Predictors of postconcussion syndrome in collegiate student-athletes

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OBJECTIVE Sport-related concussion (SRC) has emerged as a public health problem, especially among student-athletes. Whereas most concussions resolve by 2 weeks, a minority of patients experience postconcussion syndrome (PCS), in which symptoms persist for months. The objective of this study was to elucidate factors predictive of PCS among a sample of National Collegiate Athletic Association (NCAA) student-athletes in the academic years 2009–2010 to 2014–2015.

METHODS The SRC data originated from the NCAA Injury Surveillance Program (ISP) in the 2009–2010 to 2014–2015 academic seasons. The NCAA ISP is a prospective database made up of a convenience sample of schools across all divisions. All SRCs are reported by certified athletic trainers. The PCS group consisted of concussed student-athletes with concussion-related symptoms that lasted ≥ 4 weeks. The non-PCS group consisted of concussed student-athletes with symptom resolution in ≤ 2 weeks. Those with symptoms that resolved in the intermediate area of 2–4 weeks were excluded. Odds ratios (ORs) were estimated using logistic regression.

RESULTS During the 2009–2010 to 2014–2015 seasons, 1507 NCAA student-athletes sustained an SRC, 112 (7.4%) of whom developed PCS (i.e., concussion-related symptoms that lasted ≥ 4 weeks). Men's ice hockey contributed the largest proportion of concussions to the PCS group (28.6%), whereas men's football contributed the largest proportion of concussions in the non-PCS group (38.6%). In multivariate analysis, recurrent concussion was associated with increased odds of PCS (OR 2.08, 95% CI 1.28–3.36). Concussion symptoms that were also associated with increased odds of PCS included retrograde amnesia (OR 2.75, 95% CI 1.34–5.64), difficulty concentrating (OR 2.35, 95% CI 1.23–4.50), sensitivity to light (OR 1.97, 95% CI 1.09–3.57), and insomnia (OR 2.19, 95% CI 1.30–3.68). Contact level, sex, and loss of consciousness were not associated with PCS.

CONCLUSIONS Postconcussion syndrome represents one of the most impactful sequelae of SRC. In this study of exclusively collegiate student-athletes, the authors found that recurrent concussions and various concussion-related symptoms were associated with PCS. The identification of initial risk factors for the development of PCS may assist sports medicine clinicians in providing timely interventions and treatments to prevent morbidity and shorten recovery time after SRC.

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KEY WORDS sport-related concussion; traumatic brain injury; collegiate athletics; NCAA; postconcussion syndrome

SPORT-RELATED concussion (SRC), which affects athletes of all ages and levels of competition, has taken hold of the national spotlight. An estimated 1.6–3.8 million SRCs occur each year in the United States, but this may be an underestimation because of those who fail to seek medical care.^{11,20,22,29} Concussion in college athletics has been studied extensively.^{11,52} In 2010, the National

Collegiate Athletic Association (NCAA) implemented a 4-pronged concussion policy that included mandatory education, immediate removal from play, no same-day return to play, and a requirement for clearance by a medical professional.^{5,34} Recent reports have summarized SRC epidemiology at the collegiate level,^{48,52} yet concussion remains an evolving injury in need of study.

ABBREVIATIONS AT = athletic trainer; ISP = Injury Surveillance Program; LOC = loss of consciousness; NCAA = National Collegiate Athletic Association; PCS = postconcussion syndrome; SRC = sport-related concussion.

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Whereas 85%–90% of athletes with SRC are asymptomatic by 10–14 days after injury,^{24,26,29} a subset of them experience unremitting symptoms, referred to as postconcussion syndrome (PCS).^{21,43} This syndrome has many definitions. The *International Statistical Classification of Diseases and Related Health Problems, 10th Revision*, defines PCS as 3 or more symptoms persisting for greater than 4 weeks. Similarly, the *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV)*, defines it as 3 or more symptoms but persisting for a minimum of 3 months,² and the DSM-V does not include the diagnosis.³ In a survey of more than 500 physicians, the majority of them diagnosed PCS in patients who endorsed at least 1 symptom for a minimum of 4 weeks.⁴²

Many reports have outlined risk factors for PCS,^{8,13,15,17,23,25,28,40,45,50,51} but few studies have been performed in an exclusively sports population.^{12,26,30,31,33} Documented risk factors for PCS in athletes include initial symptom score,^{26,31} loss of consciousness (LOC),²³ amnesia,²⁶ and female sex,^{28,50} although considerable debate has surrounded each factor.⁴⁵ Whereas individual factors such as concussion history and learning disability have been well studied, few studies have aimed to elucidate sport-specific factors that may predispose athletes to PCS. If predictive factors can be identified in a homogeneous population, symptoms can be managed more aggressively in an effort to minimize symptom duration and improve quality of life. Compared with the general population, collegiate student-athletes represent a viable starting point because they have access to a full cohort of certified athletic trainers (ATs) and physicians with limited insurance restrictions.

Given the potentially debilitating effects of prolonged postconcussion symptoms in collegiate student-athletes, we sought to further investigate risk factors for PCS after SRC. The objective of this study was to elucidate factors predictive of PCS among an exclusive group of collegiate student-athletes who sustained an SRC in the 2009–2010 to 2014–2015 academic years.

Methods

The NCAA Injury Surveillance Program (ISP) is a prospective surveillance program managed by the Datalys Center for Sports Injury Research and Prevention, an independent nonprofit research organization. Data from the 2009–2010 to 2014–2015 academic years were obtained from the NCAA ISP. This study was approved by the NCAA Research Review Board.

Data Collection

The methodology of the NCAA ISP during the 2009–2010 to 2014–2015 academic years was described previously.¹⁶ The ISP collects student-athlete data from a convenience sample of NCAA varsity teams across 25 sports among all 3 divisions. Individual school sponsorship varies by sport and year; for example, during the 2009–2010 to 2014–2015 seasons, 57 men's football programs provided 153 team-seasons, and of these programs, 29 were Division I (76 team-seasons), 9 were Division II (28 team-seasons), and 19 were Division III (49 team-seasons).

Similar trends, summarized in a separate paper, were seen across other sports.¹⁶

Athletic trainers recorded injury data during all school-sanctioned practices, workouts, and competitions. In the event of an injury, or, in this case, an SRC, the AT reported the injury in real time through an electronic health record program used by the team medical staff throughout the academic year. The ISP captured other sports-related adverse health events such as illness, heat-related conditions, and general medical conditions. Although team workouts were captured, individual weight-lifting and conditioning sessions were excluded.

For each SRC, the AT completed a detailed event report on the injury or condition (e.g., body part, diagnosis) and the circumstances (e.g., activity, mechanism, recurrence, event type [i.e., competition or practice]). Recurrent concussion was determined in student-athletes who had more than 1 concussion reported during their team's participation in the ISP or who had their most recent concussion noted by ATs as being recurrent. In other words, a concussion was classified as recurrent if the athlete had suffered a previous concussion during his or her collegiate athletic career. Thus, for each concussed athlete used in the data analysis, only the most recent concussion reported in the ISP was examined. Furthermore, the total duration of symptoms was collected longitudinally. The ATs updated the electronic medical record as needed to update injury information, such as time lost and time to symptom resolution.

Common data elements, including injury, exposure, and longitudinal information, were stripped of any personally identifiable information and retained only relevant variables.¹⁶ The frequency of export or submission of data varied slightly among vendors providing health information to each team's medical staff. Because the program removed any identifiers, ATs were subsequently allowed to document injuries as part of their daily clinical practice and did not have to complete separate reports specifically for the ISP. Furthermore, all electronic health record information was subjected to a data-validation process for certification. Once entered, exported data were put through an automated verification process to check for consistency. These data were reviewed and flagged for invalid values. Any discrepancies or invalid values were resolved mutually by the AT and data quality assurance staff. All data that passed the verification process were then placed into the aggregate data sets.

It should be noted that, although some studies that evaluated PCS included individual and family medical histories,^{25,32–35,50} the sport-focused nature of the ISP prevented any in-depth medical history from being collected. However, the ISP allowed us to collect sport-specific information surrounding the inciting injury.

Definitions

A reportable injury in the ISP was defined as an injury that occurred as a result of participation in an organized intercollegiate practice/competition and required attention from an AT or physician. Multiple injuries could be included as a result of 1 injury event. Although the ATs were encouraged to follow the international definition of con-

cussion provided by the Consensus Statement on Concussion in Sport,²⁷ a predetermined definition of concussion was not provided. We relied on the medical expertise of the ATs providing data for the NCAA ISP.

Cases were defined as those that involved a student-athlete who experienced 1 or more symptom related to an SRC for greater than 4 weeks, as has been characterized in previous reports of PCS.^{6,7,25,31,47} Controls were defined as student-athletes with symptom resolution at ≤ 2 weeks. Any student-athlete with symptom resolution in the intermediate area of > 2 weeks but < 4 weeks was excluded from our analysis to sharply demarcate the control and PCS groups, which is similar to the methodology used in previous studies.^{32,33} This exclusionary criterion was imposed to sharply delineate the continuum of typical to prolonged trajectory, because the primary objective of this study was not epidemiological or prevalence based but, rather, to elucidate factors associated with PCS. The remaining exclusion criteria included student-athletes with missing concussion history data or symptomatology information. After imposing these exclusionary measures, all remaining concussed student-athletes were included in the analysis.

The student-athletes were drawn from all 25 collegiate sports, recently reported in a pair of NCAA SRC epidemiology studies.^{48,52} All predictive factors are outlined in Table 1. Contact level was determined by using a preexisting classification system.^{41,44} Helmet status was determined as previously described, and those sports played partly with helmets were included in the helmeted group, except when only the goalie was helmeted.⁵³ Recurrent SRC was defined as more than 1 SRC suffered during the student-athlete's participation in the ISP. A comprehensive list of 17 symptoms was used.

Statistical Analysis

Data were analyzed using SAS-Enterprise Guide soft-

ware version 4.3 (SAS Institute Inc.). Unlike other studies that used the ISP,^{48,52} the unit of analysis was not concussions but each concussed person, because the primary purpose of this study was to assess factors associated with prolonged SRC symptomatology and not SRC per se. Thus, for each concussed individual used in the data analysis, only the most recent concussion reported in the ISP was examined.

Demographic data were analyzed to describe student-athletes with PCS. Continuous variables are presented as means and standard deviations. Categorical variables are presented as percentages of the total population. Odds ratios and 95% CIs were estimated using logistic regression. Simple univariate logistic regressions were used to predict the odds of PCS. The variables assessed were sex, contact level, helmet status, recurrent concussion, number of symptoms, and prevalence of each of 17 symptoms. Number of symptoms was treated as a continuous variable (i.e., the beta for number of symptoms represents the increase in log odds of PCS for each additional symptom reported). All variables for which univariate analyses yielded a *p* value of < 0.010 were included in a multiple logistic regression model. For the multivariate analysis, all ORs with a 95% CI that did not include 1.0 were considered statistically significant.

Results

Demographics

During the 2009–2010 to 2014–2015 seasons, 1866 concussed NCAA student-athletes were reported in the NCAA ISP, and 1507 met the criteria for inclusion (Fig. 1). Student-athlete characteristics are provided in Table 2. One hundred-twelve (7.4%) student-athletes developed PCS. Men's ice hockey was the sport played by the majority of athletes in the PCS group (28.6%), whereas men's football was the most common sport played by those in the

TABLE 1. Variables considered for the model predicting prevalence of PCS among concussed student-athletes in NCAA sports

Variable	Values
Sex	Men [M], women [W]
Contact level	Collision (football [M], ice hockey [M], wrestling [M]) High contact (soccer [M/W], basketball [M/W], lacrosse [M], ice hockey [W]) Low/noncontact (baseball [M], softball [W], lacrosse [W], volleyball [W], gymnastics [W], field hockey [W], cross-country/track [M/W], tennis [M/W], swimming/diving [M/W])
Helmet status	Helmeted (football [M], ice hockey [M/W], lacrosse [M], wrestling [M], baseball [M],* softball [W]*) Unhelmeted (basketball [M/W], soccer [M/W], lacrosse [W], volleyball [W], gymnastics [W], field hockey [W],† cross-country/track [M/W], tennis [M/W], swimming/diving [M/W])
Recurrent concussion	Yes, no
Symptom prevalence	Yes or no for 17 symptoms (posttraumatic amnesia, retrograde amnesia, difficulty concentrating, disorientation, dizziness, headache, excess excitability, excess irritability, LOC, nausea/vomiting, tinnitus, loss of balance, visual disturbance, sensitivity to light, sensitivity to noise, insomnia, and excess drowsiness)
No. of symptoms	Range of 1–17

* Because baseball and softball are played partly while wearing helmets, student-athletes who played this sport were included in the helmeted group.

† There was 1 concussion sustained by a goalie in field hockey. Because goalies in this sport wear helmets, this case was included in the helmeted group.

FIG. 1. Flow chart of final cohort.

non-PCS group (38.6%). The PCS and non-PCS groups did not differ in regards to sex, contact level, or helmet status. However, compared with the non-PCS group, the PCS group had a greater proportion of student-athletes with recurrent concussion ($p < 0.001$) and a higher average number of symptoms ($p < 0.001$).

Univariate Analysis

The odds of PCS increased among student-athletes with recurrent concussion (OR 2.22, 95% CI 1.41–3.50; Table 3). The odds of PCS also increased among student-athletes who played helmeted sports (OR 1.48, 95% CI 0.95–2.30). In terms of symptoms, the odds of PCS increased 26% for each additional symptom reported (OR 1.26, 95% CI 1.18–1.34). In addition, the odds of PCS were higher among those who reported the following concussion symptoms than those who did not report them: posttraumatic amnesia, retrograde amnesia, difficulty concentrating, dizziness, excess irritability, nausea/vomiting, loss of balance, visual disturbance, sensitivity to light, sensitivity to noise, insomnia, and excess drowsiness. In addition, the univariate analysis for helmet status yielded a p value of < 0.08 .

Multivariate Analysis

A multivariate model was constructed by using all the

variables for which the OR in univariate analyses yielded a p value of < 0.10 (Table 4). Controlling for other variables, recurrent concussion was associated with increased odds of PCS (OR 2.08, 95% CI 1.28–3.36). Concussion symptoms also associated with increased odds of PCS, when controlling for other variables, included retrograde amnesia (OR 2.75, 95% CI 1.34–5.64), difficulty concentrating (OR 2.35, 95% CI 1.23–4.50), sensitivity to light (OR 1.97, 95% CI 1.09–3.57), and insomnia (OR 2.19, 95% CI 1.30–3.68).

Discussion

Our findings originate from surveillance data that examined concussions sustained in 25 NCAA sports throughout the 2009–2010 to 2014–2015 seasons. Several variables were found to be associated with the odds of PCS, including recurrent concussion, retrograde amnesia, difficulty concentrating, light sensitivity, and insomnia. Sex, helmet status, contact level, and LOC were not associated with PCS. Our results highlight the importance of identifying potential risk factors before and at the onset of concussion.

As in previous research,^{33,39} recurrent concussion was associated with protracted recovery. Morgan et al.³³ studied a pediatric sports-related population by using multivariate analysis and found that history of concussion was

TABLE 2. Characteristics of concussed student-athletes in NCAA sports

Characteristic	Total	PCS	No PCS	p Value*
Sex (no. [%])				0.14
Male	1037 (68.8)	70 (62.5)	967 (69.3)	
Female	470 (31.2)	42 (37.5)	428 (30.7)	
Sport (no. [%])				NA
Men's football	563 (37.4)	25 (22.3)	538 (38.6)	
Men's ice hockey	200 (13.3)	32 (28.6)	168 (12)	
Women's soccer	121 (8)	8 (7.1)	113 (8.1)	
Women's basketball	86 (5.7)	6 (5.4)	80 (5.7)	
Men's basketball	76 (5)	1 (0.9)	75 (5.4)	
Men's wrestling	72 (4.8)	5 (4.5)	67 (4.8)	
Women's ice hockey	72 (4.8)	15 (13.4)	57 (4.1)	
Women's volleyball	56 (3.7)	1 (0.9)	55 (3.9)	
Men's soccer	52 (3.5)	2 (1.8)	50 (3.6)	
Women's lacrosse	50 (3.3)	3 (2.7)	47 (3.4)	
Men's lacrosse	48 (3.2)	3 (2.7)	45 (3.2)	
Women's softball	47 (3.1)	2 (1.8)	45 (3.2)	
Men's baseball	15 (1)	2 (1.8)	13 (0.9)	
Women's field hockey	14 (0.9)	2 (1.8)	12 (0.9)	
Women's gymnastics	13 (0.9)	4 (3.6)	9 (0.6)	
Men's swimming & diving	7 (0.5)	0	7 (0.5)	
Men's track & field	4 (0.3)	0	4 (0.3)	
Women's swimming & diving	4 (0.3)	1 (0.9)	3 (0.2)	
Women's track & field	4 (0.3)	0	4 (0.3)	
Women's tennis	2 (0.1)	0	2 (0.1)	
Women's cross-country	1 (0.1)	0	1 (0.1)	
Contact level (no. [%])				0.93
Collision	835 (55.4)	62 (55.4)	773 (55.4)	
High contact	455 (30.2)	35 (31.3)	420 (30.1)	
Low/noncontact	217 (14.4)	15 (13.4)	202 (14.5)	
Helmet status (no. [%])				0.08
Helmeted	1018 (67.6)	84 (75.0)	934 (67.0)	
Unhelmeted	489 (32.4)	28 (25.0)	461 (33.0)	
Recurrent concussion (no. [%])				<0.001
Yes	210 (13.9)	28 (25.0)	182 (13.0)	
No	1297 (86.1)	84 (75.0)	1213 (87.0)	
No. of symptoms (mean [SD])	5.4 (2.8)	7.2 (3.2)	5.2 (2.7)	<0.001
Total (no. [%])	1507 (100.0)	112 (100.0)	1395 (100.0)	

NA = not applicable.

* p value from tests that examined differences between the PCS and non-PCS groups. For sex, contact level, helmet status, and recurrent concussion, chi-square tests were used. For the number of symptoms, independent-sample t-tests were used. The test was not run for sport type.

positively associated with PCS. Concussion history has been associated with PCS in other studies as well.³⁹ These findings highlight the need for those working with student-athletes to be acutely aware of previous concussions, although they may be difficult to elicit on history. Once an athlete has suffered numerous SRCs, each with an expanded recovery time, it has been our anecdotal experience that the student-athlete may be less likely to return to sport as willingly as after previous injuries, especially if there has been a negative academic impact.

Alongside recurrent concussions, specific concussion-

related symptoms were also associated with PCS, including retrograde amnesia, difficulty with concentration, insomnia, and sensitivity to light. Retrograde amnesia is defined as the inability to retain information from events that occurred before onset of the cerebral pathology.^{23,37} Although studies in non-sports-related populations have shown no association with PCS,^{17,23} McCrea et al.²⁶ found post-traumatic amnesia (similar but different from retrograde amnesia) to be associated with longer symptom recovery; however, their groups were dichotomized at greater than 7 days, a time frame inconsistent with the most standard

TABLE 3. Univariate analyses predicting odds of PCS in concussed student-athletes in NCAA sports

Variable	Value	PCS (no./total [%])*	OR (95% CI)†	p Value
Sex	Male	70/1037 (6.7)	0.74 (0.49–1.10)	0.14
	Female	42/470 (8.9)	1.0	
Contact level	Collision	62/835 (7.4)	1.08 (0.60–1.93)	0.80
	High contact	35/455 (7.7)	1.12 (0.60–2.10)	0.72
	Low/noncontact	15/217 (6.9)	1.0	
Helmet status	Helmeted	84/1018 (8.3)	1.48 (0.95–2.30)	0.08
	Unhelmeted	28/489 (5.7)	1.0	
Recurrent concussion	Yes	28/210 (13.3)	2.22 (1.41–3.50)†	<0.001
	No	84/1297 (6.5)	1.0	
No. of symptoms	(1-unit increase)		1.26 (1.18–1.34)†	<0.001
Symptom prevalence				
Posttraumatic amnesia	Yes	22/195 (11.3)	1.73 (1.06–2.83)†	0.03
	No	90/1312 (6.9)	1.0	
Retrograde amnesia	Yes	20/132 (15.2)	2.49 (1.48–4.19)†	<0.001
	No	92/1375 (6.7)	1.0	
Difficulty concentrating	Yes	92/898 (10.2)	3.36 (2.05–5.52)†	<0.001
	No	20/609 (3.3)	1.0	
Disorientation	Yes	40/492 (8.1)	1.15 (0.78–1.73)	0.47
	No	72/1015 (7.1)	1.0	
Dizziness	Yes	88/1037 (8.5)	1.72 (1.08–2.74)†	0.02
	No	24/470 (5.1)	1.0	
Headache	Yes	109/1415 (7.7)	2.48 (0.77–7.95)	0.13
	No	3/92 (3.3)	1.0	
Excess excitability	Yes	6/60 (10.0)	1.41 (0.59–3.34)	0.44
	No	106/1447 (7.3)	1.0	
Excess irritability	Yes	24/225 (10.7)	1.62 (1.01–2.61)†	0.05
	No	88/1282 (6.9)	1.0	
LOC	Yes	8/79 (10.1)	1.43 (0.67–3.06)	0.35
	No	104/1428 (7.3)	1.0	
Nausea/vomiting	Yes	47/465 (10.1)	1.69 (1.14–2.50)†	0.009
	No	65/1042 (6.2)	1.0	
Tinnitus	Yes	12/118 (10.2)	1.46 (0.78–2.74)	0.24
	No	100/1389 (7.2)	1.0	
Loss of balance	Yes	53/552 (9.6)	1.61 (1.10–2.37)†	0.02
	No	59/955 (6.2)	1.0	
Visual disturbance	Yes	46/440 (10.5)	1.77 (1.19–2.63)†	0.005
	No	66/1067 (6.2)	1.0	
Sensitivity to light	Yes	81/755 (10.7)	2.80 (1.82–4.28)†	<0.001
	No	31/752 (4.1)	1.0	
Sensitivity to noise	Yes	60/472 (12.7)	2.75 (1.87–4.06)†	<0.001
	No	52/1035 (5.0)	1.0	
Insomnia	Yes	49/332 (14.8)	3.06 (2.06–4.54)†	<0.001
	No	63/1175 (5.4)	1.0	
Excess drowsiness	Yes	51/433 (11.8)	2.22 (1.50–3.27)†	<0.001
	No	61/1074 (5.7)	1.0	

* Of note – denominators added are raw totals in each category

† Statistically significant.

TABLE 4. Multivariate analyses predicting odds of PCS in concussed student-athletes in NCAA sports

Variable	Value	OR (95% CI)	p Value
Helmet status	Helmeted	1.43 (0.90–2.29)	0.13
	Unhelmeted	1.0	
Recurrent concussion	Yes	2.08 (1.28–3.36)*	0.003
	No	1.0	
No. of symptoms	(1-unit increase)	0.88 (0.65–1.19)	0.40
Symptom prevalence			
Posttraumatic amnesia	Yes	1.34 (0.67–2.67)	0.41
	No	1.0	
Retrograde amnesia	Yes	2.75 (1.34–5.64)*	0.006
	No	1.0	
Difficulty concentrating	Yes	2.35 (1.23–4.50)*	0.01
	No	1.0	
Dizziness	Yes	1.35 (0.71–2.56)	0.36
	No	1.0	
Excess irritability	Yes	0.97 (0.52–1.82)	0.93
	No	1.0	
Nausea/vomiting	Yes	1.19 (0.69–2.07)	0.53
	No	1.0	
Loss of balance	Yes	1.05 (0.59–1.87)	0.87
	No	1.0	
Visual disturbance	Yes	1.31 (0.76–2.24)	0.33
	No	1.0	
Sensitivity to light	Yes	1.97 (1.09–3.57)*	0.004
	No	1.0	
Sensitivity to noise	Yes	1.53 (0.86–2.74)	0.15
	No	1.0	
Insomnia	Yes	2.19 (1.30–3.68)*	0.003
	No	1.0	
Excess drowsiness	Yes	1.56 (0.88–2.77)	0.12
	No	1.0	

* Statistically significant.

PCS definition of approximately greater than 4 weeks. We also found that the total number of symptoms was not associated with PCS. Although definitions of PCS specify a threshold for the number of symptoms that a concussed person must identify,^{2,3} our findings may suggest that the type of symptoms reported are more important than the quantity. As mentioned previously, in a study in which more than 500 physicians were surveyed, the majority of the physicians diagnosed PCS in patients with 1 symptom for a minimum of 4 weeks.⁴²

However, it is important to note that other studies have found an association between concussion symptom inventory scores and PCS. Meehan et al.³⁰ reported that among a host of possible signs and symptoms, only total score on a symptom inventory was associated with symptoms lasting more than 4 weeks. In a comprehensive systematic review of general traumatic brain injury,⁴⁵ the total symptom severity score was associated with PCS in 4 of the 8 studies discussed. Although the ISP uses a 17-symptom checklist, it does not measure the severity of the symp-

toms. Future research should continue to examine how the type, number, and severity of symptoms are associated with long-term outcomes associated with SRC.

Our findings contradict previous results in that several variables included in our models had null associations with PCS. For example, our findings did not detect an association between sex and PCS, whereas previous research has found an increased risk among females,^{28,50} although those studies were conducted in children/adolescents, not collegiate student-athletes. In addition, a meta-analysis of studies that examined individuals who sustained a traumatic brain injury found that only 6 of the 12 studies examined reported worse symptomatic outcomes for women.⁴⁵ Previous research also identified LOC as a risk factor associated with PCS.²⁶ McCrea et al.²⁶ studied a sport-specific cohort and found a positive correlation between LOC and PCS; however, prolonged recovery was defined at only > 7 days.²⁶ A recent meta-analysis found LOC not to be associated with outcomes in only 2 of 8 studies, and 1 of the 2 positive studies was unblinded.⁴⁵ All those studies

were conducted in a general population, and most were in children and adolescents who presented to the emergency department.

Also, although 1 previous study identified helmeted versus unhelmeted status as a predictor of acute outcome after SRC,⁵³ we did not find helmet status to be associated with PCS. Although most media attention surrounds collision sports such as football and hockey, contact level did not predict PCS in our cohort. Given the body of mixed findings in the literature, we recommend additional prospective research with large samples of concussed individuals to better identify the risk factors associated with PCS.

When interpreting the results of this study, the setting and context of a collegiate environment must be considered. The current NCAA guidelines mandate that clearance for a concussed student-athlete to return to athletic activity must be determined by a physician or physician designee.³⁴ Furthermore, same-day return to play is not permitted.³⁴ A recent survey of coaches, sports medicine clinicians, and compliance administrators at 907 NCAA institutions reported that more than one-third of the respondents thought that concussion safety education among coaches and players could be improved.⁵ Another potential area of improvement is communication between team medical staff and academic advisors. In an academic setting, memory, concentration, and sleep are crucial for successful scholastic performance. Thus, in the collegiate population, the student-athlete may be hyperaware of small declines in concentration, memory, and sleep, leading to appropriately increased reporting of these specific symptoms. For example, the concentration, memory, and sleep of college student-athletes who are studying for an examination will need to be at a high level, or at least at their previous baseline level, or they will be aware of their suboptimal performance. Some studies have discussed guidelines for students returning to class after a concussion—including deadline extensions, rest periods, and accommodation for light or noise sensitivity—although such guidelines have been used mostly at the high school level and below.^{4,36,49} One study evaluated 34 collegiate concussions among a greater cohort of 159 patients and found that recurrence or worsening of symptoms was seen in almost half (44.7%) of the patients after a premature return to learning.⁹

Limitations

The NCAA ISP is a convenience sample of ATs from several NCAA member institutions and may not be generalizable to nonparticipating sports programs or other levels of competition (e.g., club sports, high school sports). Data were also collected from a previous time period that may not represent the current climate of SRC reporting. In addition, we did not provide a working definition of SRC, although the ATs were encouraged to follow the definition provided by the Consensus Statement on Concussion in Sport.²⁷ This lack of a standard may have resulted in variation in SRC reporting. Other variables of interest, such as player position, NCAA divisional differences, and SRC outcomes, were outside the scope of this study. Factors such as learning disability, depression/anxiety, psychiatric illness, and family history have been shown to modify outcomes after concussion³³; however, they could not be ac-

counted for in our study, because the ISP is strictly for surveillance and is not a database of student-athletes' medical histories. Moreover, no baseline information was available; thus, predictive factors could be accounted for only in the postconcussive setting, and association only—not causation—could be concluded. Last, the accuracy of recurrent concussion status may have been variable, because this information can be difficult to obtain retrospectively from student-athletes.

Future Directions

The literature is replete with studies that aimed to delineate the precise factors that lead to PCS. However, many studies used heterogeneous cohorts, which makes their results difficult to apply. Nevertheless, it is essential to identify interventions that can assist concussed individuals in returning to their normal daily activities. In the case of a collegiate student-athlete, normal daily activities would include return to both sports and academics. Several pharmacological agents exist to treat unremitting symptoms such as headache, sleep disturbance, nausea, and dizziness.^{38,46} Conder and Conder¹⁰ described psychological rehabilitation efforts targeted at PCS symptom resolution, including cognitive behavioral therapy, relaxation training, biofeedback, and heart-rate-variability training. Although most of these interventions have had limited empirical support for efficacy in a sports environment, they have had success with similar injuries. Preliminary studies evaluated noninvasive brain stimulation, specifically repetitive transcranial magnetic stimulation over the prefrontal cortex, for the treatment of PCS.¹⁸ With respect to imaging, diffusion tensor imaging and detailed MRI data may provide new insight into those at risk for PCS.^{1,19} Last, education among athletes, coaches, and parents remains critical for improving PCS outcomes. Novel ways of disseminating concussion and PCS information may help diagnose and make school accommodations for those with persistent symptoms, especially in more rural populations.¹⁴ However, evaluation through prospective observational research and randomized controlled trials is important for gauging the effectiveness and efficacy of these interventions.

Conclusions

Our study ventured to examine factors associated with PCS at the collegiate level. The factors in our multivariate model that predicted the odds of PCS included recurrent concussion, retrograde amnesia, difficulty concentrating, light sensitivity, and insomnia. Sex, contact level, helmet status, and LOC were not associated with PCS. Our ability to identify the determinants of PCS may enable earlier preventative care aimed at decreasing morbidity. Further study is needed to continue improving our predictive ability and to employ early treatment strategies to prevent the development of PCS.

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Disclosures

Dr. Solomon reports being a consultant for the Tennessee Titans, Nashville Predators, and ImPACT. Dr. Sills reports being a non-compensated consultant to several collegiate athletic teams including Vanderbilt University.

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Conception and design: Zuckerman, Kerr. Acquisition of data: Kerr. Analysis and interpretation of data: all authors. Drafting the article: Zuckerman, Yengo-Kahn. Critically revising the article: all authors. Reviewed submitted version of manuscript: Zuckerman, Buckley, Solomon, Sills, Kerr. Approved the final version of the manuscript on behalf of all authors: Zuckerman. Statistical analysis: Kerr. Administrative/technical/material support: Solomon, Kerr. Study supervision: Zuckerman, Solomon, Kerr.

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