is required for energy conservation, nervous system recuperation, and emotional regulation. While these may or may not be the case, it has long been demonstrated that disruption or deprivation of
sleep can have profound effects on personality, behavior, and, if prolonged, can lead to death (Berger & Oswald 1962; Klumpers et al. 2015).

While sleep deprivation has been shown to negatively impact cognition and mood, getting sleep may have a positive impact on these same factors (Vandekerckhove & Cluydts, 2010). Vandekerckhove and Cluydts made the claim that, while lack of sleep can have a host of negative effects, it is the quality of sleep that is most important (2010). Specifically, the amount of quality sleep correlates positively with markers of high cognitive function, mood, and stress adaptation (2010). Particularly, REM sleep is thought to be the primary determinant of these markers. Therefore, it is not only true that a lack of sleep will potentially cause harm, but that a greater amount of quality sleep is more beneficial. Unfortunately, many college students do not get adequate sleep as defined by PSQI (Carney et al., 2006). Most often this is the direct result of inconsistent sleep and social schedules.

While sleep is undoubtedly important for people of all ages, it is particularly crucial to college-aged young adults. In a survey by Kelly, Kelly, and Clanton (2001), students who reported a minimum of eight hours of sleep per night had an average GPA of 3.24 versus an average GPA of 2.74 for those who averaged less than seven hours. This relationship between sleep and academic achievement was supported in by Gomes, Tavares, and de Azevedo (2011), who found sleep duration and quality to be significant predictors of grades among undergraduate students; students with a Sleep Quality Index of “Very Good” had an average GPA of 3.43 and those scoring “Very Poor” had an average GPA of 3.29. This study controlled for other predictors such as class attendance, study time, and substance use, minimizing confounding effects. In 2013, a longitudinal study by Wong et al. again supported the conclusion that academic functioning is related to quality sleep, but also went further and found evidence that, in
college aged adults, quality sleep also correlated positively with physical and psychological health.

The Relationship Between Concussions and Sleep

While concussions have been demonstrated to affect sleep, the severity of the concussion does not necessarily correlate with the degree of disruption of sleep. In a 2004 correlational study, Mahmood et al. found that patients with mTBI actually reported a larger disturbance in sleep when compared to patients with severe brain injury. More recently, the findings of Mahmood et al. (2004) been called into question by other studies, such as Rao et al.’s 2013 longitudinal study that found no difference in sleep disruption between levels of TBI. Rao’s study only dealt with patients that had a loss of consciousness, GCS of less than 15, or evident brain injury on CT scan (2013) while Mahmood et al. (2004) used participants that suffered mild to severe TBI, regardless of loss of consciousness. While these two studies are contradictory, they demonstrate that more severe head injury may not result in more severe sleep disturbance, meaning it cannot be used as a tool to diagnose severity of TBI (Mahmood et al., 2004; Rao et al., 2013).

In a cross sectional study by Towns, Silva, and Belanger (2014), they found that sleep disturbance, as measured by PQSI, was reported in as many as 88% of participants who reported post-concussive symptoms. Here, this was defined as symptoms of concussion that lasted longer than 2-4 weeks. While only a small fraction of individuals are likely to suffer from post-concussion syndrome, it seems that sleep disturbance is a major comorbidity in those that do. A major weakness of this study is that it did not assess for severity of sleep disruption, only for presence.
In 2012, Fogelberg et al. also studied the effects of TBI on sleep at the one-year mark post-injury. Here, the researchers did not separate those who may have had post-concussive symptoms from those who did. The two main findings of their research were that 44% of participants reported significant sleep disruption, and that sleep disruption was significantly more likely with depression, anxiety, or a variety of other comorbidities (Fogelberg et al., 2012). This research, while not filtering those who have ceased other concussion symptoms from those who still experience symptoms, shows that sleep disturbances can linger long after traumatic brain injury, though the implicated comorbidities were not confirmed nor denied to be the result of the brain injury. The risk of comorbid disorders, particularly anxiety, is echoed in Jaffee et al.’s 2014 review, where they noted that the single biggest risk factor for developing sleep disorders in the first three months after TBI is the development of a related anxiety disorder. Thus, while sleep disruption may continue for a period of time that may exceed a year after a concussion, these studies do not distinguish what occurs as a direct result of concussion versus what is a result of comorbid disorder.

Conclusion

At least 7.9 million high school athletes and 400,000 collegiate athletes compete in some form of athletics that expose them to the risk of injury, including concussion (Rice, 2008; NCAA, 2017). While the type of injury that is most common varies by sport, many sports count head/face injuries as some of the most common suffered by athletes (Comstock, Currie, Pierpoint, 2015; Kerr et al., 2015). With so many young athletes exposed to potential head injury, the importance of understanding the effects of these injuries on athletes is critical. While the mechanical processes of concussion (McCroy et al., 2013), many common symptoms (Junn et al., 2015), and various risk factors (Guskiewicz et al., 2003; McDevitt et al., 2014; Zemper,
2003) are known, much is still uncertain regarding mTBI and concussion. Especially uncertain is the effect of concussions on sleep. This is an especially significant area of research due to the general importance of sleep, both in the general population (Siegel, 2005; Berger & Oswald, 1962; Klumpers et al. 2015) and especially in those who are high school and college-aged (Kelly, Kelly, and Clanton, 2001; Gomes, Tavares, and de Azevedo, 2011; Wong et al., 2013). While it has been demonstrated that concussions do, in fact, disrupt sleep (Junn et al., 2015; Parcell et al., 2006; Ponsford et al., 2013), the exact degree of this disruption is not well understood. Studies are often contradictory (i.e. Mahmood et al., 2004 and Rao et al., 2013) which can diminish clarity on the subject. Additionally, studies rarely agree as to the duration of sleep disruption, nor to the degree of said disruption. While there have been studies that investigate the length of sleep disturbance, these have failed to discriminate between those experiencing other lingering symptoms of concussion and those whose only remaining symptom is sleep disruption (Fogelberg et al., 2012). Considering that post concussive syndrome (PCS) is only found in 6.3% of mTBI (Voormolen et al., 2018) versus the 44% of patients with sleep disruption one year post-mTBI according to Fogelberg et al. (2012), it is important to understand what is causing this sleep disruption that cannot be explained by PCS. Accordingly, this study seeks to determine if there is evidence of sleep disruption in injured participants that is not present in matched controls.

**Methods**

**Participants**

Participants for this study were athletes recruited from University of Connecticut Club Sports, Eastern Connecticut State University Varsity and Club Sports, Central Connecticut State University Varsity, and University of Hartford Varsity Athletics Programs who sustained a
conclusion. In order to be enrolled in the study, researchers used the Conley Evaluation to
determine the subject’s ability to be consented (DeRenzo, Conley, and Love, 1998). Subjects
needed to score a “10” on this evaluation to be eligible to consent to the study. Matched control
subjects were recruited from each institution through fliers posted at each site.

Additional criteria for participants in this study included: the concussion was sustained
during sports activity, participant was between the age of 18 and 29 years, loss of consciousness
was less than 20 minutes in total duration, no evidence of abnormality visible on Computerized
Tomography of the head related to the traumatic event, and no hospital admission due to either
head injury or collateral injuries for >24 hours.

Participants were excluded if they suffered brain injuries more severe than a concussion,
including (but not limited to) skull fractures, subdural hematoma, epidural hematoma, or any
kind of brain bleed; loss of consciousness greater than 20 minutes, hospitalization for more than
24 hours as a result of head injury or collateral injuries. Additional exclusion criteria include:
inability to read or speak English; active CNS prescriptions taken daily except for those used to
treat Attention Deficit Disorder (ADD) or Attention Deficit Hyperactive Disorder (ADHD);
forehead, skull, or scalp abnormalities preventing the collection of data with portable EEG
device; history of brain surgery or neurological disease; current pregnancy or plans to become
pregnant within 6-8 months; participation in any previous BrainScope study. Additionally,
matched controls were excluded if they had a history of a prior concussion within one year.

Procedure

Data for this study was collected as part of a larger study examining the BrainScope
Ahead® 200 Device within the BrainScope protocol, investigating the relationship between a
history of concussion and lower extremity injuries and injury risk factors, and investigating the
possible association between concussion history and personality characteristics. This was collected over two separate periods of time, Brainscope 1 from August 2016-January 2017 and Brainscope 2 from March 2017-January 2018. The Pittsburgh Sleep Quality Index (Buysse et al., 1988) survey was administered to both injured participants and matched controls 45 days after the athlete’s return to play (RTP+) in order to evaluate the subjects’ mood and sleep patterns. Demographic data was collected from each participant at the initial data collection that occurred within 72 hours of injury (Day0).

Measures

**Pittsburgh Sleep Quality Index.** The PSQI was administered to injured participants and matched controls at RTP+ testing in order to evaluate subjects’ sleep patterns. It has been previously validated for use in patients with history of TBI (Mathias and Alvaro, 2012). The PSQI contains 19 questions and an included scoring matrix that produces a global score between 0 and 21, with higher scores indicating poorer sleep quality. A global score greater than 5 indicates poor sleep quality (Buysse et al., 1998).

**Demographics Questionnaire.** At Day0 testing, participants and matched controls were asked to complete a questionnaire regarding both their sport history and injury history. This serves the purpose of controlling for confounding variables and allows comparison to post-concussion playing status.

Data Analysis

Data analyses were performed using SPSS Version 25 (IBM SPSS Inc, Chicago, Illinois). Between-group comparisons were performed using Analysis of Variance (ANOVA) testing and associations between selected variables were conducted using Pearson r correlation. Between-subjects effects were also analyzed with ANOVA as well as with the F-test.
Results

Participants in the study included 32 injured and 25 matched control individuals for a total of 57 subjects. Demographic information for the participants is included in Table 1. While the PSQI global score was 8.22 for the injured group and 6.44 for the matched control group, the one-way group ANOVA analysis found no significant difference (p=.081) between the groups (Table 2).

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<tr>
<th>Table 1 - Demographic Data</th>
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<td>BrainScope 1</td>
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<td>Concussion</td>
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<td>Age (y)</td>
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<td>Sex (% male)</td>
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<td>Average GPA</td>
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When considering only the data from BrainScope 1, mean global score was 7.7 ± 4.201. There was no significant difference (p=.202) between the mean global score of the injured group (8.43 ± 4.737) versus the matched control group (6.71 ± 3.216) (Table 3). In BrainScope 2, there was also no significant difference (p=.187) between the mean global score of the injured group (7.67 ± 2.646) versus the matched control group (5.88 ± 2.696) (Table 3).

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<th>Table 2 - ANOVA Analysis of Total Study</th>
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<tr>
<td>Average PSQI Global Score</td>
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<td>Poor Sleep Quality % (PSQI &gt;5)</td>
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<td>Global Score ANOVA</td>
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Between-subjects effects were also analyzed via two-way ANOVA. There was no statistically significant difference between injured PSQI data and matched control PSQI (p=.238). However, there was a statistically significant difference in mean PSQI between those
who experience sleep disruption and those who do not (p=.000). Lastly, the final step of the two-way ANOVA examined the combined effects of injured vs. non-injured and presence of sleep disruption on mean PSQI. However, this relationship was found to be not significant (p=.126).

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<th>Table 3 - ANOVA Analysis of BrainScope 1 &amp; 2</th>
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<td><strong>Concussion</strong></td>
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<td><strong>Average PSQI</strong></td>
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<td><strong>Global Score</strong></td>
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<td><strong>Poor Sleep Quality % (PSQI &gt;5)</strong></td>
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Additionally, a Pearson correlation was performed to analyze the relationship between GPA and hours slept. There was no significant relationship discovered between the number of hours slept per night and the students’ GPA (p=.120).

**Discussion**

Many of the relationships examined in this study were found not significant, conflicting with former findings by Ponsford et al. (2013) and Parcell et al. (2006) that found a significant relationship between mTBI and PSQI score. In both BrainScope 1 and BrainScope 2, as well as in the combined data between the two studies, there was no significant relationship between injury/non-injury and PSQI. Ponsford et al. (2013) found that the TBI group reported significantly poorer sleep quality compared to the non-injured group. This echoed earlier findings by Parcell et al. (2006). Importantly, though the findings of these studies differ from the findings here, it is also noteworthy that neither Ponsford et al. (2013) nor Parcell et al. (2006) studied college age athletes. Compared to the average age of 20.0 years in this study, Ponsford et al. (2013) reported an average age of 34.0 years for injured participants, and 31.3 years for
matched controls while Parcell et al. (2006) does not report age data. In a 2006 study examining the effects of social rhythms on sleep quality, Carney et al. (2006) determined that college students have poor sleep quality due to their sleeping habits, particularly the irregularity of their sleeping schedule. This is especially important because it demonstrates that the college age group is particularly susceptible to sleep disruption as a result of their daily schedule compared to the average person. This can lead to a skew in PSQI data when compared to the general population. While further testing would need to be done in order to confirm this theory, it is entirely possible that the difference in population could contribute to the different findings.

Towns, Silva, and Belanger (2015) found that up to 88% of those with post-concussive symptoms were found to have sleep disruption (PSQI>5). While this study suffers from the same age limitations as Ponsford et al. (2013) and Parcell et al. (2006) in comparison to the current study, as only 14.6% of subjects were college-aged (18-25), the findings are similar to the 75% of injured subjects that reported suffering from sleep disruption in this study. As we observed sleep disruption 45 days after the return to play date, this is well outside of the timeframe of 2-4 weeks post-concussion that was used by Towns, Silva, and Belanger (2015). While we do not report a significant relationship between concussion and sleep disruption, we did observe a similar proportion of injured participants who report sleep disruption as Towns, Silva, and Belanger (2015).

The results of our study also conflict with the findings of Gomes, Tavares, and de Azevedo (2011) and Kelly, Kelly, and Clanton (2001), who both found a significant relationship between self-reported sleep duration and GPA in college students. They found that those with less hours slept had a significantly lower GPA than those with longer sleep duration. Our data does not match this conclusion, since we found that the relationship between GPA and sleep
duration was not significant (p=.120). The presence of concussion in the data could be a confounding variable, as this was not present in either Gomes, Tavares, and de Azevedo (2011) or Kelly, Kelly, and Clanton (2001).

The only significant relationship of this study, the relationship between sleep disruption and mean PSQI score (p=.000) is a validation of the legitimacy of the analysis. Here, sleep disruption is defined as it is defined by the PSQI, with a global score >5 indicating sleep disruptions (Buysse et al., 1988). In performing this analysis, the fact that a significant relationship was found is evidence that the analysis tests are accurate. Since every “Yes” for sleep disruption is greater than 5 and every “No” is equal to or less than 5, any non-significant finding would indicate an error in the analysis.

Conclusions

This study investigated sleep disturbance in concussed, college-aged athletes 40 days after they were cleared to return to play, as well as in matched controls. There was no significant difference found between the mean global score for injured and matched control participants in BrainScope 1, BrainScope 2, or when these studies were analyzed together. Additionally, there was no significant relation between number of hours slept and GPA. There was a significant relationship found between PSQI and the presence of sleep disruption (PSQI > 5), validating the analysis test.

There were numerous limitations to this study. The biggest limitation here is that the sleep data is self-reported. Self-reported data is prone to inaccuracy, both due to biases and genuine mistake. The data is quite possibly inaccurate due to this and would be more accurate if we were to measure the sleep of participants directly. Additionally, the self-reported data does not allow for the direct analysis of sleep quality, as the PSQI does not factor in interruptions of
sleep. There is also no trending of sleep quality, preventing us from analyzing potential differences in sleep disruption between athletes who are recently concussed and those who have recovered.

This study offers evidence that there is no significant relationship between sleep quality and concussion 40 days after return to play in college-aged student-athletes. While the findings of this study seem to counter much of the existing literature, there have been no similar studies done on this population. In order to more adequately assess the potential risks to quality sleep that are posed by concussions, this study could be repeated in a population with more stable sleep patterns, potentially allowing for a better analysis of concussion’s effect on sleep. It may help the quality of data collected if participants in a future study were to all follow a standardized sleep schedule. This would eliminate a potential confounding variable and allow for greater emphasis on the relationship between sleep quality and concussion. Future study should attempt to combine more accurate data collection methods and reduce variables other than presence of concussion and quality of sleep. While the results of this study may not shed as much light on the effects of concussion on sleep in college athletes as originally envisioned, it can be used as a going off point to continue research in an area with relatively little study, yet a great amount of importance.
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