Higher rates of concussion following COVID-19 infection in high school athletes

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ABSTRACT

Objective To compare concussion rates (CRs) over one academic year in high school athletes with and without a COVID-19 infection prior to concussion.

Methods Illness and concussion were prospectively reported for male and female high school athletes across six states over one academic year in the Players Health Rehab surveillance system. Concussion was truncated to 60 days following recovery and return to sport from COVID-19. CRs were estimated per 1000 athletes per academic year and stratified by those who tested positive for COVID-19 infection (with COVID-19) and those who did not (no COVID-19). Poisson regression analyses estimated rate ratio (RR) of concussion controlling for state, gender and an offset of the log athlete participation (with COVID-19 and no COVID-19).

Results Of 72 522 athletes, 430 COVID-19 infections and 1273 concussions were reported. The CR was greater in athletes who reported COVID-19 (CR=74.4/1000 athletes/year, 95% CI 49.6 to 99.3) compared with those who did not (CR=17.2, 95% CI 16.3 to 18.2). Athletes with recent COVID-19 had a threefold higher rate of concussion (RR=3.1, 95% CI 2.0 to 4.7).

Conclusion Athletes returning from COVID-19 had higher CRs than those who did not experience COVID-19. This may be related to ongoing COVID-19 sequelae or deconditioning related to reduced training and competition load during the illness and when returning to sport. Further research is needed to understand the association of recent COVID-19 infection and concussion in order to inform preventive strategies.

WHAT IS ALREADY KNOWN ON THE TOPIC

⇒ Concussions can have serious consequences, particularly in adolescents. It is currently unclear how COVID-19 infections may impact subsequent concussion risk in sport.

WHAT THIS STUDY ADDS

⇒ Athletes with COVID-19 infection had greater than threefold rates of concussion within 60 days following recovery from infection compared with athletes without COVID-19 infection.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Additional research is warranted to explore why athletes with a recent COVID-19 infection are at higher risk of concussion. Clinical judgement or concern may guide further evaluation or a more cautious return to sport in athletes recovering from COVID-19.

INTRODUCTION

Concussions in high school athletes are a serious problem. Almost 20% of all adolescents in the USA report experiencing a concussion during high school,[1 2] with over 700 000 concussions sustained by high school athletes annually.[3] Concussion rates (CRs) range from 2 to 20 concussions per 10 000 athletic exposures, and from 10% to 13% of all injuries suffered by high school athletes are concussions.[3 4] Adolescent athletes may be at higher risk of sustaining a concussion compared with adult athletes,[5 6] with more severe symptoms and potential developmental implications including cognitive dysfunction.[7]

Higher CRs are reported for girl athletes compared with boy athletes in gender comparable sports.[8 9] These gender discrepancies may be resultant of differences in physiology,[10 11] with likelihood of reporting concussions,[12] protective gear,[8] player contact and strategy,[13] ball to head ratio[13] or practices.[14 15] There are also differences in CRs between sports. Sports with high levels of player contact have greater exposure to potential head trauma, including both collisions and field and court sports.[4 16]

SARS-CoV-2 and the resultant disease, COVID-19 infection, have significantly impacted adolescent health.[17 18] COVID-19 infections can result in respiratory, cardiovascular, neurological and musculoskeletal system issues, long after acute COVID-19 has resolved.[19] COVID-19 can also impair neurophysiological processes,[20] potentially resulting in impaired cognition.[21] While adults report increased COVID-19 symptoms, adolescents report a high prevalence of symptoms, ranging from 4% to 80%.[22]

Concussions have serious consequences including memory loss and behaviour issues,[15 23] with adolescents being more vulnerable to downstream sequela due to their developing brains.[5–7] While COVID-19 infection rates have been established and long-term physiological and neurological consequences have been identified,[19] it is currently unknown how COVID-19 infections may impact subsequent concussion risk following illness recovery. This information would improve clinical examination, decision making, and athlete and parent education regarding returning to sport. Therefore, the purpose of this study was to compare CRs over one academic year in high school athletes with and without a COVID-19 infection prior to concussion.

METHODS

Study design

A prospective cohort study was conducted over one academic year to compare CRs in athletes who reported a COVID-19 infection prior to concussion and those who did not. The Strengthening the Reporting of Observational Studies in Epidemiology for Sport Injury and Illness Surveillance was used for reporting.[24]

Patient and public involvement

Physicians, athletic trainers, physical therapists, former athletes, high school coaches and school administrators from multiple geographical regions, urban and rural communities, and different socioeconomic backgrounds were interviewed and gave input into the collection methods and electronic medical record dashboard. Findings from this concussion study were presented to these stakeholders along with one-page reports in lay language.

Equity, diversity and inclusion

High schools from multiple geographical regions, urban and rural communities, and different socioeconomic backgrounds were recruited for this study. Participants could report gender beyond binary terms. The author team included early, middle and late career researchers with balance from people who identify as male and female.

Outcomes

An illness was defined as a new physical complaint or disorder experienced by an athlete who was not related to an injury. Illnesses included health problems relating to physical complaints or removal or loss of vital elements (ie, dehydration, hypothermia or fever).[24–26] A COVID-19 infection was defined as a positive test administered by a healthcare professional. COVID-19 screening was performed daily by the high school assigned athletic trainers for each athlete, prior to clearance for sports participation. Screening included measurement of body temperature, along with symptom reporting. Any athletes who had elevated body temperatures and/or reported COVID-like symptoms were tested for COVID-19. Athletes were quarantined within 24 hours following documentation of COVID-19 infection, with athletes being asymptomatic or symptomatic at the time of quarantine. Chronic pre-existing illnesses (eg, asthma) were not included unless there was an acute exacerbation requiring medical attention. Illness severity was calculated for overall time loss, with further illness severity stratified by 1–6 (minor), 7–27 (moderate) and 28+ (severe) days.[24]

Concussion was defined as a traumatic brain injury, integrating clinical, pathological and biomechanical features.[27] Concussion was induced by contact to the head, neck or body that resulted in forces sustained to head, which resulted in rapid or delayed onset of neurological symptoms.[27] Potential concussions were evaluated on field and within the on-site training room. All potential concussions were referred to a sport physician for follow-up. The time frame whereby a concussion was deemed as following a COVID-19 infection was truncated to 60 days following illness recovery. Illness recovery was defined as a full return to training and/or competition following symptom resolution.[24 25]

All athletes presenting with any illness reported to their school athletic trainer to verify the complaint. The athletic trainer documented the illness in the Players Health Rehab system. The documentation included the illness date, athlete gender, sport of participation, problem type, the participation status of the athlete, athlete phase of recovery and days until return to sport.

Data collection

Athlete illness data were recorded by the high school athletic trainer, including the date and duration of time loss during a team-sponsored practice or game. Sport coverage was determined through the proportion of high school students who participated in sport, not on high school or school district funding. High school sport participation per season was determined through rosters by each athletic trainer. The high school athletic trainers collected athlete participation each day. Internal validity data checks were performed by the regional athletic supervisor and the regional and national quality control supervisors on a quarterly basis.

Participants

High school athletes from six states (Alabama, Delaware, Illinois, Maryland, Michigan and Pennsylvania) were included. High schools had to participate in all three sport seasons (eg, fall, winter and spring) of the 2020–2021 academic year for inclusion.

Exposure

An athlete exposure (AE) was defined as one athlete participating in one practice or competition where a player was at risk of sustaining an injury.[28] AE was not calculated for days of school suspension, medical visits that were not musculoskeletal related (eg, dentist) or extramural school activities not related to sport. Exposure following illness was not recorded until the athlete had recovered from illness, which was defined as when an athlete fully returned to training and/or competition.[24 25]

Explanatory variables

Self-identified gender, state and sport were identified as important covariables. Due to the large number of sports played, four categories were identified: collision (American football, lacrosse, wrestling, ice hockey and rugby), field and court (basketball, field hockey, soccer, tennis, volleyball, gymnastics, softball and baseball), individual (track and field, swimming, mixed rifle, mixed skiing, golf, dance, diving, cross country, bowling, archery, rowing and cheerleading) and other. Other was used for sport classification when no sport was connected to injury records.

Statistical analyses

With a previously reported high school athlete COVID-19 incidence rate of 5.2 per 1000 athlete-years,[29] CR of 2.6 per 100 athlete-years[8] and the recommended overall model fit of 0.21,[30] a total of 418 COVID-19 infections and up to 5 df would be required to reduce risk of model overfitting.[30]

All data were assessed for missingness prior to analyses (gender, 0%; age, 0%; date of injury, 3%; sport, 1.7%; body part, 1.6%; return to play, <0.1%; and pain, <0.1%), with data demonstrating minimal missingness. Complete case analyses were performed. Participant statistics were described using mean (SD) for continuous, normally distributed variables, median (25th percentile, 75th percentile) for non-normally distributed continuous variables and frequencies (percentages) for categorical variables. Concussion injury incidence rate for athletes who sustained a COVID-19 infection prior to a concussion and those who did not,[31] with 95% CIs was calculated per 1000 athletes who participated within 1 academic year (1000 athlete-years).[31] As normality cannot be assumed for incidence rates, point estimates and 95% CIs were logarithmically transformed. All 0 point estimate 95%

Table 1 Participant demographics

	No COVID-19 (n=72 092)	With COVID-19 (n=430)
Age (years)	17.1 (2.7)	17.0 (1.9)
Gender (female), n (%)	32 766 (45)	202 (47)
Sport, n (%)		
Collision	29 558 (41)	133 (31)
Field and court	28 837 (40)	198 (46)
Individual	12 256 (17)	86 (20)
Other	1441 (2)	13 (3)

Results are reported as mean (SD) or count (percentage).

CIs were calculated using the exact method.[32] Results were stratified by gender, severity and sport. Rate ratios (RR) with 95% CIs were calculated.

Poisson regressions were performed to estimate the rate of concussions following COVID-19 infection. Overdispersion was not present. All models controlled for included important covariables of state, gender, and an offset of the log of COVID-19 infections or athletes who did not sustain a COVID-19 infection in person-years. A cluster at the school level was considered for inclusion in the primary analyses. However, due to the number of athletes who suffered from COVID-19 and then a concussion, it was determined that clustering would only be included as a sensitivity analysis. Potential non-linear associations between factors and outcome were assessed prior to analyses, with all factors demonstrating linear associations. Sensitivity analyses included (1) incorporating high schools as clusters with cluster-robust SEs, (2) stratifying by gender, and (3) comparing athlete concussion risk for those who sustained a bacterial or viral infection that was not a COVID-19 illness and those who did not suffer any illness prior to concussion. All analyses were performed in R V.4.01 (R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org/) using the *naniar* package for missingness assessment, *fmsb* package for rate ratio analyses, the *glm* function for Poisson models, the *AER* package to assess for overdispersion and the *GenBinomApps* package for exact method 95% CIs.

RESULTS

General demographics

A total of 72 522 athletes (female, 32 968; male, 39,554) participated in high school sport during the 2020–2021 academic school year (table 1).

General concussion results

High school athletes tested positive for 430 COVID-19 infections during the academic year. A total of 1273 concussions were documented during the school year, resulting in a CR of 17.6 (95% CI 14.8 to 20.8) per 1000 athlete-years. A total of 1241 concussions occurred in athletes who did not previously have a COVID-19 infection and 32 concussions from athletes who did have COVID-19 (table 1). The median time loss from concussion in both groups was 18 (7, 30). The median time from COVID-19 infection to concussion was 14 (7, 22) days. No athletes who tested positive for COVID-19 and then had a concussion sustained a concussion prior to COVID-19 or after 60 days following return from COVID-19. All COVID-19 athletes who suffered a concussion demonstrated COVID-19 symptoms (table 2).

Table 2 Participant concussion rates (number of concussions per 1000 athlete-years) by COVID-19-infected athletes and severity

	Concussion	
	No COVID-19 (n=72 092)	With COVID-19 (n=430)
Overall	17.2 (14.5 to 20.5)	74.4 (55.2 to 100.4)
Minor	4.1 (3.4 to 4.9)	13.9 (10.1 to 19.2)
Moderate	8.9 (7.5 to 10.6)	46.6 (34.2 to 63.3)
Severe	4.3 (3.6 to 5.1)	13.9 (10.2 to 19.2)

All injury rates are reported per 1000 athlete-years with 95% CIs.
Minor injuries are time loss injuries of 1–7 days, moderate=8–27 days, severe=28+ days.

Gender differences in CRs

Girl athletes who sustained a COVID-19 infection were 3.2 (95% CI 1.8 to 5.9) times more likely to suffer from a concussion following return to sport after COVID-19 infection compared with those not sustaining a COVID-19 infection. Boy athletes who sustained a COVID-19 infection were 2.8 (95% CI 1.6 to 4.8) times more likely to suffer from a concussion following return to sport after infection compared with those not sustaining a COVID-19 infection (table 3).

Sport-specific differences in CRs

Collision sport athletes who sustained a COVID-19 infection were 8.9 (95% CI 4.9 to 16.3) times more likely to sustain a concussion following return to sport after infection compared with those collision athletes not sustaining a COVID-19 infection. Field and court sport athletes who sustained a COVID-19 infection were 9.7 (95% CI 5.6 to 17.0) times more likely to suffer from a concussion following return to sport after infection compared with those field and court athletes not sustaining a COVID-19 infection. No individual or other sport athletes suffered a concussion following return to sport after infection (table 4).

Risk of concussion following COVID-19 infection

High school athletes who sustained a COVID-19 infection demonstrated an unadjusted (2.9, 95% CI 1.9 to 4.5, p<0.001) and adjusted (3.1, 95% CI 2.0 to 4.7, p<0.001) increased rate of concussion following recovery from illness compared with athletes who did not sustain a COVID-19 infection.

Sensitivity analyses

When controlling for clustering at the high school level, athletes who sustained a COVID-19 infection demonstrated (1.6, 95% CI 1.1, 25.9, p<0.001) a higher CR following recovery from illness compared with athletes who did not sustain a COVID-19 infection. Female high school athletes who sustained a COVID-19 infection demonstrated (5.7, 95% CI 3.1 to 10.7, p<0.001) a higher CR

Table 3 Concussion rates stratified by gender per 1000 athletes-years by COVID-19-infected athletes and severity

	Concussion			
	Girls		Boys	
	No COVID-19 (n=32 766)	With COVID-19 (n=202)	No COVID-19 (n=39 326)	With COVID-19 (n=228)
Overall	15.4 (12.8 to 18.5)	49.5 (34.7 to 70.0)	19.0 (15.9 to 22.8)	52.6 (37.4 to 74.1)
Minor	3.7 (3.0 to 4.5)	14.8 (10.3 to 21.4)	4.4 (3.7 to 5.4)	0 (0 to 10.0)
Moderate	8.0 (6.6 to 9.6)	24.8 (17.3 to 35.5)	9.8 (8.1 to 11.7)	48.2 (34.2 to 60.0)
Severe	3.7 (3.0 to 4.6)	9.9 (0.0 to 23.6)	4.8 (4.0 to 5.8)	4.4 (0.0 to 13.0)

All injury rates are reported per 1000 athlete-years with 95% CIs.
Minor injuries are time loss injuries of 1–7 days, moderate=8–27 days, severe=28+ days.

Table 4 Concussion rates stratified by sport groups per 1000 athlete-years by COVID-19-infected athletes

	Concussion	
	No COVID-19	With COVID-19
Collision	8.5 (7.1 to 10.1)	75.8 (52.3 to 109.8)
Field and court	6.2 (5.2 to 7.4)	60.6 (42.8 to 85.8)
Individual	2.0 (1.7 to 2.5)	0 (0 to 26.7)
Other	0.6 (0.5 to 0.8)	0 (0 to 142.3)

All injury rates are reported per 1000 athlete-years with 95% CIs.

following recovery from illness compared with athletes who did not sustain a COVID-19 infection. Male high school athletes who sustained a COVID-19 infection demonstrated an (3.4, 95% CI 1.9 to 6.1, p<0.001) increased CR following recovery form illness compared with athletes who did not sustain a COVID-19 infection.

Out of the 123 illnesses who were not infected with COVID-19, only one athlete sustained a concussion following recovery from illness. As a result, it was not possible to perform any statistical analyses using these data.

DISCUSSION

The main findings of this study were that in athletes with a COVID-19 infection, when controlling for gender and state, there was a threefold rate of concussion following COVID-19 infection compared with athletes who did not report a COVID-19 infection. Those who identified as girls and boys demonstrated similar CRs following COVID-19. Collision, field and court athletes who reported a COVID-19 infection had ninefold higher rates of concussion following recovery from illness. Only one concussion was sustained following a general infection, suggesting that concussion risk following a general infection may be dissimilar to COVID-19.

High school athletes who reported a previous COVID-19 infection demonstrated greater rates of sustaining a concussion within 60 days following return to sporting activities. The overall count and rates of concussion[8 16] and COVID-19 infection[33] in these data were similar to previous literature, suggesting the generalisability of these epidemiological findings. Athletes who suffer from an infection can encounter fatigue and chronic respiratory or cardiac symptoms.[34] These symptoms can diminish physical activity or sport training,[35] potentially increasing injury risk following recovery from illness.[29] High school athletes who sustain a COVID-19 infection have reported similar musculoskeletal injury following illness compared with other infections.[29] However, a concussion has different mechanisms of injury[4] and aetiology[5 6 23] compared with general musculoskeletal injury. Further, within these data, no high school athletes who sustained a concussion following COVID-19 recovery suffered a musculoskeletal injury prior to either COVID-19 infection or concussion. Prior research has observed an association between previous lower extremity injury and increased concussion risk in high school athletes.[36] These findings suggest that other mechanisms may impact concussion risk following COVID-19 recovery. Potential explanations include detriments to spatial–temporal cognition,[37] dynamic balance deficits[38] or increased inflammation.[39] However, these are only speculative. Causal investigations are necessary to determine the underlying causes of this risk.

Female and male athletes demonstrated similar CRs following COVID-19 infections. This is in contrast to previous literature where high school female athletes have reported greater CRs compared with comparable sports by both genders, such as soccer and basketball.[8 9] Within these data, female athletes did report a higher rate of minor and severe concussions compared with male athletes. High school female athletes are more likely to report concussions compared with male athletes[12 40] and are far more likely to have severe concussion symptoms.[41]

Collision, field and court sports reported similar CRs following COVID-19 infections. While American football has the highest concussion rates for any sport,[4 16] rates reported for girl athletes are higher than for boy athletes in sports comparable for both genders,[8 9] with girls' soccer reporting the highest rates.[8] These discrepancies between genders may influence these sport findings. Individual sports, such as cross country and golf, reported no concussions following COVID-19 infections. While individual sports report lower CRs compared with collision, field and court sport,[4 16] the absence of concussions following recovery from COVID-19 may be related to the lack of contact with other athletes. However, further research is needed to investigate these potential sport differences.

These results have practical clinical applications. Following recovery from COVID-19 infections, clinicians may consider examining high school athletes for spatial–temporal reasoning,[42] dynamic balance[43] and cardiovascular conditioning.[44 45] Further, a return to a sport programme involving gradual training and practice loading[46] to avoid acute spikes in overall sport loading may be considered.[47] Athletes who participate in sports with high levels of potential head contacts may benefit from limited player-to-player contact initially when returning to sport.[48]

Limitations of this study include the potential for selection bias, as high schools opted into sport participation within the 2020–2021 season. Athlete injury reporting bias may have influenced these results in either direction. There are limited data on individual state COVID-19 exposure prevalence and temporality. Due to the number of concussions sustained by athletes who reported COVID-19, there was insufficient power to control for more covariables. Previous injury data were not collected, which may confound these results. Sport was collapsed for reporting and analysis, which increases the risk of residual confounding. Training and competition minutes or hours of exposure were not collected, decreasing the precision of these findings. States within these data sustained different COVID-19 infection rates, which may influence these findings. There is the potential for sparse data bias, as some data were reported with zero outcomes. Causality cannot be interpreted with these data.

CONCLUSION

Athletes with a COVID-19 infection had higher CRs within 60 days following recovery from infection compared with athletes without an infection. Female and male high school athletes demonstrated similar CRs following COVID-19 infections. Athletes participating in collision, field and court sports were the most vulnerable to concussion following COVID-19 infection. Additional research is needed to understand why athletes with a recent COVID-19 infection are at higher risk of concussion. Clinical judgement or concern may guide further evaluation or a more cautious return to sport in athletes recovering from COVID-19.

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Contributors GSB, VRN and ES conceived the study idea. GSB, CE, VRN, AP-U and ES were involved in the design and planning. GSB and ES wrote the first draft of the manuscript. GSB, CE, VRN, AP-U, RGG, CT and ES critically revised the manuscript.

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