Original research

Neurocognitive functioning and symptoms across levels of collision and contact in male high school athletes

Jessie R. Oldham ,[1] David Howell,[2,3] Corey Lanois,[4] Paul Berkner,[5] Grant L. Iverson,[6] Rebekah Mannix,[7,8] William Meehan[7,9]

[1]Department of Physical Medicine and Rehabilitation, Virginia Commonwealth University School of Medicine, Richmond, Virginia, USA
[2]Children's Hospital Colorado Sports Medicine Center, Aurora, Colorado, USA
[3]Department of Orthopedics, University of Colorado School of Medicine, Aurora, CO, USA
[4]Department of Physical Therapy, Movement and Rehabilitation Sciences, Northeastern University, Boston, MA, USA
[5]University of New England College of Osteopathic Medicine, Biddeford, Maine, USA
[6]Department of Physical Medicine and Rehabilitation, Harvard Medical School, Boston, MA, USA
[7]Boston Children's Hospital, Boston, Massachusetts, USA
[8]Department of Pediatrics and Emergency Medicine, Harvard Medical School, Boston, MA, USA
[9]Department of Pediatrics and Orthopedics, Harvard Medical School, Boston, MA, USA

Correspondence to
Dr Jessie R. Oldham, Physical Medicine and Rehabilitation, Virginia Commonwealth University School of Medicine, Richmond, Virginia, USA; jessie.oldham@vcuhealth.org

Received 15 November 2021
Accepted 11 April 2022
Published Online First 27 April 2022

To cite: Oldham JR, Howell D, Lanois C, *et al*. *J Neurol Neurosurg Psychiatry* 2022;**93**:828–832.

ABSTRACT

Objective We sought to determine whether male collision sport athletes perform worse on computerised neurocognitive assessments and report higher symptom burdens than athletes in contact (but not collision) sports and athletes in non-contact sports.

Methods This cross-sectional study used data collected by the Massachusetts Concussion Management Coalition on high school boys who underwent computerised neurocognitive testing between 2009 and 2018. We divided sports participation in three different sport types: (1) collision, (2) contact, non-collision and (3) non-contact. Our outcomes included the four computerised neurocognitive composite scores (verbal memory, visual memory, visual motor speed and reaction time) and the total symptom score. The independent variable was sport type (collision, contact, non-contact), adjusted for age, concussion history and comorbidities.

Results Of the 92 979 athletes (age: 15.59±2.08 years) included in our study, collision sport athletes performed minimally but significantly worse than other athletes on neurocognitive composite scores (verbal memory: β=−1.64, 95% CI −1.85 to −1.44; visual memory: β=−1.87, 95% CI −2.14 to −1.60; visual motor speed: β=−2.12, 95% CI −2.26 to −1.97; reaction time: β=0.02, 95% CI 0.02 to 0.02). Collision and contact sport athletes also had slightly but significantly lower total symptom scores (collision: 3.99±7.17; contact: 3.78±6.81; non-contact: 4.32±7.51, $p<0.001$, $\eta^2=0.001$) than non-contact sport athletes.

Conclusion There are minimal observed differences in performance on neurocognitive assessments between collision sport, contact sport and non-contact sport athletes. The repetitive subconcussive head impacts associated with collision sport participation do not appear to negatively affect self-reported symptoms or neurocognitive functioning in current youth athletes.

Key messages

What is already known on this topic

⇒ Youth athletes participating in collision and contact sports may experience more repetitive head impacts, which have been theorised as a potential catalyst for later life cognitive problems. However, the relationship between these repetitive impacts, symptoms and cognitive functioning remains unknown at the high school level.

What this study adds

⇒ Negative consequences associated with boys playing collison sports were not detectable on cognitive testing or in self-reported symptoms.

How this study might affect research, practice and/or policy

⇒ These findings may potentially influence the recommendations surrounding adolescent participation in collision or contact sports.

INTRODUCTION

Nearly 8 million individuals in the USA participate in high school sports annually, with the number of participants rising each year. Collision and contact sports remain popular among high school boys.[1 2] Adolescence is a critical period for brain development, particularly for executive functioning,[3] and there is growing concern surrounding repetitive head impacts in youth sports and the resulting effects on brain health. The acute effects of concussion are reasonably understood, but the potential long-term repercussions remain debated.[4]

Beyond diagnosed concussions, some have suggested an association between repetitive subconcussive head impacts, those blows to the head that are not associated with the clinical signs or symptoms required for diagnosing a concussion, and both short-term and long-term neurological impairments. Some studies have reported cognitive decline and brain alterations, both functional and microstructural, across a single high school athletic season.[5–7] Moreover, high school football players may potentially sustain upwards of 1800 collisions over the course of a single season, while some studies suggest that fewer than 3000 repetitive head impacts may be associated with an elevated risk of later life impairments in executive functioning.[5 8] Other studies, however, suggest that collision and contact sport participation does not necessarily result in worse neurocognitive outcomes.[9–13] Furthermore, recent studies suggest that collision and contact sport athletes have fewer anxiety and depression symptoms compared with non-contact sport athletes,[10 14] and they are not more likely to have depression or cognitive deficits long term.[15 16] Given the lack of clarity, additional comparisons of health outcomes across the different sport types is warranted.

Investigations into the age at which an individual is first exposed to repetitive head impacts from collision/contact sport participation have yielded no significant associations with cognitive function at the collegiate level,[9–11 17 18] but the influence of current sport type participation on neurocognitive performance in younger athletes warrants further study. Compared with other sport types, males make up the majority of collision sport athletes, and these athletes are likely to experience more repetitive head impacts,[19 20] but the relationship between repetitive subconcussive head impacts, symptoms and cognitive functioning remains uncertain.[21 22] Therefore, we investigated the association between sport type (collision, contact, non-contact), symptoms, and baseline neurocognitive test scores in a population of male high school athletes. Specifically, we sought to determine whether or not male collision sport athletes perform worse on computerised neurocognitive assessments and report greater baseline preseason symptoms than male counterparts in contact (but not collision) sports or non-contact sports. We hypothesised that there would be no meaningful differences in symptom reporting or cognitive functioning after controlling for other factors, such as attention-deficit hyperactivity disorder (ADHD) and learning problems.

METHODS

Participants

We conducted a cross-sectional study of data from the Massachusetts Concussion Management Coalition. We focused on male high school student-athletes who underwent computerised neurocognitive testing using the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT). Athletes in this database usually are baseline tested prior to participating in their first sport of the athletic year. If they play more than one sport they are tested prior to the first sport. For the purpose of this study, we only included each athlete's very first baseline neurocognitive test in the database. This is a study of adolescent boys only because our intention is to complete a separate study with adolescent girls. High school boys and girls play different collision and contact sports and perform differently on the outcomes of interest, and it is important both conceptually and clinically to study them separately. All athletes completed baseline testing prior to the start of their athletic seasons between 2009 and 2018. We excluded any tests considered 'invalid' according to the established criteria.[23] In addition, we excluded (1) those who did not take the test in English, (2) those who did not report their current sport, (3) those who participated in a sport that had fewer than 1000 participants in the dataset, (4) those who did not report their concussion history and (5) those with a self-reported history of brain surgery, treatment for epilepsy, treatment for meningitis, treatment for substance abuse or an autism diagnosis. We excluded sports with fewer than 1000 participants as those sports were less common (ie, archery, badminton, bass fishing, fencing); the 12 sports we included provide a more accurate representation of the male high school athletic population.

Participants were grouped into three categories, collision sports, contact sports and non-contact sports, based on their self-reported sport. Consistent with prior work specific to collision sports,[24] we defined collision sports as those in which purposeful, body-to-body collisions occur as a legal and expected part of the game; these included football, ice hockey and lacrosse. Contact sports were defined as those during which body-to-body contact occurs as a recognised part of the sport, but purposeful body-to-body collisions are not allowed, these included baseball, basketball, soccer, and wrestling. Non-contact sports were defined as those during which body-to-body contact is a rare, unexpected occurrence; these included cross country, golf, swimming, tennis, and track and field (table 1). Our data were limited to the current sport being played because our database did not have a lifetime history of sports participation for each participant. This study was a retrospective review of deidentified data; thus, participant informed consent was not applicable. There has been no patient and public involvement in this study, as it was not appropriate for the study design.

Table 1 Participant exclusion criteria

	Total valid baseline neurocognitive tests (n=106 239)
Exclusion Ccriteria Total Eexcluded (n=13 260)	Did not take the neurocognitive test in English (n=999)
	Did not report current sport (n=2276)
	Did not report concussion history (n=1762)
	Sport had <1000 participants (n=6295)
	Self-reported history of brain surgery (n=121)
	Self-reported treatment for epilepsy (n=898)
	Self-reported treatment for meningitis (n=319)
	Self-reported treatment for substance abuse (n=183)
	Self-reported autism diagnosis (n=407)
	Total no of participants Included in final analysis (n=92 979)

Materials

Computerised neurocognitive assessments were conducted using ImPACT, which is composed of eight specific testing modules (immediate and delayed word memory, immediate and delayed design memory, x's and o's, symbol match, colour match, three letters) that are used to derive composite scores (verbal memory, visual memory, visual motor speed, reaction time).[25]

All demographic information and comorbidities were self-reported and included a personal history of treatment for a psychiatric condition (defined as anxiety/depression), treatment for headaches, treatment for migraines, diagnosed with a learning disability (including dyslexia), diagnosed ADHD, special education, repeating one or more years of school and speech therapy (table 1).

In order to obtain this information, the participants were asked to indicate whether or not they (1) were treated for anxiety or depression; (2) were treated for headaches or migraines by a physician; (3) had ever been diagnosed with ADHD or a learning disability (including dyslexia); or (4) ever repeated one or more years of school, took special education classes or had speech therapy, all as yes/no responses. Additionally, participants were asked to report the number of times they had previously been diagnosed with a concussion. Symptoms were measured with the Post-Concussion Symptom Scale,[26] a standardised questionnaire embedded in ImPACT that requires individuals to rate 22 symptoms from 0 to 6 with 0 meaning that the athlete is not experiencing the symptom, 1–2 meaning that the symptom is mild, 3–4 meaning that the symptom is moderate and 5–6 meaning the symptom is severe.[27]

Statistical analysis

The dependent variables were the composite scores (verbal memory, visual memory, visual motor speed, reaction time) and the total symptom score from each athlete's first recorded baseline test. The main independent variable was sport type (collision, contact, non-contact), adjusted for age, concussion history, psychiatric diagnoses, headache, migraines, learning disability, ADHD, special education, repeating one or more years of school and speech therapy.

We used univariable one-way analyses of variance (ANOVAs) to compare demographic characteristics and composite scores between sport types. Significant ANOVAs ($p<0.05$) were followed up with Tukey pairwise comparisons to examine specific differences between the three sport types. We examined the proportional differences of individuals with comorbidities across each sport type using χ^2 analyses. To examine the independent association between sport type and neurocognitive composite scores and total symptom scores, we conducted a series of multivariable regression models, adjusting for the potential effect of age, prior concussions,[28 29] and comorbidities that previous research suggests are associated with baseline preseason symptoms and/or neurocognitive test scores, such as prior treatment for a psychiatric condition,[27] ADHD,[27 30 31] learning disability[27 30 31] and migraines.[27]

Due to our large sample size and high statistical power we used effect sizes (eta-squared and partial eta-squared) to interpret clinically meaningful results with 0.01, 0.06 and 0.14 corresponding to small, medium, and large effects, respectively, for the ANOVA, and 0.02, 0.13 and 0.26 corresponding to small, medium and large effects, respectively, for the regressions.[32] The p value alone informs the existence of an effect but does not reveal the size of the effect.[33] Large samples, such as ours, will frequently demonstrate statistical significance with no context of the meaningfulness of the findings; thus, we felt it was necessary to include effect sizes to avoid any misinterpretation of our findings. All analyses were completing using Stata/IC V.15.1 (StataCorp).

RESULTS

A total of 106 239 high school boys had valid baseline neurocognitive tests. We excluded 13 260 individuals based on the above exclusion criteria (table 1), leaving 92 979 male athletes included in the final analysis. Athletes were similar in age across sport type (table 2). Collision sport athletes were more likely to report prior concussions and ADHD (table 2). On univariable comparisons, collision sport athletes performed slightly but significantly worse on the neurocognitive composite scores, and collision and contact sport athletes both reported slightly but significantly lower baseline symptom scores compared with the contact and non-contact sport athletes (table 3). After adjusting for the effects of age, concussion history and comorbidities, collision and contact sport athletes still performed slightly but significantly worse on composite scores and had slightly but significantly lower symptom scores than non-contact sport athletes (table 4).

DISCUSSION

High school boys competing in collision and contact sports performed slightly worse on baseline preseason neurocognitive testing compared with boys participating in non-contact sports. Collision and contact athletes also reported slightly fewer symptoms than non-contact sport athletes. Neither of these findings is of likely clinical significance.

Previous studies of adolescent[12] and collegiate[10 11] athletes found no association between sport and neurocognitive test performance and no significant differences for sport type on composite scores during baseline preseason evaluations. A similar large scale investigation of male NCAA athletes undergoing preseason testing found that football players had lower (worse) visual motor processing speed and slower (worse) reaction time compared with non-contact sport athletes, however, the authors reported small effect sizes and minimal clinical relevance, similar to our study.[9] Others have examined the influence of sport on cognition across an athletic season and found small but measurable short-term differences in neurocognitive outcomes between collision, contact and non-contact high school and collegiate athletes,[13] although the magnitude of the differences between sport type did not reach the thresholds deemed to be clinically significant and did not persist across subsequent athletic seasons.[13] Similarly, previous studies have found lower symptom scores

Table 2 Self-reported demographics from the impact test for each sport category

Demographics	Collision sports (n=42 332)	Contact sports (n=37 074)	Non-contact sports (n=13 573)
Age (years)	15.6±2.0	15.6±2.1	15.8±2.1
Height (cm)	174.2±8.6	173.0±9.9	173.2±9.7
Weight (kg)	72.3±16.3	64.9±13.9	64.2±14.2
Concussion history (n, %)	0: 33 083 (78) 1: 6549 (15) 2: 1922 (5) 3+: 777 (2)	0: 31 241 (84) 1: 4233 (12) 2: 1087 (3) 3+: 512 (1)	0: 12 065 (89) 1: 1138 (8) 2: 231 (2) 3+: 139 (1)
Learning problem (n,%)	2141 (5)	1241 (3)	581 (4)
ADHD (n, %)	5461 (13)	3441 (9)	1418 (10)
Psychiatric condition* (n/total, %)	1596/38 956 (4)	1253/34 183 (4)	658/12 669 (5)
Headaches* (n/total, %)	4331/39 291 (11)	3229/34 468 (9)	1060/12 722 (8)
Migraines* (n/total, %)	2725/39 048 (7)	2027/34 251 (6)	675/12 676 (5)
Speech therapy* (n/total, %)	3101/42 315 (7)	2375/37 059 (6)	1105/13 569 (8)
Special education* (n/total, %)	3103/42 315 (7)	1873/37 058 (5)	691/13 568 (5)
Repeated school year(s)* (n/total, %)	3100/42 316 (7)	1910/37 057 (5)	557/13 569 (4)
Sport breakdown (% of total sports)	Football (31) Ice Hockey (9) Lacrosse (6)	Baseball (6) Basketball (10) Soccer (21) Wrestling (3)	Cross Country (4) Golf (2) Swimming (1) Tennis (2) Track and field (5)

There were significant differences between all three sport types ($p<0.001$) across the demographics categories.
*Not all participants answered the questions regarding treatment for psychiatric conditions, headaches, migraines, speech therapy, special education, or repeating at least 1 year of school, so the reported number is out of fewer total participants than that given for each sport type. The number of total responses is bolded in those categories.

Table 3 Impact composite scores across the three sport types

ImPACT variable	Collision sports	Contact sports	Non-contact sports	η^2
Verbal memory	82.13±10.32	83.15±10.27	83.97±10.20	0.004
Visual memory	71.28±13.47	72.66±13.47	73.38±13.47	0.004
Visual motor speed	34.44±7.02	36.05±7.28	36.80±7.24	0.017
Reaction time	0.63±0.11	0.62±0.14	0.61±0.10	0.004
Total symptoms	3.99±7.17	3.78±6.81	4.32±7.51	0.001

Effect sizes of 0.01, 0.06 and 0.14 corresponded to small, medium, and large effects, respectively.[32] All p values were <0.001.
ImPACT, Immediate Post-concussion Assessment and Cognitive Testing.

Table 4 The association between collision sports, contact sports, and shown variables using non-contact sports as a reference

	Collision sports		Contact sports	
Composite Score	**β (95% CI)**	**η²**	**β (95% CI)**	**η²**
Verbal memory	−1.64 (−1.85 to 1.44)	0.003	−0.83 (−1.04 to 0.62)	0.001
Visual memory	−1.87 (−2.14 to 1.60)	0.002	−0.75 (−1.03 to 0.48)	0.000
Visual motor speed	−2.12 (−2.26 to 1.97)	0.010	−0.72 (−0.86 to 0.58)	0.001
Reaction time	0.02 (0.02 to 0.02)	0.002	0.01 (0.01 to 0.01)	0.001
Total symptoms	−0.48 (−0.61 to 0.34)	0.001	−0.46 (−0.59 to 0.32)	0.000

We adjusted for age, concussion history, psychiatric diagnoses, headaches, migraines, learning disability, ADHD, speech therapy, special education and repeating one or more years of school. Effect sizes of 0.02, 0.13 and 0.26 correspond to small, medium and large effects, respectively.[32] All p values were <0.001. The remaining results of the multivariable analyses can be found in supplemental table.
ADHD, attention-deficit hyperactivity disorder.

in adolescent[12] and collegiate athletes[10] associated with collision sport participation. It is not known as to why collision sport athletes report fewer symptoms, but it is possibly due, at least in part, to collision sports being predominantly male, as sex has been associated with baseline symptom reporting in a number of studies.[26 27 34] This would not have been a factor in our study, however, because all included athletes were boys.

Adolescent student-athletes with ADHD have a greater lifetime history of concussions[35] and perform somewhat worse on computerised neurocognitive testing than those without ADHD.[36] A modestly higher percentage of collision sport athletes (13%) reported ADHD compared with contact (9%) and non-contact (10%) sport athletes. This did not influence our findings, however, because we controlled for this variable in our analyses. The percentages of collision and contact sport athletes (4%) reporting a psychiatric condition (anxiety and/or depression) was similar to non-contact (5%) athletes, although previous investigations have found better quality of life outcomes in high school collision and contact sport athletes,[14] and lower depression levels in collegiate football players.[10]

The observed differences in neurocognitive test performance and total symptom scores in our study are of questionable clinical relevance. Each of the differences in composite and symptom scores had small or very small effect sizes. Given the large number of athletes involved, even very small effects are likely to be statistically significant. The distributions of neurocognitive test scores and total symptom scores across the three groups are mostly overlapping. Moreover, the magnitudes of the differences between the groups in this study are much smaller than those observed when an uninjured athletes takes ImPACT twice.[37]

This study has several limitations. By design, we included only male high school athletes. We are currently performing similar analyses for female athletes. A computerised neurocognitive screening battery was used, so it is possible that a more comprehensive neuropsychological assessment may have detected stronger associations with sport type. Additionally, there were a number of individuals who had multiple baseline neurocognitive scores in the dataset, and while our analysis only included composite scores from the first assessment, we had no way of knowing how many times the participants had taken the test prior to reaching high school. It is possible that collision and contact sport athletes have a greater history of computerised neurocognitive testing due to the higher risk of concussion in their sports compared with non-contact sport athletes. Therefore, we cannot rule out the possible influence of a learning effect for some individuals. Most importantly, our athletes were grouped based on the sport type that they reported currently playing, but the scope of our database made us unable to account for prior, simultaneous or future sports participation. Thus, it is possible that (1) some individuals participated in more than one sport during the school year and (2) non-contact sport participants had a history of collision or contact sports participation. We classified soccer as a contact sport, based on prior literature,[24] but the classification may warrant reconsideration in future studies, as repeated head trauma, particularly subconcussive impacts, routinely occur. We cannot speculate, based on the results of this study, on possible later in life brain health for these student athletes. There are ongoing research efforts to examine long-term brain health in former elite or professional soccer players in Europe,[38 39] for example, and more research is needed regarding the later in life brain health of those who played high school sports.

High school boys playing collision and contact sports perform slightly worse and have slightly lower symptom scores on neurocognitive baseline testing than non-contact sport participants, but the differences are of unlikely clinical significance. Our findings suggest that sports type and the associated risk of subconcussive impacts do not result in clinically relevant differences in self-reported symptoms or neurocognitive functioning in current youth athletes.

Twitter Jessie R. Oldham @jroldham

Contributors JRO conceptualised and designed the study, carried out the analyses, drafted the original manuscript, revised and reviewed the final manuscript, and served as the guarantor. WM and GLI assisted with study conceptualisation and design, revised and reviewed the final manuscript, and critically reviewed the manuscript for intellectual content. DH, PB and RM all contributed to the revision and review of the final manuscript and critically reviewed the manuscript for intellectual content. CL contributed to the structure and organisation of the collected data, and revised and reviewed the final manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests WM receives royalties from (1) ABC-Clio publishing for the sale of his books, Kids, Sports and Concussion: A guide for coaches and parents, and Concussions; (2) Springer International for the book Head and Neck Injuries in Young Athlete and (3) Wolters Kluwer for working as an author for UpToDate. His research is funded, in part, by philanthropic support from the National Hockey League Alumni Association through the Corey C. Griffin Pro-Am Tournament and the National Football League. DH receives research support from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (R03HD094560) and the National Institute of Neurological Disorders And Stroke (R01NS100952 and R41NS103698) of the National Institutes of Health. He has previously received research support from a research contract between Boston Children's Hospital, Cincinnati Children's Hospital Medical Center and ElMindA, and the Eastern Athletic Trainers Association. GLI serves as a scientific advisor for NanoDx(formerly BioDirection), Sway Operations, and Highmark. He has a clinical and consulting practice in forensic neuropsychology, including expert testimony, involving individuals who have sustained mild TBIs (including athletes). He has received research funding from several test publishing companies, including ImPACT Applications, CNS Vital Signs and Psychological Assessment Resources (PAR). He has received research funding as a principal investigator from the National Football League, and salary support as a collaborator from the Harvard Integrated Program to Protect and Improve the Health of National Football League Players Association Members. GLI acknowledges unrestricted philanthropic support was provided by the National Rugby League, ImPACT Applications, the Mooney-Reed Charitable Foundation, the Boston Bolts, and the Spaulding Research Institute. Those entities were not involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication.

Patient consent for publication Not applicable.

Ethics approval The Boston Children's Hospital Institutional Review Board (IRB-P00030699) approved this study prior to any data analysis.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as online supplemental information.

ORCID iD
Jessie R. Oldham http://orcid.org/0000-0003-2801-2110

REFERENCES

1 Hammer E, Brooks MA, Hetzel S, *et al*. Epidemiology of Injuries Sustained in Boys' High School Contact and Collision Sports, 2008-2009 Through 2012-2013. *Orthop J Sports Med* 2020;8:1–8.
2 NFHS. *High school sports participation increases for 29th consecutive year*. NFHS News, 2018.
3 Johnson SB, Blum RW, Giedd JN. Adolescent maturity and the brain: the promise and pitfalls of neuroscience research in adolescent health policy. *J Adolesc Health* 2009;45:216–21.
4 McCrea M, Guskiewicz KM, Marshall SW, *et al*. Acute effects and recovery time following concussion in collegiate football players: the NCAA concussion study. *JAMA* 2003;290:2556–63.
5 Talavage TM, Nauman EA, Breedlove EL, *et al*. Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion. *J Neurotrauma* 2014;31:327–38.
6 Breedlove EL, Robinson M, Talavage TM, *et al*. Biomechanical correlates of symptomatic and asymptomatic neurophysiological impairment in high school football. *J Biomech* 2012;45:1265–72.
7 Davenport EM, Whitlow CT, Urban JE. Abnormal white matter integrity related to head impact exposure in a season of high school varsity football. *J Neurotrauma* 2014;8:1–32.
8 Montenigro PH, Alosco ML, Martin BM, *et al*. Cumulative head impact exposure predicts later-life depression, apathy, executive dysfunction, and cognitive impairment in former high school and College football players. *J Neurotrauma* 2017;34:328–40.
9 Caccese JB, DeWolf RM, Kaminski TW, *et al*. Estimated age of first exposure to American football and neurocognitive performance amongst NCAA male Student-Athletes: a cohort study. *Sports Med* 2019;49:477–87.
10 Caccese JB, Bodt BA, Iverson GL, *et al*. Estimated age of first exposure to contact sports and neurocognitive, psychological, and physical outcomes in healthy NCAA collegiate athletes: a cohort study. *Sports Med* 2020;50:1377–92.
11 Caccese JB, Iverson GL, Cameron KL, *et al*. Estimated age of first exposure to contact sports is not associated with greater symptoms or worse cognitive functioning in male U.S. service Academy athletes. *J Neurotrauma* 2020;37:334–9.
12 French J, Huber P, McShane J, *et al*. Influence of test environment, age, sex, and sport on baseline computerized neurocognitive test performance. *Am J Sports Med* 2019;47:3263–9.
13 Eckner JT, Wang J, Nelson LD, *et al*. Effect of routine sport participation on short-term clinical neurological outcomes: a comparison of non-contact, contact, and collision sport athletes. *Sports Med* 2020;50:1027–38.
14 Howell DR, Kirkwood MW, Laker S, *et al*. Collision and contact sport participation and quality of life among adolescent athletes. *J Athl Train* 2020;55:1174–80.
15 Deshpande SK, Hasegawa RB, Rabinowitz AR, *et al*. Association of playing high school football with cognition and mental health later in life. *JAMA Neurol* 2017;74:909–18.
16 Iverson G, Merz Z, Terry D. High-School football and midlife brain health problems. *Clin J Sport Med* 2021.
17 Brett BL, Huber DL, Wild A, *et al*. Age of first exposure to American football and behavioral, cognitive, psychological, and physical outcomes in high school and collegiate football players. *Sports Health* 2019;11:332–42.
18 Houck Z, Asken B, Clugston J, *et al*. Socioeconomic status and race outperform concussion history and sport participation in predicting collegiate athlete baseline neurocognitive scores. *J Int Neuropsychol Soc* 2018;24:1–10.
19 Broglio SP, Martini D, Kasper L, *et al*. Estimation of head impact exposure in high school football: implications for regulating contact practices. *Am J Sports Med* 2013;41:2877–84.
20 Rowson S, Duma SM. Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration. *Ann Biomed Eng* 2013;41:873–82.
21 Gysland SM, Mihalik JP, Register-Mihalik JK, *et al*. The relationship between subconcussive impacts and concussion history on clinical measures of neurologic function in collegiate football players. *Ann Biomed Eng* 2012;40:14–22.
22 Miller JR, Adamson GJ, Pink MM, *et al*. Comparison of preseason, midseason, and postseason neurocognitive scores in uninjured collegiate football players. *Am J Sports Med* 2007;35:1284–8.
23 ImPACT Applications. *Administration and interpretation Manual- version 4*, 2021.
24 Meehan WP, Taylor AM, Berkner P. Division III collision sports are not associated with neurobehavioral quality of life. *J Neurotrauma* 2015;6:150720092705003.
25 Burkhart S. ImPACT Raw Data & Composite Scores. ImPACT Appl. Inc, 2018. Available: https://concussioncaretraining.com/wp-content/uploads/Slides_RawData_Burkhart.pdf
26 Lovell MR, Iverson GL, Collins MW, *et al*. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Appl Neuropsychol* 2006;13:166–74.
27 Iverson GL, Silverberg ND, Mannix R, *et al*. Factors associated with Concussion-like symptom reporting in high school athletes. *JAMA Pediatr* 2015;169:1132–40.
28 Mannix R, Iverson GL, Maxwell B, *et al*. Multiple prior concussions are associated with symptoms in high school athletes. *Ann Clin Transl Neurol* 2014;1:433–8.
29 Brooks B, McKay C, Mrazik M. Subjective, but not objective, lingering effects of multiple past concussions in adolescents. *J Neurotrauma* 2013;29:257–64.
30 Elbin RJ, Kontos AP, Kegel N, *et al*. Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Arch Clin Neuropsychol* 2013;28:476–84.
31 Zuckerman SL, Lee YM, Odom MJ, *et al*. Baseline neurocognitive scores in athletes with attention deficit-spectrum disorders and/or learning disability. *J Neurosurg Pediatr* 2013;12:103–9.
32 Miles J, Shevlin M. *Applying regression & correlation: a Guide for Students and Researchers*. 1st ed. SAGE Publications Ltd, 2000.
33 Sullivan GM, Feinn R. Using effect Size-or why the *P* value is not enough. *J Grad Med Educ* 2012;4:279–82.
34 Covassin T, Swanik CB, Sachs M, *et al*. Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. *Br J Sports Med* 2006;40:923–7.
35 Iverson GL, Wojtowicz M, Brooks BL, *et al*. High school athletes with ADHD and learning difficulties have a greater lifetime concussion history. *J Atten Disord* 2020;24:1095–101.
36 Cook NE, Huang DS, Silverberg ND, *et al*. Baseline cognitive test performance and concussion-like symptoms among adolescent athletes with ADHD: examining differences based on medication use. *Clin Neuropsychol* 2017;31:1341–52.
37 Iverson GL, Lovell MR, Collins MW. Interpreting change on impact following sport concussion. *Clin Neuropsychol* 2003;17:460–7.
38 Mackay DF, Russell ER, Stewart K, *et al*. Neurodegenerative disease mortality among former professional soccer players. *N Engl J Med* 2019;381:1801–8.
39 Russell ER, Mackay DF, Stewart K, *et al*. Association of field position and career length with risk of neurodegenerative disease in male former professional soccer players. *JAMA Neurol* 2021;78:1057–63.