Insomnia and daytime sleepiness: risk factors for sports-related concussion

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Abstract

Objective/Background: Poor quality and inadequate sleep are associated with impaired cognitive, motor, and behavioral components of sport performance and increased injury risk. While prior work identifies sports-related concussions as predisposing factors for poor sleep, the role of sleep as a sports-related concussion risk factor is unknown. The purpose of this study was to quantify the effect of poor sleep quality and insomnia symptoms on future sports-related concussion risk.

Patients/Methods: 190 NCAA Division-1 athletes completed a survey battery, including the Insomnia Sleep Index (ISI) and National Health and Nutrition Examination Survey (NHANES) Sleep module. Univariate risk ratios for future sports-related concussions were computed with ISI and NHANES sleepiness scores as independent predictors. An additional multiple logistic regression model including sport, sports-related concussion history, and significant univariate predictors jointly assessed the odds of sustaining a concussion.

Results: Clinically moderate-to-severe insomnia severity (RR = 3.13, 95% CI: 1.320-7.424, p = 0.015) and excessive daytime sleepiness two or more times per month (RR = 2.856, 95% CI: 0.681-11.977, p = 0.037) increased concussion risk. These variables remained significant and comparable in magnitude in a multivariate model adjusted for sport participation.

Conclusion: Insomnia and daytime sleepiness are independently associated with increased sports-related concussion risk. More completely identifying bidirectional relationships between concussions and sleep requires further research. Clinicians and athletes should be cognizant of this relationship and take proactive measures – including assessing and treating sleep-disordered breathing, limiting insomnia risk factors, improving sleep hygiene, and developing daytime sleepiness management strategies – to reduce sports-related concussion risk and support overall athletic performance.

Key Terms: Sports-related concussion, sleep quality, Insomnia Severity Index, relative risk, daytime sleepiness, college athletes

1. Introduction

An estimated 3.3 million mild traumatic head injuries, including those from motor vehicle accidents and sports-related concussions, are reported by emergency departments in the United States each year.[1–3] Many more sports-related concussions are managed by sports medicine teams and an estimated 50% of sports-related concussions go unreported by those who sustain them.[4–6] Consequently, reducing sports-related concussion risk is a significant public health focus and identifying predisposing concussion risk factors is of paramount importance.

Prior research indicates that the risk of sustaining a sports-related concussion is anywhere from 1.75 to 11 times greater for those with a history of one or more prior concussions.[7–11] In one of the largest retrospective studies to date (n = 12,320 participants), the odds of sustaining a sports-related concussion was 10.65 times greater than for those with a history than those without.[8] Therefore, while the specific magnitude of this effect is not necessarily clear, it is apparent that prior sports-related concussion is a predisposing factor.

Other sports-related concussion risk factors include sex,[12–19] age,[16,17,20–22] and attention-deficit hyperactive disorder (ADHD) or other learning disorders (LD).[23,24] However, the findings are less clear, and often conflicting, for these risk factors. For example, some reports indicate that females are at greater risk for sports-related concussions,[12,15,18] whereas others indicate that males are[13,17] and yet others indicate no differences in risk.[16,19] Many of these risk factors likely interact with each other. One recent study utilized multiple risk factors to create a composite weighted risk score based on univariate odds ratios. This study identified sports-related concussion history as the most indicative risk factor, with level of play, history of headache treatment, contact sport participation, and ADHD/LD as additional risk factors.[8]

One previously uninvestigated, or unreported, potential risk factor is the role of sleep. Currently the National Sleep Foundation recommends that teenagers (14-17 years old) and young adults

(18-25 years), the populations in whom most sports-related concussion research is currently conducted, obtain 8-10 or 7-9 hours of sleep per night respectively.[25] However, recent estimates suggest that many individuals in these age categories, including athletes, do not obtain sufficient nightly sleep.[26–28] With respect to athletics, this is especially problematic. Chronic under-sleeping, sleep restriction, and sleep deprivation are associated with, and can result in, mental fatigue;[29,30] attentional lapses;[30,31] increased reaction time;[29,32] impaired predictive visual tracking;[31,32] reduced postural and dynamic motor control;[29,33] degraded intra- and inter-personal emotion regulation, perception, and responsiveness[34]; and increased impulsivity and risk-taking behavior.[35–37] Furthermore, sport performance indices – including cardiovascular,[38,39] endurance,[38] strength,[40,41] and accuracy[31,32] outcomes – are reduced or impaired under inadequate or low quality sleeping conditions as well as daytime sleepiness or fatigue. Thus, individuals with habitually poor sleep may be more likely to have degraded overall sport performance, take more on-field risks, make poorer in-the-moment decisions, have less body control to appropriately act and react to cues, as well as experience brief lapses in attention to, and poor visual tracking of, in-game activities. These effects may reduce athletes' capacity to avoid or minimize injury, including sports-related concussions.

In addition to these adverse performance outcomes, less than optimal amounts of sleep (≤ 7-8 hours of sleep per night) is associated with increased injury risk.[42–44] However, prior investigations into injury risk have not specifically identified the risk for head injury or sports-related concussion. The purpose of this study was, therefore, to identify the extent to which self-reported, sleep-related outcomes affect the risk of sustaining a sports-related concussion in a sample of college athletes. We hypothesized that, in addition to concussion history, poor self-reported sleep would be associated with increased concussion risk.

2. Methods

2.1 Participants

Data were collected from surveys administered to NCAA Division-1 athletes (*n* = 190) over the summer and during the first 2 weeks of the Fall 2016 semester. In order to be eligible for the survey, students had to be at least 18 years of age. Selection favored returning students. Students were recruited through flyers, in-person solicitations at training facilities, and word of mouth among students and athletics staff. All surveys were administered online, using the student's phone, tablet, computer, or a study-provided tablet. Participants were paid for completing surveys. The Institutional Review Board of the University of Arizona approved this study.

2.2 Questionnaires

Individuals participating in the study completed a comprehensive battery of questionnaires. This battery included demographic information (i.e., age, sex, sport, self-reported sports-related concussion history) and validated self-report measures related to sleep including the Insomnia Severity Index (ISI),[45] Pittsburgh Sleep Quality Index (PSQI),[46] and Fatigue Severity Scale (FSS).[47] These are all standard screening measures used across a wide variety of populations. Of note, the PSQI was scored using two different cutoff scores to identify poor quality sleep, ≥5 and ≥8. This is because even though ≥5 is the standard cutoff for the PSQI[46], more recent work has shown that ≥8 may be more appropriate for individuals following a traumatic brain injury.[48]

The National Health and Nutrition Examination Survey's (NHANES) Sleep module was used to assess daytime sleepiness with the item, "In the past month, how often did you feel excessively or overly sleepy during the day?" Response options included Never, Rarely (1 time per month), Sometimes (2-4 times per month), Often (5-15 times per month), or Almost Always (16-30 times per month).[49]

Injury data were extracted from the student's athletic medical record at least 1 year after completing the survey (with consent) and linked to individual survey responses. All medical visits during the student's time at the university were examined and coded. All instances of a sports-related concussion (sports-related concussion) were noted and the date of that injury was also recorded so that time from survey could be computed.

2.3 Statistical Analyses

2.3.1 Primary analyses

Individuals were grouped by sport-related concussion occurrence following the survey (0 = no future sports-related concussion; 1 = one or more future sports-related concussions). Demographic and self-reported sleep-related outcome scores (including total scores and individual item scores) were analyzed using two sample Mann-Whitney *U* tests and Fisher's exact tests as appropriate. All *p*-values for the ISI, PSQI, and FSS individual item scores were Holm-adjusted within-questionnaire to control for multiple comparisons. We computed univariate risk ratios for future incidence of a sports-related concussion to test our primary hypothesis. Individual binary predictors included:

- Subclinical to more severe insomnia (1 = ISI score ≥ 8)
- Moderate-to-severe clinical insomnia (1 = ISI score ≥ 15)
- Clinically significant sleep disruption for healthy individuals (1 = PSQI total score ≥ 5)
- Clinically significant sleep disruption for post-TBI individuals (1 = PSQI total score ≥ 8)
- Clinically significant fatigue (1 = FSS ≥ 36)
- Excessive daytime sleepiness occurring at least twice per month (1 = NHANES Sleepiness response 2, 3, or 4)

Additional univariate risk ratios were computed for prior history of sports-related concussion (1 = any history of sports-related concussion), sex (1 = Male), and higher concussion prevalence sport participation in our sample[50,51] (1 = football, soccer, women's basketball; 0 = any other sport). In order to identify independent sports-related concussion risk factors, a multiple logistic regression model was fit using all statistically significant ($p < 0.05$) univariate predictors. An automated forward-and-backward stepwise variable selection method simplified this model to limit multi-collinearity between predictors.

2.3.2 Secondary analyses

To examine further the association between self-reported sleep outcomes and sports-related concussion risk, two additional logistic multiple logistic regression models were fit. First, total scores on the questionnaires exhibiting statistically significant between-group differences were entered as continuous variables, with sport participation and sports-related concussion history as additional covariates. The purpose of this model was to determine the association between increasing total scores and sports-related concussion risk, rather than classification based on dichotomized values. Second, to examine how individual elements of the questionnaires (e.g., nighttime insomnia items versus daytime impairment items on the ISI) may increase sports-related concussion risk, individual sleep questionnaire item scores were entered into a logistic regression model, along with NHANES sleepiness scores, sport participation, and sports-related concussion history. To limit the number of individual items entered into the initial model, candidate questionnaire items included only those that were statistically significant (adjusted $p < 0.05$) based on the two sample Mann-Whitney U tests. Both additional models utilized the automated forward stepwise variable selection as before.

All statistical analyses were conducted in R (v. 3.5.0).[52] Data wrangling and cleaning was performed using functions from the dplyr,[53] tidyr,[54] stringr,[55] and lubridate[56] packages. Stepwise variable selection was accomplished using the *stepAIC* function in the MASS package.[57] Plots were created using the ggplot2 package.[58] Univariate relative risk and odds ratios were computed using the *epitab* function in the epitools package[59] with small sample adjustment.

3. Results

3.1 Demographics

Descriptive characteristics for this sample, stratified by sports-related concussion occurrence after the survey, are contained in Tables 1 and 2 as well as Figure 1. The two subsamples were well-matched in terms of age, sex, race/ethnicity, academic year, and relationship status. While no association between individual sport participation and sports-related concussion occurrence was observed, an association was present when dichotomizing sports by relative concussion prevalence.[50,51] Individuals sustaining a concussion exhibited statistically significantly greater ISI and FSS total scores at the time of the survey. The average time from the survey until a sports-related concussion was 100.2 ± 62.7 days and only one individual sustained two or more concussions within the follow-up time-frame.

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3.2 Risk ratios

Details of the univariate relative risk ratios are contained in Table 3. Any prior history of concussion, participating in a sport with a traditionally high sports-related concussion prevalence, self-reported moderate-to-severe insomnia via the ISI (scores ≥ 15), and experiencing excessive daytime sleepiness on two or more days per month via the NHANES were individually associated with sustaining a future sports-related concussion. Interestingly, dichotomized fatigue severity scores were not associated with an increased risk of future concussion despite the total scores being significantly greater in the concussed group (Table 1).

< Insert Table 3 here >

3.3 Multiple logistic regression

The initial multiple logistic regression model included all statistically significant binary predictors indicated by the univariate relative risk models (prior sports-related concussion history, high sports-related concussion prevalence sport participation, ISI scores $\geq$ 15, and NHANES-rated excessive daytime sleepiness on two or more days per month). After variable selection, high concussion prevalence sport participation, insomnia severity, and daytime sleepiness were independently associated with increased odds of sustaining a sports-related concussion (Table 4 <u>Primary model</u>).

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3.4 Secondary analyses of risk factors

Initial secondary models were fit using high concussion prevalence sport participation, sports-related concussion history, NHANES sleepiness scores, and total scores on the Insomnia Severity Index and the Fatigue Severity Scale or individual items scores that were statistically significantly different between groups (see Table 1 for statistically significant individual items). After stepwise variable selection, sport participation and experiencing excessive daytime sleepiness on two or more days per month were retained for both models and independently associated with increased odds of future sports related concussion (Table 4). For <u>secondary model 2</u>, daytime motivation on the PSQI was also independently associated with increased sports-related concussion odds (Table 4).

Supplemental Tables 1, 2, 3, and 4 explore further the relationship between sub-optimal sleep outcomes, high versus low concussion prevalence sport participation, and sports-related concussion occurrence. These tables highlight the fact that, while there were no differences in questionnaire outcomes between low- and high prevalence sports, the relative frequency of sports-related concussions in this sample was higher for those with greater insomnia severity and/or more frequent daytime sleepiness than for those without, regardless of the overall prevalence for sports-related concussion.

4. Discussion

The purpose of this study was to test the hypothesis that poorer self-reported sleep-related outcomes are associated with an increased risk of future sports-related concussion in a sample of Division 1 college athletes. We hypothesized that self-reported indicators of sub-optimal sleep would be associated with an increased risk for sports-related concussion. These hypotheses were confirmed.

The relative risk of sustaining a sports-related concussion was 2-3x higher for individuals participating in a sport with a high prevalence of sports-related concussions, reporting any history of sports-related concussion prior to the survey date, self-reporting daytime sleepiness on two or more days in a month (via the NHANES Sleepiness questionnaire) or reporting moderate-to-severe levels of insomnia (via the Insomnia Severity Index). Furthermore, after controlling for sport participation, the *odds* of sustaining a future sports-related concussion were 3.66-5.58x greater for individuals reporting moderate-to-severe insomnia and/or daytime sleepiness on two or more days per month. Collectively, the odds of sustaining a sports-related concussion for individuals who reported both moderate-to-severe insomnia severity and two or more days of excessive daytime sleepiness (n = 20) was 14.6x higher than for those who reported neither.

4.1 sports-related concussion risk factors

Reducing the incidence of sports-related concussion is a public health concern. Consequently, identifying individual risk factors for sustaining a sports-related concussion has been the focus of considerable effort. Prior work has consistently demonstrated that individuals with previous concussions are at increased risk to sustain a future concussion.[7–11] Our present findings are consistent in magnitude with the majority of these findings (~2-3 times higher risk of future sports-related concussion with any prior history of concussion). However, in contrast to prior work, history of concussion was not retained in multivariate models in this sample. Rather, after controlling for participating in a sport with a traditionally higher sports-related concussion prevalence, self-report insomnia and daytime sleepiness were strong indicators of sustaining a concussion.

Additional studies have indicated that sex[12–19], age,[16,17,20–22] and ADHD/LD,[23,24] among others, may all increase the risk of sustaining a sports-related concussion. However, these findings are inconsistent. Relative to our findings, males were more likely than females to sustain a sports-related concussion, though this finding was not statistically significant. However, diagnoses of ADHD/LD were not available for analysis. Furthermore, age in our sample was not associated with an increased likelihood of sustaining a sports-related concussion, though this is not surprising given the narrow age range considered here.

4.2 Bidirectional relationships between sports-related concussion and sleep

There is evidence indicating that self-reported sleep disruption, daytime sleepiness, and fatigue are consequences of sports-related concussions. An estimated 30-80% of individuals with mixed severity traumatic brain injuries, of which sports-related concussions are a subset, report insomnia symptoms lasting well beyond the generally accepted clinical time course of recovery.[60–62] Recent evidence suggests that there may additionally be objective indicators of altered sleep quantity and quality following sports-related concussion.[63–67] However, the natural evolution of sleep disruption and recovery post-injury has not been clearly identified to date.

To our knowledge, this is the first study that has examined self-report sleep-related outcomes as a risk factor, rather than necessarily an outcome, for sports-related concussion. We observed a three- to five-fold increased likelihood of sustaining a sports-related concussion with either moderate-to-severe insomnia severity or daytime sleepiness, even after controlling for participating in a higher concussion prevalence sport. While likely not directly causative, there are several plausible explanations as to why individuals with these self-reported outcomes may be at increased sports-related concussion risk.

First, sub-optimal sleep is associated with increased reaction times;[30,32,39] attentional lapses;[29,31] degraded visual tracking;[31,32] reduced postural control and strength;[29,33,40,41] impaired emotional recognition, responsiveness, and control[34]; and increased impulsivity and risky behavior.[35–37] Second, the cardiovascular,[38,39] endurance,[38] strength,[40,41] and accuracy[31,32] components of sport performance are reduced or impaired under inadequate or low quality sleeping conditions as well as daytime sleepiness. Consequently, individuals who experience poor sleep may be more likely to have degraded overall physical sport performance as well as brief lapses in attention to and poor visual tracking of in-game activities. Simultaneously, these individuals may make unusually poor or risky sport decisions (e.g., take on-field risks), be unable to manage negative emotional responses to in-game situations, and have poorer body control during sport maneuvers at critical moments. Collectively, these effects may reduce an individual's capacity to avoid or minimize injury. However, reports for the majority of these adverse sports-related effects are isolated from one another (i.e., studies on reduced sport performance after sleep restriction only; studies on impaired visual tracking follow sleep deprivation only) and therefore multivariate effects are not fully explained. Furthermore, prior investigations into injury risk have not specifically identified sports-related concussion risk, and therefore any translation of this hypothesis requires further corroboration.

Despite the lack of comprehensive analyses of sleep-related influences on injury risk, the present findings contribute to a larger body of work identifying poor or insufficient sleep as a contributory factor to sports-related injury risk.[42–44,68] Additionally, these findings contribute a critically absent piece of information to this literature base, highlighting the specific risk of sports-related concussion in the presence of poor sleep (e.g., insomnia) and daytime sleepiness. Furthermore, these findings identify a plausible means by which prior sports-related concussions increase future risk. Namely, prior sports-related concussions often result in increased incidences of insomnia and daytime sleepiness, which, on the basis of the present findings, likely contribute to increased risk of future concussions. This, therefore, may create a feed-forward cycle where sports-related concussions increase the risk of poor sleep outcomes that, in turn, increase the risk of future concussions. While unconfirmed at present, this hypothesis merits further investigation.

Apart from the noted effects of sports-related concussions on sleep, collegiate and professional athletes are more generally at increased risk for insomnia[69] and sleep disordered breathing[70,71] compared to sub-elite and non-athlete populations. Evidence suggests that training schedules,[72] travel requirements,[73,74] and competition[71,72] may all contribute to poor quality sleep and insomnia, plausibly resulting in daytime sleepiness. Likewise, the prevalence of sleep-disordered breathing is higher in athletes, particularly football players, and is associated with increased complaints of daytime sleepiness and poor sleep quality.[71,75,76]

Within the present sample, approximately 60% of the athletes reported daytime sleepiness or sleepiness on two or more days per month and approximately 12% reported moderate-to-severe insomnia symptom severity (Supplementary Tables). Despite a limited number of observed sports-related concussions in the follow-up period (*n* = 19), individuals reporting frequent daytime sleepiness accounted for the majority (*n* = 17; 89.4%). Furthermore, almost one-third of the sustained sports-related concussions occurred in individuals reporting ***both*** frequent daytime sleepiness and moderate-to-severe insomnia severity (*n* = 6; 31.6%). Combined with previously reported detrimental effects of sleep disruption on athletic performance and overall health, the present findings highlight the need for assessing and improving sleep, either quantitatively or qualitatively, as means of reducing sports-related concussion risk as well as supporting high-quality sport performance. Collegiate and professional athletes, in particular, may benefit from assessment for and treatment of sleep-disordered breathing, sleep hygiene education, and developing habits to obtain sufficient, high-quality sleep and manage daytime sleepiness.

4.3 Limitations

Several limitations must be considered when interpreting the present findings. First, a limited number of individuals sustained a sports-related concussion in the follow-up time-frame (n = 19; 10% of the sample). This limited proportion of our sample may have resulted in overestimating the relative risk and odds ratios and limited our ability to detect statistically significant effects. To minimize this concern, we used small sample size adjustments for the univariate risk ratio confidence intervals to provide conservative estimates of overall risk and the stepwise variable selection method restricted multivariate models to variables containing model information, rather than strictly statistical significance, while limiting multi-collinearity. However, all of the univariate (Table 3) and multivariate models (Table 4) as well as simple descriptive cross-tabulation (Supplemental Tables) converge on the interpretation that frequent daytime sleepiness, both apart from and in conjunction with moderate-to-severe insomnia severity, is associated with an increased occurrence of sports-related concussions.

Second, our analyses relied on diagnosed sports-related concussions. Historically, as many as 50% of sports-related concussions go unreported and therefore undiagnosed.[4–6] Independent of the research presented here, athletes and coaches in the present sample received routine education on concussion symptoms and reporting. Additionally, the sports medicine team maintains a high vigilance for detecting possible concussions, including the addition of independent medical spotters during football games. Therefore, we have reasonable confidence that the majority of the sustained concussions were diagnosed and recorded. However, given the vast number of sports-related concussions that do go unreported, it is possible that participants under-reported prior sports-related concussions to research staff and medical providers, potentially confounding the results of the multiple logistic regression models.

Consequently, our findings may not reflect the true relative risk of sports-related concussion based on self-reported sleep-related outcomes when considering both diagnosed and unreported injuries.

Third, the *a priori* data collection methods in the present study did not allow for follow-up or on-going sleep tracking throughout the course of the season. Therefore, it was not possible to track in-season sleep changes, correlate sleep changes with academic or sport demands, or quantify the extent to which poor sleep outcomes immediately prior to injury may have predisposed individuals to subsequently poorer sleep post-injury. This is an important consideration in light of the prevalence of sleep disruption following sports-related concussions.

Lastly, all athletes completed surveys prior to the start of the fall semester but may not have had practice or competition until the spring. Consequently, sleep characteristics leading up to the injury (e.g., sleep patterns, habits, and daytime sleepiness in the days and weeks preceding injury, advanced or delayed sleep phase due to travel), rather than more remote sleep outcomes, may be a more sensitive indicator of sports-related concussion risk.

4.4 Future research

The findings from the present study highlight a critical need for further research in this area. Specific research efforts should include the following:

1. <u>Fine-grained sleep assessments leading up to, and following, injury:</u> Wearable activity trackers (e.g., actigraphs) can objectively quantify sleep and sleep habits over time and are appropriate for sleep tracking in numerous populations. Prior investigations have included actigraphy-related findings following concussions. In the present study, we were unable to follow athletes during their sport season to quantify how self-reported and measured sleep may change. Prospective sleep tracking in athletes, with a particular emphasis on preinjury risks and post-injury outcomes, would provide essential,

quantifiable data on the role of sleep leading up to injury. Likewise, sleep tracking following sports-related concussion would provide needed clarity on how sleep changes with injury as well as the extent to, and timing at, which recovery occurs.

2. Sport and academic demands, and travel as risk factors for concussion. Sport and academic demands – such as travel to and from competitions, early morning or late evening practices, and studying for exams – may negatively impact sleep (e.g., self-imposed sleep restriction; phase advanced/delayed sleep) prior to and following a concussion. Consequently, sleep-related risks for, and outcomes from, a concussion may change throughout the sport and academic year as a function of these factors and requires further examination.
3. The interplay between sleep and biopsychosocial risk factors for sports-related concussions. Further studies are needed to more fully identify biopsychosocial (e.g., training response, age, sex and/or gender, self-esteem, stress, nutrition, training load) risk factors in conjunction with sleep that may more fully identify individuals at increased risk for injury. Of particular interest would be the identification of modifiable risk factors – such as stress, nutrition, sleep and sleep hygiene, daytime sleepiness – that can be leveraged to prevent avoidable injury.

5. Conclusions

The results of this study indicate that self-reported poor sleep outcomes, specifically moderate-to-severe insomnia severity and frequent excessive daytime sleepiness, are independently associated with an increased risk for subsequent sports-related concussions. Further research is needed to more completely identify the bidirectional relationship between sports-related concussion and both objective and subjective sleep disruption. Additionally, our findings highlight the need for both clinicians and athletes to be cognizant of the relationship between sleep and sports-related concussions and to take proactive measures to improve athletes' sleep

– quantitatively, qualitatively, or both – in order to reduce sports-related concussion risk as well as support and improve overall athletic performance.

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Figure captions

Figure 1. Proportions of individuals sustaining (blue) or not sustaining (red) a sports-related concussion (blue) broken down by (A) racial/ethnic groups, (B) individual sports, (C) academic years, and (D) relationship statuses. Fisher’s exact tests were used to assess associations between these demographics and sports-related concussion occurrence after the survey date. No statistically significant associations were observed.