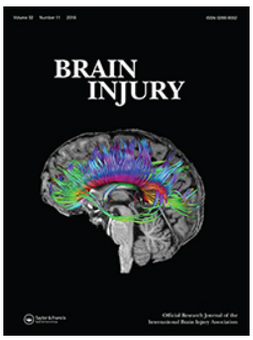

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Sex and number of concussions influence the association between concussion and musculoskeletal injury history in collegiate athletes

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ABSTRACT

Objectives: Examine the association between concussion and lower extremity injury in collegiate athletes and the influence of sex and the number of concussions on this relationship.

Methods: A total of 468 collegiate student-athletes (200 Males, 268 Females) were recruited from collegiate athletic facilities of three universities to participate in this retrospective review. Participants provided injury history (concussions, ankle sprains, and knee injuries) information through a survey. Chi-square tests and odds ratios examined the relationship between concussion and ankle sprain or knee injury history within each sex and based on concussion history (0, 1, >1).

Results: Females athletes with a concussion history had greater odds of reporting an ankle sprain or knee injury compared to females with no concussion history (OR = 1.88–2.54; $p \leq 0.020$). Male athletes with a concussion history did not have greater odds of reporting an ankle sprain or knee injury. Athletes reporting multiple concussions had the greatest odds of ankle sprain or knee injury history compared to athletes with no previous concussions (OR = 2.43–2.56; $p \leq 0.004$). No differences were identified between athletes with a single or multiple concussion history.

Conclusion: Female athletes with a concussion history or participants with a multiple concussion history had the greatest odds of reporting an ankle or knee injury history compared to athletes with no concussion history.

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Introduction

Participation in collegiate athletics is currently at an all-time high, with over 500 000 student-athletes participating in sanctioned collegiate sports in the USA (1). While there are many benefits to increased sport participation, a consequence is the increased number of sport-related injuries. Sport-related concussion and musculoskeletal injuries (MSI) are of particular concern because of the high incidence, long-term health consequences, and financial burden associated with these conditions (2–5). For every 10 000 athlete exposures, there are roughly 4.47 concussions in National Collegiate Athletic Association (NCAA) athletics (6). Females have exhibited greater concussion rates compared to males (7) and sports such as women's soccer, football, men's and women's ice hockey, and wrestling have displayed the highest concussion rates (8,9). In addition to concussion, lower extremity MSI represents over 50% of the injuries suffered by collegiate athletes (10). Injuries to the ankle and knee are the most common, with 15% of all injuries classified as ankle sprains (10). While concussions and lower extremity MSI seem to be unrelated conditions, recent studies have determined that athletes are at greater risk for lower extremity MSI following concussion (11–18). This unique relationship adds a complex dimension to concussion management and warrants further investigation.

Athletes with a history of concussion, from various levels of competition including high school (16), collegiate (11,12,14,15), and professional (17,18), have exhibited increased risk for lower extremity MSI. A recent synthesis of this evidence determined that there are consistent findings supporting the relationship between concussion and MSI in athletes (19). Specific to collegiate athletes, Herman et al. (11) determined that athletes were 3.4 times more likely to sustain a lower extremity MSI within 90 days of return to participation from a concussion compared to age, gender, and sport-matched athletes who did not sustain a concussion. Within this study, the rate of lower extremity MSI in athletes who sustained a concussion was 50% compared to only 20% in matched control athletes (11). In a separate study, athletes were twice as likely to sustain a lower extremity MSI in the 12 months following return to participation post-concussion compared to the 12 months preceding concussion (15). Based on the existing literature, the risk of sustaining a MSI following concussion appears to be elevated for at least one year (19). It is plausible that this elevated risk may be related to attention and motor system deficits that persist post-concussion (19).

The most commonly reported lower extremity MSI following concussion are ankle sprains (33–40%), muscle strains (33%), and knee sprains (15–26%) (11,12). Gilbert et al. (14) determined that collegiate athletes reported a strong association between concussion and each of these MSI when surveyed about their health history over their collegiate career. This

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study also confirmed this relationship for athletes with concussions that were diagnosed by medical staff, as well as for athletes with concussions that were unreported or unrecognized. These data suggest that the MSI burden following concussion is not isolated to the patients treated by medical professionals, and concussion may be a larger contributing factor to MSI than previously documented. Although this study examined the relationship between concussion and MSI over a multi-year retrospective period, unfortunately injury order was not examined. Thus, these individuals may have been more injury prone to begin with or if the MSI occurred first it may have affected their motor control thereby elevating the risk of subsequent concussion (14). These findings suggest that the relationship between concussion and MSI may be part of a larger injury reoccurrence cycle which may or may not have started with concussion as the index injury suggesting a more comprehensive examination of injury history may be warranted.

Limited research has examined the influence of additional factors, such as sex or the number of concussions, on the relationship between concussion and lower extremity MSI. Sustaining more than one concussion may further predispose athletes to lower extremity MSI because of greater residual deficits in neurocognitive performance (20,21), alterations in cortical electrophysiology (22), and impairments in sensorimotor function such as dual-task gait (23,24). This is supported by research in retired National Football League athletes, which demonstrated that as the number of sustained concussions increased, the odds of reporting MSI also increased (18). Similarly, female collegiate athletes have demonstrated a greater risk for concussion (8) and lower extremity MSI compared to male collegiate athletes (25,26). Therefore, the concussion–MSI relationship may be exacerbated in female athletes because of heightened sport-related injury risk. Although sex and the number of concussions may be rational contributing factors to further understand the concussion–MSI relationship, these factors have not been systematically examined in the context of this clinical problem. Therefore, the purpose of this study was to examine the association between concussion and lower extremity MSI history in collegiate athletes and determine the influence of sex and the number of self-reported concussions on this relationship. We hypothesized that collegiate athletes who reported a concussion history would be more likely to report a history of ankle sprain or knee injury. Additionally, these associations would be stronger in athletes with a history of multiple concussions and female athletes with a history of concussion.

Methods

Participants

Over a 6-month period, a sample of 468 NCAA student-athletes (200 males, 268 females; 19.5 ± 1.3 years; 173.9 ± 10.5 cm; 71.9 ± 13.6 kg) from 17 different sports (Table 1) was recruited from two large public universities participating at the Division I level (n = 300) and a small private college participating at the Division III level (n = 168). Regardless of their participation status, athletes eligible to compete in an NCAA sport during the 2013–2014 season were included. Club and recreational athletes were excluded. The sample included freshman (35%), sophomores (25%), juniors (23%), and seniors/fifth-year seniors (17%) with an average lifetime participation of 10.4 ± 4.0 years in their respective sport. The Institutional Review Board at all three sites approved the protocol as exempt; thus, voluntary completion of the study packet was deemed consent to participate.

Procedures

Using a cross-sectional design, the investigators recruited participants by attending team meetings and practice sessions. For each data collection session, participants were asked to review a cover letter which provided pertinent study details. If student-athletes were willing to participate in the study, they then completed a demographic and injury history form (27). Based on student-athlete availability, data were captured on participants that were both in and out of their competitive athletic season. However, all participants were formally included on team rosters and eligible to participate in team-related activities at the time of data collection. For the purposes of this study, participants with a current injury were included, regardless of participation status. Data collection sessions were held in team locker rooms and university classrooms with only researchers present. At the start of each session, the lead investigator briefed the athletes on the study and asked those who were interested to complete the anonymous survey independently. All questions pertaining to injuries were directed to the research staff. No data collection was completed immediately pre- or post-competition.

Injury history

A previously utilized injury history form captured basic demographic, self-reported injury history, and athletic participation information (27). Although not validated, the contents of the injury history form were modelled after a previously developed injury history recording form created by Powell and Barber-Foss (28). All participants completed the injury history form in pen and paper format. This questionnaire was designed to collect self-reported history information of upper extremity MSI, lower extremity MSI, and concussion. When completing the injury history form, participants were asked to describe all injuries that could be

Table 1. Study sample by sport and sex.

Sport	Female (n = 268)	Male (n = 200)
Baseball	–	39 (19.5%)
Basketball	26 (9.7%)	13 (6.5%)
Cross country	7 (2.6%)	10 (5.0%)
Field hockey	32 (11.9%)	–
Football	–	24 (12.0%)
Golf	6 (2.2%)	9 (4.5%)
Lacrosse	41 (15.3%)	–
Sailing	10 (3.7%)	7 (3.5%)
Softball	30 (11.2%)	–
Soccer	45 (16.8%)	15 (7.5%)
Swimming and diving	15 (5.6%)	22 (11.0%)
Tennis	6 (2.2%)	11 (5.5%)
Track and field	17 (6.3%)	27 (13.5%)
Volleyball	27 (10.1%)	–
Wrestling	–	22 (11.0%)
Other	6 (2.2%)	1 (0.5%)

recalled. A full description and copy of the injury history form has been previously published (27). The injury history form did not include date of injury or time since injury; thus, an injury timeline could not be established. For the purposes of this study, the extraction of injury history information was limited to self-reported concussions, ankle sprains, and knee injuries. Ankle sprains and knee injuries were selected for this study because they are the most common injuries sustained across NCAA athletics and have had the greatest association with concussion in previous studies (10–12). Based on the number of self-reported concussions, participants were categorized into three groups: no concussion history, single concussion history, and multiple concussion history. Ankle sprain and knee injury history were extracted as dichotomous variables (no history/history). Sex was self-identified on the injury history form as either male or female.

Statistical analysis

The prevalence of concussion, ankle sprain, and knee injury history was calculated for the entire sample and for each sex. Chi-square analyses (2×2 contingency tables) with corresponding odds ratios (OR) and 95% confidence intervals examined the relationship between concussion history (yes/no) and ankle sprain and knee injury history (yes/no). Additional analyses were completed by stratifying athletes based on the number of concussions (single, multiple) reported. These analyses were repeated separately within each sex (male, female) to determine if the association between concussion, ankle, and knee injury history varied based on this variable. As recommended by Hopkins et al. (29) in their review article that provided statistical-analysis considerations for sports medicine studies, we did not control for multiple comparisons. For all analyses, Fisher's exact tests were used to determine statistical significance ($p < 0.05$). All data analysis was performed using SPSS (Version 24, IBM Corporation, Armonk, NY, USA).

Results

Of the 469 survey packets distributed, 468 (99.8%) were returned with the injury history section completed. Within the entire sample ($n = 468$), the rate of concussion, ankle sprain, and knee injury history was 24.6%, 44.4%, and 35.7%, respectively. Of the participants who reported a concussion, 57.4% reported a history of a single concussion and 42.6% reported a history of multiple concussions (2.78 ± 1.24). Females were more likely to report a history of concussion (OR = 1.90, $p = 0.005$) and knee injury (OR = 1.79; $p = 0.005$) compared to males; however, the likelihood of a history of ankle sprain (OR = 1.12; $p = 0.57$) did not differ. Athletes with a history of concussion had greater odds of reporting an ankle sprain history (OR = 2.07; $p < 0.001$) and knee injury history (OR = 1.09; $p = 0.004$) compared to athletes with no history of concussion. Athletes with a history of multiple concussions (OR = 2.56; $p = 0.003$) and those who reported a single concussion (OR = 1.78; $p = 0.040$) both had greater odds of reporting a history of an ankle sprain compared to athletes with no concussion history. However, only athletes who reported multiple concussions (OR = 2.43; $p = 0.004$) had greater odds of reporting a history of knee injury compared to athletes with no concussion history. No differences were identified between athletes with a single or multiple concussion history.

Specific to females, the rate of concussion, ankle sprain, and knee injury history was 29.5%, 48.9%, and 41.0%, respectively. Females with a history of concussion had greater odds of an ankle sprain history (OR = 2.54; $p = 0.001$) and knee injury history (OR = 1.88; $p = 0.020$) compared to females with no concussion history. This finding was confirmed in females with a history of multiple concussions (OR = 2.20–4.31) but not those reporting a single concussion. Within male athletes, the rate of concussion, ankle sprain, and knee injury history was 18.0%, 43.0%, and 28.0%, respectively. Male athletes with a history of concussion did not have greater odds of an ankle sprain or knee injury history compared to males with no history of concussion, regardless of the number of previous concussions. No differences were identified between athletes with a single or multiple concussion history when examined within female or male athletes. A summary of the data for the entire sample, females, and males is reported in Tables 2 and 3, respectively.

Discussion

Our main finding was that collegiate athletes with a history of concussion were more likely to report a history of ankle sprain or knee injury compared to collegiate athletes who had never sustained a concussion. Athletes who reported more than one concussion had the greatest odds of reporting a history of ankle sprain or knee injury compared to collegiate athletes with no history of concussion. The relationship between concussion and lower extremity MSI was significant when examined in female athletes; however, the odds of sustaining a lower extremity MSI in male athletes was similar regardless of concussion history. Additionally, no differences were identified between athletes with a single or multiple concussion history, regardless of sex. While the results of this study support previous literature which has identified a relationship between concussion and MSI (19), we provide novel and provocative findings as it relates to sex and the number of concussions, which appear to be important factors that may influence the lower extremity MSI and concussion relationship.

When compared to athletes with no history of concussion, athletes who reported multiple concussions appeared to exhibit the greatest association with history of ankle sprain or knee injury. The strongest of these associations (OR = 4.31) was demonstrated in females with a history of multiple concussions in which 73.5% reported a history of ankle sprain compared to only 39% of female athletes with no history of concussion. However, no differences were identified between athletes with a single or multiple concussion history. These findings indicate that having multiple concussions appears to increase the likelihood of reporting a MSI history compared to individuals with no history of concussion; however, there was a smaller difference in the odds of reporting a MSI history compared to individuals

Table 2. Association between concussion history and ankle sprain history in collegiate athletes.

	Groups	*n*	Rate of ankle sprain history (%)	Odds ratio	Odds ratio 95% CI	*p* value
Entire sample	History of concussion	115	58.0	2.07	1.35, 3.18	< 0.001*
	No History of concussion	353	40.0			
	Single concussion	66	54.5	1.78	1.05, 3.02	0.040*
	No history of concussion	353	40.0			
	Multiple concussions	49	63.0	2.56	1.38, 4.75	0.003*
	No history of concussion	353	40.0			
	Multiple concussions	49	63.0	1.44	0.67, 3.06	0.227
	Single concussion	66	54.5			
Males	History of concussion	36	50.0	1.41	0.68, 2.91	0.360
	No history of concussion	164	41.5			
	Single concussion	21	57.0	1.88	0.75, 4.71	0.240
	No history of concussion	164	41.5			
	Multiple concussions	15	40.0	0.94	0.32, 2.77	0.920
	No history of concussion	164	41.5			
	Multiple concussions	15	40.0	0.50	0.13, 1.92	0.249
	Single concussion	21	57.0			
Females	History of concussion	79	62.0	2.54	1.48, 4.35	0.001*
	No history of concussion	189	39.0			
	Single concussion	45	53.0	1.78	0.92, 3.42	0.090
	No history of concussion	189	39.0			
	Multiple concussions	34	73.5	4.31	1.90, 9.76	< 0.001*
	No history of concussion	189	39.0			
	Multiple concussions	34	73.5	2.43	0.93, 6.35	0.054
	Single concussion	45	53.0			

*p value < 0.05

Table 3. Association between concussion history and knee injury history in collegiate athletes.

	Groups	*n*	Rate of knee injury history (%)	Odds ratio	Odds ratio 95% CI	*p* value
Entire sample	History of concussion	115	47.0	1.90	1.24, 2.92	0.004*
	No history of concussion	353	32.0			
	Single concussion	66	42.0	1.58	0.93, 2.71	0.120
	No history of concussion	353	32.0			
	Multiple concussions	49	53.0	2.43	1.33, 4.45	0.004*
	No history of concussion	353	32.0			
	Multiple concussions	49	53.0	1.52	0.73, 3.23	0.173
	Single concussion	66	42.0			
Males	History of concussion	36	36.0	1.59	0.74, 3.41	0.300
	No history of concussion	164	26.0			
	Single concussion	21	28.5	1.13	0.41, 3.09	0.990
	No history of concussion	164	26.0			
	Multiple concussions	15	47.0	2.46	0.84, 7.19	0.130
	No history of concussion	164	26.0			
	Multiple concussions	15	47.0	2.19	0.56, 8.76	0.222
	Single concussion	21	28.5			
Females	History of concussion	79	52.0	1.88	1.10, 3.19	0.020*
	No history of concussion	189	36.5			
	Single concussion	45	49.0	1.66	0.86, 3.20	0.170
	No history of concussion	189	36.5			
	Multiple concussions	34	56.0	2.20	1.05, 4.61	0.030*
	No history of concussion	189	36.5			
	Multiple concussions	34	56.0	1.32	0.54, 3.24	0.349
	Single concussion	45	49.0			

*p value < 0.05

with a history of one concussion which was not statistically significant. Although this study had 468 subjects, future studies with larger sample sizes should continue examining if differences in the association with MSI exist between athletes with different concussion histories as some of these analyses may have lacked the power necessary to detect group differences. It is beyond the scope of this study to determine what factors may have been responsible for heightened lower extremity MSI risk; therefore, future studies should consider examining potential areas of impairment to provide additional context to epidemiological findings.

Most analyses in male athletes were associated with lower OR and wide confidence intervals which suggested concussion history was not strongly associated with an increased likelihood of ankle sprain or knee injury history in this group. This is conflicting with previous reports that have identified

elevated MSI risk exclusively in male athletes with a history of concussion (13,17). For example, Nordstrom et al. (17) identified significantly greater risk of MSI within one year in a small sample of elite male rugby players. Additionally, Cross et al. (13) determined that elite male rugby players with a history of concussion were at greater risk for subsequent time-loss injuries. Differences in the current study which may explain the variation in findings include the retrospective study design, the lack of timeline between concussion and MSI, and level of competition (collegiate versus professional athletes). Previous studies (11,12,14,15) which have examined the relationship between concussion and MSI in collegiate athletes have not stratified the results based on sex. Based on the findings of the current study, sex differences should be considered in the design of future prospective studies which examine the association between MSI and concussion in collegiate athletes to further elucidate this relationship.

Although the underlying mechanism(s) for the relationship between concussion and lower extremity MSI risk has not been established, this association should be taken into consideration during the management of these injuries. Because of the retrospective nature of this study and the methods of collecting injury history data, we were unable to determine the sequence in which concussion or MSI occurred. This suggests that there may be a cyclical relationship between concussion and MSI which may not consistently start with concussion as the index injury. While several studies have identified a linear relationship between concussion and lower extremity MSI in collegiate athletes, there is limited evidence which has examined if lower extremity MSI increases the risk of concussion. However, previous research has identified athletes who sustained concussions were more prone to other injuries both prior and subsequent to the concussion incident (17). Additionally, it is unclear if the heightened likelihood for MSI history exhibited in this study was the result of multiple MSI. Concussion and lower extremity MSI, such as ankle sprains or ACL injuries, may share common sensorimotor or neurocognitive impairments which could increase susceptibility to additional injuries over time (19). Alternatively, this association could be a function of injury proneness or personality traits associated with risk-taking behaviours (30). This is supported by a recent systematic review with meta-analysis that determined a history of lower extremity injury of any type may increase the subsequent risk of lower extremity injury at a different site (31). Therefore, continued investigation to understand the potential mechanisms for these relationships is warranted.

This study has several limitations. Due to the cross-sectional design and data capture instrument, we do not know whether lower extremity MSI or concussion happened first. We simply know that those who had a history of concussion were also more likely to have a history of lower extremity MSI. It is possible that participants with a history of MSI were also more likely to sustain another MSI. Therefore, it is unclear whether MSI history creates a causal or confounding factor when examining the relationship between concussion and MSI. Future prospective studies should attempt to control for prior history of concussion and MSI to better under the interaction between these conditions. Also, this study relied on self-reported medical history which may have been limited by recall and accuracy. The limitations of injury history recall have been documented in previous studies particularly for some of the injuries of interest in this study (32,33). Similarly, it is unknown if concussions were reported, unreported, or unrecognized. Despite the limitations associated with our methods of collecting of injury history, this study demonstrated similar findings to those reported by Gilbert et al. (14) who collected retrospective injury history over the college career and categorized concussions as reported, unreported, and unrecognized. While electronic medical record systems may provide more systematic documentation of medical encounters, it is challenging to capture incidents which may have happened outside of athletic participation, prior to system availability, or went unreported to medical personnel. Future prospective studies which collect both self-reported injury history and query electronic medical records may overcome these limitations.

Conclusion

Overall, collegiate athletes who reported a concussion history were more likely to report a history of ankle sprain or knee injury. When further stratifying athletes based on the number of self-reported concussions, a stronger association between concussion and MSI was demonstrated in athletes with multiple concussions compared to athletes with no concussion history. Additionally, female athletes who reported a history of concussion were more likely to report an ankle sprain or knee injury while male athletes were not. Therefore, females with a history of concussion or individuals who have sustained multiple concussions may be more susceptible to also experiencing MSI. These factors should be explored in future prospective research studies to provide greater insight into the interaction between concussion, ankle sprain, and knee injuries in athletic populations.

Declaration of interest

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Disclosures

The authors have no conflicts of interest to disclose.

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