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Sport Type and Risk of Subsequent Injury in Collegiate Athletes Following Concussion: a LIMBIC MATARS Consortium Investigation

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ABSTRACT

Objective: To investigate the association between sport type (collision, contact, non-contact) and subsequent injury risk following concussion in collegiate athletes.

Materials and Methods: This retrospective chart review of 248 collegiate athletes with diagnosed concussions (age: 20.0 ± 1.4 years; height: 179.6 ± 10.9 cm; mass: 79.0 ± 13.6 kg, 63% male) from NCAA athletic programs ($n = 11$) occurred between the 2015–2020 athletic seasons. Acute injuries that occurred within six months following concussion were evaluated. Subsequent injuries were grouped by lower extremity, upper extremity, trunk, or concussion. The independent variable was sport type: collision, contact, non-contact. A Cox proportional hazard model was used to assess the risk of subsequent injury between sport types.

Results: Approximately 28% (70/248) of athletes sustained a subsequent acute injury within six months post-concussion. Collision sport athletes had a significantly higher risk of sustaining any injury (HR: 0.41, $p < 0.001$, 95% CI: 0.28, 0.62), lower extremity (HR: 0.55, $p = 0.04$, 95% CI: 0.32, 0.97), and upper extremity (HR: 0.41, $p = 0.01$, 95% CI: 0.20, 0.81) injuries following concussion. No differences between sport types were observed for other injuries.

Conclusion: Collision sport athletes had a higher rate of any subsequent injury, lower, and upper extremity injuries following concussion. Future research should focus on sport-specific secondary injury prevention efforts.

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Mild traumatic brain injury; musculoskeletal injury; sport; repetitive head impacts; survival analysis

Introduction

Concussions are a significant public health problem (1). Most concussion-related symptoms resolve within two to three weeks in adult athletes; however, a true window of physiological recovery has not been established (2,3). Lingering neurological impairments (e.g., neurometabolic disturbance or neuroinflammation) may contribute to the ~ 2.5× increased risk of musculoskeletal (MSK) injury (e.g., ankle sprain, ACL tear) that has been observed in collegiate athletes following concussion (4–11). This relationship is noteworthy, and a similar post-concussion injury risk has been observed in high school, professional, and community athletes across a variety of sports (12–16). Furthermore, time-loss MSK injuries can reduce athletic career longevity, and may ultimately cause lifelong comorbidities such as osteoarthritis (17–19). Conversely, recent studies have also demonstrated no relationship between concussion and subsequent injury risk (20,21), suggesting more research is necessary to further examine this potential relationship and its underpinnings. Although an association between concussion and subsequent MSK injury has been documented, we are currently unable to predict which athletes are most at risk for sustaining an acute injury following concussion.

Standard clinical concussion assessments used in the decision-making process to clear athletes to return to sport (RTS) currently lack the sensitivity to detect deficits that may underlie injury susceptibility and are unable to predict subsequent injury risk in collegiate athletes (8). Several mechanisms that may contribute to the elevated risk of subsequent injury following concussion have been proposed, such as action-perception coupling (22), lower extremity biomechanics (23–26), and measures related to mental health symptoms (27). However, the most consistently discussed theory is impaired neuromuscular control (i.e., how the nervous system controls muscle activation and postural control) (4,5,7). Neuromuscular control deficits are frequently seen following concussion, particularly under dual-task conditions that involve the simultaneous evaluation of cognitive and motor

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performance (5). Furthermore, these deficits (e.g., worsening dual-task gait cost, slower dual-task gait speed) have been observed beyond clearance to RTS and have been associated with subsequent injury up to one year following concussion, providing some of the only mechanistic evidence of this relationship (28,29).

While different complexities of neuromuscular control have been considered as risk factors for post-concussion subsequent injury, a potential contributing factor that has been minimally explored is the role of sport type (i.e., collision, contact, non-contact) on subsequent injury risk following concussion. Approximately 20% of National Collegiate Athletic Associaton (NCAA) athletes compete in collision sports (30), and compared to other sport types, collision sport participation is inherently associated with a higher prevalence of concussions and lower extremity musculoskeletal injuries (31). Beyond clinically diagnosed concussions, collision sport athletes are also exposed to more subconcussive repetitive head impacts (i.e., head impacts that do not result in overt clinical signs or symptoms), which may have effects on short- and long-term brain health, including neuromuscular control (32–34). The literature exploring the relationship between repetitive head impacts and neuromuscular control is growing but remains sparse, and a recent systematic review reported the findings of the existing studies are mixed (32). In collegiate athletes and early to mid-adults, earlier exposure to repetitive head impacts, a single season of repetitive head impacts, and longer career duration of collision sports were not associated with worse postural control (35–40). Conversely, a sample of college-aged athletes did present with postural control and neuromuscular function impairments across a season of rugby, which is classified as a collision sport (41). Thus, the relationship between repetitive head impacts and neuromuscular control remains to be elucidated.

Further research is warranted to examine whether collision sport athletes are potentially at an increased risk for subsequent injury following concussion. Therefore, the purpose of this investigation was to examine the relationship between sport type (collision, contact, and non-contact) and the risk of subsequent injury in the six months following concussion. We grouped collegiate athletes who incurred a concussion by their primary sport and reviewed whether they sustained subsequent injuries, while controlling for previous injury history. We hypothesized that collision sports participation would be significantly associated with greater subsequent injury risk following concussion when compared to contact or non-contact sports.

Materials and methods

The study was a retrospective cohort design chart review of athlete patient data from institutions sponsoring NCAA athletics within the Long-Term Impact of Military-Relevant Brain Injury Consortium (LIMBIC) Military and Tactical Athlete Research Study (MATARS) Consortium ($n = 11$). The details of the LIMBIC MATARS Consortium have been described elsewhere. *(Cite: Methods paper in this same special issue)* We conducted chart reviews on collegiate athletes who sustained concussions between the 2015–16' and 2019–20' academic years. The medical chart data was entered into medical records by licensed healthcare providers (e.g., certified athletic trainer) at each consortium institution. Concussions were defined based on criteria from the most recent consensus statement on concussion in sport at the time of injury (42,43), and all concussions were clinically diagnosed by a certified athletic trainer. Prior to data review and extraction, the primary investigators from each participating consortium site conferred with their Institutional Review Board and received approval to proceed with the study. Data use agreements and confidentiality disclosure agreements were established between all LIMBIC MATARS sites.

Participants

There were 1,311 total concussion cases across the study period in our cohort of collegiate athletes. Participants were excluded for the following reasons: 1) no subsequent injury data included in the dataset, 2) no RTS date following concussion (which precluded our ability to calculate the days between concussion and subsequent injury), and 3) incomplete or inappropriate injury data (i.e., injury data not applicable to our inclusion criteria) as detailed below. (Figure 1) After removing case data according to our exclusion criteria, 248 athletes with an index concussion and subsequent injury remained for analysis. (Table 1). For participants who had more than one concussion within the study period, the earliest reported concussion in this time frame was used as the index concussion injury, and any subsequent concussions were considered as outcomes for our analyses.

Sport type

Participants were grouped into three categories (collision, contact, non-contact) (44) based on their sports participation at the time of their index concussion. Collision sports were operationally defined as those involving purposeful, legal body-to-body collisions and included football and wrestling. Contact sports were those during which regular body-to-body contact occurs during sport, but purposeful body-to-body collisions are not allowed; these included basketball, baseball, softball, cheerleading, women's lacrosse, and soccer. Non-contact sports were those during which body-to-body contact is rare and not expected as a regular part of the game, including dance, swimming and diving, golf, gymnastics, track and field, rowing, squash, tennis, volleyball, and cross country.

Subsequent injury

All concussions and subsequent injuries were captured through each institution's electronic medical record database and compiled into a master file across all consortium sites. The injuries included in the analysis must have required attention from a certified athletic trainer or physician, and resulted in restriction of participation for one or more days (45). We only included acute injuries (i.e., sudden onset injuries requiring medical attention) in our analyses. Chronic or overuse injuries (e.g., tendinitis) were excluded from the final analysis. The lead author (JO) and two coauthors (TC, SW), who are certified athletic trainers, examined the full list of injuries to

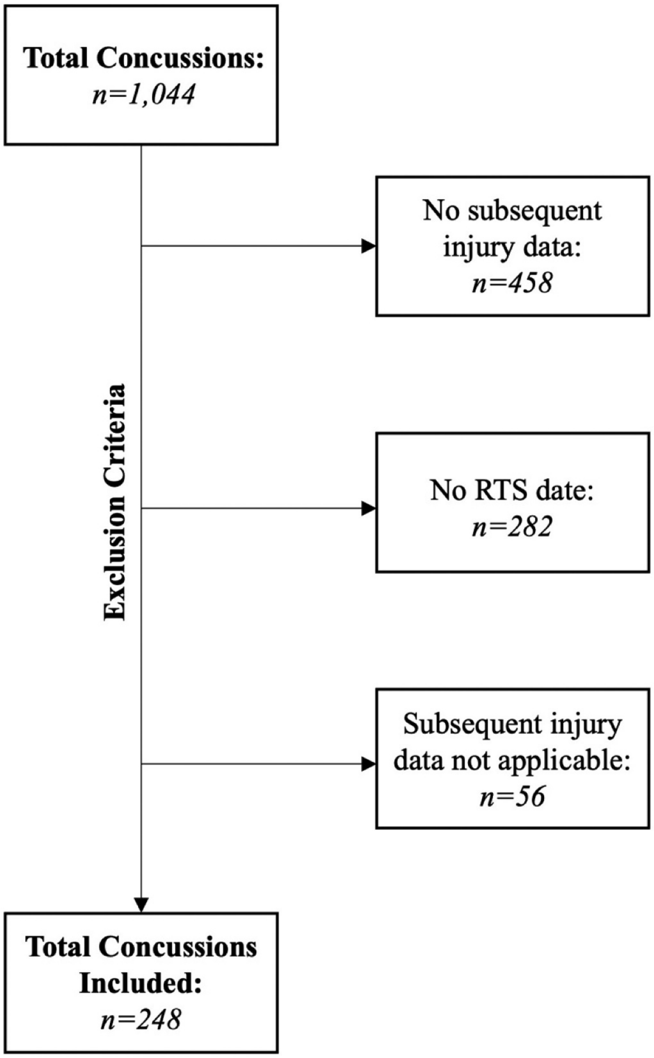

Figure 1. Participant exclusion criteria.

determine inclusion/exclusion criteria on a case-by-case basis. Although most prior studies of post-concussion injury risk have focused on lower extremity injuries, we expanded our investigation by considering four distinct categories of injury: lower extremity, upper extremity, trunk, and concussion.

Data and statistical analysis

We used univariable one-way analyses of variance and chi-squared tests to compare demographic characteristics between the three sport groups. The independent variable was sport type with collision, contact, and non-contact groups. We used a Cox proportional hazard model to evaluate the risk of subsequent injury (any injury, upper extremity, lower extremity, trunk, and concussion) between the sport groups with self-reported concussion history (continuous) and lower extremity injury (dichotomous) history included as covariates. Prior concussions must have been diagnosed by a medical provider, and prior lower extremity injuries must have been acute injuries that resulted in at least one day of restricted athletic activity. These covariates were chosen as there is evidence that prior concussion and prior MSK injury are risk factors for subsequent injury (10,12,46). The study endpoint was six months (180 days) from the date of RTS following their index concussion or the number of days to the first subsequent injury following the index concussion. Statistical significance was set at $p < 0.05$ *a priori*. All statistical analyses were completed using Stata/IC 15.1 (StataCorp LLC, College Station, TX, USA).

Results

Half of the concussions included in the final analysis occurred in collision sport athletes ($n = 123$; 50%) due to the large number of athletes ($n = 114$) participating in football. There were significant differences between the three sport type groups for age ($p < 0.001$), sex ($p < 0.001$), height ($p < 0.001$), weight ($p < 0.001$), and subsequent injury incidence ($p < 0.001$). The sport type groups did not significantly differ in concussion history ($p = 0.26$), sport career duration ($p = 0.14$), or subsequent injury category ($p = 0.92$). Approximately 28% of the included athletes sustained an acute injury within the six months following concussion. Lower extremity MSK injuries were the most common injuries sustained, followed by upper extremity MSK injuries, concussions, and trunk injuries (Table 1).

Table 1. Demographic data based on sport type. *Indicates a significant difference between groups. †Indicates not all participants in the category reported. *abbreviations: LE = lower extremity, UE = upper extremity, y = years, M = males, F= females, cm = centimeters, kg = kilograms.*

	Collision ($n = 123$, 50%)	Contact ($n = 76$, 30%)	Non-Contact ($n = 49$, 20%)	Total ($n = 248$, 100%)
Age (y)*	20.3 ± 1.4	19.7 ± 1.4	19.7 ± 1.3	20.0 ± 1.4
Sex (M/F)*	123/0	25/51	9/40	157/91
Height (cm)*	184.3 ± 6.4	175.5 ± 13.1	174.2 ± 11.0	179.6 ± 10.9
Mass (kg)*	86.8 ± 9.8	72.4 ± 13.9	69.2 ± 9.7	79.0 ± 13.6
Concussion History (%)	0: 67 (54%)	0: 47 (62%)	0: 35 (72%)	0: 149 (60%)
	1: 28 (23%)	1: 16 (21%)	1: 8 (16%)	1: 52 (21%)
	2: 17 (14%)	2: 6 (8%)	2: 2 (4%)	2: 25 (10%)
	3+: 11 (9%)	3+: 7 (9%)	3+: 4 (8%)	3+: 22 (9%)
LE Injury History	Yes: 47 (38%)	Yes: 17 (22%)	Yes: 17 (35%)	Yes: 81 (33%)
	No: 76 (62%)	No: 59 78%)	No: 32 (65%)	No: 167 (67%)
Sport Career Duration*† (y)	5.2 ± 4.7	3.7 ± 4.2	3.3 ± 3.0	4.4 ± 4.3
Subsequent Injury Over 6 Months* (%)	Yes: 50 (41%)	Yes: 15 (20%)	Yes: 5 (10%)	Yes: 70 (28%)
	No: 73 (59%)	No: 61 (80%)	No: 44 (90%)	No: 178 (72%)
Injury Type (%)	LE: 20 (40%)	LE: 7 (50%)	LE: 3 (60%)	LE: 30 (43%)
	UE: 19 (38%)	UE: 4 (29%)	UE: 2 (40%)	UE: 25 (36%)
	Trunk: 3 (6%)	Trunk: 1 (7%)	Trunk: 0 (0%)	Trunk: 4 (6%)
	Concussion: 8 (16%)	Concussion: 2 (14%)	Concussion: 0 (0%)	Concussion: 10 (15%)

Table 2. Cox proportional hazard model results. *Indicates a significant model at $p < 0.05$. *abbreviations: LE= lower extremity.*

Injury	Hazard Ratio	Hazard Ratio 95% Confidence Interval	p-value
Any Injury			
*Sport Type**	0.41	0.28, 0.62	< 0.001*
Prior Concussion	0.87	0.69, 1.11	0.26
Prior LE Injury	0.70	0.43, 1.14	0.15
Lower Extremity			
*Sport Type**	0.55	0.32, 0.97	0.04*
Prior Concussion	0.80	0.54, 1.20	0.28
Prior LE Injury	0.67	0.32, 1.42	0.30
Upper Extremity			
*Sport Type**	0.41	0.20, 0.81	0.01*
Prior Concussion	0.91	0.61, 1.34	0.63
Prior LE Injury	1.35	0.56, 3.27	0.50
Trunk			
Sport Type	0.36	0.05, 2.35	0.28
Prior Concussion	0.72	0.23, 2.27	0.57
Prior LE Injury	0.50	0.07, 3.59	0.49
Concussion			
Sport Type	0.19	0.03, 1.21	0.08
Prior Concussion	1.07	0.64, 1.80	0.80
Prior LE Injury	0.28	0.07, 1.15	0.08

The collision sport group had a significantly higher risk of sustaining any subsequent injury, lower extremity injury, and upper extremity injury but not trunk injury, or additional concussion compared to the other sport type groups (Table 2). Following RTS, a higher percentage of athletes in the collision sport group sustained any injury (Figure 2), lower extremity subsequent injury (Figure 3), and upper extremity subsequent injury (Figure 4) within the six months following their concussion.

Discussion

Our study sought to understand how risk for subsequent injury following concussion varies by sport type in a large, multi-site, retrospective chart review. Rates of MSK injury following concussion are associated with increased exposure to risk (47). Thus, a novel aspect of this study is the direct comparison of subsequent injury following concussion between athletes participating in collision, contact, and non-contact sports. Consistent with our hypothesis, the percentage of collision sport athletes (41%) who sustained a subsequent injury in the six months following their initial concussion was more than double that of athletes in contact (20%) or non-contact (10%) sport groups. In total across all groups, almost one third of included athletes sustained an acute subsequent injury in the six months following their initial concussion, with lower extremity MSK injuries being the most common. The higher rate of lower extremity injuries following concussion observed in our study is consistent with the growing body of literature summarized in a recent systematic review including studies of athletes at high school, collegiate, and professional levels of competition (48), but it is in contrast to data from the NCAA

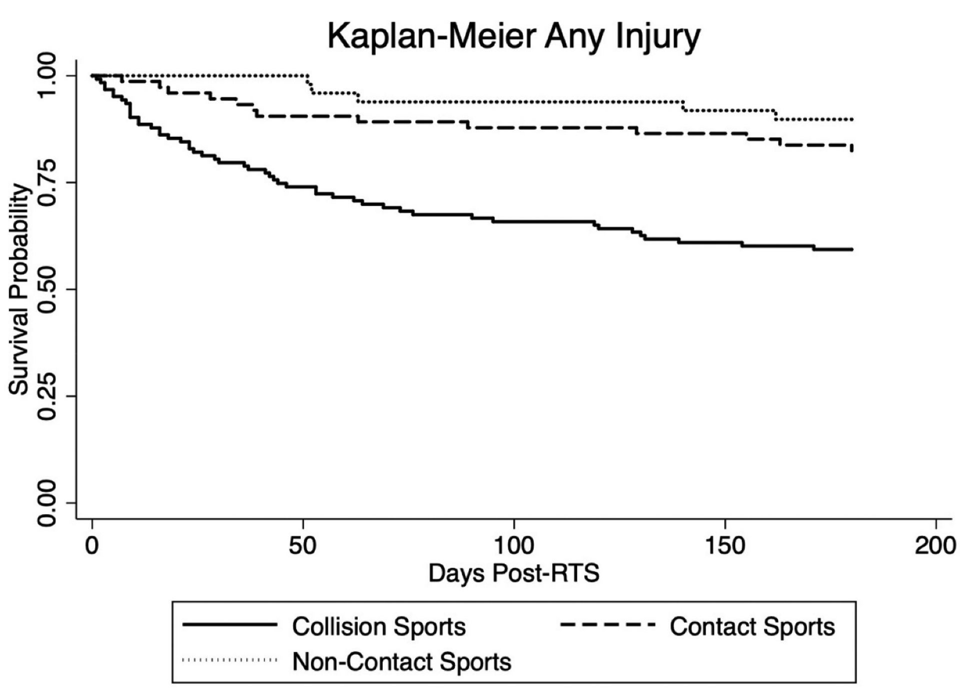

Figure 2. Injury-free survival between sport types for any injury.

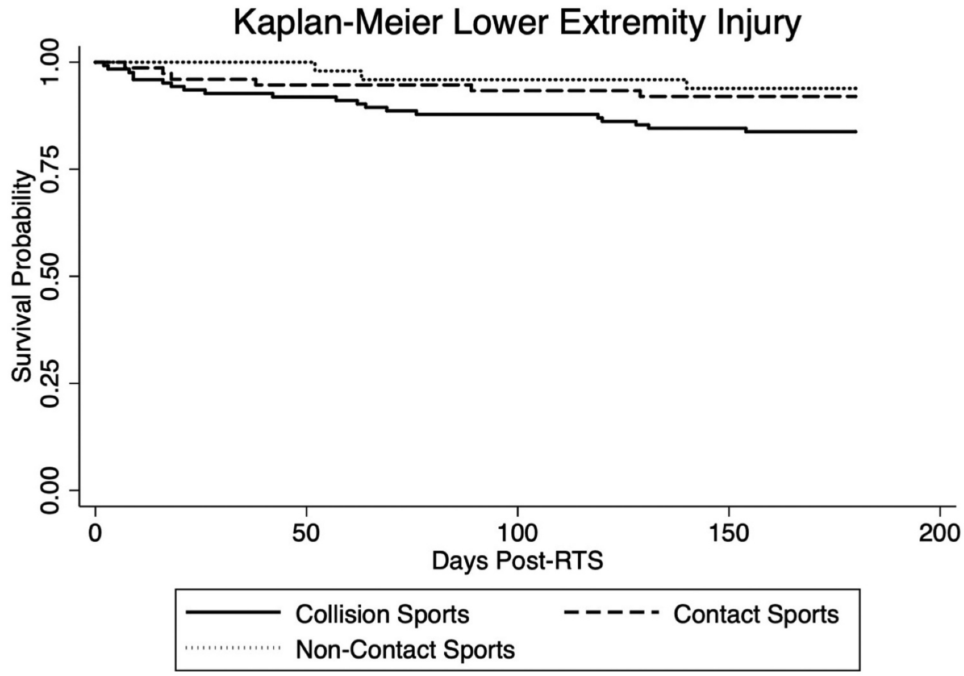

Figure 3. Injury-free survival between sport types for lower extremity injury.

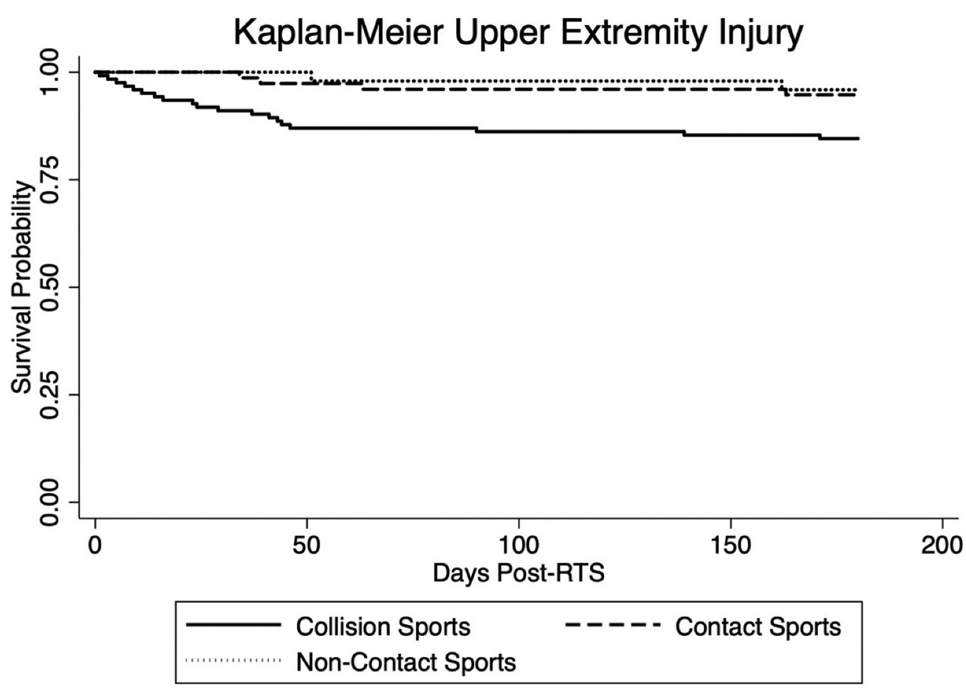

Figure 4. Injury-free survival between sport types for upper extremity injury.

Injury Surveillance Program (20). Additionally, the higher rate of upper extremity injuries following concussion aligns with recent findings in a similar college-aged population (49).

We found that collision sport athletes had a higher MSK injury rate, including both lower and upper extremity, over the six months following their concussions compared to contact or non-contact athletes. These findings differ from a smaller investigation by Buckley and colleagues, who did not find a significant association between sport type and subsequent injury in collegiate athletes following concussion (8). However, the previous study grouped collision and contact sports together in comparison with non-contact sports, which may explain the discrepancy between our findings and theirs. Our findings were similar to the Buckley study in that a history of prior injury (both concussion and MSK) did not appear to increase risk of subsequent injury following concussion (8). This finding aligns with additional previous work that reported prior lower extremity injury history was not a significant contributor to future injury risk in collegiate athletes (50), but opposes others who have proposed concussion history as a risk factor for subsequent injury in adult athletes (10–12). The same previous study also found an association between higher body mass index and increased risk of lower extremity injury (50). Therefore, we cannot rule out athlete mass as a contributing factor for the higher injury rate observed herein, as our collision sport group weighed significantly more than the contact and non-contact sport athletes. Lastly, athlete behavior must be considered as a potential risk factor. While the topic is largely understudied, personality traits and athlete behavior (e.g., playing with a lack of caution) have been hypothesized as other contributors to post-concussion subsequent injury (51,52). Athletes participating in high-risk sports, such as football and ice hockey, were found to have greater risk-taking personalities, and increased sensation-seeking and aggressive behavior are common in high-risk athletes (51,53,54). Furthermore, differences in aggressive behavior have been observed between contact and non-contact sport athletes, which suggests the inherent nature of collision sports and the behaviors of those who select to participate in those sports could explain why those athletes are more likely to sustain subsequent injuries (55).

Collision sport athletes in this study reported longer career duration as compared to contact and non-contact sport athletes. This increased career duration suggests that collision sport athletes may have had greater exposure to repetitive head impacts during their athletic career. Evidence linking repetitive head impacts to decline in short-term neurologic function is limited (56). A systematic review investigating the effects of repetitive head impacts on neuromuscular control reported heterogeneous findings (32), and several studies examining repetitive head impacts over a single season have found minimal differences in postural control (37,38,40). However, it is possible that these repetitive impacts that do not result in concussion clinical signs or symptoms may still be influencing subsequent injury risk. Herman and colleagues proposed that impaired neuromuscular control following concussion may be due to reduced excitability in the motor cortex (4), and an imaging study of college athletes with no concussion history found that those participating in heavy contact sports had higher levels of inflammatory neurometabolites (e.g., myo-inositol) in their primary motor cortex compared to non-contact athletes and non-athletes (57). Therefore, neuroinflammation caused by repetitive head impacts could be an influential factor driving alterations in neuromuscular control and ultimately increasing future injury risk. Furthermore, increased myo-inositol in collegiate athletes following concussion was associated with slower gait speed, which is a conservative gait strategy that has been previously associated with subsequent injury (28,29). Conversely, a longer career duration to collision sports was not associated with worse gait performance in a similar study of collegiate athletes, and exposure to repetitive head impacts at an earlier age yielded no significant associations with postural control (35,36).

In addition to neuromuscular control, higher injury rates following concussion may be driven by persistent deficits in neurocognitive function (4). Alterations in neurocognitive function are a risk factor for injury even in the absence of concussion (58–60). Current literature supports that athletes with worse neurocognitive test performance may be unable to create the appropriate neuromuscular responses to successfully carry out athletic maneuvers, subjecting them to increased injury risk (58). Worse performance on computerized neurocognitive assessments has also been suggested to associate with an increased injury risk in college athletes (59,60). Whether or not neurocognitive impairments result from exposure to repetitive subconcussive head impacts alone remains to be elucidated. Studies of youth athletes suggest exposure to repetitive head impacts may impair neurocognitive performance over time (61,62); however, investigations into whether earlier exposure to repetitive head impacts affected cognitive function in collegiate athletes and cadets found no significant associations (35,63–66). Additional investigations into the short and long-term consequences of repetitive head impacts on both neuromuscular control and neurocognitive function are needed.

Trunk and subsequent concussive injuries did not differ between collision, contact, and non-contact sport types. However, when considering the clinical applications of the presented findings, attention should be given to the rate of all subsequent injuries following concussion, not just lower and upper extremity injuries. In relation to rehabilitation following concussion, clinicians must consider the varied demands of individual sports and recognize that different sport types carry different rehabilitation demands. Return to sport progressions following concussion should acknowledge these nuances and be individualized to each athlete's needs. Emerging evidence has indicated that neuromuscular and motor control training strategies following concussion may reduce the risk of subsequent injury (67,68); however, it is currently unknown how these training programs should be tailored and how exercise should be dosed to specific athletes based on sport type. Healthcare providers may need to allocate more resources toward secondary injury prevention measures for collision sport athletes following concussion, particularly when considering neuromuscular control. This is an area for future research.

As this was a preliminary investigation, the limitations should be considered when interpreting our findings. This was a retrospective chart review across multiple institutions, and while the inclusion of concussion cases was operationalized for analyses, concussion management was unique to each institution. Although each case included in our study was cleared for RTS by licensed medical professionals, treatment following concussion was likely different across institutions which may have influenced our results. We did not have a control group of athletes without concussion in our study, so we cannot definitively say that the risk of subsequent injury would differ among sport types in the absence of concussion, nor that concussion is definitively associated with increased risk of subsequent injury in the present study sample. The sport type groups were not equally represented, with the collision sport group having the largest representation among the groups. Future studies should include datasets based on a prospective design with a larger number of athletes in contact and non-contact sport groups. Additionally, our dataset only tracked subsequent injuries across six months following concussion, and there is evidence that injury risk increases beyond that time point (10). Therefore, we had a limited view of all subsequent injuries due to our available follow-up window. It is possible that this limited window resulted in different exposure time for subsequent injury across athletes, depending on at what point in the season their initial concussion occurred. However, the highest percentage (40%) of concussions occurred during the first two months of the season across all sport types, and we were unable to definitively determine the exposure for any of the athletes in our sample. We did not exclude athletes who were seniors at the time of their concussion, despite the possibility that they may have had less risk/exposure for subsequent injury, since we had no way of confirming from the dataset that their eligibility was up solely based on their year in school.

Collegiate athletes participating in collision sports had a higher rate of any subsequent injury, subsequent lower extremity MSK injuries, and subsequent upper extremity MSK injuries in the six months following concussion compared to athletes in contact and non-contact sports. Contact and non-contact sport athletes appeared to have a similar risk of injury following concussion, so it is possible that the nature of collision sports and behavioral characteristics of those participating athletes put collision sport athletes at increased risk for injury. Future research is warranted to further investigate the role that repetitive head impacts, athlete behaviors, and other sport type characteristics may play in subsequent injury risk and whether sport-specific rehabilitation protocols may reduce secondary injury risk.

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