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Baseline Neurocognitive Testing in Sports-Related Concussions

The Importance of a Prior Night's Sleep

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Background: The management of sports-related concussions (SRCs) utilizes serial neurocognitive assessments and self-reported symptom inventories to assess recovery and safety for return to play (RTP). Because postconcussive RTP goals include symptom resolution and a return to neurocognitive baseline levels, clinical decisions rest in part on understanding modifiers of this baseline. Several studies have reported age and sex to influence baseline neurocognitive performance, but few have assessed the potential effect of sleep. We chose to investigate the effect of reported sleep duration on baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) performance and the number of patient-reported symptoms.

Hypothesis: We hypothesized that athletes receiving less sleep before baseline testing would perform worse on neurocognitive metrics and report more symptoms.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: We retrospectively reviewed 3686 nonconcussed athletes (2371 male, 1315 female; 3305 high school, 381 college) with baseline symptom and ImPACT neurocognitive scores. Patients were stratified into 3 groups based on self-reported sleep duration the night before testing: (1) short, $<$7 hours; (2) intermediate, 7-9 hours; and (3) long, $\geq$9 hours. A multivariate analysis of covariance (MANCOVA) with an α level of .05 was used to assess the influence of sleep duration on baseline ImPACT performance. A univariate ANCOVA was performed to investigate the influence of sleep on total self-reported symptoms.

Results: When controlling for age and sex as covariates, the MANCOVA revealed significant group differences on ImPACT reaction time, verbal memory, and visual memory scores but not visual-motor (processing) speed scores. An ANCOVA also revealed significant group differences in total reported symptoms. For baseline symptoms and ImPACT scores, subsequent pairwise comparisons revealed these associations to be most significant when comparing the short and intermediate sleep groups.

Conclusion: Our results indicate that athletes sleeping fewer than 7 hours before baseline testing perform worse on 3 of 4 ImPACT scores and report more symptoms. Because SRC management and RTP decisions hinge on the comparison with a reliable baseline evaluation, clinicians should consider sleep duration before baseline neurocognitive testing as a potential factor in the assessment of athletes' recovery.

Keywords: concussion; ImPACT; athletes; sleep; mild traumatic brain injury

In the United States, an estimated 1.6 to 3.8 million traumatic brain injuries (TBIs) are reported annually. For those ages 15 to 24 years, athletics are second only to vehicular trauma as a leading cause of TBIs.[46] In youth athletes, sports-related TBIs account for 150,000 to nearly 250,000 annual emergency department visits, where over 60,000 are high school–aged athletes.[13,18] Compared with this typical high school age group, Gessel et al[17] found the overall sports-related concussion (SRC) rate for 2005 to 2006 to be higher in collegiate players.

Given an increasing incidence of SRCs and the potential complications that may occur if athletes return to play (RTP) before medically appropriate, an accurate monitoring of athletes' recovery depends on the use of reliable metrics. The Concussion in Sport Group (CISG) advocates a multifaceted approach in the clinical evaluation of

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SRCs, including a return to baseline levels in cognition and self-reported symptoms, before ensuring an athlete's ability to safely RTP.[34,35] Serial neurocognitive testing and self-reported symptom inventories are utilized as intraindividual measurements during this recovery period to assess an athlete's return to baseline levels. Clinical management guidelines recommend delaying RTP for athletes who remain symptomatic or perform more poorly on neurocognitive testing.[35] To judge an athlete's return to baseline levels, clinicians must therefore have an accurate understanding of potential modifiers of baseline symptoms and neurocognitive performance.

The recent expert consensus (CISG) details several "modifying" factors with the potential to influence the management of concussions and, in some cases, may predict persistent symptoms.[34] Although not exhaustive, this list includes the number, quantity, and severity of symptoms; loss of consciousness for >1 minute; age <18 years; and comorbid neuropsychiatric diagnoses such as migraine, depression, attention deficit hyperactivity disorder (ADHD), and learning disabilities.[34] These factors may necessitate a multidisciplinary management and considerations beyond simple RTP advice, such as in-depth neuropsychological testing, balance assessment, or functional neuroimaging. Although several authors have documented that prior concussions,[7] age,[15] and sex[9] are each individual modifiers of baseline neurocognitive performance, to our knowledge, there is no literature in the management of SRCs pertaining to the subject of sleep quantity and its effect on baseline neurocognitive performance and self-report of symptoms.

However, literature exists reporting sleep difficulty after SRCs. In a small sample of young adults, Gosselin et al[20] compared patients' quality of sleep after sustaining SRCs to those without a concussion history and found that, subjectively, concussed athletes reported more symptoms and worse sleep quality than controls. However, no objective between-group differences were noted on sleep polysomnographic or electroencephalographic variables. Lau et al[28] showed the persistence of sleep-clustered symptoms to be sensitive in predicting a protracted recovery after SRCs (defined as remaining symptomatic for >14 days).

Outside the concussion literature, a strong relationship between sleep quantity and neurocognitive performance has been established. In a meta-analysis of sleep and cognition in 35,936 children aged 5 to 12 years, Astill et al[1] reported a correlation between reduced sleep quantity and decreased executive functioning and performance in school and on cognitive tasks but not tasks assessing sustained attention and memory. Compared with fragmented sleep, Ferri et al[14] found uninterrupted sleep to be associated with positive effects on neurocognitive functioning. However, in healthy elderly patients, Saint Martin et al[41] showed subjective sleep quality and duration to not significantly affect subjective and objective cognitive performances.

From our brief review of the non-TBI literature, it appears a relationship exists between decreased sleep quantity and decreased neurocognitive functioning. Sleep differences, at least subjectively, also appear to have a correlation with an increased quantity of reported symptoms. By categorizing athletes into 3 groups based on self-reported sleep duration the night before neurocognitive testing, we hypothesized that athletes reporting the least amount of sleep before baseline testing would perform more poorly on neurocognitive testing and report more symptoms than either of the other 2 longer sleep duration groups.

MATERIALS AND METHODS

Institutional review board approval was obtained before beginning this study. We performed a retrospective, cross-sectional review of high school– and college-aged athletes in the greater middle Tennessee area who underwent preparticipatory neurocognitive testing at our concussion center.

Selection of Participants

Patients considered for inclusion in this study were those (1) aged 14 to 23 years at the time of neurocognitive testing, (2) participating in high school or collegiate athletics, and (3) having complete valid results of baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). Of note, participants who had invalid baseline neurocognitive test scores, defined operationally as an ImPACT Impulse Control Composite score of >30, were excluded from the study.[43] This rule of invalidity was employed because athletes in this study took the desktop version of ImPACT.[29] Patients were excluded from this study for (1) a self-reported history of concussions; (2) failing to specify a nonzero sleep duration the night before ImPACT; (3) a self-reported history of receiving special education or speech therapy; (4) a self-reported history of a learning disability, ADHD, dyslexia, autistic spectrum disorder, or having repeated a year of school; (5) the self-reported use of stimulants or atomoxetine for the treatment of ADHD; (6) a self-reported history of prior brain surgery or seizure disorder; (7) a self-reported history of treatment for drug/alcohol abuse or psychiatric illness; and (8) the self-reported use of antipsychotics, antiepileptics, benzodiazepines, antidepressants, zolpidem, pseudoephedrine, opiates, diphenhydramine, or melatonin. The use of all other nonpsychiatric and other over-the-counter medications was allowed.

Categorization of Participants

Seven thousand and six hundred sixty-nine patients underwent group baseline testing through local concussion centers from August 2007 to March 2012, of which 7409 were considered age eligible. One hundred fifty and 110 patients were <14 and ≥23 years old at the time of testing, respectively, and were thus excluded from this study. Age-eligible patients ≥14 and <18 years old were categorized as high school aged, and those ≥18 but <23 years were classified as college aged. Five hundred six patients were excluded for a positive history of having sustained a concussion, and 13 were excluded for an invalid Impulse Control Composite score. After applying the remainder of this study's exclusion criteria (Figure 1), a total of 3686 athletes

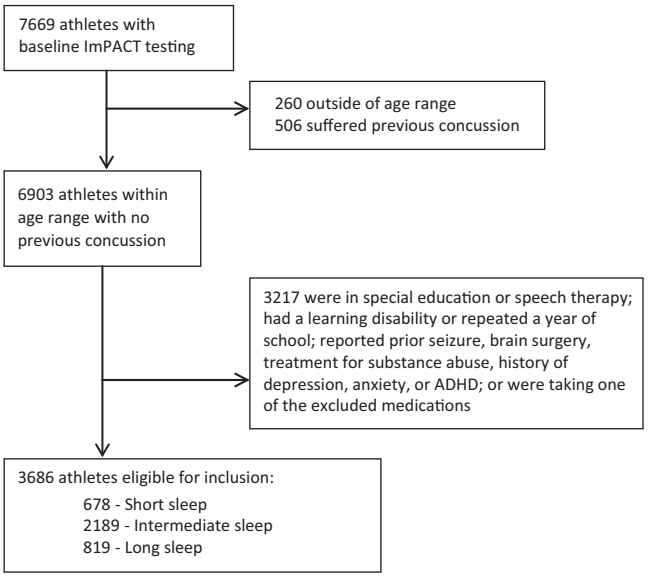

Figure 1. Participant screening and exclusion of ineligible athletes.

were eligible for inclusion. Three thousand and three hundred five were high school aged, and the remaining 381 were college aged. Eligible patients were then assigned to 1 of 3 groups based on self-reported sleep duration the night before the administration of ImPACT. Patients reporting <7 hours of sleep were assigned to the "short" duration group, those reporting ≥9 hours were assigned to the "long" group, and the "intermediate" group included all those reporting ≥7 but <9 hours of sleep.

Data Collection

After obtaining informed consent from the athlete or his/her guardian, ImPACT was administered for baseline purposes primarily in group settings and always under the supervision of a health care provider trained in the administration of the test. ImPACT[32] is a computer-based testing modality that provides demographic information, patient-reported concussion symptoms (Post-Concussion Symptom Scale [PCSS]), and neurocognitive performance data. The PCSS is an inventory of 22 patient-reported concussion symptoms with severity measured on a 7-point (range, 0-6) Likert scale. In the same manner as previous studies,[25,27] this study tabulated a score for the total number of reported symptoms and also grouped each symptom into 1 of 4 symptom clusters: somatic (eg, headache, nausea, balance problems, dizziness), cognitive (eg, fatigue, drowsiness, sleeping more than usual), emotional (eg, irritability, sadness, nervousness), and sleep (ie, sleeping less than usual, trouble sleeping). The 4 neurocognitive tests in ImPACT measure immediate and delayed verbal learning and recognition memory, immediate and delayed visual learning and recognition memory, visual-motor processing speed, reaction time, and attention. ImPACT generates 4 composite scores for the areas of verbal memory, visual memory, visual-motor (processing) speed, and reaction time. The Impulse Control Composite score is a validity check for integrity of the test data. For the assessment of SRCs, the reliability[12,22,30,42] and validity[21,23,44] of ImPACT have been demonstrated in previous studies.

Statistical Analysis

Continuous variables are reported as means ± standard deviations; frequencies for categorical variables are reported as percentages. Baseline mean values of ImPACT scores, total symptoms, and symptoms by cluster were initially compared across the 3 sleep duration groups. None of the participants included in the final analyses had any missing data. Statistical analyses were performed using SPSS (SPSS Inc, Chicago, Illinois) with statistical significance evaluated at $\alpha = .05$.

A multivariate analysis of covariance (MANCOVA) was conducted to quantify the influence of the 3 sleep duration groups (ie, short, intermediate, and long) on neurocognition, and a subsequent review of a series of ANCOVAs assessed the influence of sleep duration on the 4 neurocognitive scores (ie, verbal memory, visual memory, visual-motor [processing] speed, and reaction time). Because symptom clusters are derived components from the PCSS, a MANCOVA model including both total symptoms and each of the 4 symptom clusters would introduce redundancy into the model. Thus, the influence of sleep on self-reported symptoms in the PCSS was assessed initially with a univariate ANCOVA. This was followed by a MANCOVA incorporating each of the symptom clusters (ie, somatic, cognitive, emotional, and sleep), which underwent a subsequent review as a series of univariate ANCOVAs. Age and sex were considered covariates in all of these analyses.

Follow-up pairwise comparisons were utilized for each of the ImPACT scores and self-reported symptom clusters that were found to be significant in the review of the series of ANCOVAs. A Bonferroni correction was made for the multiple pairwise comparisons of the 3 sleep groups, and an adjusted α level was utilized to evaluate significance ($\alpha' = .05/3 = .017$). These pairwise evaluations aimed to identify which sleep group comparison(s) contributed most to the overall level of significance for each dependent variable.

RESULTS

Our study included 3686 nonconcussed athletes, of which 3305 (89.7%) were of high school age and 2371 (64.3%) were male. Categorized by self-reported sleep duration, 2189 age-eligible athletes (59.4%) slept an intermediate length (7-9 hours), 819 (22.2%) slept a long duration (≥9 hours), and 678 (18.4%) slept a short duration (<7 hours) (Table 1). Table 2 summarizes the frequencies for each of the sleep duration groups based on age and sex.

Stratified by sleep group, Table 3 features a summary of mean values for ImPACT performance and self-reported symptoms. The short duration sleep group slept a mean of 5.8 hours (median, 6.0 hours), the intermediate group

TABLE 1
Age and Sleep Demographics

	Total, n	Short (<7 h), n (%)	Intermediate (7-9 h), n (%)	Long (≥9 h), n (%)
High school age, y				
14	976	124 (12.7)	532 (54.5)	320 (32.8)
15	1011	155 (15.3)	637 (63.0)	219 (21.7)
16	727	149 (20.5)	441 (60.7)	137 (18.8)
17	591	140 (23.7)	361 (61.1)	90 (15.2)
College age, y				
18	208	59 (28.4)	116 (55.8)	33 (15.9)
19	65	13 (20.0)	43 (66.2)	9 (13.8)
20	47	15 (31.9)	26 (55.3)	6 (12.8)
21	49	19 (38.8)	25 (51.0)	5 (10.2)
22	12	4 (33.3)	8 (66.7)	0 (0.0)
Total	3686	678 (18.4)	2189 (59.4)	819 (22.2)

TABLE 2
Frequencies of Sleep Duration Groups

	Short (<7 h), n (%)	Intermediate (7-9 h), n (%)	Long (≥9 h), n (%)
Total	678 (18.4)	2189 (59.4)	819 (22.2)
High school			
Male	352 (16.5)	1247 (58.4)	536 (25.1)
Female	216 (18.5)	724 (61.9)	230 (19.7)
Total	568 (17.2)	1971 (59.6)	766 (23.2)
College			
Male	69 (29.2)	136 (57.6)	31 (13.1)
Female	41 (28.3)	82 (56.6)	22 (15.2)
Total	110 (28.9)	218 (57.2)	53 (13.9)

slept a mean of 7.7 hours (median, 7.5 hours), and the long group slept a mean of 9.7 hours (median, 9.5 hours). The MANCOVA revealed a statistically significant difference between neurocognition and sleep duration (Wilks $\lambda = .995$; $F_{8,7356} = 2.18$; $P < .001$). Separate consideration of the ANCOVA for each dependent variable revealed significant differences for each ImPACT score except visual-motor (processing) speed: verbal memory ($F_{2,3681} = 3.58$; $P = .028$), visual memory ($F_{2,3681} = 3.86$; $P = .021$), and reaction time ($F_{2,3681} = 3.78$; $P = .023$).

Regarding self-reported symptoms, a univariate ANCOVA revealed differences in sleep duration having a significant effect on the quantity of total symptoms reported ($F_{2,3681} = 40.79$; $P < .0001$). The 4 symptom clusters, assessed in a subsequent MANCOVA, revealed an overall significant difference between sleep duration and symptom frequencies (Wilks $\lambda = .947$; $F_{8,7356} = 25.60$; $P < .0001$). Each of the 4 clusters demonstrated statistical significance once the univariate ANCOVA for each cluster was considered: somatic ($F_{2,3681} = 11.49$; $P < .0001$), cognitive ($F_{2,3681} = 19.73$; $P < .0001$), emotional ($F_{2,3681} = 20.27$; $P < .0001$), and sleep ($F_{2,3681} = 99.82$; $P < .0001$).

Because sleep duration contributed to statistically significant differences upon separate consideration of several ANCOVAs (total number of symptoms, each of the 4 symptom clusters, and 3 of the 4 ImPACT scores), we performed pairwise comparisons with a Bonferroni adjustment to identify which between-group difference(s) contributed to overall statistical significance. A significant pairwise difference between the short and intermediate sleep groups' performance was noted for both verbal memory ($P = .025$) and reaction time ($P = .020$). Pairwise comparisons of both (1) short and intermediate ($P = .027$) and (2) short and long ($P = .046$) sleep groups' visual memory performance were found to be significant. These same 2 pairwise comparisons were also significant, each at a significance level of $P < .0001$, for total symptoms and the somatic, cognitive, and emotional clusters. Only the sleep symptom cluster had significant differences for each of the 3 pairwise comparisons ($P < .001$): (1) short and intermediate, (2) short and long, and (3) intermediate and long groups.

DISCUSSION

Because postconcussive clinical management monitors for a return to baseline symptoms and neurocognition, we aimed to investigate the influence of sleep quantity on these baseline metrics in nonconcussed high school and collegiate athletes by comparing baseline self-reported symptoms and neurocognitive performance on ImPACT across 3 distinct groups defined by sleep duration the night before testing. Our results showed that athletes sleeping fewer than 7 hours performed significantly worse on 3 of the 4 ImPACT composite scores and were significantly more symptomatic regarding total symptoms on the PCSS.

Aside from pubertal alterations of sleep/wake patterns, the demands of work, school, socializing, and sport can potentially foster inconsistent sleep schedules, resulting in insufficient sleep duration.[4,5,50] Wolfson and Carskadon[51] reported that high school students sleep an average of 7.5 to 8 hours per night, and a recent survey of 1125 college students found this population to sleep an average of 7 hours per night.[31] Many have shown total sleep deprivation to result in neurocognitive performance deficits[19,24,26]; however, considerably less has been published on the effects of partial sleep deprivation or chronic partial sleep

TABLE 3
ImPACT Scores and Self-reported Symptoms Based on Sleep Duration[a]

	Short (n = 678)	Intermediate (n = 2189)	Long (n = 819)	*P* Value
ImPACT				
Verbal memory[b]	84.301 ± 10.763	85.260 ± 10.381	84.774 ± 10.557	.028
Visual memory[c]	73.304 ± 13.577	74.512 ± 12.871	74.331 ± 13.346	.021
Visual-motor processing	37.821 ± 6.938	37.606 ± 6.743	37.216 ± 6.770	.226
Reaction time[b]	0.608 ± 0.092	0.601 ± 0.085	0.606 ± 0.085	.023
Total concussion symptoms[c]	5.134 ± 8.951	2.695 ± 6.012	2.245 ± 5.740	<.0001
Symptom clusters				
Somatic[c]	1.155 ± 2.702	0.691 ± 2.096	0.702 ± 2.377	<.0001
Cognitive[c]	1.562 ± 3.403	0.894 ± 2.332	0.805 ± 2.303	<.0001
Emotional[c]	1.087 ± 2.687	0.584 ± 1.718	0.477 ± 1.633	<.0001
Sleep[d]	1.330 ± 2.257	0.525 ± 1.313	0.261 ± 0.925	<.0001

[a]Values are expressed as mean ± standard deviation. ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.
[b]Short and intermediate sleep durations.
[c]Short and intermediate; short and long sleep durations.
[d]Short and intermediate; short and long; intermediate and long sleep durations.

restriction,[19] and it is clinically more realistic to consider the effects of partial sleep restriction.

Relative to previous sleep literature, our study does present several distinguishing features, notably a study population predominantly composed of high school athletes, making it one of the largest studies to investigate sleep in adolescents. Furthermore, while most studies of neurocognitive performance and sleep involve a highly controlled setting, this study was able to validate established sleep research in a real-world environment and is the first to demonstrate an effect of shorter sleep duration on baseline self-reported symptoms and neurocognitive testing for SRCs.

Although no studies have examined the effect of restricted sleep on baseline neurocognitive testing in the management of SRCs, controlled studies in the sleep literature on partial sleep deprivation in healthy patients have demonstrated poorer neurocognitive performance, including slower reaction times and an increased number of lapses on psychomotor vigilance testing along with reduced working memory speed and accuracy, with as much as 7 hours of sleep per night.[2,11,48] For comparison, athletes in our study who slept <7 hours the night before ImPACT (short sleep duration group) had significantly slower reaction time scores and poorer visual memory and verbal memory performances. The best mean reaction time score in our study was seen in athletes sleeping 7 to 9 hours per night, and athletes sleeping <7 hours per night had slower reaction times than those sleeping ≥9 hours per night.

While it should not be surprising that athletes in our study obtaining less sleep report more sleep cluster symptoms, the significant inverse relationship between total sleep time and the number of symptoms in the other 3 symptom clusters is striking. Although evidence associating self-reported symptoms and sleep loss has historically been demonstrated in sleep disorder populations (eg, insomnia, narcolepsy, sleep apnea), previous literature does suggest an association between chronic partial sleep loss and symptoms such as heightened anxiety, depression, fatigue, and increased sleepiness.[36,48] In adolescents and young adults, a small number of population-based studies have shown a significant correlation between chronically reduced sleep and symptoms of depression, anxiety, and somatic pain.[16,37,40] As previously mentioned, the many demands of student-athletes may perpetuate chronically restricted sleep schedules. Thus, it is relevant to consider sleep duration, especially in the setting of chronic sleep loss, as a potential modifier of baseline testing because many of these symptoms are featured in the self-reporting symptom inventory (PCSS) administered in ImPACT. Although the literature shows chronic sleep restriction to consistently result in neurocognitive deficits, many of these findings should be considered in the context of evidence that between-patient differences exist for baseline sleep duration needs.[47]

Specifically, in the SRC literature, a recent study by Covassin et al[8] on depression and baseline symptoms reported that high school athletes reported more somatic cluster symptoms, whereas collegiate athletes reported more emotional and sleep cluster symptoms. Although not published here, a review of our data set stratified by age revealed consistent findings. In our study, after controlling for age and sex, as sleep duration decreased across our study's 3 sleep groups, we noted increased self-reported results for total concussion symptoms and each symptom cluster except somatic. Although self-reported results for total symptoms and each cluster differed significantly across sleep groups, for the somatic cluster, self-reporting was not sleep duration dependent, as athletes in our intermediate group reported the fewest somatic symptoms.

All of this begs the question: are our athletes sleeping enough? Whether adolescents and college students are truly sleeping more or less than prior generations is controversial[33]; however, the prevalence of both erratic sleep schedules and decremental progression in total sleep time as youth proceed from childhood to college is more well established.[37] Considering this in light of our findings that sleep may be a modifying factor for baseline testing, we present our results as a relevant contribution to the growing literature on concussion management in high school and

collegiate athletes. A modifying factor that alters an athlete's baseline neurocognitive performance has potential to confound the interpretation of post-SRC ImPACT, further complicating safe and timely RTP decisions.

Considering the single modifying factor of sleep, one can postulate scenarios where RTP decisions are complicated by perceived differences in baseline and postconcussive sleep durations. For example, postconcussive athletes often report more sleep symptoms and longer sleep durations compared with their recorded baseline levels,[38,39] particularly when rest is recommended as a first-line therapy. Interestingly, as originally categorized by Lau et al,[27] reporting "sleeping more" versus "less than usual" on the PCSS falls into different symptomatic clusters: cognitive and sleep, respectively. Sleep symptoms, such as longer sleep onset latency, difficulty maintaining sleep, and increased daytime sleepiness, are some of the most common sleep disturbances that persist after mild TBIs[38,39]; however, despite such a high incidence, objective sleep changes have been less of an investigative interest and are often limited by patient numbers. Only Schreiber et al[45] have been able to show that patients sustaining mild TBIs sleep significantly less than controls. Over a postconcussive range of 1 to 11 days, Gosselin et al[20] compared polysomnographic results for 10 concussed athletes versus 11 nonconcussed controls and reported that both groups sleep an average of 7.5 hours. Regarding sleep as a potential modifying factor on baseline neurocognitive testing, these complicated clinical scenarios highlight the importance of employing a multifaceted approach when making RTP decisions.

A similar example is seen with sex, which has been heavily investigated in SRCs[3,6,9,52] and found to be a modifying factor on baseline neurocognitive scores.[10,49] In the college-aged population, when compared with male patients who perform better on visual memory tasks, female patients have been shown to perform better on verbal memory tasks and report more symptoms of headache, fatigue, sleep difficulty, irritability, sadness, nervousness, and difficulty concentrating.[10,49] Thus, sex has been shown to be a modifying factor in neurocognitive testing before any reported trauma, rendering its inclusion as a modifying factor relevant for accurate post-SRC evaluation when interpreting symptoms and neurocognition.

We similarly endeavored to determine the influence of prior night's sleep duration on baseline neurocognitive performance and subsequently found it to modify neurocognitive performance and symptom reporting. Because a multifaceted approach when making RTP decisions is, in part, based on the athlete's return to symptomatic and neurocognitive baseline levels, it is imperative that these statistical differences translate to clinical significance as well. Certainly, statistically significant differences in symptom self-reporting will be helpful to clinicians making RTP decisions. With further investigation and validation, the effect of sleep duration on baseline ImPACT performance may become a more integral consideration when evaluating athletes before and after concussions. In light of our findings, clinicians will invariably encounter management decisions for a subset of concussed athletes who report a considerable number of postconcussion symptoms but also slept fewer than 7 hours before baseline testing. Athletes in this scenario are not afforded sleep-adjusted symptom inventories and ImPACT scores; therefore, we recommend clinicians rely on expertise derived from experience as well as following the athlete's temporal progression and improvement. Pertinent to this scenario specifically and to continue improving post-SRC management, health care providers can incorporate this study's findings by recommending that athletes sleep a specified duration the night before neurocognitive testing. By standardizing this potential modifying factor, variation in the baseline neurocognitive assessment before the start of the sporting season can be minimized or negated.

Our findings should be interpreted in light of the study limitations. First, our study was retrospective. Second, we relied solely on athletes' self-report of the prior night's sleep quantity, which does not include the athlete's assessment of sleep quality, and although self-reported durations are commonly utilized in the literature, the majority of the sleep literature is methodologically based on sleep durations recorded over several consecutive nights.[22,39] Therefore, future studies should consider including multiple nights' sleep as a weighted average, or preferably consecutive nights' sleep, to more accurately reflect sleep durations, and athletes' self-report of consecutive nights' sleep durations would be a useful addition to future modifications of the ImPACT software. Also, independent confirmation of self-reported total sleep duration was not available. Third, history of concussions and medication use was also based on self-reporting, without independent confirmation. Fourth, all study participants hailed from a specific region of the country and may not be generalizable to other regions; thus, our results warrant cross-validation in other areas of the country and the world. The limitations of our study do, however, provide new areas of investigation for future research.

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