Journal of Athletic Training 2025;60(10):707–712
doi: 10.4085/1062-6050-0629.24

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Acute Changes in Sleep Stages After Concussion in Collegiate Athletes: A Pilot Study

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Context: Sleep has been suggested to be a modifier of recovery after a concussion and is associated with greater symptomatology and the number of days until symptom resolution. However, the physiological mechanism for why sleep disturbances occur remains poorly understood. Alterations in time spent in the stages of a sleep cycle after a concussion may contribute to recovery.

Objective: The purpose of our study was to use a noninvasive, sensor-derived measure of sleep stages to determine differences between collegiate athletes with or without a concussion, acutely after injury (<72 hours).

Design: Case-control study.

Setting: Division I collegiate athletics.

Patients or Other Participants: Division I collegiate athletes diagnosed with a concussion were compared with healthy-matched controls based on health history, demographics, and sport.

Intervention(s): Individuals in both groups were provided with and instructed to wear an OURA ring actigraphy device nightly within 72 hours of their concussion.

Main Outcome Measure(s): Differences in sensor-derived time spent in light, deep, and rapid eye-movement sleep, time awake, and total sleep time between groups.

Results: A total of 18 athletes was included in our analyses (9 concussed, 9 controls) with an average age of 19.3 ± 1.3 years. Individuals with a concussion spent less time in deep sleep (113.11 ± 33.1 versus 134.44 ± 51.1 minutes, $P = .03$) and more time awake (90.22 ± 30.0 versus 49.28 ± 11.5 minutes, $P = .02$) than individuals without a concussion. No significant differences were found for total sleep time or time spent in light or rapid eye-movement sleep.

Conclusions: Acutely after concussion, individuals may demonstrate changes in sleep stages. Our results suggest that time spent in different stages of sleep may be a potential mechanism underlying recovery from concussion. Our results provide an important step in using wearable sensors to better understand sleep disturbances after concussion to help mitigate risk of a prolonged recovery.

Key Words: REM, NREM, sleep architecture, recovery, symptoms

Key Points

- Collegiate athletes with a concussion spend up to 54% more time awake throughout the night than healthy controls, suggesting significant sleep disruption in the acute phase of injury.
- Deep sleep duration was reduced by an average of 21 minutes in concussed athletes, which may impair essential neurophysiological recovery processes, including glymphatic clearance and synaptic plasticity.
- Our findings provide new evidence that alterations in sleep architecture occur within 72 hours of concussion, highlighting a potential target for monitoring and intervention to optimize recovery.

Concussion-related sleep disturbances are a known modifier of recovery after a diagnosed concussion.[1–5] Through the use of self-reported symptoms and actigraphy, researchers have demonstrated that individuals who experience sleep-related symptoms take a greater number of days to report being symptom free and ultimately return to play after a diagnosed concussion.[2–6] For example, in adolescents (11–18 years of age), a fourfold increase in recovery time was observed if sleep symptoms (eg, difficulty falling asleep or staying asleep) were reported in the first week after injury when compared with those that did not endorse the same symptoms.[5] Similarly, collegiate athletes that self-reported sleep symptoms in the acute phase of injury (<72 hours) took longer to experience symptom resolution than those that did not report sleep symptoms.[7] While authors of previous studies have provided foundational work to support sleep as a modifier of recovery, they have focused on self-reported sleep disturbances or sensor-derived (eg, FitBit, Apple Watch) sleep duration or sleep efficiency, overlooking potential changes in sleep architecture (ie, time spent in different stages of sleep), particularly in the acute phase of concussion.[1,3,4,6,8–10] Given the role of sleep in recovery, understanding sleep stage alterations immediately after injury may provide new insights into how sleep influences recovery.

Continued sleep disturbances beyond the typical symptom-resolution period (ie, 10–14 days) after a concussion are common and present like trends observed in the acute and subacute phases of the injury.[11] More specifically, a decreased sleep efficiency (ie, the proportion of time spent asleep relative to the total time in bed) and increased time spent awake have been reported up to 1 year after injury.[6,12] Research in which authors have examined sleep disturbances immediately after concussion (<72 hours) remains limited. In 1 study of collegiate athletes, it was found that those with a concussion demonstrated longer time to fall asleep (15.8 minutes) than healthy-matched controls (5.8 minutes).[9] Moreover, those with a concussion demonstrated variability in the number of minutes awake after having initially fallen asleep (ie, wake after sleep onset) and greater total sleep time when compared with healthy controls.[9] Though these data support the role of sleep in recovery after concussion, the physiological mechanism of why sleep disturbances occur after injury remains poorly understood but may be linked to the physiological processes that regulate the sleep-wake cycle.

A sleep cycle can be separated into 2 stages: nonrapid eye movement (NREM) and rapid eye movement (REM).[13] More specifically, a sleep cycle consists of 3 NREM stages and 1 REM stage.[13] Typically, individuals will experience 4 to 5 sleep cycles each night, with each cycle lasting between 70 and 120 minutes.[13] However, inadequate sleep cycles (ie, time spent in each stage) can diminish the restorative benefits of sleep. The current gold standard for assessing sleep is polysomnography (PSG).[14] Polysomnography is used to monitor sleep stages and cycles to determine if or when sleep patterns are disrupted and why. Although PSG allows researchers to collect physiologic parameters of sleep, the time and cost of the technology prevent it from being widely used, especially after a concussion.

Due to the barriers associated with PSG, alternative measures of sleep based on actigraphy, such as a FitBit or Apple Watch, have been developed and used to indirectly measure sleep.[15–17] However, these devices measure overall time spent asleep as opposed to the different stages of sleep.[15,16] Additionally, the accuracy of wearable devices used to measure sleep has been brought into question. Wearable devices used to measure sleep primarily use a single accelerometer, thereby only measuring movement (or lack thereof) to determine when an individual is awake or asleep. Provided this limitation, actigraphy devices, such as a FitBit or Apple Watch, have been demonstrated to have limited reliability compared with PSG.[16,18] The OURA ring is a smart ring purported to quantify biometric data specific to sleep such as body temperature, heart rate variability, as well as time spent in the various sleep stages (REM, NREM) through use of 3 sensors. When compared with PSG, the OURA ring was demonstrated to have high sensitivity (96%) and moderate specificity (48%) for detecting sleep, making it a better option to assess sleep than traditional actigraphy devices.[19]

As mentioned, inadequate sleep cycles (ie, time spent in each stage) can diminish the restorative benefits of sleep, particularly stage 3 of NREM.[13,20] Often referred to as deep sleep, this stage is of great importance, as it is the primary stage of sleep in which the glymphatic system—a series of perivascular channels throughout the brain that serve to clear away and expel waste in the central nervous system—is active.[21] Disruption in sleep stages, particularly deep sleep, may result in decreased glymphatic clearance of metabolic waste (ie, cellular debris) from concussion.[21,22] Past researchers have demonstrated that subjective and objective measures of sleep disturbances such as night time awakenings, increased daytime drowsiness, and reports of insomnia are associated with prolonged recovery from concussion.[1–5,9,23] Despite the advancements in our understanding of sleep as a modifier of recovery, the authors of these studies have not identified how stages of sleep may be associated with recovery, particularly in the acute phase of injury (<72 hours). As sleep is a known modifier of recovery after a diagnosed concussion, examining differences in stages of sleep may provide previously unknown evidence that sleep-wake cycles are affected by concussion. Therefore, the purpose of our study is to use a noninvasive, sensor-derived measure of sleep (OURA ring) to observe differences in sleep stages within 72 hours after a diagnosed concussion in collegiate athletes.

METHODS

Participants

This was a case-control study. Data were collected on Division I, National Collegiate Athletic Association athletes from a single institution who were active in their respective sport, between the 2021–2022 and 2022–2023 academic years. For the concussed group, athletes were diagnosed with a concussion by an athletic trainer (AT) or team physician. Concussion diagnosis was adopted from the most recent international consensus statement on concussion in sport at the time of diagnosis.[24] After the diagnosis of a concussion, athletes were referred to study personnel for recruitment within 72 hours postinjury. Participants in both groups were excluded if they had any prior traumatic brain injury requiring hospitalization, the presence of brain tumor, a concussion within 6 months of study participation (excluding present concussion), or a neurologic or neurodevelopmental disorder (epilepsy, dementia, autism, or migraine, but not attention-deficit disorder). Additionally, potential participants with a concussion were excluded if they had a Glascow Coma Scale score less than 13 on initial evaluation, traumatic injury requiring intensive care unit monitoring or operative repair, a structural abnormality on brain computed tomography (if obtained), or any additional comorbidity (eg, anterior cruciate ligament tear). All participants signed an informed consent form before participation in this study. This study was approved by the university's institutional review board.

Measures

Demographic Measurements. Basic demographic information collected consisted of biological sex, age, height, weight, sport, and position played. This information was collected as part of a health history form and was the basis of how participants with a concussion were matched with their respective control subjects.

OURA Ring. The OURA ring is a consumer-based health tracking device that measures body signals (ie, heart rate, heart rate variability, temperature) as well as sleep-specific metrics (eg, time in light, deep, and REM sleep, and total sleep time [amount of time an individual spends asleep during a planned sleep period]).[19] These body signals are measured via infrared photoplethysmography, negative temperature coefficient, and a triaxial accelerometer. Accelerometer data are sampled at a frequency of 50 Hz.[19] Sleep is measured in 5-minute epochs, with sleep onset being defined as the first 5 consecutive minutes of persistent sleep. Authors of previous studies have demonstrated a sensitivity (ability to detect sleep) of 96% and a specificity (ability to detect wake) of 48% in the OURA ring when compared with PSG.[19]

Revised Head Injury Scale. The Revised Head Injury Scale (HIS-r) consists of 22 symptoms related to concussion

Table. Average Time Spent (Minutes) in Light, Deep, and REM Sleep; Time Awake; and Total Sleep Time Between Groups <72 Hours After Injury

	Concussed, min	Control, min	*P* Value	Cohen d	95% CI
Light sleep	247.61 ± 71.4	208.28 ± 72.6	.307	−0.533	−0.42, 1.46
Deep sleep	113.11 ± 33.1	134.44 ± 51.1	.027[a]	−0.500	−1.43, −0.45
REM sleep	46.94 ± 35.1	43.44 ± 32.8	.096	−0.120	−0.81, 1.04
Awake	90.22 ± 30.0	49.28 ± 11.5	.021[a]	1.82	0.69, 2.92
Total sleep time	407.66 ± 82.2	386.16 ± 112.1	.201	−0.24	−1.145, 0.709

Abbreviation: REM, rapid eye movement.
[a] $P < .05$.

and measures symptom quantity, duration, and severity over a 24-hour period. To complete the HIS-r, participants first indicated which of the 22 symptoms (yes/no) they had experienced during the previous 24 hours that were atypical for them. For each symptom endorsed, the participant then rated the symptom duration and severity over the past 24 hours. Duration is rated on a Likert scale from 1 (*briefly*) to 6 (*always*). Severity is rated on a Likert scale that ranges from 0 (*not severe*) to 6 (*as severe as possible*). In addition to the total number of symptoms endorsed (ranging from 0 to 22), total symptom duration and total symptom severity scores were calculated by summing the respective individual duration and severity scores for each endorsed symptom, resulting in total duration and severity scores each ranging from 0 to 132. The HIS-r has been demonstrated to have high sensitivity (77.5%) and specificity (100%) in recognizing collegiate athletes diagnosed with a concussion acutely after injury.[25]

Procedure

Upon diagnosis of a concussion by the athlete's AT or team physician, participants in both groups were recruited within 72 hours of injury. Upon successful recruitment, a control participant was identified and matched to their injured counterpart by sport, position played, height, weight, age, and the absence of acute medical complications (ie, illness or musculoskeletal injury) or an active injury. Participants were then sized for an OURA ring to be worn on their second, third, or fourth digit (on either hand) and instructed to wear it nightly.[19] Additionally, at this time, participants were instructed to download the OURA ring application on their personal smartphone. The application allowed for continuous collection of data from the ring while being encrypted. OURA system preferences were set so that participants could not see any of their sleep data in the application. Sleep data were automatically processed through OURA's proprietary algorithm; as such, the assessment of all sleep variables was identical for all participants. The research team acquired the data by exporting them from OURA's Cloud-based data platform. Once exported, the data were securely stored in a HIPAA-compliant digital repository before being processed and analyzed. OURA ring sleep parameters examined in this study included time (in minutes) spent in light sleep, deep sleep, and REM sleep, awake, and total sleep time in the first 72 hours after their injury.

Statistical Analysis

Independent *t* tests were performed to determine if duration of time in light, deep, or REM sleep, time awake throughout the night, and total sleep time, as measured by the OURA ring in the first 72 hours of injury, were statistically different between groups. Cohen d effect size was calculated to determine between-groups differences in the stages of sleep and interpreted as *large* (>0.8), *medium* (0.50–0.79), or *small* (0.20–0.49).[26] Data were analyzed using SPSS (version 26.0; IBM Corp) with $\alpha = .05$.

RESULTS

A total of 18 collegiate athletes (8 female, 10 male) was included in the study (9 concussed, 9 healthy-matched controls), with an average age of 19.3 ± 1.3 years. Individuals with a concussion demonstrated an initial symptom severity of 30.1 (out of 132 measured via the HIS-r) and took approximately 10.0 ± 10.5 days to self-report as asymptomatic. Day 1 (ie, <24 hours) was not included in the final analysis due to a small recruitment sample; thus, analysis of sleep data was the mean of days 2 and 3. Significant differences in time spent awake were found between groups, with individuals with a concussion spending an average of 90.22 ± 30.0 minutes awake compared with matched controls who spent an average of 49.28 ± 11.5 minutes awake ($t = -3.65$, $P = .021$, Cohen d $= -1.8$). Additionally, differences were observed in deep sleep duration, with individuals in the concussed group spending significantly less time (113.11 ± 33.1 minutes) than matched controls (134.44 ± 51.1 minutes [$t = 1.36$, $P = .027$, Cohen d $= 0.50$]). No significant differences between groups were observed in duration of light sleep ($P = .31$), REM sleep ($P = .09$), or total sleep time ($P = .20$; Table).

DISCUSSION

Our study is the first of its kind in which the duration of NREM and REM sleep stages in the acute phase of a concussion was examined using a commercially available smart ring to monitor sleep. Our results suggest that collegiate athletes with a concussion spend significantly more time awake—approximately 54% more on average—than athletes without a concussion, with a large effect size observed for this difference. Additionally, athletes with a concussion demonstrated less time in deep sleep, which may have important implications for recovery given the role of deep sleep in cellular repair.[21] Importantly, our results suggest that time spent in different sleep stages may be a potential mechanism underlying recovery from concussion that had not previously been examined in the collegiate athlete population; however, further research is needed in a larger, more diverse sample to confirm these findings. Clinicians should consider monitoring postinjury sleep disturbances, as increased wakefulness and reduced deep sleep may contribute to prolonged recovery and affect return-to-play decisions.

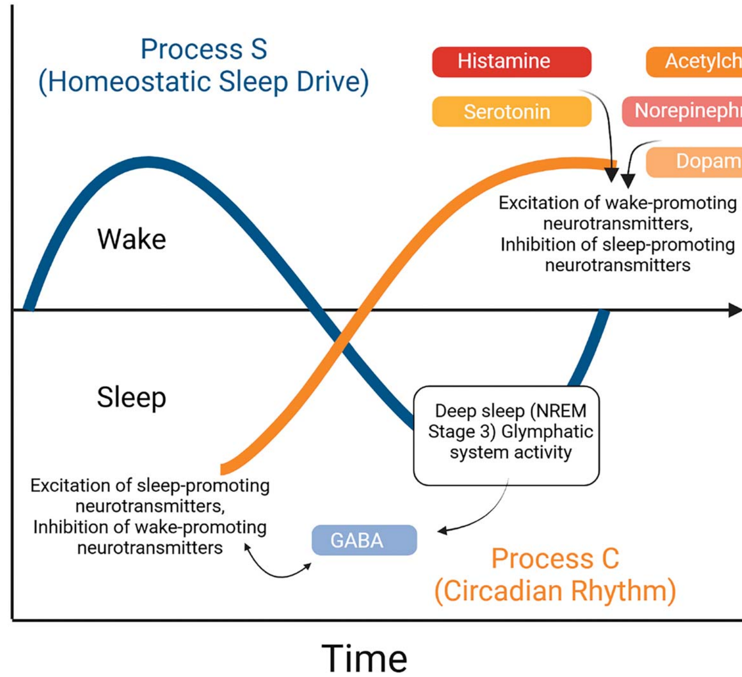

Figure. The Two-Process Model of Sleep, illustrating the interaction between the homeostatic sleep drive (Process S) and the circadian rhythm (Process C) in regulating sleep and wakefulness. Neurotransmitters involved in sleep-wake regulation are shown, with wake-promoting neurotransmitters (histamine, acetylcholine, serotonin, norepinephrine, dopamine, and hypocretin) facilitating alertness and sleep-promoting neurotransmitters (gamma-aminobutyric acid [GABA]) contributing to sleep onset and maintenance. Disruptions in these processes, such as those observed after concussion, may alter sleep architecture, particularly deep sleep, which plays a crucial role in neurophysiological recovery and glymphatic system function. Created in BioRender (https://BioRender.com/uvzpsx4). Abbreviation: NREM, nonrapid eye movement.[13,20,30–32]

In our study, no significant differences were found between groups for total sleep time, with both groups demonstrating an average of 6.5 to 7 hours of sleep. This finding is in line with previous research, in which total sleep time differences were not observed between individuals with and without a concussion.[3,6,8,9,23,27–29] This suggests that total sleep time may not fully capture sleep-related differences after a concussion, but rather the length of time spent in different stages may be more relevant to understanding how sleep is altered after concussion. An individual with a concussion may demonstrate the same hours of sleep as an individual without a concussion, and as such, total sleep time does not fully explain the frequency or duration of sleep stages that comprised the total sleep time. Additionally, we observed that individuals with a concussion spent more time awake during the night than those without a concussion. After a concussion, subjective reports of frequent nighttime awakenings and increased time spent awake via actigraphy are commonly seen throughout research.[3,5,6,23] However, authors of many of these studies included a wide range of time from injury to enrollment, ranging from weeks to months, rather than acutely after injury.[1,3–6,23]

The decreased duration of deep sleep in the concussed group immediately after injury may be explained by factors related to sleep regulation and physiology not analyzed in this study. The regulation of sleep is driven by the interaction of 2 separate biological mechanisms: the homeostatic need for sleep (Process S) and the circadian timing of when sleep happens (Process C).[13,20,30–32] The regulation of sleep and wakefulness by processes S and C is referred to as the 2-process model and is reflective of the inhibition or activation of various neurotransmitters.[13,30,31] The excitement of sleep-promoting neurons or inhibition of wake-promoting neurons may prompt sleep. Conversely, waking can be promoted through the excitement of wake-promoting neurons or the inhibition of sleep-promoting neurons.[13,20,31,32] Specifically, during sleep, various neurotransmitters are released throughout each stage that promote and maintain sleep.[31] These include histamine, acetylcholine, serotonin, norepinephrine, dopamine, hypocretin, and gamma-aminobutyric acid.[31] Changes in the inhibition or activation of these neurotransmitters can lead to a either a decreased or an increased amount of time spent in a specific sleep stage as well as the frequency of that stage.[13,31] Disrupted sleep stages, particularly stage 3 of NREM, otherwise known as deep sleep, are reflective of a decreased homeostatic drive for sleep (Process S).[33] This stage of deep sleep is of great importance, as it is the primary stage of sleep in which the glymphatic system is active.[33] The glymphatic system is a series of perivascular channels throughout the brain that serve to clear away and expel waste in the central nervous system (Figure).[21,34] Disruptions in sleep stages and their duration, particularly deep sleep, may therefore result in decreased glymphatic clearance of metabolic waste (ie, cellular debris) after injury. However, further research is needed to confirm this in a concussed population.

Though the use of the OURA ring in the present study has provided novel insight into sleep architecture after concussion, it is not yet feasible to use as a routine clinical tool for concussion management. Despite this, our findings still have meaningful implications for concussion management. Given our results that individuals with concussion spent increased time awake and decreased time in deep sleep, clinicians can integrate subjective sleep assessments into standard care. Incorporating sleep diaries, using validated questionnaires such as the Pittsburgh Sleep Quality Index, or directly asking athletes about their sleep may help identify those at risk for prolonged recovery.[35,36] Moreover, incorporating these assessments may serve as an early indication that sleep disturbances may be contributing to persisting symptoms. Finally, as deep sleep plays a vital role in neural recovery, mood regulation, and cognition, clinicians can place an emphasis on strategies that aid in promoting good sleep quality such as maintaining a consistent sleep schedule or limiting screen time before bedtime.[37]

This study was not without limitations. Our sample size was small; however, given the limited number of prospective studies in which authors have assessed sleep in the acute phase of a concussion, in this study, we provide valuable information regarding duration of sleep stages in individuals with or without a concussion. Second, we were unable to capture participants' sleep patterns before injury and, as such, can only draw limited conclusions by comparing with healthy controls. Additionally, we acknowledge that, being a consumer wearable device, the OURA ring is limited in its accuracy of measurement.

CONCLUSIONS

With this study, we extend the current literature by using a commercially available, wearable device to assess sleep acutely after concussion, during which data are limited. Individuals with a concussion demonstrated decreased duration of deep sleep and increased time spent awake during the acute phase after concussion. These findings provide new insight into the underlying mechanism by which sleep influences recovery from concussion.

ACKNOWLEDGMENTS

This study was partially funded by the Virginia Athletic Trainers' Association.

FINANCIAL DISCLOSURES

Dr. Donahue reports grants from the Virginia Athletic Trainers' Association during the conduct of the study. Dr. Resch reports grants from the Virginia Athletic Trainers' Association and grants from the University of Virginia during the conduct of the study.

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