OXFORD
UNIVERSITY PRESS

Archives of Clinical Neuropsychology 37 (2022) 19–29

Archives of CLINICAL NEUROPSYCHOLOGY

# Sport Contact Level Affects Post-Concussion Neurocognitive Performance in Young Athletes

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Received 22 December 2020; revised 25 February 2021; Accepted 22 March 2021

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## Abstract

**Objective:** Contact level affects the incidence of sports-related concussion. However, the effects of contact level on injury severity and recovery are less clear and are the focus of this study.
**Method:** Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) for athletes aged 12–22 was performed at baseline ($n = 10{,}907$ for 7,058 athletes), after suspected concussion determined by physicians or athletic trainers ($n = 5{,}062$ for 4,419 athletes), and during follow-up visits ($n = 3{,}264$ for 2,098 athletes). Athletes played contact/collision (CC), limited contact (LC), and noncontact (NC) sports. Injury incidence, severity, and recovery were measured using raw and change from baseline neurocognitive test scores. Comparisons between groups used univariate analysis and multivariable regression controlling for demographic variables.
**Results:** Compared to CC athletes, LC and NC athletes showed decreased suspected concussion incidence. At initial post-injury testing, all neurocognitive test scores were similar between groups except changes from baseline for processing speed were improved for LC compared to CC athletes. Upon follow-up testing, raw neurocognitive scores were better for NC compared to the contact collision athletes in verbal memory, processing speed, total symptom score, migraine cluster, cognitive cluster, and neuropsychiatric cluster scores. For change from baseline scores, LC athletes exhibited better performance on verbal memory, processing speed, and reaction time but also showed higher neuropsychiatric scores than CC athletes.
**Conclusion:** Neurocognitive scores between contact levels were similar at the first post-injury test. However, follow up showed many improved scores and symptoms for limited and NC sports compared to CC sports, which may indicate faster recovery.

*Keywords:* Childhood brain insult; Childhood neurologic disorders; Head injury, traumatic brain injury

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## Introduction

Adolescent participation in sports has been associated with improved cognitive function, confidence, character-building, and development of important relationships (Fraser-Thomas, Côté, & Deakin, 2005). However, increased participation in sports has also led to increased incidence of sports-related concussion (SRC), creating a large public health concern due to neuropsychological consequences on developing brains (Lincoln et al., 2011). Many factors may affect incidence of SRC including sex, age, competition level, and number of previous concussions (Marar, McIlvain, Fields, & Comstock, 2012; O'Connor et al., 2017).

https://doi.org/10.1093/arclin/acab021 Advance Access publication 7 April 2021

Neuropsychologists are an important part of an athlete's care team and often use computerized neurocognitive testing to track athletes both before and after SRC (McCrory et al., 2005). Neuropsychological testing has been shown to be both sensitive in the diagnosis of SRC and tracking of recovery and a cost-effective method of obtaining reliable data (Collins et al., 1999; Kontos, Elbin 3rd, Covassin, & Larson, 2010). The first computerized neurocognitive test developed was Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), which is currently well validated and commonly used in the assessment and management of SRC (Brett, Smyk, Solomon, Baughman, & Schatz, 2016). Additionally, it has played a role in identifying factors that affect neurocognitive testing outcomes before and after injury such as age, gender, learning disability, and concussion history (Buzzini & Guskiewicz, 2006; Collins et al., 1999; Covassin et al., 2006; Iverson, Gaetz, Lovell, & Collins, 2004).

Differences in contact level between sports have also been shown to modulate the incidence and risk of SRC. Sports have been previously classified into contact/collision (CC), limited contact (LC), and noncontact (NC) sports by the Committee on Sports Medicine and Fitness based on an estimated risk of acute traumatic injury (Medical Conditions Affecting Sports Participation, 1994). Higher contact and collision sports have been associated with greater incidence of SRC, whereas risk of SRC decreases in LC sports and is lowest for NC sports (Lincoln et al., 2011; Pfister, Pfister, Hagel, Ghali, & Ronksley, 2016; Tsushima, Siu, Ahn, Chang, & Murata, 2019). For example, Pfister et al. identified that out of 12 sports, CC sports including rugby, hockey, and American football had the highest reported incidence of SRC, whereas LC sports including cheerleading and volleyball had lower incidence of SRC. Tsushima et al. found that CC sports such as wrestling, martial arts, and football have a higher incidence of concussion than NC sports such as tennis and cross country. However, there has been limited investigation into the effects of contact level on different features of cognitive functioning, symptom burden, or symptom resolution time following a concussion. A few prior studies have shown a lack of consensus on the role of contact level on SRC recovery (Brett et al., 2018; D'Lauro et al., 2018; Zuckerman et al., 2016). Although it is possible that LC and NC athletes show different SRC incidence and recovery patterns than CC athletes due to lower frequency of impact, differences between contact level have not been extensively studied, possibly due to lower incidence of injury in LC and NC sports (Pfister et al., 2016; Tsushima et al., 2019).

Further study of association between contact level and SRC in young athletes is also important due to limited understanding of how brain maturation and development affect the clinical course of concussion (Casey, Jones, & Hare, 2008; Moser, Davis, & Schatz, 2017). It has been hypothesized that sub-concussive impacts are higher in CC sports which may affect post-concussion recovery due to negative effects on brain health and function (Bailes, Petraglia, Omalu, Nauman, & Talavage, 2013; Hirad et al., 2019; Rawlings, Takechi, & Lavender, 2020). Consistent with this hypothesis, Brett et al. found that football athletes sustaining concussions later in the season have increased post concussive symptoms when compared to athletes with concussion early in the season.

In addition to symptoms, sports contact level may affect cognitive domains including verbal memory, visual memory, processing speed, and reaction time. Verbal and visual memory impairments have been found to correlate with severity of traumatic brain injury (TBI; Lowther & Mayfield, 2004). Athletes with severe TBI show significant impairments in verbal and visual memory compared to non-injured controls (Ewing-Cobbs, Levin, Fletcher, Miner, & Eisenberg, 1990; Farmer et al., 1999; Fay et al., 1994; Levin et al., 1994; Levin, Eisenberg, Wigg, & Kobayashi, 1982), whereas athletes with mild or moderate TBI are reported to have similar verbal memory and visual memory scores than non-injured controls (Farmer et al., 1999; Yeates, Blumenstein, Patterson, & Delis, 1995). Athletes participating in contact sports without a prior diagnosed concussion have been shown to have memory impairments, possibly due to mild sub-concussive impacts (Killam, Cautin, & Santucci, 2005). Processing speed and reaction time are also reported to be more affected by more severe injury, possibly due to diffuse axonal injury and damage to white matter tracts in TBI (Felmingham, Baguley, & Green, 2004; Tombaugh, Rees, Stormer, Harrison, & Smith, 2007). Damage to white matter tracts may reduce the number of interconnections between neural networks and slow speed of information processing (Timmerman & Brouwer, 1999; Tombaugh et al., 2007).

The objectives of this study were to investigate the potential effects of different contact levels between sports on the incidence, initial severity, and recovery of SRC in young athletes utilizing a database with 10 years of computerized neurocognitive testing data across multiple sport types. Although prior studies have included contact level as a variable (D'Lauro et al., 2018; Zuckerman et al., 2016), this is the first study to focus on how contact level affects computerized neurocognitive testing results after SRC. Due to the decreased level of impacts in LC and NC sports, we hypothesized that (a) LC and NC athletes would have decreased incidence of SRC compared to CC athletes, (b) LC and NC athletes would report fewer cognitive symptoms and demonstrate improved performance on verbal memory, visual memory, processing speed, and reaction time compared with CC athletes after SRC, and (c) NC athletes would also show different recovery patterns from SRC compared to LC athletes on computerized neurocognitive testing due to decreased contact.

## Materials and Methods

### *Design and Participants*

Data from ImPACT results were collected between July 1, 2009 and June 30, 2019. Eligible subjects aged 12–22 years were part of athletic organizations in Florida and Colorado following standardized care, which included preseason baseline testing, same day head injury assessment by physicians and athletic trainers at sites of injury, and post-injury ImPACT testing for athletes with symptoms consistent with suspected concussions. Follow-up post-injury ImPACT tests were conducted at different intervals depending on symptom severity and student availability. Out of 25,815 ImPACT results, 10,907 (42.3%) were preseason baseline tests for 7,058 athletes, and 5,062 (19.6%) were initial post-injury 1 (PI1) tests after suspected concussion for 4,419 of these athletes. Some of the athletes with PI1 testing underwent follow-up post-injury tests, 3,264 tests (12.6%) for 2,098 athletes, to measure recovery. And, 6,582 (25.5%) remaining post-injury tests were excluded because athletes lacked baseline tests or sport type information. This study was approved by the institutional review board for human subject research. The study was deemed exempt from informed consent because the data were de-identified and previously collected for clinical use.

### *Demographic Information and Medical History*

Demographic information and medical history were self-reported during ImPACT testing. Demographic data included age, gender, and sport played. Sports were categorized into CC, LC, and NC sports based on a statement by the Committee on Sports Medicine and Fitness outlining estimated risk of acute traumatic injuries from blows to the body (Medical Conditions Affecting Sports Participation, 1994). Contact/collision sports included basketball, boxing, diving, field hockey, football, ice hockey, lacrosse, martial arts, rodeo, rugby, soccer, water polo, and wrestling. Limited contact sports included baseball, cheerleading, horseback riding, fencing, gymnastics, skiing, softball, and volleyball. Noncontact sports included bowling, dance, golf, powerlifting, swimming, tennis, track and field, and cross country running. Medical history data included diagnosed attention-deficit hyperactivity disorder (ADHD), attention-deficit disorder (ADD), diagnosed learning disability, depression, anxiety, chronic headaches, chronic migraines, and previous concussion history.

### *ImPACT Testing*

The ImPACT test conducts a post-concussion symptom scale survey before testing the neurocognitive function of the patient using a variety of tests including word memory, design memory, X’s and O’s and Three letter working memory, symbol matching, and color matching tasks over a 20 min session (Iverson, Lovell, & Collins, 2003). The post-concussion symptom score migraine, cognitive, sleep, and neuropsychiatric clusters were calculated as previously described (Lau, Collins, & Lovell, 2011, 2012). Migraine symptoms include headache, vomiting, nausea, balance problems, dizziness, sensitivity to light and noise, numbness, and vision problems. Cognitive symptoms include fatigue, drowsiness, feeling slowed down, fogginess, difficulty concentrating, and memory problems. Sleep variables include difficulty falling asleep, sleeping, more, and sleeping less. Neuropsychiatric symptoms include irritability, sadness, feeling more emotional, and nervousness. The range of possible scores is 0–54 for the migraine cluster, 0–36 for the cognitive cluster, 0–18 for the sleep cluster, and 0–24 for the neuropsychiatric cluster. ImPACT evaluates changes from baseline in 5 composite scores to provide a surrogate marker for concussions. The composite scores are verbal memory, visual memory, reaction time, processing speed, and post-concussion symptom scale Iverson et al., 2003).

### *Incidence of Suspected Concussion*

Incidence rates were calculated as the number of suspected concussions per person-years at risk for injury. Patients required a baseline test to be considered at risk for injury. ImPACT baseline tests are reported to be stable for 2 years, and patients with greater than 2 years between baseline tests were considered lost to follow-up (Brett et al., 2016; Brett, Solomon, Hill, & Schatz, 2018).

### *Statistical Analyses*

Statistical analyses were performed with Prism 8.0 (GraphPad Software, San Diego, CA) and SAS 9.4 (SAS Institute Inc., Cary, NC). Descriptive statistics described demographics and medical history. Players without a listed sport were excluded from analysis. Chi-square and analysis of variance compared incidence rates between sport types and means for patient demographics and medical history. Multivariable logistic and linear regression analyses were used to compare suspected concussion incidence and ImPACT composite scores between sport types while controlling for demographic differences. For all analyses, $\alpha = .05$.

## Results

### *Demographics*

Of the 25,815 ImPACT tests conducted during the study period, 10,907 (42.3%) were preseason baseline tests for 7,058 athletes, 5,062 (19.6%) were initial PI1 tests after suspected concussion for 4,419 athletes, and 3,264 (12.6%) were follow-up post-injury tests to measure recovery for 2,098 athletes. And, 6,582 (25.5%) remaining tests were missing baseline tests or sport type information and were excluded. Patients were divided into CC, LC, and NC sport types, and patient demographic information for the three groups at baseline, at the first post-injury test, and during follow up is detailed in Table 1. At baseline, CC athletes were slightly older than the LC cohort (15.4 vs. 15.2 years, $p < .05$) and had more male athletes compared to either the LC or NC groups (79.3% vs. 20.8% vs. 45.9%, $p < .05$). The CC cohort also contained slightly higher numbers of participants with ADD/ADHD (5.4% vs. 3.4%, $p < .05$) and previous concussions (12.1% vs. 7.9%, $p < .05$) compared to the LC group. Compared to the CC cohort, depression/anxiety rates were different for the NC (2.8% vs. 7.2%, $p < .05$) cohort. Rates of chronic headaches, chronic migraines, and diagnosed learning disability were not different between groups.

### *Incidence and Post-Injury Test 1 ImPACT Composite Scores*

Incidence of suspected concussion was highest for CC (0.51 per person-year) compared to LC (0.40 per person-year, $p < .0001$), and NC (0.15 per person-year, $p < .0001$). Results were confirmed on multivariable regression controlling for differences in demographic variables including age, gender, ADHD, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and $\geq 2$ previous concussions. Compared to the CC group, the LC (odds ratio [OR] = 0.78, 95% confidence interval [CI]: 0.70–0.88, $p < .0001$) and NC (OR = 0.27, 95% CI: 0.21–0.34, $p < .0001$) groups showed decreased odds of suspected concussion (Table 2).

When assessing individual outcomes for ImPACT PI1 testing, raw scores for verbal memory, processing speed, symptom score, migraine symptoms, cognitive symptoms, sleep symptoms, and neuropsychiatric symptom cluster scores had significant differences between the three cohorts (Table 3). However, none of these differences remained significant after multivariable analysis controlling for gender, ADHD, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and $\geq 2$ previous concussions (Table 4). When assessing changes from baseline values, symptom scores, migraine symptoms, and cognitive symptoms had significant differences between the three cohorts on univariate analysis, but after multivariable analysis these differences also became nonsignificant. On multivariable analysis controlling for the same demographic variables, processing speed scores in the LC cohort were significantly faster relative to baseline compared to the CC cohort ($\beta = .69$, 95% CI: 0.09–1.29, $p = .02$). All other results were not significantly different between contact levels (Table 4).

### *Follow-Up Post-Injury Test ImPACT Composite Scores*

The median interquartile range (IQR) follow-up times were 8 days (IQR, 5–15) for CC, 9 days (IQR, 5–17) for LC, and 7.5 days (IQR 3.75–14 days) for NC cohorts, and they were not statistically different ($p = .53$). Univariate analysis of the raw ImPACT composite scores for follow-up post-injury tests showed significant differences between contact levels in processing speed, symptom score, migraine symptom cluster, and neuropsychiatric symptom cluster scores (Table 3). In multivariable analysis adjusting for time between follow-up tests as well as gender, ADHD, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and $\geq 2$ previous concussions, raw ImPACT composite scores for follow-up post-injury tests were significantly different for the NC cohort compared to the CC cohort. The NC cohort showed higher verbal memory ($\beta = 3.59$, 95% CI: 0.05–7.13, $p = .047$), and higher processing speed ($\beta = 2.50$, 95% CI: 0.49–4.509, $p = .02$) when compared to CC. The NC group also reported lower total symptom score ($\beta = -3.78$, 95% CI: $-7.03$ to $-0.52$, $p = .02$), migraine cluster score ($\beta = -1.39$, 95% CI: $-2.70$ to $-0.08$, $p = .04$), cognitive cluster score ($\beta = -1.24$, 95% CI: $-2.42$ to $-0.06$, $p = .04$) and neuropsychiatric cluster score ($\beta = -.80$, 95% CI: $-1.47$ to $-0.13$, $p = .02$) than the CC cohort. Raw ImPACT composite scores were not significantly different for the LC cohort compared to the CC cohort (Table 5).

Univariate analysis of changes from baseline for follow-up post-injury tests did not show significant differences between contact levels (Table 3). In multivariable analysis adjusting for time between follow-up tests as well as gender, ADHD, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and $\geq 2$ previous concussions, changes from

**Table 1.** Cohort demographics

| Variables | Baseline tests | | | | Initial post-injury tests | | | | Follow-up post-injury tests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All ($n = 10{,}907$) for 7,058 athletes | NC ($n = 516$) for 300 athletes | LC ($n = 2{,}142$) for 1,411 athletes | CC ($n = 8{,}249$) for 5,347 athletes | All ($n = 5{,}062$) for 4,419 athletes | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4{,}050$) for 3,527 athletes | All ($n = 3{,}264$) for 2,098 athletes | NC ($n = 50$) for 36 athletes | LC ($n = 534$) for 360 athletes | CC ($n = 2{,}680$) for 1,702 athletes |
| Age | 15.4 (*SD* 1.5, range 12–22) | 15.4 (*SD* 1.5, range 12–21) | 15.2 (*SD* 1.5, range 12–22) | 15.4 (*SD* 1.5, range 12–22)[a] | 16.0 (*SD* 1.6, range 12–22) | 16.0 (*SD* 1.6, range 13–21) | 15.8 (*SD* 1.5, range 12–22) | 16.0 (*SD* 1.7, range 12–22)[a] | 15.9 (*SD* 1.6, range 12–22) | 15.8 (*SD* 1.9, range 13–21) | 15.8 (*SD* 1.4, Range 12–22) | 15.9 (*SD* 1.6, range 12–22)[a] |
| Male gender | 7,221 (66.2%) | 237 (45.9%) | 446 (20.8%) | 6,538 (79.3%)[b] | 3,365 (66.5%) | 35 (36.8%) | 131 (14.3%) | 3,199 (79.0%)[b] | 2,170 (66.5%) | 19 (38.0%) | 71 (13.3%) | 2,080 (77.6%)[b] |
| ADHD | 536 (4.9%) | 20 (3.9%) | 73 (3.4%) | 443 (5.4%)[b] | 242 (4.8%) | 1 (1.1%) | 20 (2.2%) | 221 (5.5%)[b] | 175 (5.4%) | 0 (0.0%) | 13 (2.4%) | 162 6.0%)[b] |
| Diagnosed learning disability | 296 (2.7%) | 18 (3.5%) | 54 (2.5%) | 224 (2.7%) | 141 (2.8%) | 3 (3.2%) | 15 (1.6%) | 123 (3.0%) | 90 (2.8%) | 2 (4.0%) | 7 (1.3%) | 81 (3.0%) |
| Depression/anxiety | 419 (3.8%) | 37 (7.2%) | 105 (4.9%) | 277 (2.8%)[b] | 185 (3.7%) | 6 (6.3%) | 28 (3.1%) | 151 (3.7%) | 124 (3.8%) | 3 (6.0%) | 13 (2.4%) | 108 (4.0%) |
| Chronic headaches | 1,243 (11.4%) | 48 (9.3%) | 259 (12.1%) | 936 (11.3%) | 600 (11.9%) | 10 (10.5%) | 110 (12.0%) | 480 (11.9%) | 394 (12.1%) | 10 (20.0%) | 85 (15.9%) | 299 (11.1%)[b] |
| Chronic migraines | 868 (8.0%) | 36 (7.0%) | 169 (7.9%) | 663 (8.0%) | 449 (8.9%) | 10 (10.5%) | 74 (8.1%) | 365 (9.0%) | 306 (9.4%) | 8 (16.0%) | 57 (10.7%) | 241 (9.0%) |
| Previous concussion history ≥2 | 1,223 (11.2%) | 53 (10.3%) | 169 (7.9%) | 1,001 (12.1%)[b] | 822 (16.2%) | 15 (15.8%) | 121 (13.2%) | 686 (16.9%)[b] | 479 (14.7%) | 7 (14.0%) | 75 (14.0%) | 397 (14.8%) |

*Notes:* ADHD = attention-deficit/hyperactivity disorder; CC = contact/collision; LC = limited contact; NC = noncontact.

[a] Analysis of variance, $p < .05$.

[b] Chi-square test, $p < .05$.

**Table 2.** Incidence of suspected concussion between sport types

| Analysis type | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4{,}050$) for 3,527 athletes |
|---|---|---|---|
| Unadjusted incidence of suspected concussion | .15/ person-year | .40/ person-year | .51/ person-year[a] |
| Adjusted odds of suspected concussion (95% CI) | OR = .27[b] (.21–.34) | OR = .78[b] (.70–.88) | Reference |

*Note:* Multivariable logistic regression controlled for variables: age, gender, attention-deficit/hyperactivity disorder, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and previous concussion history ≥2.

[a] Analysis of variance, $p < .0001$.

[b] Multivariable logistic regression, $p < .0001$.

baseline for follow-up post-injury tests were significantly different for the LC cohort compared to the CC cohort. The LC cohort exhibited better scores on verbal memory ($\beta = 1.62$, 95% CI: 0.14–3.11, $p = .03$), processing speed ($\beta = 1.05$, 95% CI: 0.38–1.71, $p = .002$), and reaction time ($\beta = -.020$, 95% CI: $-0.034$ to $-0.006$, $p = .004$). The LC group also demonstrated a higher neuropsychiatric cluster score ($\beta = .35$, 95% CI: 0.02–0.69, $p = .04$) than the CC group compared with baseline. The NC group did not show significant changes from baseline compared to the CC cohort (Table 5).

Lastly, while this study is well powered to detect differences in SRC incidence among the three cohorts, many of the sub score comparisons for both initial post-injury and follow-up testing are not powered at an 80% confidence level. Thus, some nonsignificant results for the LC and NC groups could be due to the small size of the LC and NC cohorts.

## Discussion

This study utilized 19,233 ImPACT tests across sports of varying contact levels to assess the effects of sport type on incidence, severity, and recovery of SRC in adolescent student athletes. Athletes who participated in higher contact sports had a higher incidence of suspected concussion than LC and NC groups. Young athletes who compete in sports with varying contact levels may have differing clinical presentation and recovery following a suspected concussion. At the first post-injury tests, almost no differences between contact levels were detected on ImPACT. However, follow-up ImPACT testing showed many improved scores for NC and LC groups compared to the CC group.

### *Concussion Incidence*

Previous studies have shown that contact sports have an increased incidence of SRC compared to limited and NC sports (Lincoln et al., 2011; Pfister et al., 2016; Rosenthal, Foraker, Collins, & Comstock, 2014). Pfister et al. reported the incidence of concussion in rugby, hockey, and football is higher than in lower contact sports such as baseball and cheerleading (Pfister et al., 2016). Tsushima et al. found that collision sports such as wrestling, martial arts, and football have a higher incidence of concussion than in NC sports such as tennis and cross country (Tsushima et al., 2019). Our study reports similar findings, as CC sports had the highest incidence of suspected concussion while NC sports had the lowest incidence of suspected concussion. Increased concussion rate in CC sports was expected because player-to-player contact causes the majority of SRC (Marar et al., 2012; Rawlings et al., 2020). Additionally, although many CC sports leagues mandate the use of helmets and mouthguards, previous studies have postulated that athletes may rely too heavily on this protective equipment and act more aggressively, resulting in increased risk of concussion (Koh, Cassidy, & Watkinson, 2003).

### *Initial Concussion Severity*

Despite strong consensus regarding higher incidence of concussions in contact sports, there has been a relative lack of research on initial severity of suspected concussions between sport types. Some factors associated with increased concussion severity include female gender, lack of helmet use, and premature return to sports following concussion (Halstead, Walter, & Moffatt, 2018; Makdissi et al., 2010; Mollayeva, El-Khechen-Richandi, & Colantonio, 2018). The need for prolonged recovery from SRC has also been associated with increased initial concussion severity (Hannah et al., 2020; Grant L. Iverson et al., 2017; Makdissi et al., 2010). In the present study, the majority of results obtained at the first post-injury test showed no significant differences between contact levels, with the exception of improved processing speed for the LC cohort compared to the CC cohort. These similarities between initial ImPACT scores may indicate that initial severity of suspected concussion across contact levels is

**Table 3.** Unadjusted scores at the first post-injury test and follow-up tests between sport types

| Composite scores | First post-injury test | | | | | | Follow-up tests | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw scores | | | Deviation from baseline | | | Raw scores | | | Deviation from baseline | | |
| | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4,050$) for 3,527 athletes | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4,050$) for 3,527 athletes | NC ($n = 50$) for 36 athletes | LC ($n = 534$) for 360 athletes | CC ($n = 2,680$) for 1,702 athletes | NC ($n = 50$) for 36 athletes | LC ($n = 534$) for 360 athletes | CC ($n = 2,680$) for 1,702 athletes |
| Verbal memory (*SD*) | 82.16 (13.26) | 81.42 (14.48) | 80.08 (14.75)[a] | −1.25 (14.83) | −2.17 (14.91) | −2.44 (15.06) | 87.46 (10.00) | 85.24 (11.72) | 84.02 (12.09) | 2.90 (11.92) | 1.84 (13.71) | 1.41 (13.84) |
| Visual memory (*SD*) | 71.63 (14.90) | 69.50 (15.17) | 70.47 (15.14) | −1.85 (13.47) | −2.84 (15.77) | −2.15 (16.11) | 72.66 (14.61) | 71.27 (13.22) | 72.24 (14.06) | −.82 (14.67) | −1.62 (14.59) | −.50 (15.29) |
| Processing speed (*SD*) | 36.32 (8.05) | 35.98 (8.08) | 35.04 (8.13)[a] | 1.46 (6.67) | .47 (7.37) | .69 (7.09) | 40.44 (7.53) | 38.65 (7.25) | 37.58 (7.31)[a] | 4.06 (5.78) | 3.25 (6.86) | 3.08 (6.08) |
| Reaction time (*SD*) | .65 (.11) | .66 (.16) | .66 (.15) | .01 (.10) | .03 (.17) | .03 (.16) | .62 (.11) | .63 (.13) | .63 (.12) | −.01 (.12) | −.007 (.147) | .004 (.124) |
| Symptom score (*SD*) | 14.68 (17.56) | 18.12 (20.88) | 14.72 (18.78)[a] | 9.12 (18.89) | 10.68 (20.74) | 8.59 (18.93)[a] | 2.98 (7.77) | 6.85 (12.89) | 5.29 (11.49)[a] | −3.14 (9.69) | −.53 (14.44) | −1.25 (13.54) |
| Migraine cluster (*SD*) | 5.72 (7.25) | 7.92 (8.98) | 6.37 (8.09)[a] | 4.50 (7.57) | 5.88 (9.09) | 4.59 (8.20)[a] | 1.22 (3.84) | 2.60 (5.20) | 2.01 (4.60)[a] | −.34 (4.56) | .46 (5.83) | .054 (5.42) |
| Cognitive cluster (*SD*) | 5.25 (6.65) | 5.90 (7.30) | 5.10 (6.97)[a] | 3.78 (7.04) | 4.10 (7.10) | 3.33 (7.07)[a] | 1.08 (3.09) | 2.32 (4.50) | 1.91 (4.19) | −.68 (2.85) | .40 (5.15) | .02 (4.92) |
| Sleep cluster (*SD*) | 1.93 (3.17) | 1.86 (2.82) | 1.59 (2.67)[a] | .71 (3.47) | .09 (3.30) | .27 (3.11) | .46 (1.39) | .79 (1.92) | .66 (1.76) | −.96 (2.31) | −.84 (2.80) | −.73 (2.72) |
| Neuropsychiatric cluster (*SD*) | 1.79 (3.11) | 2.44 (4.19) | 1.66 (3.44)[a] | .14 (3.71) | .61 (4.63) | .40 (3.72) | .22 (.76) | 1.15 (3.04) | .71 (2.27)[a] | −1.16 (2.81) | −.55 (3.80) | −.59 (3.00) |

[a] Analysis of variance, $p < .05$.

**Table 4.** Multivariable analysis of scores between sport types at the first post-injury test

| Composite scores | Raw scores | | | Deviation from baseline | | |
|---|---|---|---|---|---|---|
| | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4{,}050$) for 3,527 athletes | NC ($n = 95$) for 91 athletes | LC ($n = 917$) for 801 athletes | CC ($n = 4{,}050$) for 3,527 athletes |
| Verbal memory (95% CI) | $\beta = 1.75$ (−1.24 to 4.74) | $\beta = 1.07$ (−.16 to 2.31) | Reference | $\beta = 1.50$ (−1.57 to 4.58) | $\beta = 1.07$ (−.20 to 2.34) | Reference |
| Visual memory (95% CI) | $\beta = 1.96$ (−1.13 to 5.03) | $\beta = .58$ (−.70 to 1.85) | Reference | $\beta = .86$ (−2.42 to 4.13) | $\beta = .51$ (−.84 to 1.86) | Reference |
| Processing speed (95% CI) | $\beta = .94$ (−.68 to 2.56) | $\beta = .48$ (−.19 to 1.15) | Reference | $\beta = 1.35$ (−.11 to 2.81) | $\beta = .69$[a] (.09 to 1.29) | Reference |
| Reaction time (95% CI) | $\beta = -.01$ (−.04 to .02) | $\beta = -.003$ (−.02 to .01) | Reference | $\beta = -.02$ (−.05 to .01) | $\beta = -.01$ (−.02 to .003) | Reference |
| Symptom score (95% CI) | $\beta = -2.22$ (−6.12 to 1.68) | $\beta = -.05$ (−1.66 to 1.56) | Reference | $\beta = -.28$ (−4.23 to 3.68) | $\beta = .49$ (−1.15 to 2.12) | Reference |
| Migraine cluster (95% CI) | $\beta = -1.52$ (−3.20 to .16) | $\beta = .15$ (−.54 to .85) | Reference | $\beta = -.61$ (−2.32 to 1.10) | $\beta = .37$ (−.33 to 1.08) | Reference |
| Cognitive cluster (95% CI) | $\beta = -.48$ (−1.91 to .96) | $\beta = .18$ (−.78 to .41) | Reference | $\beta = .12$ (−1.34 to 1.57) | $\beta = .19$ (−.41 to .79) | Reference |
| Sleep cluster (95% CI) | $\beta = .19$ (−.37 to .74) | $\beta = .02$ (−.21 to .25) | Reference | $\beta = .51$ (−.14 to 1.15) | $\beta = .14$ (−.40 to .14) | Reference |
| Neuropsychiatric cluster (95% CI) | $\beta = -.41$ (−1.13 to .32) | $\beta = -.04$ (−.34 to .26) | Reference | $\beta = -.29$ (−1.09 to .51) | $\beta = .05$ (−.28 to .38) | Reference |

*Note:* Multivariable logistic regression controlled for variables: age, gender, attention-deficit/hyperactivity disorder, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and previous concussion history ≥2.

[a] Multivariable logistic regression, $p < .05$.

**Table 5.** Multivariable analysis of follow-up test scores between sport types

| Composite scores | Raw scores | | | Deviation from baseline | | |
|---|---|---|---|---|---|---|
| | NC ($n = 50$) for 36 athletes | LC ($n = 534$) for 360 athletes | CC ($n = 2{,}680$) for 1,702 athletes | NC ($n = 50$) for 36 athletes | LC ($n = 534$) for 360 athletes | CC ($n = 2{,}680$) for 1,702 athletes |
| Verbal memory (95% CI) | $\beta = 3.59$[a] (.05 to 7.13) | $\beta = 1.03$ (−.33 to 2.38) | Reference | $\beta = 2.27$ (−1.60 to 6.14) | $\beta = 1.62$[a] (.14 to 3.11) | Reference |
| Visual memory (95% CI) | $\beta = 1.30$ (−2.62 to 5.20) | $\beta = .03$ (−1.47 to 1.53) | Reference | $\beta = .36$ (−3.91 to 4.63) | $\beta = -.03$ (−1.67 to 1.61) | Reference |
| Processing speed (95% CI) | $\beta = 2.50$[a] (.49 to 4.51) | $\beta = .21$ (−.56 to .98) | Reference | $\beta = 1.62$ (−.12 to 3.37) | $\beta = 1.05$[a] (.38 to 1.71) | Reference |
| Reaction time (95% CI) | $\beta = -.01$ (−.05 to .02) | $\beta = -.002$ (−.02 to .01) | Reference | $\beta = -.02$ (−.06 to .02) | $\beta = -.02$[a] (−.03 to −.006) | Reference |
| Symptom score (95% CI) | $\beta = -3.78$[a] (−7.03 to −.52) | $\beta = -.58$ (−1.82 to .67) | Reference | $\beta = -1.42$ (−5.25 to 2.42) | $\beta = .88$ (−.59 to 2.35) | Reference |
| Migraine cluster (95% CI) | $\beta = -1.39$[a] (−2.70 to −.08) | $\beta = -.28$ (−.79 to .22) | Reference | $\beta = -.37$ (−1.91 to 1.17) | $\beta = .26$ (−.33 to .85) | Reference |
| Cognitive cluster (95% CI) | $\beta = -1.24$[a] (−2.42 to −.06) | $\beta = -.22$ (−.67 to .23) | Reference | $\beta = -.72$ (−2.11 to .67) | $\beta = .21$ (−.33 to .74) | Reference |
| Sleep cluster (95% CI) | $\beta = -.35$ (−.85 to .15) | $\beta = -.08$ (−.27 to .11) | Reference | $\beta = -.08$ (−.84 to .69) | $\beta = .06$ (−.24 to .35) | Reference |
| Neuropsychiatric cluster (95% CI) | $\beta = -.80$[a] (−1.47 to −.13) | $\beta = .007$ (−.25 to .26) | Reference | $\beta = -.26$ (−1.13 to .62) | $\beta = .35$[a] (.02 to .69) | Reference |

*Notes:* Median interquartile range (IQR) follow-up times were 8 days (IQR, 5–15) for CC, 9 days (IQR, 5–17) for LC, and 7.5 days (IQR 3.75–14 days) for NC cohorts; multivariable logistic regression controlled for variables: time between follow up, age, gender, attention-deficit/hyperactivity disorder, diagnosed learning disability, depression/anxiety, chronic headaches, chronic migraines, and previous concussion history ≥2.

[a] Multivariable logistic regression, $p < .05$.

similar. These results were not consistent with prior studies, as the increased sub-concussive impacts associated with CC sports have been shown to result in cumulative, chronic negative effects on brain health and function (Bailes et al., 2013; Hirad et al., 2019; Rawlings et al., 2020).

### *Recovery*

There has also been little investigation into the relationship between sport type and concussion recovery. Factors associated with the need for prolonged recovery from concussion include initial concussion severity, headaches, depression, mental health problems, female gender, and teenage years (Iverson et al., 2017). Examination of follow-up ImPACT scores in our study indicate that NC and LC athletes showed signs of improved recovery compared to CC. Noncontact and LC athletes both showed improved scores for verbal memory and processing speed at follow-up ImPACT tests, and LC athletes also showed improved reaction time. Additionally, the NC cohort showed reduced total symptom, migraine cluster, cognitive cluster, and neuropsychiatric cluster scores.

As mentioned before, better recovery for NC and LC athletes may be due to increased sub-concussive impacts in CC sports which result in negative effects on brain health and function (Bailes et al., 2013; Hirad et al., 2019; Rawlings et al., 2020). Even within a single season, it was found that football athletes sustaining concussions later in the season have increased symptom burden compared to athletes sustaining concussions earlier on (Brett, Kuhn, et al., 2018). Additionally, athletes in combat sports where head contact is an objective of the sport have been recommended to use longer recovery periods and treatments than most sports (Paul McCrory et al., 2017; Neidecker et al., 2019). These findings also agree with prior neuropsychological studies on cognitive domains in contact sports. Verbal and visual memory impairments have been found to directly correlate with severity of TBI (Ewing-Cobbs et al., 1990; Farmer et al., 1999; Fay et al., 1994; Levin et al., 1982; Yeates et al., 1995), and CC athletes without prior concussion diagnosis have been found to have memory impairments (Killam et al., 2005). Although verbal memory showed significant differences between contact levels and visual memory did not in our study, we cannot conclude that visual memory scores were not different between contact levels due to the underpowered nature of comparisons. Processing speed and reaction time impairments have also been found to directly correlate with severity of TBI, which may be due to more severe damage to white matter tracts and decreased neural interconnections (Felmingham et al., 2004; Timmerman & Brouwer, 1999; Tombaugh et al., 2007). Similarly, we found less severe deficits in both processing speed and reaction time for athletes with lower contact levels.

Interestingly, the NC athletes showed improvements in both subjective symptom scores and objective ImPACT scores, whereas LC athletes showed improvements in objective ImPACT scores but not subjective symptom scores. Improvements in scores also tended to be larger for NC athletes compared to LC athletes. This may indicate different recovery patterns for LC and NC sports, as LC athletes may recovery more slowly than NC from SRC. This could be due to differences in sub-concussive impacts between LC and NC sports as previously mentioned (Bailes et al., 2013; Rawlings et al., 2020). It could also be due to differences in care after concussion, as one prior study showed that NC athletes but not LC athletes were more likely to seek care after concussion than collision athletes (Anderson, Weber Rawlins, & Schmidt, 2020). Additionally, the LC cohort showed elevated neuropsychiatric symptoms after injury, but no difference in other symptom clusters compared to CC. While reasons for this result are unclear, it may be due to differences in baseline neuropsychiatric symptoms. One prior study showed differences in baseline anxiety and depressive symptoms between sport contact levels, one showed differences in total symptom score between contact levels, and another showed no differences between contact levels (French et al., 2019; Howell, Kirkwood, Laker, & Wilson, 2020; Katz et al., 2018).

Lastly, some studies have shown that contact level was not associated with improved recovery. Rates of postconcussion syndrome and return to play time have been shown to be similar between contact levels (D'Lauro et al., 2018; Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009; Zuckerman et al., 2016). It is possible that these studies are underpowered given the decreased incidence of concussion in NC and LC sports (Lincoln et al., 2011; Pfister et al., 2016; Rosenthal et al., 2014; Tsushima et al., 2019). Similarly, this study is well overpowered to detect differences in SRC incidence among the three cohorts despite lower rates or SRC in NC and LC sports. However, many of the sub score comparisons for both initial post-injury and follow-up testing are not powered at an 80% confidence level. Due to differences between this study and prior studies, further study of effects of contact level on concussion recovery is needed. The results of this study suggest less uniformity in protocol could be beneficial based upon sport contact level. Current return to play guidelines follow a graduated return to play protocol, which is uniform across all high school sports regardless of contact level (May, Marshall, Burns, Popoli, & Polikandriotis, 2014). Similarly to how combat sports have recommended longer recovery periods, LC and NC sports may be able to recommend a shorter return to play protocol if it is shown that recovery from SRC is more rapid for these athletes (Neidecker et al., 2019). Therefore, a larger study examining differences in SRC recovery between contact levels should be conducted.

### *Study Limitations*

The current study provides the largest sample of pre- and post-concussion testing of adolescent athletes across multiple sport types. However, given the strengths of the study, there are limitations that warrant discussion. ImPACT may be available at schools with increased resources, which may insert bias into the study population. While concussion was suspected after examination by physicians or athletic trainers, it is not known whether athletes were officially diagnosed with a concussion by a physician. However, diagnosis of concussion by athletic trainers has been shown to be up to 98.5% concordant with physician diagnoses (Lombardi et al., 2016). Although initial severity of injury was measured by ImPACT, initial clinical assessment of injury severity is unknown. Results for raw ImPACT scores and change from baseline ImPACT scores were often not consistent. However, many nonsignificant results in one category were similar to significant results in the other category. This is especially true of the NC cohort, where many comparisons with the CC and LC cohorts are underpowered at an 80% level. This affects this study's ability to draw conclusions about negative results. Treatment protocols and timing of post-injury testing were not standardized, which could impact results. We believe differences in timing did not significantly affect results because time of testing was not statistically different between groups, and it was controlled for in post-concussive symptom analysis. Additionally, a random portion of athletes with initial post-injury testing did not undergo follow-up testing. It is common for high school athletes to participate in multiple sports with different contact levels during different seasons of play. It is unclear how participating in multiple sports may affect an individual's concussion severity, recovery, or ImPACT scores. Additionally, while the analysis relied on self-reported symptoms and ImPACT data to indicate recovery among athletes, it did not have access to clinical evaluations, which could have aided in tracking recovery. There is significant variation in demographic factors such as age and gender, which may have affected results. We attempted to minimize this variation by using multivariable regression. Lastly, there are limitations to the retrospective nature of the study, although the criteria for athletes receiving ImPACT testing were determined prospectively.

## Conclusion

Increased level of sport contact was associated with increased incidence of suspected concussion. ImPACT composite scores between contact levels were mostly similar at the first post-injury test. However, ImPACT composite scores at follow up showed many improved scores and symptoms for LC and NC sports compared to CC sports. This may indicate different SRC recovery patterns between different levels of contact in sports.

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