Relationship Between Short Sleep Duration and Preseason Concussion Testing

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Objective: Baseline, preseason assessment of cognition, symptoms, and balance has been recommended as part of a comprehensive sport concussion management program. We examined the relationship between sleep and baseline test results. We hypothesized that adolescents who slept fewer hours the night before would report more symptoms and perform more poorly on cognitive testing than students who had a full night sleep.

Design: Cross-sectional observation study.

Setting: Preseason concussion testing for high school athletes.

Participants: A large sample (n = 2928) of student athletes from Maine, USA, between the ages of 13 and 18 years completed preseason testing. Participants with developmental problems, a history of treatment for neurological or psychiatric problems, recent concussion, or 3 or more prior concussions were excluded.

Assessment of Risk Factors: Athletes were divided into 4 groups based on their sleep duration the night before testing.

Main Outcome Measures: Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; ImPACT Applications, Inc, Pittsburgh, PA) cognitive composite scores and the embedded Post-Concussion Symptom Scale.

Results: Sleep was not related to any ImPACT cognitive composite score, after covarying for age and controlling for multiple comparisons. In contrast, there were sleep duration, sex, and sleep duration by sex effects on the Post-Concussion Symptom Scale. The effect of sleep duration on symptom reporting was more pronounced in girls. Supplementary analyses suggested that sleep insufficiency was associated with a diverse array of postconcussion-like symptoms.

Conclusions: Poor sleep the night before baseline or postinjury testing may be an important confound when assessing postconcussion symptoms. Girls may be more vulnerable to experiencing and reporting symptoms following insufficient sleep.

Clinical Relevance: Clinicians should routinely ask how the athlete slept the night before preseason baseline testing and consider deferring the symptom assessment or later retesting athletes who slept poorly.

Key Words: sleep deprivation, sleep initiation and maintenance disorders, cognition, athletes, brain concussion

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INTRODUCTION

Baseline, preseason assessment of cognition, symptoms, and balance is sometimes used as part of a comprehensive sport concussion management program. Having a reliable and accurate estimate of athletes' preinjury functioning provides a useful reference and comparison point for postinjury assessments. However, both dispositional and situational factors are associated with baseline test results. For example, girls report more baseline symptoms than boys,[1–3] and student athletes with clinical conditions such as attention-deficit hyperactivity disorder (ADHD) or depression report more symptoms and perform more poorly on cognitive testing.[2,4–6] Students tested in group settings obtain lower scores on cognitive testing than students tested individually.[7] And, athletes with a history of ankle injuries perform more poorly on balance testing than athletes without this injury history.[8] Therefore, it is important to conduct research on a diverse

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range of both dispositional and situational factors that can influence baseline test results.

There is considerable evidence indicating that sleep deprivation can have adverse effects on objectively measured cognitive functioning.[9–13] Researchers have reported that sleep deprivation is associated with subjective symptoms,[12,14,15] such as decreased vigor,[16] stress,[17] anger,[17] aggression,[18] fatigue,[16,17,19] irritability,[20] anxiety,[17,21] depression,[17] headaches,[22–24] and cognitive difficulty.[19,25–29] Most of this evidence comes from experimental studies that deprive healthy people of sleep for 24 or more hours, or restrict sleep over a longer period (eg, 1 week). Observational studies that recruited people with short sleep duration as measured by retrospective self-report also contribute to this literature. Sleeping less than 5 hours has an adverse effect on cognitive functioning in some studies.[12,26–29] A recent meta-analysis in school-aged children found that sleep duration was associated with worse cognitive performance and emotional and behavioral problems.[30] The significant heterogeneity between studies was not accounted for by variation in design (naturally occurring insomnia vs imposed sleep restriction) or the number of nights of short sleep duration.

Two recently published studies have addressed the relationship between a poor night sleep and baseline test results.[31,32] In a sample of college student athletes, short sleep duration the night before baseline testing was associated with greater symptom reporting the next day. Sleep duration was not, however, associated with an adverse effect on cognitive testing or balance testing.[31] McClure et al[32] examined the association of sleep duration with baseline symptom reporting in 3686 student athletes who underwent baseline testing with Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT; ImPACT Applications, Inc, Pittsburgh, PA). The students were stratified into 3 groups based on self-reported sleep duration the night before testing: (1) <7 hours, (2) 7 to 8 hours, and (3) ≥ 9 hours. The authors reported that the students who slept fewer than 7 hours the night before performed more poorly on 3 of 4 of the ImPACT cognitive composite scores, and they reported more subjectively experienced symptoms. Given their very large sample sizes, tiny differences between groups on the cognitive testing were statistically significantly (ie, $P < 0.05$). However, the differences between groups were so small that they may have no practical or clinical significance (we computed all Cohen effect sizes as less than 0.10). For example, using an IQ score metric, the differences between groups were 1.5 points or less, and using a T-score metric, the differences between groups were 1 point or less.

Based on the 2 studies reviewed above, we conclude that student athletes who report fewer hours of sleep the night before testing will endorse more subjectively experienced symptoms. There does not, however, seem to be a conclusive effect on cognitive functioning based on how the first 2 studies were designed and analyzed. The present study further examines the relationship between sleep and baseline test results in a large cohort of adolescent student athletes. Similar to the results of 2 previous studies,[31,32] we hypothesized that adolescents who slept 5 or fewer hours the night before baseline testing would report more symptoms the following day. We also hypothesized that those with insufficient sleep would score lower on at least 1 cognitive composite score than students who slept 8 or more hours, but that the effect size would be small.

METHODS

Participants

Participants in this cross-sectional, descriptive, cohort study were 2928 adolescent student athletes from Maine, USA, between the ages of 13 and 18 years (mean = 15.7 years, SD = 1.3 years), who completed baseline preseason testing with ImPACT in 2010. There were 1569 boys (53.6%) and 1359 girls (46.4%) who completed a demographics and history questionnaire embedded in the ImPACT program and met none of the following exclusion criteria based on self-report: (1) concussion within the past 6 months, (2) lifetime history of 3 or more concussions, (3) diagnosis of learning disability or ADHD, (4) received special education services, (5) repeated 1 or more years of school, or (6) treatment for a neurological disorder (including headache and migraine) or psychiatric condition. Almost all (94.9%) learned English as their first language. A minority had 1 (n = 314; 10.7%) or 2 (n = 82; 2.8%) prior concussions by self-report, occurring on average 3.2 (SD = 3.3) years before. The information regarding sleep is based on self-report. Athletes were simply asked to estimate the number of hours that they slept the night before. Half-hour increments were allowed. A visual inspection of the data (with box plots and histograms) identified 2 outliers on the sleep duration variable. These 2 participants ($<0.1\%$ of the sample), who reported 19.0 and 22.5 hours of sleep, respectively, were not included in the analyses. For analyses involving the ImPACT cognition composites, 2 additional exclusion criteria were applied (invalid ImPACT and first language other than English), resulting in n = 2627 remaining. Institutional review board (IRB) approval to create this de-identified database was obtained from Colby College, and IRB approval for analyses was also obtained from Spaulding Rehabilitation Hospital.

ImPACT

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT Applications, Inc) is a brief computer-administered neuropsychological test battery that consists of 6 individual test modules and produces 5 cognition composite scores: Verbal Memory, Visual Memory, Reaction Time, Processing Speed, and Impulse Control. In addition to the cognitive measures, ImPACT contains a Post-Concussion Symptom Scale that consists of 22 commonly reported symptoms (eg, headache, dizziness, "fogginess"). The dependent measure is the total score derived from this 21-item scale.

Analysis

The present study involved a retrospective analysis of an existing database. The number of hours slept was categorized into 4 levels: 5 or less (n = 66), 5.5 to 6.5 (n = 375), 7 to 8.5 (n = 1848), and 9 or more (n = 639). We

categorized this continuous variable to enhance interpretability and clinical application, to facilitate comparison with previous studies, and because the relationship between sleep duration and cognition may not be linear. The third category (7-8.5 hours) corresponds to the interquartile range in the sample. We then formed a long sleep group (9 or more) and 2 distinct short sleep groups (5 or less, 5.5-6.5) to study the graded impact of insufficient sleep. Dividing participants with less than 7 hours of sleep into subgroups might be important because some previous studies only illustrated performance decrements when participants sleep very little (eg, less than 5 or 4 hours).[26,27]

A series of analyses of covariance (ANCOVAs) were conducted for each ImPACT cognition composite score, using the categorized sleep duration variable and sex as fixed factors and age as a covariate. Sex was a key variable of interest because previous research indicates that girls report more postconcussion-like symptoms than boys on preseason testing,[1] and sleep may differentially impact boys and girls. To control for family-wise type I error, we adopted a Bonferroni-corrected alpha of 0.01 (ie, 0.5/5 for 5 composite scores). An ANCOVA with the same fixed factors and covariate was run for the Post-Concussion Symptom Scale. We chose this statistical test despite unequal error variances [$F(7,2920) = 28.59$, $P < 0.001$ for Levene test] and sample sizes to parallel the analyses of the ImPACT cognition composite scores. As a result of these ANCOVA assumption violations, the effect size metrics (Cohen *d*) should be given interpretative weight over the *F* and *P* values. Of note, reanalyzing the Post-Concussion Symptom Scale data with nonparametric methods produced the same pattern of results.

RESULTS

Comparisons between the sleep duration groups on the ImPACT cognition composites are presented in Table 1. Note that each of these ANCOVAs produced no significant main effects for sleep duration or sex and no sleep duration by sex interactions. When the Post-Concussion Symptom Scale was considered as the dependent variable, there were sleep duration and sex main effects as well as a sleep duration by sex interaction, that is, (1) participants who slept less reported more symptoms, (2) girls reported more symptoms than boys, and (3) sex differences were not equivalent across the sleep duration groups. The Figure and Table 2 display these findings. Girls tended to have more pronounced symptoms with less sleep, although both boys and girls with severe sleep insufficiency (5 or fewer hours) reported more symptoms (Cohen $d = 0.74$ and 0.81, respectively, vs average sleep duration). To contrast the most extreme group differences, girls who slept very little (5 or fewer hours) had 3.4 to 4.1 times higher scores on the Post-Concussion Symptom Scale than boys who slept at least 7 hours.

The Post-Concussion Symptom Scale includes 5 items that relate to sleep, fatigue, and drowsiness. To ensure that the relationship between sleep duration and symptoms was not entirely attributable to sleep-related item content, supplementary analyses using a modified version of the Post-Concussion

TABLE 1. Results of Analysis of Covariance

Dependent Variable	Sleep Group	Sleep Group, Mean (SD)	Effect	*F*	*df*	*P*	Partial eta
Verbal memory	≤5	84.69 (10.03)	Sleep duration	0.61	3	0.61	<0.005
	5.5-6.5	85.57 (9.68)	Gender	1.38	1	0.24	<0.005
	7-8.5	85.52 (9.25)	Sleep duration × gender	0.90	3	0.44	<0.005
	≥9	85.12 (8.86)					
Visual memory	≤5	70.41 (12.81)	Sleep duration	1.11	3	0.34	<0.005
	5.5-6.5	72.45 (12.65)	Gender	1.30	1	0.25	<0.005
	7-8.5	73.27 (12.53)	Sleep duration × gender	0.90	3	0.44	<0.005
	≥9	72.95 (12.97)					
Processing speed	≤5	37.14 (6.61)	Sleep duration	1.06	3	0.36	<0.005
	5.5-6.5	36.76 (7.17)	Gender	2.33	1	0.13	<0.005
	7-8.5	36.77 (7.10)	Sleep duration × gender	0.13	3	0.94	<0.005
	≥9	36.26 (6.96)					
Reaction time	≤5	0.60 (0.07)	Sleep duration	1.17	3	0.32	<0.005
	5.5-6.5	0.59 (0.08)	Gender	0.06	1	0.81	<0.005
	7-8.5	0.59 (0.08)	Sleep duration × gender	2.18	3	0.09	<0.005
	≥9	0.60 (0.09)					
Impulse control	≤5	6.97 (5.81)	Sleep duration	1.77	3	0.15	<0.005
	5.5-6.5	7.12 (4.72)	Gender	0.52	1	0.47	<0.005
	7-8.5	7.42 (5.07)	Sleep duration × gender	0.59	3	0.62	<0.005
	≥9	7.13 (4.77)					
Total symptoms	≤5	10.67 (10.15)	Sleep duration	44.43	3	<0.001	0.04
	5.5-6.5	6.86 (8.13)	Gender	39.93	1	<0.001	0.01
	7-8.5	3.69 (5.99)	Sleep duration × gender	6.19	3	<0.001	0.01
	≥9	3.96 (7.69)					

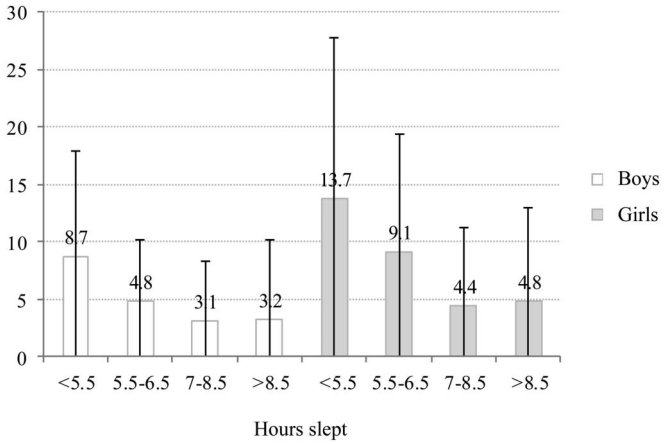

FIGURE. Post-Concussion Symptom Scale total scores stratified by sex and hours of sleep. Note: The bars represent mean scores and the error lines show 1 SD. A substantial minority of each group obtain total scores above the error lines (ie, 26.0%-41.4%, due to non-normal distributions).

Symptom Scale that omits these 5 items were conducted. The 17-item modified scale has comparable internal consistency (Cronbach alpha = 0.82) to the full scale (Cronbach alpha = 0.85). An ANCOVA using this modified symptom scale similarly yielded a sleep duration main effect [$F(3,2919) = 14.8$, $P < 0.001$], sex main effect [$F(1,2919) = 38.69$, $P < 0.001$], and sleep duration by sex interaction [$F(3,2919) = 6.0$, $P < 0.001$]. Examination of the effect size differences (Table 2) highlights that the association between sleep duration, and the Post-Concussion Symptom Scale was attenuated but not eliminated by excluding the sleep-related items. Sex differences with mild sleep insufficiency are even more noticeable. For boys, sleeping somewhat less (5.5-6.5 hours) had little impact on symptom reporting (Cohen $d = 0.10$) comparable to sleeping more (9 or more hours; Cohen $d = 0.08$). Mild sleep insufficiency (5.5-6.5 hours) was more strongly associated with higher symptom reporting in girls (Cohen $d = 0.41$ vs average sleep duration).

The frequency of endorsing specific symptoms (ie, item score ≥ 1), stratified by sex and sleep duration, are presented in Table 3. Note that items related to insomnia and fatigue are most commonly endorsed by all participants, and as expected, even more common in participants who reported sleeping less the night before testing. Importantly, several other symptoms (eg, sensitivity to light, irritability, and mental fogginess) tracked in the same direction. They are endorsed at a rate 2 to 4 times higher in the groups sleeping the least (5 or fewer hours) relative to the groups sleeping an average amount (7-8.5 hours). Other symptoms (eg, vomiting, vision problems, numbness/tingling), however, are endorsed at very low rates and vary little with sleep.

DISCUSSION

Healthy adolescent athletes with insufficient sleep the night before baseline preseason testing reported more postconcussion-like symptoms but demonstrated normal cognition on ImPACT testing, similar to a previous study.[31] The present study also found that insufficient sleep was associated not only with increased endorsement of sleep and fatigue-related items on a postconcussion symptom inventory (Post-Concussion Symptom Scale) but also elevated rates of other

TABLE 2. Descriptive Statistics and Effect Sizes for the Post-Concussion Symptom Scale

Composite Score	Sleep Duration Group	Median	Mean	SD	IQR	Cohen *d*†
Total symptom score						
Boys	≤5	6.0	8.68	9.24	0.5-15.0	0.74
	5.5-6.5	3.0	4.76	5.26	0.0-7.0	0.32
	7-8.5	1.0	3.11	5.18	0.0-4.0	—†
	≥9	0.0	3.22	7.03	0.0-4.0	0.02
Girls	≤5	7.0	13.72	14.09	2.5-24.5	0.84
	5.5-6.5	5.5	9.05	10.31	1.0-13.0	0.53
	7-8.5	2.0	4.43	6.77	0.0-6.0	—†
	≥9	2.0	4.79	8.22	0.0-5.0	0.05
Modified symptom score*						
Boys	≤5	1.0	3.62	5.29	0.0-5.0	0.45
	5.5-6.5	0.0	1.95	3.07	0.0-3.0	0.10
	7-8.5	0.0	1.64	3.31	0.0-2.0	—†
	≥9	0.0	1.98	5.13	0.0-2.0	0.08
Girls	≤5	3.0	6.66	9.08	0.0-12.0	0.57
	5.5-6.5	2.0	4.95	6.73	0.0-7.0	0.41
	7-8.5	1.0	2.56	4.72	0.0-3.0	—†
	≥9	1.0	3.07	5.50	0.0-3.5	0.10

*Total symptom score, excluding the 5 items that relate to sleep, fatigue, and drowsiness.
†The average sleep duration (7-8.5) group was used to contrast the other groups.
IQR, interquartile range.

TABLE 3. Individual Symptom Reporting by Gender and Hours Slept

	Boys				Girls			
Self-reported Symptoms	**≤5 h**	**5.5-6.5 h**	**7-8.5 h**	**≥9 h**	**≤5 h**	**5.5-6.5 h**	**7-8.5 h**	**≥9 h**
Headache	24.3%	17.4%	13.5%	13.0%	27.6%	33.3%	18.8%	25.5%
Nausea	5.4%	7.2%	3.6%	4.6%	3.5%	9.4%	4.3%	6.0%
Vomiting	2.7%	0.5%	0.8%	1.2%	0.0%	1.1%	0.8%	1.3%
Balance problems	2.7%	3.1%	2.7%	3.7%	10.3%	8.9%	3.4%	3.2%
Dizziness	10.8%	7.7%	3.7%	5.0%	13.8%	15.6%	8.5%	9.8%
Fatigue	24.3%	34.4%	21.1%	18.5%	34.5%	39.4%	24.5%	26.0%
Trouble falling asleep	51.4%	25.6%	16.3%	15.2%	55.2%	39.4%	22.8%	20.3%
Sleeping more than usual	13.5%	5.1%	3.9%	5.9%	6.9%	7.2%	4.3%	6.7%
Sleeping less than usual	51.4%	40.5%	17.7%	9.0%	75.9%	48.9%	24.1%	11.7%
Drowsiness	32.4%	25.6%	18.2%	16.1%	44.8%	35.6%	20.0%	20.3%
Sensitivity to light	13.5%	4.1%	4.6%	4.6%	24.1%	11.7%	6.6%	8.2%
Sensitivity to noise	2.7%	4.1%	3.8%	4.0%	6.9%	7.8%	4.3%	3.8%
Irritability	18.9%	14.4%	9.3%	10.2%	33.3%	28.9%	15.8%	15.2%
Sadness	13.5%	6.2%	4.1%	4.6%	18.5%	18.9%	9.0%	10.4%
Nervousness	16.2%	8.7%	12.3%	14.2%	20.7%	23.3%	18.2%	21.8%
Feeling more emotional	13.5%	4.6%	4.9%	4.6%	37.9%	28.3%	16.7%	19.3%
Numbness or tingling	5.5%	1.5%	2.0%	3.4%	0.0%	3.9%	1.9%	3.5%
Feeling slowed down	18.9%	8.2%	6.0%	5.6%	20.7%	14.4%	7.1%	7.0%
Feeling mentally "foggy"	18.9%	5.1%	4.9%	4.3%	20.7%	12.8%	4.3%	5.7%
Difficulty concentrating	18.9%	14.4%	13.3%	13.0%	37.9%	30.6%	16.6%	13.9%
Difficulty remembering	18.9%	6.2%	5.6%	6.8%	17.2%	13.9%	7.4%	8.5%
Visual problems	2.7%	4.6%	3.2%	5.9%	0.0%	4.4%	5.4%	8.5%
"High" symptom reporting*	29.7%	8.7%	5.9%	5.0%	31.0%	13.3%	3.8%	6.0%

The percentages of students who endorsed the symptom as present is presented (ie, score of 1 or greater).

*High symptom reporting for boys: total score 13 or greater. High symptom reporting for girls: total score 21 or greater. Adapted from Lovell et al.[1] Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

symptoms, such as headaches, sensitivity to light, irritability, and mental fogginess. This is consistent with a large body of evidence that sleep deprivation, including a single night of short sleep duration, has wide-ranging effects on human performance and subjective well-being.[12,30] A number of neurophysiological processes (eg, hypothalamic–pituitary–adrenal axis activation) have been proposed to account for these effects.[30,33]

Another key finding was that higher symptom reporting associated with insufficient sleep was more pronounced in girls than in boys. Supplementary analyses suggested that mild sleep insufficiency (more than 5 but less than 7 hours) was associated with higher symptom reporting in girls only, whereas both girls and boys with severe sleep insufficiency (5 or less hours) reported high levels of postconcussion-like symptoms. There are several possible explanations for this sex difference. For example, girls may have a greater physiological need for sleep[34] or may be more aware of subtle changes in their physical well-being.[35] Sex differences in hormone secretion[36] and sleep schedule preference[37] may be contributory.

The strengths of this study include the large sample size and widely used outcome measures (ImPACT). There are also important limitations. Sleep duration was measured by a single self-report item, which may have been unreliable. However, it is an efficient way of assessing sleep duration that can very easily be replicated in the clinic. Considering individual differences in sleep patterns, it may also have been informative to ask athletes to rate their sleep the night before in relation to a "usual" night's sleep. We could not differentiate between a single night of poor sleep and chronic sleep insufficiency. The causes of poor sleep, such as a sudden change in daily schedule at the start of a school year, alcohol consumption, or other factors, were not measured in this study. We also did not collect information on prior sleep disorders or use of medications for sleep. Because of the correlational study design, we cannot conclude that poor sleep the night before caused postconcussion-like symptoms. They are, however, clearly associated. Sleep quality or the chronicity of sleep disturbance may also be important factors in postconcussion-like symptom reporting. To better understand the relationship between sleep and postconcussion-like symptoms, future research studies should take a comprehensive sleep history, screen for health conditions that can impact sleep (eg, depression) as well as medication and substance use, objectively measure sleep the night before assessment (eg, with polysomnography or wrist actigraphy), and reassess symptoms after sleep restoration.

The results of this study are important for clinicians who assess athletes for baseline preseason testing or following sport-related concussions. By routinely asking about sleep the night before testing, clinicians may be able to more accurately conceptualize factors related to increased symptom reporting after concussion and track postinjury symptom resolution. The present findings also suggest that clinicians should encourage

student athletes to get a good night sleep before preseason baseline testing, to decrease the likelihood that poor sleep will influence the symptom scale component of this assessment. Clinicians should consider deferring symptom assessment or later retesting student athletes who report sleeping poorly the night before their scheduled preseason baseline testing session. At the very least, poor sleep the night before baseline testing should be clearly documented so that clinicians can integrate this potential confound into their interpretation of a concussed athlete's test results.

There are also implications for future research. Studies involving baseline testing in athletes should control for the potential confound of insufficient sleep, at least for analyses involving postconcussion-like symptoms. Future research should also consider that poor sleep the night before testing might have an even more pronounced impact on the recently concussed athlete, potentially exacerbating and/or mimicking the lingering effects of a concussion. Athletes with other health conditions such as ADHD may also be more prone to negative consequences of disturbed sleep.[38] Athletes with preexisting neurological or psychiatric conditions were not included in the present study. Although sleep duration the night before testing did not relate to cognitive performance on ImPACT in the present study, it is quite possible that chronic sleep deprivation could result in measurable cognitive deficits.

In summary, healthy uninjured adolescents who slept poorly the night before reported significant postconcussion-like symptoms on preseason baseline testing. Although cause and effect cannot be determined, the present study highlights a relationship between insufficient sleep and a diverse range of postconcussion-like symptoms, especially in girls. Cognitive performance, at least as measured by ImPACT, may not vary depending on how long the athlete slept the night before testing. Future research is needed to identify if and how chronic sleep insufficiency impacts performance on preseason baseline testing and whether concussed athletes are more susceptible to the effects of sleep disturbance.

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