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RESEARCH ARTICLE

Concussion and Academic Impairment Among U.S. High School Students

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Introduction: Sports and physical activities are a frequent cause of traumatic brain injury, primarily concussions, among adolescents. These concussions may adversely affect students' ability to learn and impair academic achievement in educational settings.

Methods: The 2017 Youth Risk Behavior Survey, conducted among a nationally representative sample of 14,765 U.S. high school students, was analyzed in 2018 to examine associations between self-reported sports- and physical activity-related concussions and symptoms of cognitive impairment (difficulty concentrating, remembering, or making decisions) and self-reported academic grades (mostly A's=4.0, mostly B's=3.0, mostly C's=2.0, mostly D's=1.0, mostly F's=0.0). Adjusted prevalence ratio and the difference in self-reported estimated grade point average were adjusted for sex, race/ethnicity, grade, and athlete status (participation on sports teams) and considered statistically significant if $p<0.05$.

Results: Male students were more likely than female students (17.1% vs 13.0%), and athletes were more likely than nonathletes (21.4% vs 7.6%) to have a self-reported sports- and physical activity-related concussion in the 12 months preceding the survey. Students with a reported sports- and physical activity-related concussion were more likely than students without one to report symptoms of cognitive impairment regardless of whether they were male (adjusted prevalence ratio=1.49), female (adjusted prevalence ratio=1.37), athletes (adjusted prevalence ratio=1.45), or nonathletes (adjusted prevalence ratio=1.42). Self-reported grade point averagedecreased significantly from 3.14 among students who reported no concussions (referent), to 3.04 among students who reported a single concussion, and 2.81 among students who reported ≥2 concussions.

Conclusions: School-based programs are needed to monitor students' academic performance and provide educational support and resources to promote academic success following a concussion.
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INTRODUCTION

In 2013, there was 2.8 million traumatic brain injury (TBI)-related emergency department visits (2.5 million), hospitalizations (282,000), and deaths (56,000) in the U.S.[1] Most TBIs are mild in severity and are commonly called concussions.[2] In the U.S., 3.42 million emergency department visits for sports- and recreation-related TBI occurred from 2001 to 2012, with the overall age-adjusted rate of these visits more than doubling during this time.[3] Most of the sports- and recreation-related TBIs resulting in emergency department visits (70%) occurred among youth aged ≤19 years.[3]

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Youth with mild TBI and concussions may present to clinical locations other than the emergency departments, such as pediatricians' offices,[4] or may not seek care at all, making it difficult to accurately estimate the true incidence of injury, which in turn complicates the understanding of overall outcomes.[5–7] National estimates of sports-related concussions experienced by high school students have found that high school athletes experience 300,000 concussions per year in organized school-based sports, with a higher frequency in competition compared with practice.[8,9] However, these estimates do not include concussions experienced in nonschool-based sports leagues, as well as concussions experienced while engaged in sports and recreational activities or play outside of sports leagues (e.g., pick-up games, free play, bicycle riding).

Although most youths recover fully within weeks of a mild TBI, a TBI of any severity can negatively impact a child's future ability to learn and succeed in an educational setting.[2,10–13] A recent prospective study followed high school and college students seen at 3 emergency departments for either a sports-related concussion or extremity injury.[14] At 1 week post-injury, self-reports of academic dysfunction were significantly higher among the concussed group compared with the extremity injury group, especially among female students and those with multiple prior concussions. These effects appeared to resolve after 1 month. Among studies that have been conducted, results indicate that children with moderate-to-severe TBI earn lower grades, show higher rates of grade retention, and receive more special education services than their uninjured peers.[15–18] One mechanism by which mild TBI and concussion may influence academic performance is through trauma-induced cognitive impairment, which sometimes manifests as difficulty concentrating, remembering, and making decisions.[19,20] Though experiencing a TBI can result in cognitive changes that affect a student's readiness to learn, only a few studies have examined the impact of these changes on classroom performance. In one prospective study, relationships between cognitive skills and classroom performance metrics were examined in children several years after sustaining a mild, moderate, or severe TBI between the ages of 3 and 7 years.[21] Findings from this study indicated that difficulties in classroom functioning several years later were associated with higher injury severity, neuropsychological difficulties in cognitive flexibility and fluid reasoning, and parent and teacher ratings of poor executive skills. However, the long-term impact of concussion on academic performance is not entirely clear.[22–25] A Canadian study of grade 9–12 students matched students who experienced a concussion to nonconcussed controls. Changes in grade point average (GPA) from the academic year before the concussion to the academic year the concussion occurred (or could have occurred among nonconcussed matched students) were compared, and the results showed that concussion had minimal long-term effects on academic performance during high school.[25]

This study is the first to examine the relationship between sports- and physical activity-related concussion (SPAC) and indicators of academic impairment among a nationally representative sample of U.S. high school students. Information on the prevalence of these types of concussions and their association with cognitive impairment and academic grades is needed to inform school-based programs that seek to reduce SPAC among U.S. high school students and to mitigate their potential for adverse impact on academic achievement. Data from the 2017 national Youth Risk Behavior Survey (YRBS) were analyzed to examine the occurrence of self-reported SPAC among U.S. high school students, and its associations with self-reported cognitive impairment and academic grades.

METHODS

Study Sample

The 2017 national YRBS collected cross-sectional data on a wide range of priority health-risk behaviors from a nationally representative sample of public and private high school students in Grades 9–12. The survey used a 3-stage probability sampling methodology that has been described previously.[26,27] A weighting factor was applied to each student record to adjust for the varying probabilities of selection at each stage of sampling, student nonresponse, and the oversampling of black and Hispanic students. The questionnaire was administered in the classroom during a regular class period by trained data collectors. Responses were recorded directly on computer-scannable questionnaire booklets or answer sheets. Student participation in the survey was anonymous and voluntary, and local procedures were used to obtain parental consent. The national YRBS has been reviewed and approved by an IRB at the Centers for Disease Control and Prevention.

Measures

In 2017, the national YRBS added a question on SPAC: *The next question asks about concussions. A concussion is when a blow or jolt to the head causes problems such as headaches, dizziness, being dazed or confused, difficulty remembering or concentrating, vomiting, blurred vision, or being knocked out. During the past 12 months, how many times did you have a concussion from playing a sport or being physically active?* Response options were: *0 times*, *1 time*, *2 times*, *3 times*, or *four or more times.*

The YRBS also measures a wide range of other priority risk behaviors, including a self-reported indicator of cognitive impairment, which may adversely impact a student's ability to learn (i.e., *Because of a physical, mental, or emotional problem, do*

you have serious difficulty concentrating, remembering, or making decisions? Response options: *Yes* or *No*). The YRBS also measures self-reported academic grades (i.e., *During the past 12 months, how would you describe your grades in school?* Response options: *mostly A's*, *Mostly B's*, *Mostly C's*, *Mostly D's*, *Mostly F's*, *None of these grades*, *Not sure*). This question was also used to estimate a self-reported GPA, as follows: mostly A's=4.0, mostly B's=3.0, mostly C's=2.0, mostly D's=1.0, and mostly F's=0.0 (Appendix Table 1, available online).

Several studies have demonstrated that self-reported grades are highly correlated with actual grades among high school students.[28–30] One study of 7th and 8th-grade students estimated GPAs based on self-reported typical grades (i.e., students were asked: *What grade do you get most*?). These estimated GPAs were highly correlated with actual GPAs, based on grades received in core junior high subjects (i.e., English, math, science, and social studies).[28]

Statistical Analysis

In 2018, data were analyzed using SUDAAN, version 11 (RTI International, Research Triangle Park, NC). Prevalence estimates with 95% CIs were calculated using Taylor series linearization. The authors used *t*-test statistics to test pairwise prevalence comparisons, and chi-square statistics to test multilevel prevalence comparisons. Differences in prevalence estimates were considered statistically significant if $p<0.05$. Logistic regression models were used to calculate adjusted prevalence ratios (APRs) for cognitive impairment and the prevalence of getting mostly A's, by SPAC (*yes* versus *no*) and by frequency of SPAC (*zero times*, *one time*, *two or more times*). Linear regression models were used to test adjusted differences in self-reported GPA, by SPAC and by frequency of SPAC. Logistic regression models and linear regression models were adjusted for sex, race/ethnicity, grade, and athlete status (participation in ≥1 school- or community-run sports teams, during the past 12 months). APRs were considered statistically significant if $p<0.05$ or the 95% CI did not include 1.0. Adjusted differences were considered statistically significant if $p<0.05$ or the 95% CI did not include 0.0.

RESULTS

The 2017 national YRBS had a school response rate of 75% and a student response rate of 81%, for an overall response rate of 60% and a sample size of 14,765.

Among U.S. high school students, 49.3% (95% CI=46.7, 51.9) were male and 50.7% (95% CI=48.1, 53.3) were female. Approximately 53.5% (95% CI=48.4, 58.5) were white, non-Hispanic, 13.4% (95% CI=11.0, 16.3) were black, non-Hispanic, 22.8% (95% CI=19.2, 26.9) were Hispanic (of any race), and 10.3% (95% CI=8.9, 11.7) were other race/ethnicity; 27.3% (25.7, 29.0) were in 9th grade, 25.7% (24.6, 26.8) were in 10th grade, 23.9% (23.3, 24.6) were in 11th grade, and 23.1% (22.0, 24.2) were in 12th grade.

Approximately 15.1% (95% CI=13.6, 16.6) of all high school students self-reported ≥1 SPACs during the past 12 months. Male students represented 49.3% of the student population, yet they accounted for 56.9% of all SPACs. Student-athletes represented 54.3% of all students, yet they accounted for 76.0% of all SPACs (Table 1).

Male students were more likely than female students to have had ≥1 SPACs in the past 12 months (17.1% vs 13.0%) and were more likely to have had multiple (≥2) SPACs (6.9% vs 4.9%); similarly, athletes were more likely than nonathletes to have had ≥1 SPACs (21.4% vs 7.6%) and were more likely to have had multiple SPACs (8.3% vs 3.1%; Table 2). Male students were less likely than female students, and athletes were less likely than nonathletes, to report symptoms of cognitive impairment. Male students were less likely than female students to report making mostly A's (33.0% vs 45.6%) and had a lower self-reported GPA (2.97 vs 3.23) than female students; athletes had a higher self-reported GPA than nonathletes (3.18 vs 3.02; Table 2).

Table 1. Weighted Prevalence of SPAC Among U.S. High School Students, by Sex and Athlete Status

Demographic category	Percent of population (95% CI)	Percent of all SPAC	Frequency of SPAC[a]					χ^2	*p*-value[d]
			0	1	2	3	≥4		
Total	100 (–)	100	12,160 (84.9)	1,304 (9.1)	424 (3.0)	147 (1.0)	283 (2.0)		
Sex									
Male	49.3 (46.7, 51.9)	56.9	5,757 (82.9)	711 (10.2)	228 (3.3)	85 (1.2)	168 (2.4)	**5.5**	**<0.01**
Female	50.7 (48.1, 53.3)	43.1	6,321 (87.0)	584 (8.0)	188 (2.6)	61 (0.8)	110 (1.5)		
Athlete status[a]									
Athlete[b]	54.3 (50.6, 58.0)	76.0	5,811 (78.6)	968 (13.1)	313 (4.2)	113 (1.5)	189 (2.6)	**22.2**	**<0.001**
Nonathlete[c]	45.7 (42.0, 49.4)	24.0	5,750 (92.4)	277 (4.5)	87 (1.4)	25 (0.4)	80 (1.3)		

Source: YRBS, 2017.
Note: Values are weighted n (%) unless otherwise noted. Boldface indicates statistical significance ($p<0.05$)
[a]During the 12 months preceding the survey.
[b]Played on ≥1 or more sports teams through school or a community group.
[c]Did not play on a sports team through school or a community group.
[d]*p*-value based on $\chi 2$ tests (4 degrees of freedom).
SPAC, sports- and physical activity-related concussion; YRBS, Youth Risk Behavior Survey.

Table 2. Prevalence of SPAC, Cognitive Impairment, and Academic Grades Among U.S. High School Students, by Sex and Athlete Status

Demographic category	SPAC[a]			Cognitive impairment[b]	Academic grades[a,c]	
	0	1	≥2		Mostly A's	GPA
Total population	84.9 (83.4, 86.4)	9.1 (8.1, 10.2)	6.0 (5.3, 6.8)	32.0 (30.1, 34.0)	39.4 (36.4, 42.4)	3.11 (3.04, 3.17)
Sex						
Male	**82.9 (81.1, 84.4)**	**10.2 (9.2, 11.3)**	**6.9 (6.0, 8.0)**	**25.4 (23.7, 27.2)**	**33.0 (30.2, 35.8)**	**2.97 (2.91, 3.04)**
Female	87.0 (85.3, 88.6)	8.0 (6.8, 9.5)	4.9 (4.3, 5.7)	38.2 (34.6, 41.9)	45.6(42.0, 49.2)	3.23 (3.16, 3.30)
Athlete status[a]						
Athlete[d]	**78.6 (76.3, 80.7)**	**13.1 (11.7, 14.6)**	**8.3 (7.2, 9.6)**	**28.4 (26.6, 30.2)**	41.4 (38.2, 44.6)	**3.18 (3.12, 3.25)**
Nonathlete[e]	92.4 (91.2, 93.5)	4.5 (3.7, 5.4)	3.1 (2.5, 3.8)	36.4 (32.9, 40.2)	37.2 (32.2, 42.5)	3.02 (2.90, 3.14)

Source: YRBS, 2017.
Note: Values are % (95% CI) or mean (95% CI; GPA only). Boldface indicates statistical significance ($p<0.05$). Self-reported grade point average (GPA): Mostly A's=4.0; Mostly B's=3.0; Mostly C's=2.0; Mostly D's=1.0; and Mostly F's=0.0.
[a]During the 12 months preceding the survey.
[b]*Answered yes to Because of a physical, mental, or emotional problem, do you have serious difficulty concentrating, remembering, or making decisions?*
[c]How would you describe your grades in school?
[d]Played on ≥1 or more sports teams through school or a community group.
[e]Did not play on a sports team through school or a community group.
SPAC, sports- and physical activity-related concussion; YRBS, Youth Risk Behavior Survey.

Students with a self-reported SPAC during the past 12 months were significantly more likely than those without a SPAC to report symptoms of cognitive impairment, regardless of whether they were male (APR=1.49), female (APR=1.37), athletes (APR=1.45), or nonathletes (APR=1.42; Table 3). Self-reported cognitive impairment also was positively associated with the frequency of SPACs, but the strength of this association varied significantly by sex (Table 3). Among male students, self-reported cognitive impairment was significantly higher among those with a single concussion (APR=1.24), compared with students without a SPAC, but reached its strongest association among those reporting multiple concussions (APR=1.85). Among female students, self-reported cognitive impairment reached its strongest association with a single concussion (APR=1.41) and did not

Table 3. Association of Cognitive Impairment With SPAC Among U.S. High School Students, by Sex and Athlete Status

SPAC	Cognitive impairment[a]							
	Males		Females		Athletes[b,c]		Nonathletes[b,d]	
	%	APR (95% CI)	%	APR (95% CI)	%	APR (95% CI)	%	APR (95% CI)
One or more times[b]								
Yes	32.6	**1.49[f] (1.31, 1.69)**	48.4	**1.37[f] (1.23, 1.53)**	37.0	**1.45[f] (1.28, 1.64)**	50.8	**1.42[f] (1.20, 1.68)**
No	23.8	1.0 (ref)	36.7	1.0 (Ref)	25.9	1.0 (ref)	35.4	1.0 (ref)
Interaction	By sex: Wald F=0.11; p=0.7455				By athlete status: Wald F=0.13; p=0.7206			
Frequency of occurrence[b]								
≥2	41.0	**1.85[e,f] (1.56, 2.19)**	46.7	**1.31[e] (1.12, 1.52)**	41.2	**1.61[e] (1.35, 1.92)**	53.7	**1.47[e] (1.22, 1.76)**
1	27.0	**1.24[e] (1.05, 1.47)**	49.4	**1.41[e] (1.23, 1.62)**	34.4	**1.34[e] (1.16, 1.56)**	48.9	**1.39[e] (1.12, 1.72)**
0	23.8	1.0 (ref)	36.7	1.0 (Ref)	25.9	1.0 (ref)	35.4	1.0 (ref)
Interaction	By sex: Wald F=4.16; p=0.0237				By athlete status: Wald F=0.21; p=0.8087			

Source: YRBS, 2017.
Note:Boldface indicates statistical significance ($p<0.05$ or 95% CI does not include 1.0). APRs adjusted for sex, race/ethnicity, grade, and participation on school- or community-run sports teams.
[a]Answered yes to *Because of a physical, mental, or emotional problem, do you have serious difficulty concentrating, remembering, or making decisions*?
[b]During the 12 months preceding the survey.
[c]Played on 1 or more sports teams run by their school or a community group.
[d]Did not play on a sports team run by their school or a community group.
[e]Significantly different than students who did not have a sport- or physical activity-related concussion during the 12 months preceding the survey.
[f]Significantly different than students who had one sport- or physical activity-related concussion during the 12 months preceding the survey.
APR, adjusted prevalence ratio; SPAC, sports- and physical activity-related concussion; YRBS, Youth Risk Behavior Survey.

Table 4. Association of Academic Grades With SPAC Among U.S. High School Students

	Academic grades[a,b]					
	Mostly A's			GPA		
SPAC	%	APR	(95% CI)	GPA	β	β (95% CI)
One or more times[a]						
Yes	30.7	**0.73**[c]	**(0.68, 0.79)**	**2.95**	−0.22[c]	**(−0.27, −0.16)**
No	41.1	1.0	(ref)	3.14	0.0	(ref)
Frequency of occurrence[a]						
≥2	26.7	**0.66**[c]	**(0.55, 0.79)**	2.81	**−0.32**[c,d]	**(−0.44, −0.21)**
1	33.1	**0.77**[c]	**(0.69, 0.87)**	3.04	**−0.15**[c]	**(−0.23, −0.07)**
0	41.1	1.0	(ref)	3.14	0.0	(ref)

Source: YRBS, 2017.
Note: Boldface indicates statistical significance ($p<0.05$, or 95% CI does not include 1.0 for APRs, or 95% CI does not include 0.0 for regression βs). APRs and linear regression βs adjusted for sex, race/ethnicity, grade, and participation on school- or community-run sports teams. Self-reported GPA: Mostly A's=4.0; Mostly B's=3.0; Mostly C's=2.0; Mostly D's=1.0; and Mostly F's=0.0.
[a]During the 12 months preceding the survey.
[b]How would you describe your grades in school?
[c]Significantly different than students who did not have a sport- or physical activity-related concussion during the 12 months preceding the survey.
[d]Significantly different than students who had one sport- or physical activity-related concussion during the 12 months preceding the survey.
APR, adjusted prevalence ratio; GPA, grade point average; SPAC, sports- and physical activity-related concussion; YRBS, Youth Risk Behavior Survey.

increase with multiple concussions (APR=1.31). The strength of the association between self-reported cognitive impairment and frequency of SPACs did not vary significantly by athlete status (Table 3).

Students who had a SPAC during the past 12 months were less likely than those without a SPAC to report making mostly A's (30.7% vs 41.1%; APR=0.73), and self-reported GPA was significantly lower (2.95 vs 3.14, β= −0.22; Table 4). The estimated GPA was highest among students who reported no concussions (GPA= 3.14), significantly lower among students who had a single concussion (GPA=3.04), and was lowest among students who reported ≥2 concussions (GPA=2.81; Table 4). The associations between academic grades and SPAC or frequency of SPAC did not vary significantly by sex or athlete status (i.e., no effect modification); therefore, those results were not stratified by sex or athlete status.

DISCUSSION

Our study is the first to examine the relationship between self-reported SPAC, cognitive impairment, and academic performance among a nationally representative sample of U.S. high school students. Of all SPACs experienced by high school students, more than half (56.9%) occurred among male students, and 3 of 4 (76.0%) occurred among student-athletes. During the 12 months preceding the survey, 15.1% of all high school students experienced at ≥1 concussion, and 6.0% experienced multiple (≥2) concussions. Both single and multiple occurrences of SPAC were more common among male versus female students and were more common among student-athletes compared with nonathletes. The increased prevalence of SPAC among male versus female students may reflect the greater participation of male students in physical activity and sports relative to female students.[26]

Post-concussive symptoms experienced by most children who suffer mild TBI resolve within 1–3 months after injury.[20,31–33] Also, some recent evidence suggests aerobic activity can improve recovery even with symptoms.[34,35] However, continuing to play sports or be physically active with an asymptomatic concussion may increase the risk for a subsequent concussion, and repeated mild TBI over months or years can result in cumulative neurologic and cognitive defects.[36,37] Thus, students who reported multiple concussions during the past 12 months are of particular concern. Among male and female students, as well as student-athletes and nonathletes, self-reported cognitive impairment was more prevalent among those who experienced one or more concussions. In addition, among male students, self-reported cognitive impairment was significantly higher among students who experienced multiple concussions compared with those who experienced a single concussion. Among female students, the strength of the association between SPAC and cognitive impairment did not vary by frequency of concussion, which may be related to the high prevalence of self-reported cognitive impairment in the general student population (32.0%) and among female students in particular (38.2%). The association between SPAC and self-reported cognitive impairment cannot be attributed directly to the occurrence of TBI, as the study was cross-sectional and there

could be other causes of difficulty concentrating, remembering, or making decisions. However, these symptoms are linked to classroom performance following TBI and should be monitored when students return to school.[21] Other explanations for the association between SPAC and cognitive impairment include co-occurring health conditions such as learning disabilities, attention deficit disorder, and other mental health disorders which may have been present at the time of SPAC, each of which previously have been associated with a lifetime history of TBI.[38] Longitudinal studies are needed to disentangle the relationship between SPAC and the development or decline of later cognitive dysfunction.

Following mild TBI, most children will follow a course of spontaneous recovery back to their preinjury functional level.[31–33] However, some children with mild TBI will go on to experience persistent symptoms that may affect their long-term social function and academic success.[15,16,20,31,32,39] This study found students who experienced ≥1 SPAC during the past 12 months were less likely to report making mostly A's and had a significantly lower self-reported GPA compared with students who did not have a concussion. The negative association between SPAC and academic grades was highest among students who experienced multiple concussions. Among students who did not have a concussion, 41.1% reported making mostly A's (GPA=3.14); among students who had a single concussion, 33.1% reported making mostly A's (GPA=3.04); and among students who had ≥2 concussions, 26.7% reported making mostly A's (GPA=2.81) during the past 12 months. One study found that recently concussed youth athletes had lower cumulative GPAs at the time of injury, suggesting that youth athletes with lower GPAs may be more susceptible to sustaining concussions.[11] Additional prospective studies with standardized cognitive testing and documentation of school performance are needed to document any temporal relationships between SPAC, cognitive impairment, and academic achievement. Although these decreases in self-reported academic grades may reflect, in part, temporary changes (including decreased attendance) that occur around the time of the injury, even a temporary drop in grades may create additional stress for students.

Limitations

This study has several limitations. YRBS data apply only to youth who attend school and therefore are not representative of all youth in this age group. The data on SPAC, cognitive impairment, and academic grades are self-reported, and the extent of under-reporting or over-reporting of self-reported behaviors cannot be determined, although the YRBS survey questions generally demonstrate good test-retest reliability,[40] and studies have shown self-reported grades to be highly correlated with actual grades.[28–30] YRBS data are cross-sectional and thus can only indicate association, not causality. There may have been pre-existing learning disabilities and other social and individual factors the authors were unable to control for, and these have the potential to confound the findings. Finally, the authors did not have access to specific data on the timing of the SPAC relative to completing the survey, nor did they have access to official data on student GPAs based on grades achieved in individual courses.

CONCLUSIONS

There is a growing consensus that SPAC symptoms can persist for months and even years in approximately 10%–20% of patients, with children and adolescents at highest risk for persistent concussion symptoms.[39,41] Further, even mild repeated brain injuries experienced during the school-age years have the potential to lead to permanent learning disabilities and neuropsychiatric problems.[31,32,39] In this study, nearly 1 of 6 high school students reported experiencing a concussion while participating in sports or physical activity, and one in 20 students experienced multiple concussions. To provide comprehensive, evidence-based guidance to healthcare professionals who diagnose and treat concussions, as well as school-based return to learn programs, the Centers for Disease Control and Prevention recently published a guideline on the diagnosis and management of mild TBI among children.[31] Regarding return to school programs, the guideline recommends healthcare providers give parents a plan for the student to return to school at discharge and that post-concussion symptoms and academic progress in school be monitored collaboratively by the student, family, healthcare professionals, and school teams. Ideally, this group can jointly determine what modifications or accommodations are needed to maintain an academic workload without significantly exacerbating symptoms or increasing risk for another concussion.

Of concern was that self-reported concussion was associated with self-reported symptoms of cognitive impairment and lower self-reported grades. Unfortunately, these data are cross-sectional and cannot establish the direction of the associations between SPAC and academic impairment. There may be modifiable cognitive or psychosocial risk factors that are associated with both lower grades and concussion that were not identified in our study. Addressing such pre-existing risks might improve students' grades and minimize risk for future concussions. However, regardless of causal mechanisms, comprehensive efforts are needed to support students

with SPAC, through schools, clinicians, parents, and sports program coaches and leaders. In particular, schools can play an essential role by monitoring students' academic performance and providing educational support and resources to promote academic success following a concussion.

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SUPPLEMENTAL MATERIAL

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