# Concussion Exposure and Suicidal Ideation, Planning, and Attempts Among US High School Students

# Jacob J. M. Kay, PhD, MSc\*†; Colt A. Coffman, BSc‡; Adam Harrison, PhD, MSc§; Abbas S. Tavakoli, DrPH, MPH, ME¶; Toni M. Torres-McGehee, PhD, ATC†; Steven P. Broglio, PhD, ATCII; Robert Davis Moore, PhD†

\*Department of Pediatrics, Prisma Health Children's Hospital, Columbia, SC; †Arnold School of Public Health, §Department of Exercise Science and ¶College of Nursing, University of South Carolina, Columbia; ‡Michigan State University, East Lansing; IlMichigan Concussion Center, University of Michigan, Ann Arbor

**Context:** Interest is growing in the association between repetitive concussions and mental health. However, studies on the relationship between concussion frequency and adverse mental health outcomes among female and male youth are lacking.

**Objectives:** To examine the association between selfreported concussion frequency and nonfatal suicidal behaviors among youth and to explore the possible interaction of biological sex.

Design: Retrospective cross-sectional survey.

**Setting:** National Youth Risk Behavior Surveillance System. **Patients or Other Participants:** United States secondary school students (N = 28442).

**Main Outcome Measure(s):** Exposure variables were the frequency of self-reported sport- or recreation-related concussion in the previous 12 months  $(0, 1, \ge 2)$ . Outcome variables were feelings of self-reported sadness or hopelessness and suicidal ideation, planning, and attempts. Covariates were age, sex, race and ethnicity, bullying victimization, sexual orientation, and physical activity.

**Results:** Students who reported  $\geq 2$  concussions were at significantly greater odds of reporting suicidal attempts (adjusted odds ratio = 2.03; 95% CI = 1.43, 2.88) when compared with students reporting a single concussive event during the past 12 months. However, sex interactions revealed that this finding may have been driven by males; the strength of associations did not increase from single to multiple concussions among females.

**Conclusions:** Our findings suggest that adolescents who reported concussion were at increased odds of reporting poor mental health and suicidal behaviors. Moreover, an increased number of concussive events may be associated with significantly greater odds of reporting suicidal attempts, particularly among males. Irrespective of sex, health care professionals should closely monitor mental health behaviors in adolescents with repetitive concussions, especially those that occur in close temporal proximity.

Key Words: mild traumatic brain injury, youth, mental health

#### **Key Points**

- Youth who reported a history of concussion in the last 12 months were at greater odds of engaging in suicidal ideation, planning, and attempts than their nonconcussed counterparts.
- A higher frequency of concussion in the previous 12 months was associated with greater odds of reporting suicidal attempts, particularly among males.
- Medical professionals should closely evaluate and monitor mental health in youth, especially those with a recent history of repetitive concussions.

he accurate diagnosis and management of sport- and recreation-related concussions (SRRCs), especially among youth and adolescent populations, represent a significant burden to medical professionals. An estimated 1.9 million adolescent SRRCs occur annually in the United States.<sup>1</sup> Furthermore, the incidence of reported SRRCs among adolescents continues to steadily increase each year.<sup>2</sup> It is difficult to determine whether this rise is due to a higher incidence of injury, increased public awareness of symptoms, or improvements in clinical diagnosis.<sup>3</sup> Regardless, adolescence marks a time of robust neurodevelopment,

and sustaining a brain injury during this stage of life may increase the risk of complicated recovery.<sup>4</sup> Thus, it is important for health care professionals to completely understand the spectrum of psychological and behavioral consequences after concussion in youth.

Mechanistically, SRRCs result in diffuse neurochemical and neuroanatomical alterations that cause widespread disruption in neurologic function, leading to a constellation of immediate or delayed emotional, cognitive, and behavioral symptoms.<sup>5</sup> Repeated exposure to concussive and subconcussive head trauma has been linked to an increased risk of subsequent head injuries and more prolonged recovery.<sup>4</sup> Moreover, repeated exposure in retired professional contact athletes and military veterans is associated with increased risks of chronic traumatic encephalopathy<sup>6</sup> and posttraumatic stress disorder,<sup>7</sup> respectively. Both chronic traumatic encephalopathy and posttraumatic stress disorder are associated with emotional dysregulation as highlighted by unpredictable mood swings, severe depression, and increased suicidal ideation and behaviors.<sup>8,9</sup>

Suicide is the second leading cause of death among adolescents in the United States.<sup>10</sup> Between 2001 and 2017, youth suicide rates increased from 10.7 per 100000 to 14.0 per 100000.<sup>10</sup> The term *suicidality* refers to suicidal ideation (serious thoughts about taking one's own life), suicide planning, and nonfatal suicide attempts (intentional self-harm). Adolescents who experience suicidal thoughts and behaviors are at significant risk of attempting suicide.<sup>11</sup> In 2020, roughly 100 000 adolescents (aged 10–19 years) were hospitalized for intentional self-harm (according to the latest available data).<sup>12</sup> Thus, it is critical for health care professionals to understand the factors that influence suicidality in adolescents.

The authors of several recent epidemiologic studies investigated the potential effect of SRRC on suicidal behaviors and ideation in adolescents. Previous researchers<sup>13–15</sup> who used the National Youth Risk Behavior Surveillance System (YRBSS) data suggested that individuals with a history of SRRC demonstrated greater odds of suicidal behaviors and attempts compared with individuals with no history. However, suicidality among youth is a complex concept affected by numerous factors, such as depression, bullying and victimization, and sexual orientation.<sup>16</sup> When the results were adjusted for these variables, most of the general associations among SRRC and suicidality seemed to dissipate, leaving sex-specific differences.<sup>17</sup> Unfortunately, no authors to date have investigated the role of SRRC frequency, leaving us with an incomplete understanding of suicidality after concussion among youth.

Accordingly, the purpose of our study was to examine the associations between concussion frequency, depressive symptoms, and suicidal thoughts and behaviors in a nationally representative sample of adolescents using data from the 2017 and 2019 National YRBSS.<sup>18</sup> In line with previous work, we anticipated that adolescents reporting at least 1 SRRC in the last 12 months would exhibit increased odds of reporting sadness or hopelessness and suicidal ideation, planning, and attempts when compared with adolescents with no history of concussion. We further hypothesized that adolescents reporting  $\geq 2$  injuries would demonstrate the greatest odds of suicidal ideation and behaviors compared with those reporting 1 SRRC or none. A secondary aim was to explore possible sex differences across associations. We proposed that males and females would demonstrate different risk behavior profiles when factoring for concussion frequency.

#### **METHODS**

#### Survey Sample

Data from the 2017 and 2019 National YRBSS were combined and cross-sectionally analyzed. A detailed description of the YRBSS sampling methods can be found elsewhere.<sup>19</sup> The YRBSS administers a school-based

survey biennially with the goal of monitoring the prevalence of priority health risk behaviors among youth. A 3-stage cluster-sampling design was used to produce a nationally representative sample of public and private school students in grades 9 through 12. Weight factors were applied to each respondent record to adjust for nonresponse and oversampling of certain grades, sex, and racial and ethnic demographics. Data from the YRBSS provide valid measures of health risk behaviors among this cohort.<sup>20</sup> Parental permission was obtained at each collection site, and survey participation was voluntary. Respondents provided their information anonymously on computer-scannable answer sheets. An institutional review board at the Centers for Disease Control and Prevention approved all procedures.

### Measures

A detailed description of questionnaire items, including prompts, response options, and statistical coding, can be found in the Supplemental Table (available online at http:// dx.doi.org/10.4085/1062-6050-0117.22.S1). Concussion exposure is a new variable included in the national YRBSS and was consistent across the 2017 and 2019 survey years. The relevant question in the survey is specific to the respondent's participation in sport or recreational activities. Concussion exposure was the independent variable of interest in our study. To investigate the role of concussion frequency in suicidality, we categorized responses as *no concussion history* (0), *a single concussion* (1), and *multiple concussions* ( $\geq 2$ ) in the past 12 months.

The outcome variables for this investigation were 5 questions from the YRBSS regarding mental health and suicidal behaviors and were consistent across the 2017 and 2019 survey years. Self-reported indicators of mental health and suicidality were (1) sadness or hopelessness, (2) suicidal ideation, (3) suicidal planning, (4) suicide attempts, and (5) injurious suicide attempts in the past 12 months. Responses to all suicidality questions were dichotomized as 0 = no (reference) or 1 or more = yes.

Demographic factors (grade, sex, and race and ethnicity) were analyzed as covariates. Sex was dichotomized as male or female. Grade was categorized as 9th, 10th, 11th, or 12th. Race and ethnicity were categorized as Hispanic/ Latino, non-Hispanic Black, non-Hispanic White, or other (which included American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander, non-Hispanic, and multiracial). Lifestyle factors known to negatively affect mental health (eg, bullying victimization, sexual orientation),<sup>16</sup> as well as those known to positively affect mental health (eg, physical activity)<sup>21,22</sup> were controlled for in our analyses. Two survey questions about bullying were combined into a single covariate for analyses; students who responded yes to either of these questions were considered to have experienced bully victimization in the past 12 months. Current physical activity guidelines for children<sup>22</sup> were used to dichotomize student responses into those who did (*yes*) or did not (*no*; reference) report  $\geq 5$  days of physical activity a week for  $\geq 60$  minutes.

# **Statistical Analysis**

A total combined sample of 28442 respondent questionnaires were available for analysis across the 2017 and 2019 survey years. Minimal data were missing for concussion history (9.69%), sadness or hopelessness (1.17%), suicidal ideation (1.59%), suicidal planning (1.68%), and other covariates (0.97%–4.78%); thus, we were left with a final sample of 23 445 students (82.43% of the total sample). However, considerable data were missing for attempted suicide and injurious attempted suicide (21.26%); therefore, a final sample of 17 397 students was analyzed using these outcome measures (61.16% of the total sample). Substantial missing data for these 2 variables presented the potential for selection bias.<sup>19</sup> As such, we conducted attrition analyses using  $\chi^2$  tests and post hoc examination of  $\varphi$  coefficients to observe the degree to which participants differed between the 2017 and 2019 samples across the study variables.

All hypothesis testing was conducted using SAS (version 9.4; SAS Institute). Descriptive statistics were calculated and provided in frequency tables. Inferential statistics consisted of  $\chi^2$  tests to examine bivariate associations between categorical outcomes and predictors. The GEN-MOD procedure in SAS was applied to evaluate the association between concussion history and (1) sadness or hopelessness, (2) suicidal ideation, (3) suicidal planning, (4) suicidal attempts, and (5) injurious suicidal attempts. In addition, adjusted odds ratios (AORs) with 95% CIs were computed. Weighted generalized linear models, including logistic and probit models, were used to examine binary response data (ves versus no) for each of the 5 associations of concussion history and suicidality. Additional generalized linear models, including log-linear and Poisson regression models, were performed to determine the association between concussion frequency (3 levels: no SRRC history [0 times; reference], 1 SRRC [1 time], and multiple SRRCs [>2 times]) and suicidality. All statistical models were adjusted for the covariates of age, sex, race and ethnicity, bully victimization, sexual orientation, and physical activity. For each model, an interaction term between concussion exposure and sex was included to explore possible differences between males and females. An a priori  $\alpha$  level of .05 was set for all analyses, and Bonferroni correction was applied to adjust for multiple comparisons ( $P \leq .005$ ).

# RESULTS

#### **Sample Demographics**

Attrition analyses revealed statistical differences across the various study variables between the 2017 and 2019 survey years. However, post hoc examination of  $\varphi$ coefficients indicated no substantial potential for selection bias, as the strengths of associations were considered small.<sup>23</sup> Only race and ethnicity was substantive ( $\varphi =$ 0.164); however, this was still considered a small effect. Thus, rather than sample bias, this suggests that the observed differences may have been due to the large sample size.<sup>23</sup>

Among respondents, 15.0% reported  $\geq 1$  SRRC during the past 12 months, with 5.6% reporting  $\geq 2$  SRRCs during the past 12 months. A greater proportion of male students than female students reported  $\geq 1$  SRRC during the past 12 months (16.7% versus 13.2%, respectively; Cramer V = 0.048). See Table 1 for complete respondent demographics stratified by SRRC frequency. A greater proportion of female students than male students reported feeling sad or hopeless (44.3% versus 23.6%, respectively; Cramer V = 0.218), suicidal ideation (23.6% versus 12.5%, respectively; Cramer V = 0.145), suicidal planning (18.8% versus 10.3%, respectively; Cramer V = 0.120), attempting suicide (10.1% versus 5.4%; Cramer V = 0.089), or being injured from an attempted suicide (3.1% versus 1.4%, respectively; Cramer V = 0.056) in the past 12 months. Table 2 shows the demographic characteristics among participants responding *yes* to depression and suicidality variables.

#### Suicidality and Frequency of Concussion

Similar to previous investigators<sup>13–15</sup> who used the YRBSS, we found significant associations between concussion history and the odds of reporting feelings of depression and suicidal ideation and behaviors (Tables 3 and 4). Those who reported  $\geq 2$  SRRCs in the past 12 months were not at significantly greater odds of reporting feelings of depression, suicidal ideation, or suicidal planning than those who reported a single SRRC. However, students who reported  $\geq 2$  SRRCs in the past 12 months were at significantly greater odds of reporting suicidal attempts (AOR = 2.03; 95% CI = 1.43, 2.88).

#### **Sex Comparisons**

The association between SRRC frequency and suicidal behavior in the past 12 months differed significantly by sex. Among female students, those who reported a single SRRC during the past 12 months were at significantly greater odds of reporting feelings of sadness or hopelessness (AOR =1.30; 95% CI = 1.15, 1.49), suicidal ideation (AOR = 1.54;95% CI = 1.32, 1.78), suicidal planning (AOR = 1.46; 95%) CI = 1.25, 1.71, attempting suicide (AOR = 1.54; 95%) CI = 1.25, 1.89), or being injured from an attempted suicide (AOR = 1.90; 95% CI = 1.38, 2.60) than those who did not report an SRRC, but the strengths of these associations did not significantly increase with multiple (>2) SRRCs (Tables 3 and 4). Among male students, the odds of reporting suicidal behaviors increased significantly with a single concussion for feeling sad or hopeless (AOR = 1.27; 95% CI = 1.10, 1.47), suicide attempts (AOR = 1.67; 95% CI = 1.26, 2.21), or injurious suicide attempts (AOR = 2.79; 95% CI = 1.74, 4.47; Tables 3 and 4).Furthermore, males who reported  $\geq 2$  SRRCs during the past 12 months were at significantly greater odds of reporting attempting suicide (AOR = 1.99; 95% CI = 1.39, 2.83) than males who reported a single SRRC event during the past 12 months (Table 4).

#### DISCUSSION

Our findings contribute to a growing body of literature regarding the association between concussion and suicidal behaviors among adolescents. To our knowledge, we are the first to examine the relationship between concussion frequency and suicidality in a nationally representative sample of US high school students. These results suggest that high school students who experienced a recent SRRC were at greater odds of reporting depressive symptoms and suicidal ideation, planning, and attempts when compared with students who did not experience a recent SRRC.

Table 1.	Weighted Prevalence of Demographic Characteristics Among US High School Students by Frequency of Sport- and Recreation-
<b>Related</b> C	Concussion <sup>a</sup>

		F Recre			
Variable	No. (Weighted %)	0	1	<u>≥</u> 2	$\chi^2$ Value
Total	23445 (100.0)	20014 (85.0)	2100 (9.4)	1331 (5.6)	
Sex					
Male	11291 (50.1)	9437 (83.3)	1089 (10.0)	765 (6.7)	71.56
Female	12154 (49.9)	10577 (86.8)	1011 (8.7)	566 (4.5)	
Grade					
9	6080 (26.4)	5117 (83.6)	605 (10.8)	358 (5.6)	41.87
10	6108 (25.5)	5176 (85.1)	551 (8.7)	381 (6.2)	
11	5883 (24.4)	5045 (84.6)	516 (9.7)	322 (5.7)	
12	5374 (23.7)	4676 (87.0)	428 (8.1)	270 (4.9)	
Race or ethnicity					
Black non-Hispanic	3833 (12.0)	3206 (83.4)	310 (8.2)	317 (8.4)	
Hispanic or Latino	5921 (25.4)	5102 (85.6)	463 (8.5)	356 (5.9)	
White non-Hispanic	10935 (51.9)	9346 (81.9)	1099 (10.3)	490 (7.8)	82.99
Other <sup>c</sup>	2756 (10.7)	2360 (86.2)	228 (8.1)	168 (5.7)	
Sexual orientation					
Heterosexual	20001 (85.5)	17074 (85.1)	1825 (9.5)	1102 (5.4)	23.34
Gay or lesbian	570 (2.3)	484 (85.2)	50 (9.3)	36 (5.5)	
Bisexual	1911 (8.2)	1651 (85.3)	153 (8.8)	107 (5.9)	
Not sure	963 (4.0)	805 (84.2)	72 (7.2)	86 (8.6)	
Physically active				. ,	
Yes <sup>d</sup>	10384 (46.3)	8530 (81.4)	1159 (11.7)	695 (6.9)	220.45
No	13061 (53.7)	11484 (88.2)	941 (7.3)	636 (4.5)	
Bullying victimization				. ,	
Yes <sup>e</sup>	5545 (24.0)	4480 (79.4)	665 (12.8)	400 (7.8)	189.13
No	17900 (76.0)	15534 (86.8)	1435 (8.3)	931 (4.9)	

<sup>a</sup> Source: Youth Risk Behavior Surveillance System, 2017, 2019.<sup>18</sup> Boldface indicates statistical significance (*P* < .001).

<sup>b</sup> During the 12 mo before the survey.

° Other corresponds to American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander, non-Hispanic, and multiracial.

<sup>d</sup> Answered *yes* to being physically active at least 60 min/d on  $\geq$ 5 d/wk.

<sup>e</sup> Answered yes to being bullied on school property or electronically (via texting, social media) or both during the past 12 mo.

Furthermore, the odds of reporting such risk behaviors (specifically, suicide attempts) may be compounded by increased SRRC exposure. Also, the association between concussion frequency and suicidality may differ between males and females.

Prior YRBSS investigators<sup>14,15,24,25</sup> have demonstrated that individuals experiencing  $\geq 1$  concussion in the last 12 months were at greater odds of reporting increased feelings of sadness or hopelessness (AORs = 1.48-1.87), as well as suicidal ideation (AORs = 1.26-1.95), planning (AORs = 1.27-1.97), and attempts (AORs = 1.33-3.10). Importantly, our study builds upon this initial research by exploring the possible association between adolescent concussion and suicidality, stratified by the number of self-reported SRRCs during the preceding 12 months. The odds of reporting suicidality may increase along with the number of concussive injuries, suggesting a potentially compounding relationship between concussion and adolescent suicidality within a 12-month period. Specifically, high school students who reported  $\geq 2$  concussive injuries exhibited 2-fold greater odds of reporting attempted suicide when compared with adolescents who reported a single concussive event in the preceding 12 months.

Our findings corroborate those of investigators<sup>26</sup> who demonstrated that a history of multiple concussions and incomplete physiological recovery before subsequent injury was associated with longer and more complicated recovery profiles among adults. Furthermore, repeated head trauma

in athletes and military service members has been linked to chronic and debilitating alterations in mental and psychological health.<sup>27,28</sup> Repeated concussive events may lead to an exaggerated neuroinflammatory response, thereby impairing recovery and disrupting neurologic function.<sup>29</sup> Increased neuroinflammation is also associated with severe psychiatric conditions such as major depressive disorder,<sup>30</sup> suicidality,<sup>31</sup> and posttraumatic stress disorder.<sup>27</sup>

A secondary aim of our work was to assess differences in suicidality among male and female adolescents with a history of SRRC. Consistent with prior authors,<sup>32</sup> we observed that a greater proportion of females than males reported feelings of sadness or hopelessness (44.3% versus 23.6%, respectively), as well as suicidal ideation (23.6%) versus 12.5%, respectively), planning (18.8% versus 10.3%, respectively), and attempts (10.1% versus 5.4%, respectively) during the preceding 12 months, regardless of concussion status. We failed to detect any sex differences when factoring in concussion status (ie, no history of SRRC versus a history of SRRC). However, when factoring in concussion frequency, unique sex-based reporting differences emerged. Specifically, increased odds of reporting suicidal behaviors were similar across females who reported 1 or multiple concussions when compared with females who reported no concussion history during the preceding 12 months. In contrast, although the odds of reporting suicidal behaviors also increased significantly among males who reported a single concussive event, these

Table 2.	Weighted Prev	alence of Depression	and Suicidality	Characteristics	Among US High	School Students <sup>a</sup>
----------	---------------	----------------------	-----------------	-----------------	---------------	------------------------------

Variable	Sadness/Hopelessness <sup>b</sup>	Suicidal Ideation <sup>c</sup>	Suicidal Planning <sup>d</sup>	Suicide Attempt(s) <sup>e</sup>	Injurious Suicide Attempt(s) <sup>f</sup>
Total	7948 (34.0)	4290 (18.0)	3432 (14.5)	1392 (8.0)	412 (2.4)
Sex					
Male	2671 (23.6)	1418 (12.5)	1186 (10.3)	441 (5.4)	116 (1.4)
Female	5277 (44.3)	2872 (23.6)	2246 (18.8)	951 (10.1)	296 (3.1)
Grade					
9	1954 (31.9)	1140 (17.3)	900 (13.8)	395 (8.4)	119 (2.3)
10	2114 (34.6)	1118 (18.1)	909 (14.8)	389 (8.6)	102 (2.4)
11	2013 (34.8)	1095 (18.4)	847 (15.2)	328 (7.1)	96 (2.2)
12	1867 (34.9)	937 (18.4)	776 (14.5)	280 (6.9)	95 (2.2)
Race or ethnicity					
Black non-Hispanic	1120 (29.7)	605 (15.5)	522 (13.5)	233 (9.7)	72 (3.2)
Hispanic or Latino	2196 (36.5)	1021 (16.5)	836 (13.6)	385 (7.9)	128 (2.6)
White non-Hispanic	3649 (33.3)	2058 (18.6)	1571 (14.4)	578 (7.0)	153 (1.9)
Other <sup>g</sup>	983 (36.3)	606 (21.8)	503 (18.5)	196 (9.8)	59 (3.0)
Sexual orientation					
Heterosexual	5895 (29.6)	2841 (13.8)	2226 (11.0)	862 (5.6)	248 (1.6)
Gay or lesbian	326 (56.4)	231 (41.2)	192 (32.5)	76 (16.7)	28 (6.2)
Bisexual	1262 (66.7)	914 (49.2)	782 (41.3)	355 (24.2)	106 (6.8)
Not sure	465 (47.7)	304 (31.6)	232 (24.9)	99 (13.3)	30 (4.4)
Physically active					
Yes <sup>h</sup>	2884 (28.2)	1487 (14.0)	1230 (11.8)	507 (6.1)	145 (1.8)
No	5064 (39.0)	2803 (21.5)	2202 (16.9)	885 (9.2)	267 (2.7)
Bullying victimization					
Yes <sup>i</sup>	3220 (58.3)	2053 (35.8)	1656 (29.5)	768 (17.7)	255 (5.8)
No	4728 (26.3)	2237 (12.4)	1776 (9.8)	624 (4.5)	157 (1.1)

Note: Data are reported as No. (weighted %). Boldface indicates statistical significance (P < .001).

<sup>a</sup> Source: Youth Risk Behavior Surveillance System, 2017, 2019.<sup>18</sup>

<sup>b</sup> Answered *yes* to "During the past 12 months, did you ever feel so sad or hopeless almost every day for 2 weeks or more in a row that you stopped doing some usual activities?"

° Answered yes to "During the past 12 months, did you ever seriously consider attempting suicide?"

<sup>d</sup> Answered yes to "During the past 12 months, did you make a plan about how you would attempt suicide?"

<sup>e</sup> Attempted suicide 1 or more times during the past 12 months.

<sup>f</sup> Answered yes to "If you attempted suicide during the past 12 months, did any attempt result in an injury, poisoning, or overdose that had to be treated by a doctor or nurse?"

<sup>9</sup> Other includes American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander, non-Hispanic, and multiracial.

<sup>h</sup> Answered yes to being physically active at least at least 60 min/d on (greater than or equal to symbol) 5 d/wk.

Answered yes to being bullied on school property or electronically (via texting, social media) or both during the past 12 months.

findings were seen primarily for active (attempts, injurious attempts) versus passive (ideation, planning) behaviors. More concerning was that males who reported multiple concussions were at 2-fold greater odds of reporting suicidal attempts than males reporting a single SRRC in the preceding 12 months.

Together, these results suggest that males may engage with suicidal behaviors in a more impulsive manner. Though these outcomes may reflect trends in the broader adolescent riskbehavior literature (ie, females were more likely to report suicidal behaviors),<sup>33</sup> this evidence likely does not fully explain the sex differences we demonstrated. Current research<sup>34</sup> on concussion and adolescent mental health indicates that females may be more prone to disturbances in psychological well-being after concussion when compared with males. In addition, other investigators<sup>35</sup> who used more objective psychophysiological measures (eg, electroencephalogram) identified blunted emotional processing in males, particularly in the context of multiple concussions. Mechanisms for sex-based differences remain largely unknown, yet our study provides the first evidence for potential sex differences in the effects of multiple concussions on shortterm adolescent suicidal behavior.

Removal from everyday activities and the need for special accommodations may lead to an increased social burden and feelings of isolation after injury.<sup>36,37</sup> Additionally, persisting neurologic imbalances may hamper effective emotional regulation and coping strategies.<sup>38</sup> If left unattended, these factors may predispose individuals to severe psychiatric conditions (ie, suicidal thoughts and behaviors) and may be further exacerbated with repeated exposures. This increases the clinical burden and further complicates the management of patients with concussive brain injuries. Notably, these findings further support the need for comprehensive multidimensional evaluation protocols, including follow-up assessments of psycho-affective health incorporating domains of emotional regulation.

# Limitations

Though our results strengthen the extant knowledge regarding the association between concussion and adolescent suicidality, several limitations should be considered. Foremost, because of the YRBSS's cross-sectional nature, we were unable to establish the temporal sequence of concussive events and adolescent risk behaviors during the 12 months of each survey. This limitation prevented us

Table 3.	Adjusted Odds of Depression,	Suicidal Ideation,	and Suicidal	Planning by SRRC	Exposure	Among US Ma	le and Female High
School St	tudents <sup>a</sup>						

	Males	(n = 11291)	Female	s (n = 12154)
Frequency of SRRC <sup>b</sup>	Percentage	AOR (95% CI)	Percentage	AOR (95% CI)
Sadness or hopelessness <sup>c</sup>				
0	22.7	1.00 (ref)	43.1	1.00 (ref)
1	26.5	1.27 (1.10, 1.47) <sup>d</sup>	53.2	1.30 (1.15, 1.49) <sup>d</sup>
≥2	30.9	1.32 (1.12, 1.57) <sup>d</sup>	50.7	1.24 (1.03, 1.49)
		Interaction: likelihood ratio test	t ( $\chi^2 = 0.20$ , df = 2, $P = 0.9$	91)
Suicidal ideation <sup>e</sup>				
0	11.9	1.00 (ref)	22.4	1.00 (ref)
1	13.4	1.21 (1.01, 1.46)	33.4	1.54 (1.32, 1.78) <sup>d</sup>
≥2	18.1	1.39 (1.13, 1.70) <sup>d</sup>	27.4	1.18 (0.96, 1.46)
		Interaction: likelihood ratio tes	st ( $\chi^2 = 5.36$ , df = 2, $P = .0$	7)
Suicidal planning <sup>f</sup>				
0	9.8	1.00 (ref)	17.7	1.00 (ref)
1	11.5	1.23 (1.01, 1.50)	26.6	1.46 (1.25, 1.71) <sup>d</sup>
≥2	15.3	1.38 (1.12, 1.71) <sup>d</sup>	23.5	1.25 (1.00, 1.56)
		Interaction: likelihood ratio tes	at ( $\chi^2 = 2.11$ , df = 2, $P = .3$	5)

Abbreviations: AOR, adjusted odds ratio; ref, referent; SRRC, sport- and recreation-related concussion.

<sup>a</sup> Source: Youth Risk Behavior Surveillance System, 2017, 2019.<sup>18</sup> The AORs were adjusted for age, race or ethnicity, and alcohol use. Boldface indicates statistical significance (P < .005).

<sup>b</sup> During the 12 mo before the survey.

<sup>c</sup> Answered *yes* to "During the past 12 months, did you ever feel so sad or hopeless almost every day for 2 weeks or more in a row that you stopped doing some usual activities?"

<sup>d</sup> Significantly different from students who did not have an SRRC during the 12 mo before the survey.

<sup>e</sup> Answered yes to "During the past 12 months, did you ever seriously consider attempting suicide?"

<sup>f</sup> Answered yes to "During the past 12 months, did you make a plan about how you would attempt suicide?"

from inferring a causal relation between concussion and adolescent suicidality. Second, because of the inherent nature of the YRBSS database, we were able to investigate only nonfatal suicide behaviors. Therefore, these results cannot be generalized to include the overall suicide risk. Additionally, despite the emphasis on anonymity of respondents, YRBSS data are self-reported; thus, it is not possible to account for underreporting or overreporting of concussive events and risk behaviors. For example, students may exhibit a tendency to answer in a socially desirable manner (ie, they may report fewer concussive events or suicidal behaviors than experienced). Third, the YRBSS sampling method accounts only for youth who attend school; hence, our study did not reflect all youth in this age group (ie, sample bias). Furthermore, though a strength of our work was the evaluation of several mental health

Table 4.	Adjusted Odds of	f Suicidal Attempt(s) by	SRRC Exposure	Among US Male and	Female High School Students <sup>a</sup>
----------	------------------	--------------------------	---------------	-------------------	--

	Male	es (n = 8278)	Female	es (n = 9119)	
Frequency of SRRC <sup>b</sup>	Percentage	AOR (95% CI)	Percentage	AOR (95% CI)	
Suicide attempt(s)°					
0	4.5	1.00 (ref)	9.2	1.00 (ref)	
1	6.7	1.67 (1.26, 2.21) <sup>d</sup>	15.7	1.54 (1.25, 1.89) <sup>d</sup>	
≥2	15.3	3.30 (2.54, 4.31) <sup>d,e</sup>	17.1	1.76 (1.32, 2.35) <sup>d</sup>	
		Interaction: likelihood ratio tes	t ( $\chi^2 = 9.02$ , df = 2, $P = .0$	1)	
Injurious suicide attempt(s) <sup>c,f</sup>					
0	1.0	1.00 (ref)	2.7	1.00 (ref)	
1	2.5	2.79 (1.74, 4.47) <sup>d</sup>	6.0	1.90 (1.38, 2.60) <sup>d</sup>	
≥2	5.9	4.80 (3.13, 7.38) <sup>d</sup>	6.7	2.20 (1.44, 3.37) <sup>d</sup>	
	Interaction: likelihood ratio test ( $\chi^2 = 7.57$ , df = 2, P = .02)				

Abbreviations: AOR, adjusted odds ratio; ref, referent; SRRC, sport- and recreation-related concussion.

<sup>a</sup> Source: Youth Risk Behavior Surveillance System, 2017, 2019.<sup>18</sup> Note: AORs adjusted for age, race or ethnicity, and alcohol use. Boldface indicates statistical significance (*P* < .005).

<sup>b</sup> During the 12 mo before the survey.

 $^{\rm c}$  Attempted suicide 1 or more times during the past 12 mo.

<sup>d</sup> Different from students who did not have an SRRC during the 12 mo before the survey.

<sup>e</sup> Different from students who had 1 SRRC during the 12 mo before the survey.

<sup>f</sup> Answered *yes* to "If you attempted suicide during the past 12 mo, did any attempt result in an injury, poisoning, or overdose that had to be treated by a doctor or nurse?"

measures, we lacked access to clinical diagnoses and validated psychological inventories, increasing the potential for response bias. Lastly, whether the sex-based differences we observed were due to sociocultural or other biomechanical factors remains unknown. Future longitudinal examinations are necessary to better understand the possible cumulative effects of concussion on adolescent mental health and promote the development of earlier prevention strategies aimed at mitigating the link between concussive injury and potentially fatal risk behaviors. As such, schools would benefit from implementing regular mental health assessments and interventions to help students avoid feelings of depression and suicidality after concussion.

# CONCLUSIONS

We found that adolescents who reported concussion were at increased odds of reporting feelings of depression as well as suicidal ideation, planning, and attempts during the preceding 12 months of the YRBSS survey. More importantly, a larger number of concussions incurred in the previous 12 months was associated with greater odds of suicidal attempts and may differentially affect male and female adolescents. Overall, these results highlight the importance and exigency of clinical evaluation and close monitoring of mental health in youth, particularly those who sustain multiple concussions within a short period of time.

# ACKNOWLEDGMENTS

The findings and conclusions presented in this manuscript are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

#### REFERENCES

- Bryan MA, Rowhani-Rahbar A, Comstock RD, Rivara F. Seattle Sports Concussion Research Collaborative. Sports- and recreation-related concussions in US youth. *Pediatrics*. 2016;138(1): e20154635. doi:10.1542/peds.2015-4635
- Veliz P, McCabe SE, Eckner JT, Schulenberg JE. Trends in the prevalence of concussion reported by US adolescents, 2016–2020. *JAMA*. 2021;325(17):1789–1791. doi:10.1001/jama.2021.1538
- Cancelliere C, Coronado VG, Taylor CA, Xu L. Epidemiology of isolated versus nonisolated mild traumatic brain injury treated in emergency departments in the United States, 2006–2012: sociodemographic characteristics. *J Head Trauma Rehabil*. 2017;32(4): E37–E46. doi:10.1097/HTR.00000000000260
- Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. *Br J Sports Med.* 2017;51(12):941–948. doi:10.1136/bjsports-2017-097729
- Romeu-Mejia R, Giza CC, Goldman JT. Concussion pathophysiology and injury biomechanics. *Curr Rev Musculoskelet Med.* 2019;12(2): 105–116. doi:10.1007/s12178-019-09536-8
- McKee AC, Alosco ML, Huber BR. Repetitive head impacts and chronic traumatic encephalopathy. *Neurosurg Clin N Am.* 2016;27(4): 529–535. doi:10.1016/j.nec.2016.05.009
- Vasterling JJ, Jacob SN, Rasmusson A. Traumatic brain injury and posttraumatic stress disorder: conceptual, diagnostic, and therapeutic considerations in the context of co-occurrence. *J Neuropsychiatry Clin Neurosci.* 2018;30(2):91–100. doi:10.1176/appi.neuropsych. 17090180
- Williamson JB, Heilman KM, Porges EC, Lamb DG, Porges SW. A possible mechanism for PTSD symptoms in patients with traumatic brain injury: central autonomic network disruption. *Front Neuroeng*. 2013;6:13. doi:10.3389/fneng.2013.00013

- 9. Montenigro PH, Bernick C, Cantu RC. Clinical features of repetitive traumatic brain injury and chronic traumatic encephalopathy. *Brain Pathol.* 2015;25(3):304–317. doi:10.1111/bpa.12250
- Suicide. National Institute of Mental Health. Accessed August 7, 2022. https://www.nimh.nih.gov/health/statistics/suicide
- Shain B. Committee on Adolescence. Suicide and suicide attempts in adolescents. *Pediatrics*. 2016;138(1):e20161420. doi:10.1542/peds. 2016-1420
- 12. Injury prevention & control. Web-Based Injury Statistics Query and Reporting System Injury Center, Centers for Disease Control and Prevention. Published December 2, 2021. Accessed August 7, 2022. https://www.cdc.gov/injury/wisqars/index.html
- Mantey DS, Omega-Njemnobi O, Barroso CS, Kelder SH. Selfreported history of concussions is associated with risk factors for suicide completion among high school students. J Affect Disord. 2020;263:684–691. doi:10.1016/j.jad.2019.11.047
- Wangnoo T, Zavorsky GS, Owen-Smith A. Association between concussions and suicidal behaviors. *J Neurotrauma*. 2020;37(12): 1401–1407. doi:10.1089/neu.2018.5721
- Yang MN, Clements-Nolle K, Parrish B, Yang W. Adolescent concussion and mental health outcomes: a population-based study. *Am J Health Behav.* 2019;43(2):258–265. doi:10.5993/AJHB.43.2.3
- Dilillo D, Mauri S, Mantegazza C, Fabiano V, Mameli C, Zuccotti GV. Suicide in pediatrics: epidemiology, risk factors, warning signs and the role of the pediatrician in detecting them. *Ital J Pediatr.* 2015;41:49. doi:10.1186/s13052-015-0153-3
- Iverson GL, Karr JE. Association between concussions and suicidality in high school students in the United States. *Front Neurol.* 2022;13:810361. doi:10.3389/fneur.2022.810361
- YRBSS data & documentation. Centers for Disease Control and Prevention. Updated April 27, 2023. Accessed July 27, 2021. https:// www.cdc.gov/healthyyouth/data/yrbs/data.htm.
- Underwood JM, Brener N, Thornton J, et al. Overview and methods for the Youth Risk Behavior Surveillance System—United States, 2019. MMWR Suppl. 2020;69(1):1–10. doi:10.15585/mmwr.su6901a1
- May A, Klonsky ED. Validity of suicidality items from the Youth Risk Behavior Survey in a high school sample. *Assessment*. 2011;18(3): 379–381. doi:10.1177/1073191110374285
- Taliaferro LA, Rienzo BA, Miller MD, Pigg RM Jr, Dodd VJ. High school youth and suicide risk: exploring protection afforded through physical activity and sport participation. *J Sch Health*. 2008;78(10): 545–553. doi:10.1111/j.1746-1561.2008.00342.x
- Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320(19):2020–2028. doi:10. 1001/jama.2018.14854
- Olivier J, Bell ML. Effect sizes for 2×2 contingency tables. *PLoS One*. 2013;8(3):e58777. doi:10.1371/journal.pone.0058777
- Miller GF, DePadilla L, Jones SE, Bartholow BN, Sarmiento K, Breiding MJ. The association between sports- or physical activity-related concussions and suicidality among US high school students, 2017. Sports Health. 2021;13(2):187–197. doi:10.1177/ 1941738120939913
- Eagle SR, Brent D, Covassin T, et al. Exploration of race and ethnicity, sex, sport-related concussion, depression history, and suicide attempts in US youth. *JAMA Netw Open.* 2022;5(7): e2219934. doi:10.1001/jamanetworkopen.2022.19934
- Caron JG, Bloom GA, Johnston KM, Sabiston CM. Effects of multiple concussions on retired National Hockey League players. *J Sport Exerc Psychol.* 2013;35(2):168–179. doi:10.1123/jsep.35.2.168
- 27. Devoto C, Arcurio L, Fetta J, et al. Inflammation relates to chronic behavioral and neurological symptoms in military personnel with traumatic brain injuries. *Cell Transplant*. 2017;26(7):1169–1177. doi:10.1177/0963689717714098
- 28. Vasilevskaya A, Tartaglia MC. Neuropsychiatric symptoms of post-concussion syndrome (PCS) and chronic traumatic encephalopathy (CTE). In: Anghinah R, Paiva W, Battistella LR, Amorim R,

eds. Topics in Cognitive Rehabilitation in the TBI Post-Hospital Phase. Springer International Publishing; 2018:87–94. doi:10.1007/ 978-3-319-95376-2\_12

- Marklund N, Vedung F, Lubberink M, et al. Tau aggregation and increased neuroinflammation in athletes after sports-related concussions and in traumatic brain injury patients—a PET/MR study. *Neuroimage Clin.* 2021;30:102665. doi:10.1016/j.nicl.2021. 102665
- Jeon SW, Kim YK. The role of neuroinflammation and neurovascular dysfunction in major depressive disorder. J Inflamm Res. 2018;11:179–192. doi:10.2147/JIR.S141033
- Fernández-Sevillano J, González-Ortega I, MacDowell K, et al. Inflammation biomarkers in suicide attempts and their relation to abuse, global functioning and cognition. *World J Biol Psychiatry*. 2022;23(4):307–317. doi:10.1080/15622975.2021.1988703
- Miranda-Mendizabal A, Castellví P, Parés-Badell O, et al. Gender differences in suicidal behavior in adolescents and young adults: systematic review and meta-analysis of longitudinal studies. *Int J Public Health*. 2019;64(2):265–283. doi:10.1007/s00038-018-1196-1
- Cash SJ, Bridge JA. Epidemiology of youth suicide and suicidal behavior. *Curr Opin Pediatr*. 2009;21(5):613–619. doi:10.1097/MOP. 0b013e32833063e1

- Gabrys RL, Dixon K, Holahan MR, Anisman H. Self-reported mild traumatic brain injuries in relation to rumination and depressive symptoms: moderating role of sex differences and a brain-derived neurotrophic factor gene polymorphism. *Clin J Sport Med.* 2019;29(6):494–499. doi:10.1097/JSM.000000000000550
- Léveillé E, Guay S, Blais C, Scherzer P, Beaumont LD. Sex-related differences in emotion recognition in multi-concussed athletes. J Int Neuropsychol Soc. 2017;23(1):65–77. doi:10.1017/S1355617716001004
- Kita H, Mallory KD, Hickling A, Wilson KE, Kroshus E, Reed N. Social support during youth concussion recovery. *Brain Inj.* 2020;34(6): 782–790. doi:10.1080/02699052.2020.1753243
- Davies SC, Bernstein ER, Daprano CM. A qualitative inquiry of social and emotional support for students with persistent concussion symptoms. *J Educ Psychol Consult*. 2020;30(2):156–182. doi:10. 1080/10474412.2019.1649598
- Broshek DK, De Marco AP, Freeman JR. A review of post-concussion syndrome and psychological factors associated with concussion. *Brain Inj.* 2015;29(2):228–237. doi:10.3109/02699052.2014.974674

# SUPPLEMENTAL MATERIAL

#### Supplemental Table.

Available online at http://dx.doi.org/10.4085/1062-6050-0117.22.S1

Address correspondence to Jacob J. M. Kay, PhD, MSc, Prisma Health Children's Hospital, Pediatric Concussion Clinic, 9 Medical Park Drive, Suite 450, Columbia, SC 29203. Address email to jacob.kay@prismahealth.org.