Clinically Historical and Prospective Associations Between Learning Disorders and Concussion in Young Adult Athletes

Abstract: Background. Athletes with specific learning disorder (LD) tend to score lower on neuropsychological tests and are at increased risk of personal injury than their counterparts without such disorders. Using a retrospective historical and prospective design, we examined whether adult athletes with LD, the most prevalent of neurodevelopmental disorders, experience greater chances of past and future concussions than their counterparts without LD. We expected to find that young athletes with LD would show greater risk of past (historical) and future (prospective) cerebral concussions. Methods. Participants (95 men and 53 women aged 18 to 25 years) were recruited from university sports teams and followed during an entire season. Of these, 38 participants had a history of LD and 101 had a history of at least 1 concussion (72 males, 29 females) at the preseason baseline. One-third experienced a new concussion. Data analytic procedures

include inferential cross-tabulations. Results. Athletes with LD were twice more likely to have a concussion history at baseline and to have a history of multiple concussions than athletes without LD; 95% CI = [0.86, 4.92] and [0.77, 3.40], respectively. Athletes with LD were twice more likely to incur a new concussion than those without LD; 95% CI = [0.86, 4.92]. Conclusions. Adult athletes

individuals with neurodevelopmental disorders may not only prevent the biopsychosocial consequences of brain trauma for the individual, but also represent a cost-effective public health measure.

Keywords: mild traumatic brain injury; concussion; head injury; sport injury; learning disorder; learning disability

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with LD experience greater chances of previous and future concussions compared with counterparts without LD. Preventive practices regarding

Relative to others, some people are more prone to experiencing personal injury, just as some contexts are more injury prone. A recent

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report on sport-related concussive injury, collaboratively released by the Institute of Medicine and the National Research Council, reveals 2 disconcerting findings: (1) mild traumatic brain injury is not as benign as once thought and (2) its prevalence is far from uncommon.^{1,2} Very little is known about predisposing neurodevelopmental characteristics that make some people more prone to such injury, sometimes even more than once.³ Identifying such factors would be of great clinical pertinence, especially given the current populational emphasis on participation in sport and exercise.

Comprising 15% to 20% of all mild traumatic brain injuries, cerebral concussion refers to a sport-related injury resulting from a direct or indirect blow to the head.⁴ On the outside, the skull is violently bumped or jolted back and forth from the cerebral impact.⁵ On the inside, the brain is bumped against the internal layers of the skull, inducing a neurometabolic cascade from the sudden intense brain tissue injury and subsequent inflammatory response.⁶⁻¹⁰

Any one of the following acute symptoms meets the criteria for a clinical diagnosis of cerebral concussion: headache; cognitive lethargy and sluggish reaction times; behavioral irritability; or emotional lability; temporary loss of consciousness; amnesia; and/or insomnia.³ For 85% of people affected by concussion, functional impairment usually resolves within 1 to 3 weeks.⁴ For the remainder, the recovery period may be longer because of unresolved pathophysiological sequelae.^{9,10} In fact, the hallmark features of prolonged neuropsychological impairment are persisting alterations in mood and affect as well as executive dysfunction.³ A longer recovery typically has repercussions on social and occupational performance, and a return to sport is ill advised given the psychoaffective and cognitive difficulties associated with prolonged recovery.^{11,12} Thus, given that executive function deficits may risk another injury, it becomes difficult to draw the line regarding when a return to sport would be more of a benefit than a risk.

Having a preexisting neurodevelopmental disorder, characterized by deficits in executive functions, seems to predict a more complex recovery period.^{3,11,13} On one hand, people with attention-deficit hyperactivity disorder (ADHD) are already at increased risk of bodily injury.¹⁴ On the other hand, having ADHD is associated with prolonged neuropsychological impairment after a concussive injury.¹⁵⁻¹⁷ Not surprisingly, having ADHD also predicts first and subsequent concussions and history of concussion and performance on standard concussion assessment measures.¹⁸⁻²⁰ A compelling test of whether neurodevelopmental disorders represent a pertinent risk factor for concussion would be replication with another highly prevalent neurodevelopmental disorder of similar etiology since childhood.

Specific learning disorder (LD) refers to particular deficits in efficient and effective information perception or processing abilities.¹⁵ These are in part explained by executive system malfunction and refer to a heterogeneous group of specific skill difficulties such as inaccurate or slow word reading; reading comprehension; spelling; writing; number sense, facts, or calculations; and mathematical reasoning.²¹⁻²³ When comorbid attentional problems are accounted for, the core remaining executive deficits associated with LD are processing speed, temporal processing, and working memory.²⁴ Specifically, individuals with LD are likely to have difficulties with reduced information processing as opposed to difficulties with behavioral control and impulsiveness. Often beginning in childhood when formal schooling begins, impairment is evidenced by academic performance well below average for age, schooling, and level of intelligence. Core executive deficits differ between the most common specific skill difficulties related to reading and mathematical skills. Deficits in verbal memory are associated with both reading and mathematical difficulties, whereas reading processing speed for familiar nameable symbols tends to be more predictive of reading than mathematics

difficulties. Conversely, temporal processing and visuospatial memory impairment tend to be associated with mathematical skill difficulties, rather than difficulties with reading.²⁴ Although affected individuals typically learn compensatory strategies during the school age years, specific LDs typically produce lifelong challenges in activities that require any of the affected skills, risking functional impairment in both social and occupational (or academic) domains.¹⁵ This disorder is more prevalent among boys.²²

Much like their counterparts with ADHD, people with LD are greater at risk of personal injury from childhood onward.^{14,21,25} As athletes, they tend to demonstrate lower baseline performance on neurocognitive test batteries than their counterparts without neurodevelopmental disorders.²⁶ When compared with their developmentally normative peers, adolescent athletes with LD typically have comparatively lower verbal memory, visual memory, and visual motor processing speed, along with significantly higher reaction times and concussion-like symptoms prior to sport participation.²⁷ To date, several studies have alluded that LD may be an easily identifiable risk factor for cerebral concussion.^{11,25-27} One in particular, has documented between LD and concussion history and performance on standard concussion assessment measures.²⁰ However, none to our knowledge have directly assessed the unique contribution of LD to concussive injury in a prospective design.

Hence, the purpose of this article is to examine the relationship between LD and sport-related concussion in young adults by using a retrospective historical and prospective design. We aim to not only replicate previous work that suggests a link between neurodevelopmental disorders and past concussions, but our design also allows us to determine whether adult athletes who report LD experience greater future chances of concussion than those who do not have LD. We expect to find that athletes reporting LD will show greater chances of experiencing cerebral

concussion, both past and future, in emerging adulthood, given that people with LD experience a discernible degree of dysfunction in the brain's executive system and are thus at increased risk for personal injury.^{14,20,25}

Method

Participants

Candidate participants (118 male and 57 female), aged 18 to 25 years, were recruited from university soccer, football, and hockey teams. As part of a preseason (baseline) testing, all participants completed a structured interview under the supervision of a clinical neuropsychologist, during which pertinent medical and demographic information were collected. Participants were then followed throughout their season to track the occurrence of any new concussive injuries. All participants completed their seasons as members of their respective sports teams, resulting in a zero attrition rate.

Preexisting Predictor Variable

As part of their preseason clinical interview, participant athletes answered a series of questions regarding psychiatric disorders during which they reported whether they had a LD or whether they had ever been identified as having serious academic difficulty. Self-reports of LD were then clinically evaluated by a neuropsychologist using the most recent standardized *Diagnostic and Statistical Manual of Mental Disorders* diagnostic and psychoeducational assessment criteria.¹⁵

Clinical History and Prospective Outcome Variable: Concussion

All concussions, both prior history and new injuries, were medically diagnosed using the criteria established by the Consensus on Concussion in Sport.³ All participant athletes were then followed throughout their season to keep track of any new concussive injuries. Researchers had access to the medical files for each participant. On diagnosis of a new concussion, participant athletes returned

to our laboratory, where they once again completed a structured interview under the supervision of a clinical neuropsychologist.

Exclusion Criteria

Because other psychiatric disorders can confound the relationship between LD and concussion according to Elbin et al²⁶ and Zuckerman et al,²⁷ those reporting any other psychiatric disorder, including ADHD, were excluded from further analysis, resulting in the removal of 27 candidates. This left 148 participants (95 male and 53 female) for analyses.

Data Analytic Procedure

Our aim was to verify a link between learning disability and history of concussion, documented at the inception of the study, and prospective (future) occurrence of a new concussion, documented during the sport season. To evaluate the likelihood of a concussion for participant athletes with LD versus those without LD, inferential cross-tabulation analyses were computed, resulting in odds ratios and 95% CIs for retrospective and prospective data for all participants. Additional gender-based analyses were conducted to evaluate the retrospective and prospective odds of concussion occurrence.

Results

Descriptive analyses on both clinical history and prospective outcome data are reported in Table 1 for all participants. Of the 148 athletes, only 47 had no history of concussion. For the remainder, 101 had a history of at least 1 concussion (72 males, 29 females). In all, 32 athletes had a history of 1 concussion; 59 had a history of 2 or more concussions.

During the course of the study, one-third of the sample incurred a physician-diagnosed concussion (24 males, 24 females). This was a first concussion for 15 athletes (6 male, 9 female); 33 athletes had a prior history of concussion (18 male, 15 female). Complete information is reported in Table 2.

Inferential Results for History of Concussion

As reported in Table 1, we found a significant link between LD and history of concussion. Of the 38 athletes with LD, 30 had a history of concussion (29.7%) compared with 8 who had no history of concussion (17.0%). Athletes with LD were 2.06 times more likely to have a concussion history at baseline than those without LD; 95% CI = [0.86, 4.92]. Furthermore, 19 of the 38 athletes with LD had a history of 2 or more concussions (50.0%), compared with 42 of the 110 athletes without LD (38.2%). Athletes with LD were 1.63 times more likely to have a history of multiple concussions than those without LD; 95% CI = [0.77, 3.40].

Of the 38 participants with LD, 28 were male (24 with a concussion history = 33.3% and 4 with no concussion history = 17.4%). Male athletes with LD were 2.36 times more likely to have a history of concussion than their counterparts without LD; 95% CI = [0.76, 20.81]. A total of 10 female participants had a LD (6 concussion history, 20.7%, compared with 4 with no concussion history, 16.7%). Female athletes with LD were 1.30 times more likely to have a history of concussion than their counterparts without LD; 95% CI = [0.32, 4.81]. Thus, among athletes with LD, male athletes were 4.0 times more likely to have a history of concussion than female athletes with LD; 95% CI = [0.76, 20.81].

Inferential Results for Prospective Follow-up

We found a significant link between LD and the incidence of a new concussion during the season. A total of 48 athletes (24 male, 25.3%; 24 female, 45.3%) incurred a concussion, as reported in Table 2. In all, 17 of the 38 athletes with LD (44.7%) and 31 of the 110 athletes without LD (27.9%) incurred a new concussion. Those with LD were 2.08 times more likely to incur a new concussion than those without LD; 95% CI = [0.86, 4.92]. Furthermore, 8 athletes incurred multiple concussions (16.7%; 5 male, 3 female). Three of the 38 athletes

Table 1.

Descriptive Statistics on Both Historical and Prospective Outcome Data for All Participants.

Historical Demographics (± 1 SD)		
Measure	Concussion	Control
Number	101	47
Age	22.2 (± 0.6)	21.0 (± 0.7)
Gender	72 M/29 W	23 M/24 W
1 Injury	32 (19 LD)	N/A
2 Or more injuries	69 (19 LD)	N/A
Measure	Men With Concussion	Control Men
Number	72 (24 LD)	23 (4 LD)
Age	21.2 (± 1.8)	21.2 (± 1.2)
Height	181.5 cm (± 16.1)	182.5 cm (± 20.7)
Weight	103.7 kg (± 7.1)	106.0 kg (± 6.9)
1 Injury	21 (7 LD)	N/A
2 Or more injuries	51 (17 LD)	N/A
Football	60	17
Soccer	12	6
Measure	Women With Concussion	Control Women
Number	29 (6 LD)	24 (4 LD)
Age	21.4 (± 1.6)	20.8 (± 1.4)
Height	166.4 cm (± 10.8)	168.6 cm (± 7.6)
Weight	66.4 kg (± 6.3)	60.6 kg (± 7.6)
1 Injury	8 (4 LD)	N/A
2 Or more injuries	21 (2 LD)	N/A
Hockey	18	11
Soccer	11	13

Abbreviations: M, men; W, women; LD, learning disorder.

with LD at baseline (7.9%) and 5 of the 111 athletes without LD (4.5%) incurred multiple concussions during the study. Athletes with LD at baseline were 1.87 times more likely than athletes without

LD at baseline to incur multiple concussions during the season; 95% CI = [0.41, 7.99].

Ten of the 28 males with LD (35.7%), and 14 of the 67 male athletes without

LD (20.8%) incurred a new concussion during the season. Males with LD were 2.11 times more likely than male athletes without LD to experience a new concussion; 95% CI = [0.79, 5.55]. Seven of the 10 female athletes with LD (70.0%) and 17 of the 43 female athletes without LD (39.5%) experienced a new concussion. Female athletes with LD were 3.56 times more likely than female athletes without LD to incur a new concussion; 95% CI = [0.81, 15.74]. Thus, among those with LD at baseline, females were 4.2 times more likely than males with LD to have a concussion during the entire season; 95% CI = [0.88, 19.94].

Discussion

To play well, individuals participating in organized sports need sufficient attention and working memory to be able to rapidly dodge an incoming ball, shift planned movements, change running direction, and chase or avoid an opposing team player. Over a split-second, reduced neuropsychological functioning could affect decision making and attentional shifting while engaging in movement related to a sporting activity. It is plausible that such vulnerability could result in an increased risk for cerebral concussion during play.

In our sample, many athletes reported disabilities related to learning. Confirming previous findings from Nelson et al,²⁰ athletes with LD were twice more likely to have a concussion history at baseline than their counterparts without LD. Remarkably, having a LD was associated with significantly higher chances of having a history of multiple concussions compared with not having a LD. Of the athletes who incurred a concussion during the season, 89% of those with LD had a history of prior concussion, and 62% of those without LD had a history of prior concussion. The difference between these 2 groups suggests that having a LD appears to be an important predictor of concussion, beyond simply having a history of prior concussion.

The most important original finding from this study is the significant

Table 2.

Prospective Statistics on Concussion Incidence for All Participants and by Gender.

Prospective Demographics (± 1 SD)	
Measure	Concussion
Number	48 (31 LD)
Age	21.4 (± 0.9)
Gender	24 M/24 W
1 Injury	40 (28 LD)
Multiple injuries	8 (3 LD)
Measure	Men With Concussion
Number	24 (10 LD)
Age	21.3 (± 1.0)
Height	183.4 cm (± 6.9)
Weight	103.0 kg (± 12.4)
1 Injury	24 (8 LD)
2+ Injuries	3 (2 LD)
Football	20
Soccer	4
Measure	Women With Concussion
Number	24 (7 LD)
Age	21.5 (± 0.9)
Height	165.7 cm (± 4.9)
Weight	61.4 kg (± 5.4)
1 Injury	16 (6 LD)
2+ Injuries	5 (1 LD)
Hockey	18
Soccer	6

Abbreviations: M, men; W, women; LD, learning disorder.

head, neck, and core bumping injuries. More important, it proposes a cautionary tale for high schools that use sports programs to keep students at risk of dropout in school. Such students have a higher prevalence of learning and other neurodevelopmental disorders.²⁸

The above prospective associations are corroborated by the gender-based analyses. As expected, an overwhelming majority of LD athletes (28 out of 38) were men.²² Men in our study with LD were twice more likely than men without LD to incur a concussion. Given this overrepresentation, the 4-fold higher chance of men experiencing a history of concussion compared with women is not surprising. The link with a highly prevalent neurodevelopmental disorder such as LD suggests that individuals with a history of reported learning difficulties participating on a sports team should be assessed and attended to more closely, on a seasonal basis, for prolonged sequelae of past (suspected or confirmed) concussion.

Most astounding is that, despite their comparatively lower representation (10 out of 38 LD cases), women were three and a half times more likely to experience a new concussion. Specifically, although men were more likely to begin their season with history of concussion, women were more likely to get concussed again. We offer several explanations for this finding, which are likely confluent. First, women and men are different at season baseline neuropsychological testing.²⁹ Such differences are likely explained by the vulnerability prompted by normative hormonal changes that occur in the menstrual cycle.³⁰ Second, women are more likely to report symptoms as a factor and thus show a higher frequency and intensity of postconcussion symptoms than men (ie, weaker concentration, lightheadedness, fatigue, and “flyspots” in their vision).³¹ Such symptoms tend to last longer in women and are accompanied by a compromised performance on neurocognitive tests, even after the subjective postconcussion symptoms have resolved.³² Therefore, our findings suggest that assessment of

association between LD and the incidence of a new concussion. Individuals with LD were twice more likely to incur a new concussion than those without LD. It remains perturbing that athletes with LD were almost twice

more likely than athletes without LD to incur multiple concussions during the short course of this study. This suggests that extra care should be taken during assessment of candidates for sporting activities known for a higher risk of

women at baseline and following concussion should be managed conservatively, and return to play judgment protocols perhaps need to be more stringent for them as well.

When compared with their normative peers, athletes with a sole diagnosis of LD tend to show no difference in impulse control, a factor which behaviorally distinguishes LD from ADHD.²⁷ As such, the differences in risk observed in this study are not likely explained by impulsivity. Cognitive dysfunction caused by prolonged recovery from posttraumatic brain injuries is frequently managed with stimulant medications.³³ Although these represent the treatment of choice for ADHD, little is known about whether stimulant therapy could be a preventive practice with elite athletes with LD to prevent further cerebral concussion in high-risk sports. One can only speculate, till it is shown as beneficial, whether stimulant therapy may help prevent subsequent injury in athletes with LD, especially for those experiencing prolonged recovery from posttraumatic brain injury and wishing to return to their high-risk sport.

In this study, participants were clinically evaluated by a neuropsychologist to confirm a self-reported LD. All other psychiatric and neurodevelopmental diagnoses were excluded to isolate the association between LD and cerebral concussion risk and, thus, reduce confounding. Establishing this link is of potential interest to public health for a multitude of reasons. First, because neurodevelopmental disorders are associated with accidents and injuries, they are costly to individuals, families, and the public health purse.³⁴⁻³⁶ Second, individuals with neurodevelopmental disorders may experience a more complex recovery process. Third, head and body injuries often do not occur in a vacuum, exposing other players to risk of collision with such individuals. Thus, preventive policies regarding individuals with neurodevelopmental disorders as a special population may not only prevent the biopsychosocial consequences of brain trauma for the individual, but also

represent a cost-saving measure at a societal level. Considering that LD represents a highly prevalent neurodevelopmental disorder that is easily diagnosed and treated, our findings thus call for a better standard of care for athletes at risk of cerebral concussion and/or prolonged functional impairment associated with such injury.

This study is not without its limitations. Among the most important is the limited number of participants in this study, especially women. Nevertheless, we obtained significant results despite the minimal power offered by our small sample size. A larger sample size would have also allowed more sophisticated statistical methods that could account for potential confounds and omitted variable bias. The neurodevelopmental disorder examined in this study is commonly comorbid with other disorders.²² With larger samples, future research should verify whether highly prevalent comorbidity increases risk for injury. Finally, the term *mild* traumatic brain injury might be a misnomer, given the pervasive, deleterious sequelae associated with cerebral concussion, which remain significant from a clinical and social policy perspective.^{30,37}

Authors' Note

All authors have had full access to all data in the study and take responsibility for its integrity and the accuracy of its analysis. The data and materials can be made available for verification purposes. This international review board–approved study was conducted without specific funding to any of the authors.

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Ethical Approval

Not applicable, because this article conducts secondary analysis of already existing data and thus does not use primary data from a new collection from human or animal subjects.

Informed Consent

Not applicable, because this article does not contain any studies with human or animal subjects.

Trial Registration

Not applicable, because this article does not contain any clinical trials.

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