

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

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20 **Abstract**

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

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

33 **Results:** Clinically moderate-to-severe insomnia severity (RR = 3.13, 95% CI: 1.320-7.424, $p =$
34 0.015) and excessive daytime sleepiness two or more times per month (RR = 2.856, 95% CI:
35 0.681-11.977, $p = 0.037$) increased concussion risk. These variables remained significant and
36 comparable in magnitude in a multivariate model adjusted for sport participation.

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

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

46

47 **1. Introduction**

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

55 Prior research indicates that the risk of sustaining a sports-related concussion is anywhere from
56 1.75 to 11 times greater for those with a history of one or more prior concussions.⁷⁻¹¹ In one of
57 the largest retrospective studies to date ($n = 12,320$ participants), the odds of sustaining a
58 sports-related concussion was 10.65 times greater than for those with a history than those
59 without.⁸ Therefore, while the specific magnitude of this effect is not necessarily clear, it is
60 apparent that prior sports-related concussion is a predisposing factor.

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

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

72 (18-25 years), the populations in whom most sports-related concussion research is currently
73 conducted, obtain 8-10 or 7-9 hours of sleep per night respectively.²⁵ However, recent estimates
74 suggest that many individuals in these age categories, including athletes, do not obtain
75 sufficient nightly sleep.²⁶⁻²⁸ With respect to athletics, this is especially problematic. Chronic
76 under-sleeping, sleep restriction, and sleep deprivation are associated with, and can result in,
77 mental fatigue;^{29,30} attentional lapses;^{30,31} increased reaction time;^{29,32} impaired predictive visual
78 tracking;^{31,32} reduced postural and dynamic motor control;^{29,33} degraded intra- and inter-personal
79 emotion regulation, perception, and responsiveness³⁴; and increased impulsivity and risk-taking
80 behavior.³⁵⁻³⁷ Furthermore, sport performance indices – including cardiovascular,^{38,39}
81 endurance,³⁸ strength,^{40,41} and accuracy^{31,32} outcomes – are reduced or impaired under
82 inadequate or low quality sleeping conditions as well as daytime sleepiness or fatigue. Thus,
83 individuals with habitually poor sleep may be more likely to have degraded overall sport
84 performance, take more on-field risks, make poorer in-the-moment decisions, have less body
85 control to appropriately act and react to cues, as well as experience brief lapses in attention to,
86 and poor visual tracking of, in-game activities. These effects may reduce athletes' capacity to
87 avoid or minimize injury, including sports-related concussions.

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

95 **2. Methods**

96 **2.1 Participants**

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

105 **2.2 Questionnaires**

106 Individuals participating in the study completed a comprehensive battery of questionnaires. This
107 battery included demographic information (i.e., age, sex, sport, self-reported sports-related
108 concussion history) and validated self-report measures related to sleep including the Insomnia
109 Severity Index (ISI),⁴⁵ Pittsburgh Sleep Quality Index (PSQI),⁴⁶ and Fatigue Severity Scale
110 (FSS).⁴⁷ These are all standard screening measures used across a wide variety of populations.
111 Of note, the PSQI was scored using two different cutoff scores to identify poor quality sleep, ≥ 5
112 and ≥ 8 . This is because even though ≥ 5 is the standard cutoff for the PSQI⁴⁶, more recent work
113 has shown that ≥ 8 may be more appropriate for individuals following a traumatic brain injury.⁴⁸
114 The National Health and Nutrition Examination Survey's (NHANES) Sleep module was used to
115 assess daytime sleepiness with the item, "In the past month, how often did you feel excessively
116 or overly sleepy during the day?" Response options included Never, Rarely (1 time per month),
117 Sometimes (2-4 times per month), Often (5-15 times per month), or Almost Always (16-30 times
118 per month).⁴⁹

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

124 **2.3 Statistical Analyses**

125 *2.3.1 Primary analyses*

126 Individuals were grouped by sport-related concussion occurrence following the survey (0 = no
127 future sports-related concussion; 1 = one or more future sports-related concussions).

128 Demographic and self-reported sleep-related outcome scores (including total scores and
129 individual item scores) were analyzed using two sample Mann-Whitney *U* tests and Fisher's
130 exact tests as appropriate. All *p*-values for the ISI, PSQI, and FSS individual item scores were
131 Holm-adjusted within-questionnaire to control for multiple comparisons. We computed univariate
132 risk ratios for future incidence of a sports-related concussion to test our primary hypothesis.

133 Individual binary predictors included:

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

141 Additional univariate risk ratios were computed for prior history of sports-related concussion (1 =
142 any history of sports-related concussion), sex (1 = Male), and higher concussion prevalence
143 sport participation in our sample^{50,51} (1 = football, soccer, women's basketball; 0 = any other

144 sport). In order to identify independent sports-related concussion risk factors, a multiple logistic
145 regression model was fit using all statistically significant ($p < 0.05$) univariate predictors. An
146 automated forward-and-backward stepwise variable selection method simplified this model to
147 limit multi-collinearity between predictors.

148 2.3.2 Secondary analyses

149 To examine further the association between self-reported sleep outcomes and sports-related
150 concussion risk, two additional logistic multiple logistic regression models were fit. First, total
151 scores on the questionnaires exhibiting statistically significant between-group differences were
152 entered as continuous variables, with sport participation and sports-related concussion history
153 as additional covariates. The purpose of this model was to determine the association between
154 increasing total scores and sports-related concussion risk, rather than classification based on
155 dichotomized values. Second, to examine how individual elements of the questionnaires (e.g.,
156 nighttime insomnia items versus daytime impairment items on the ISI) may increase sports-
157 related concussion risk, individual sleep questionnaire item scores were entered into a logistic
158 regression model, along with NHANES sleepiness scores, sport participation, and sports-related
159 concussion history. To limit the number of individual items entered into the initial model,
160 candidate questionnaire items included only those that were statistically significant (adjusted $p <$
161 0.05) based on the two sample Mann-Whitney U tests. Both additional models utilized the
162 automated forward stepwise variable selection as before.

163 All statistical analyses were conducted in R (v. 3.5.0).⁵² Data wrangling and cleaning was
164 performed using functions from the dplyr,⁵³ tidyr,⁵⁴ stringr,⁵⁵ and lubridate⁵⁶ packages. Stepwise
165 variable selection was accomplished using the *stepAIC* function in the MASS package.⁵⁷ Plots
166 were created using the ggplot2 package.⁵⁸ Univariate relative risk and odds ratios were
167 computed using the *epiTab* function in the epitools package⁵⁹ with small sample adjustment.

168 **3. Results**

169 **3.1 Demographics**

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

179 < Insert Table 1 here >

180 < Insert Table 2 here >

181 < Insert Figure 1 here >

182 **3.2 Risk ratios**

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

190 < Insert Table 3 here >

191 **3.3 Multiple logistic regression**

192 The initial multiple logistic regression model included all statistically significant binary predictors
193 indicated by the univariate relative risk models (prior sports-related concussion history, high
194 sports-related concussion prevalence sport participation, ISI scores ≥ 15 , and NHANES-rated
195 excessive daytime sleepiness on two or more days per month). After variable selection, high
196 concussion prevalence sport participation, insomnia severity, and daytime sleepiness were
197 independently associated with increased odds of sustaining a sports-related concussion (Table
198 4 Primary model).

199 < Insert Table 4 here >

200 **3.4 Secondary analyses of risk factors**

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

210 Supplemental Tables 1, 2, 3, and 4 explore further the relationship between sub-optimal sleep
211 outcomes, high versus low concussion prevalence sport participation, and sports-related
212 concussion occurrence. These tables highlight the fact that, while there were no differences in
213 questionnaire outcomes between low- and high prevalence sports, the relative frequency of
214 sports-related concussions in this sample was higher for those with greater insomnia severity

215 and/or more frequent daytime sleepiness than for those without, regardless of the overall
216 prevalence for sports-related concussion.

217 **4. Discussion**

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

223 The relative risk of sustaining a sports-related concussion was 2-3x higher for individuals
224 participating in a sport with a high prevalence of sports-related concussions, reporting any
225 history of sports-related concussion prior to the survey date, self-reporting daytime sleepiness
226 on two or more days in a month (via the NHANES Sleepiness questionnaire) or reporting
227 moderate-to-severe levels of insomnia (via the Insomnia Severity Index). Furthermore, after
228 controlling for sport participation, the *odds* of sustaining a future sports-related concussion were
229 3.66-5.58x greater for individuals reporting moderate-to-severe insomnia and/or daytime
230 sleepiness on two or more days per month. Collectively, the odds of sustaining a sports-related
231 concussion for individuals who reported both moderate-to-severe insomnia severity and two or
232 more days of excessive daytime sleepiness ($n = 20$) was 14.6x higher than for those who
233 reported neither.

234 **4.1 sports-related concussion risk factors**

235 Reducing the incidence of sports-related concussion is a public health concern. Consequently,
236 identifying individual risk factors for sustaining a sports-related concussion has been the focus
237 of considerable effort. Prior work has consistently demonstrated that individuals with previous
238 concussions are at increased risk to sustain a future concussion.⁷⁻¹¹ Our present findings are
239 consistent in magnitude with the majority of these findings (~2-3 times higher risk of future

240 sports-related concussion with any prior history of concussion). However, in contrast to prior
241 work, history of concussion was not retained in multivariate models in this sample. Rather, after
242 controlling for participating in a sport with a traditionally higher sports-related concussion
243 prevalence, self-report insomnia and daytime sleepiness were strong indicators of sustaining a
244 concussion.

245 Additional studies have indicated that sex¹²⁻¹⁹, age,^{16,17,20-22} and ADHD/LD,^{23,24} among others,
246 may all increase the risk of sustaining a sports-related concussion. However, these findings are
247 inconsistent. Relative to our findings, males were more likely than females to sustain a sports-
248 related concussion, though this finding was not statistically significant. However, diagnoses of
249 ADHD/LD were not available for analysis. Furthermore, age in our sample was not associated
250 with an increased likelihood of sustaining a sports-related concussion, though this is not
251 surprising given the narrow age range considered here.

252 ***4.2 Bidirectional relationships between sports-related concussion and sleep***

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

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

265 are several plausible explanations as to why individuals with these self-reported outcomes may
266 be at increased sports-related concussion risk.

267 First, sub-optimal sleep is associated with increased reaction times;^{30,32,39} attentional lapses,^{29,31}
268 degraded visual tracking,^{31,32} reduced postural control and strength,^{29,33,40,41} impaired emotional
269 recognition, responsiveness, and control³⁴; and increased impulsivity and risky behavior.³⁵⁻³⁷
270 Second, the cardiovascular,^{38,39} endurance,³⁸ strength,^{40,41} and accuracy^{31,32} components of
271 sport performance are reduced or impaired under inadequate or low quality sleeping conditions
272 as well as daytime sleepiness. Consequently, individuals who experience poor sleep may be
273 more likely to have degraded overall physical sport performance as well as brief lapses in
274 attention to and poor visual tracking of in-game activities. Simultaneously, these individuals may
275 make unusually poor or risky sport decisions (e.g., take on-field risks), be unable to manage
276 negative emotional responses to in-game situations, and have poorer body control during sport
277 maneuvers at critical moments. Collectively, these effects may reduce an individual's capacity to
278 avoid or minimize injury. However, reports for the majority of these adverse sports-related
279 effects are isolated from one another (i.e., studies on reduced sport performance after sleep
280 restriction only; studies on impaired visual tracking follow sleep deprivation only) and therefore
281 multivariate effects are not fully explained. Furthermore, prior investigations into injury risk have
282 not specifically identified sports-related concussion risk, and therefore any translation of this
283 hypothesis requires further corroboration.

284 Despite the lack of comprehensive analyses of sleep-related influences on injury risk, the
285 present findings contribute to a larger body of work identifying poor or insufficient sleep as a
286 contributory factor to sports-related injury risk.^{42-44,68} Additionally, these findings contribute a
287 critically absent piece of information to this literature base, highlighting the specific risk of
288 sports-related concussion in the presence of poor sleep (e.g., insomnia) and daytime
289 sleepiness. Furthermore, these findings identify a plausible means by which prior sports-related

290 concussions increase future risk. Namely, prior sports-related concussions often result in
291 increased incidences of insomnia and daytime sleepiness, which, on the basis of the present
292 findings, likely contribute to increased risk of future concussions. This, therefore, may create a
293 feed-forward cycle where sports-related concussions increase the risk of poor sleep outcomes
294 that, in turn, increase the risk of future concussions. While unconfirmed at present, this
295 hypothesis merits further investigation.

296 Apart from the noted effects of sports-related concussions on sleep, collegiate and professional
297 athletes are more generally at increased risk for insomnia⁶⁹ and sleep disordered breathing^{70,71}
298 compared to sub-elite and non-athlete populations. Evidence suggests that training schedules,⁷²
299 travel requirements,^{73,74} and competition^{71,72} may all contribute to poor quality sleep and
300 insomnia, plausibly resulting in daytime sleepiness. Likewise, the prevalence of sleep-
301 disordered breathing is higher in athletes, particularly football players, and is associated with
302 increased complaints of daytime sleepiness and poor sleep quality.^{71,75,76}

303 Within the present sample, approximately 60% of the athletes reported daytime sleepiness or
304 sleepiness on two or more days per month and approximately 12% reported moderate-to-
305 severe insomnia symptom severity (Supplementary Tables). Despite a limited number of
306 observed sports-related concussions in the follow-up period ($n = 19$), individuals reporting
307 frequent daytime sleepiness accounted for the majority ($n = 17$; 89.4%). Furthermore, almost
308 one-third of the sustained sports-related concussions occurred in individuals reporting **both**
309 frequent daytime sleepiness and moderate-to-severe insomnia severity ($n = 6$; 31.6%).

310 Combined with previously reported detrimental effects of sleep disruption on athletic
311 performance and overall health, the present findings highlight the need for assessing and
312 improving sleep, either quantitatively or qualitatively, as means of reducing sports-related
313 concussion risk as well as supporting high-quality sport performance. Collegiate and
314 professional athletes, in particular, may benefit from assessment for and treatment of sleep-

315 disordered breathing, sleep hygiene education, and developing habits to obtain sufficient, high-
316 quality sleep and manage daytime sleepiness.

317 **4.3 Limitations**

318 Several limitations must be considered when interpreting the present findings. First, a limited
319 number of individuals sustained a sports-related concussion in the follow-up time-frame ($n = 19$;
320 10% of the sample). This limited proportion of our sample may have resulted in overestimating
321 the relative risk and odds ratios and limited our ability to detect statistically significant effects. To
322 minimize this concern, we used small sample size adjustments for the univariate risk ratio
323 confidence intervals to provide conservative estimates of overall risk and the stepwise variable
324 selection method restricted multivariate models to variables containing model information, rather
325 than strictly statistical significance, while limiting multi-collinearity. However, all of the univariate
326 (Table 3) and multivariate models (Table 4) as well as simple descriptive cross-tabulation
327 (Supplemental Tables) converge on the interpretation that frequent daytime sleepiness, both
328 apart from and in conjunction with moderate-to-severe insomnia severity, is associated with an
329 increased occurrence of sports-related concussions.

330 Second, our analyses relied on diagnosed sports-related concussions. Historically, as many as
331 50% of sports-related concussions go unreported and therefore undiagnosed.⁴⁻⁶ Independent of
332 the research presented here, athletes and coaches in the present sample received routine
333 education on concussion symptoms and reporting. Additionally, the sports medicine team
334 maintains a high vigilance for detecting possible concussions, including the addition of
335 independent medical spotters during football games. Therefore, we have reasonable confidence
336 that the majority of the sustained concussions were diagnosed and recorded. However, given
337 the vast number of sports-related concussions that do go unreported, it is possible that
338 participants under-reported prior sports-related concussions to research staff and medical
339 providers, potentially confounding the results of the multiple logistic regression models.

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

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

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

354 **4.4 Future research**

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

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

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

367 2. Sport and academic demands, and travel as risk factors for concussion. Sport and
368 academic demands – such as travel to and from competitions, early morning or late
369 evening practices, and studying for exams – may negatively impact sleep (e.g., self-
370 imposed sleep restriction; phase advanced/delayed sleep) prior to and following a
371 concussion. Consequently, sleep-related risks for, and outcomes from, a concussion
372 may change throughout the sport and academic year as a function of these factors and
373 requires further examination.

374 3. The interplay between sleep and biopsychosocial risk factors for sports-related
375 concussions. Further studies are needed to more fully identify biopsychosocial (e.g.,
376 training response, age, sex and/or gender, self-esteem, stress, nutrition, training load)
377 risk factors in conjunction with sleep that may more fully identify individuals at increased
378 risk for injury. Of particular interest would be the identification of modifiable risk factors –
379 such as stress, nutrition, sleep and sleep hygiene, daytime sleepiness – that can be
380 leveraged to prevent avoidable injury.

381 **5. Conclusions**

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

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

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622 **Figure captions**

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

