

[Athletic Training]

Association Between Concussion and Lower Extremity Injuries in Collegiate Athletes

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Background: Concussions have been associated with elevated musculoskeletal injury risk; however, the influence of unreported and unrecognized concussions has not been investigated.

Hypothesis: The purpose of this study was to examine the association between concussion and lower extremity musculoskeletal injury rates across a diverse array of sports among collegiate student-athletes at the conclusion of their athletic career. The hypothesis was that there will be a positive association between athletes who reported a history of concussions and higher rates of lower extremity injuries.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

Methods: Student-athletes (N = 335; 62.1% women; mean age, 21.2 ± 1.4 years) from 13 sports completed a reliable injury history questionnaire. Respondents indicated the total number of reported, unreported, and potentially unrecognized concussions as well as lower extremity injuries including ankle sprains, knee injuries, and muscle strains. Chi-square analyses were performed to identify the association between concussion and lower extremity injuries.

Results: There were significant associations between concussion and lateral ankle sprain ($P = 0.012$), knee injury ($P = 0.002$), and lower extremity muscle strain ($P = 0.031$). There were also significant associations between reported concussions and knee injury ($P = 0.003$), unreported concussions and knee injury ($P = 0.002$), and unrecognized concussions and lateral ankle sprain ($P = 0.001$) and lower extremity muscle strains ($P = 0.006$), with odds ratios ranging from 1.6 to 2.9.

Conclusion: There was a positive association between concussion history and lower extremity injuries (odds ratios, 1.6-2.9 elevated risk) among student-athletes at the conclusion of their intercollegiate athletic careers.

Clinical Relevance: Clinicians should be aware of these elevated risks when making return-to-participation decisions and should incorporate injury prevention protocols.

Keywords: injury risk; ankle sprain; anterior cruciate ligament injury; muscle strain; mild traumatic brain injury

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The majority of patients with concussions (80%-90%) recover within a relatively short timeframe (7-10 days) when utilizing standard recommended clinical assessments, and this is considered a transient injury.^{2,30,31,33} However, lingering deficits persisting months to years postinjury have been identified with instrumented measures of postural control, cognition, and neural activation patterns despite apparent clinical recovery.^{6,7,13,21,44,45} Currently, there is no biomarker or gold standard that objectively and conclusively identifies concussion recovery, and thus, neurological deficits may persist through return to sport despite apparent clinical resolution.^{21,33}

One established consequence of concussion is a dose-response relationship whereby the individual has an elevated risk for recurrent concussion.¹⁸ However, emerging evidence has identified a potential postconcussion elevated risk of musculoskeletal injury.^{3,9,28,36,39} Among retired professional American football players, retrospective analysis identified an elevated risk of serious lower extremity injuries (eg, ligament tear, muscle/tendon rupture, fracture) in players with a history of concussion.³⁹ This relationship was dose dependent, whereby the risk of serious musculoskeletal injury increased with a greater number of reported concussions.³⁹ Prospectively, an elevated risk of subsequent injury was also noted in professional European male soccer (2.2× elevated risk) and rugby players (1.6× elevated risk). Interestingly, soccer players also had an elevated injury risk in the year prior to concussion.^{11,36} Similarly, a Swedish hospital database also identified an elevated injury risk in the 2 years prior (1.98× elevated risk) or after (1.72× elevated risk) a diagnosed concussion.⁹ Most recently, 2 tightly controlled prospective studies of collegiate student-athletes identified a 1.6 to 2.5 times elevated risk of subsequent lower extremity injury postconcussion.^{3,28} These studies suggest an association between diagnosed concussion and musculoskeletal injury; however, many concussions may go undiagnosed.

Accurate and timely concussion reporting remains a substantial challenge for sports medicine clinicians, as 50% to 80% of potential concussions may go unrecognized or unreported.^{26,32} The most common reasons for not reporting concussions includes a lack of concussion knowledge, believing “dings” or “bell ringers” are a normal part of the game, not wanting to let down teammates, and not wanting to miss current or future games.^{1,32,48} Unreported and unrecognized concussions may elevate the risk of subsequent injury as the student-athlete continues participating despite neurological insult, which may impair both the balance and cognitive systems. The underreporting issue is likely exacerbated by the pressure student-athletes experience, either direct or implied, from teammates and coaches along with a culture of playing through injury.^{1,10,35} Athletes have reported worrying that their teammates would blame them for losing a game and fearing negative judgment from coaches who believe they should play through injuries, including concussions.^{1,10,35} Furthermore, athletes who experience increased pressure to perform have a

lower intention to report a suspected concussion, and this trend worsens during collegiate careers, with older athletes reporting reduced concussion symptoms than freshman athletes.^{1,27} The athlete's perception of the coach also influences concussion reporting.^{10,48} Some former collegiate athletes have acknowledged not reporting concussions during their active playing careers.^{25,27}

Emerging evidence is linking sports-related concussion with elevated risk of subsequent musculoskeletal injury; however, these studies are generally limited to medically diagnosed concussions, present a limited number of predominately male sports, and evaluate risk for only 1 to 2 years postconcussion. Therefore, the purpose of this study was to examine concussion and lower extremity musculoskeletal injury rates across a diverse array of sports among collegiate student-athletes at the conclusion of their athletic career. We hypothesize there will be association between concussion and lower extremity injuries that will be increased by including unreported/unrecognized concussions.

METHODS

The participants in this study were student-athletes who had completed their athletic participation by either exhausting their eligibility or quitting their respective team, and all student-athletes who met this criteria were recruited. From this population, we successfully enrolled 335 respondents (62.1% women; National Collegiate Athletic Association [NCAA] Division I, 71.5%; mean age, 21.2 ± 1.4 years old; mean collegiate athletic experience, 3.3 ± 1.2 years) across 13 sports from 17 NCAA and National Junior College Athletic Association (NJCAA) member institutions from 2012 to 2014 (Table 1). Student-athletes who reported they would attempt to continue participation beyond their collegiate experience were excluded. All participants provided written informed consent as approved by each of the 17 institutional review boards.

A previously utilized 21-item questionnaire pertaining to injuries experienced during a student-athlete's collegiate career was administered to participants (see Appendix, available at <http://sph.sagepub.com/content/suppl>).²⁷ This questionnaire was initially designed to investigate concussion reporting rates but also included questions related to common musculoskeletal injuries including sprains, strains, fractures, and dislocations to the trunk and extremities.²⁷ The test-retest reliability of the questionnaire was excellent (ICC, 0.92) for 10 student-athletes, not participants in the study, who were tested 4 months apart on the specific questions utilized in the analysis herein. Face validity had been previously established by academic and clinical practitioners and through pilot testing with current student-athletes.

Participants were recruited by their respective team athletic trainers either during exit physicals or at the conclusion of the season. The questionnaires were completed in private either online (SurveyMonkey.com; N = 163) or by pen and paper (N = 172) shortly after the completion of their final season. The 2

Table 1. Participant demographics, sport participation, and relative injury rates^a

Sport	Number of Respondents	Reported Concussion Rate	Self-Reported >3	Unreported Concussion Rate	Unrecognized Concussion Rate	Ankle Sprain Rate	Knee Injury Rate	Muscle Strain Rate
Soccer	94 (28.1)	49 (52.1)	12 (12.8)	17 (18.1)	48 (51.1)	65 (69.1)	35 (37.2)	55 (58.5)
Women	53 (56.4)	31 (58.5)	6 (50)	13 (76.5)	27 (56.3)	37 (69.8)	20 (37.7)	32 (60.4)
Men	41 (43.6)	18 (43.9)	6 (50)	4 (23.5)	21 (43.8)	28 (68.3)	15 (36.6)	23 (56.1)
Football	48 (14.3)	22 (45.8)	3 (6.3)	10 (20.8)	24 (50)	38 (79.2)	22 (45.8)	22 (45.8)
Cheerleading	37 (11.0)	10 (27.0)	1 (2.7)	6 (16.2)	19 (51.4)	21 (56.8)	7 (18.9)	15 (40.5)
Women	29 (78.4)	8 (80)	1 (100)	4 (66.7)	14 (73.7)	16 (76.2)	4 (57.1)	12 (80)
Men	8 (21.6)	2 (20)	0 (0)	2 (33.3)	5 (26.3)	5 (23.8)	3 (42.9)	3 (20)
Track and field	35 (10.4)	1 (2.9)	0	1 (2.9)	4 (11.4)	19 (54.3)	5 (14.3)	14 (40.0)
Women	27 (77.1)	1 (100)	0 (0)	1 (100)	4 (100)	14 (73.7)	3 (60)	13 (92.9)
Men	8 (22.9)	0 (0)	0 (0)	0 (0)	0 (0)	5 (26.3)	2 (40)	1 (7.1)
Basketball	33 (9.9)	7 (21.2)	0	1 (3.0)	2 (6.1)	25 (75.8)	12 (36.4)	8 (24.2)
Women	27 (81.8)	7 (100)	0 (0)	1 (100)	2 (100)	20 (80)	10 (83.3)	7 (87.5)
Men	6 (18.2)	0 (0)	0 (0)	0 (0)	0 (0)	5 (20)	2 (16.7)	1 (12.5)
Softball	21 (6.3)	3 (14.3)	1 (4.8)	2 (9.5)	5 (23.8)	13 (61.9)	4 (19.0)	9 (42.9)
Women's volleyball	20 (6.0)	4 (20.0)	1 (5)	0 (0.0)	2 (10.0)	13 (65.0)	9 (45.0)	10 (50.0)
Tennis	13 (3.9)	1 (7.7)	0	0 (0.0)	0 (0.0)	6 (46.2)	1 (7.7)	7 (53.8)
Women	7 (53.8)	1 (100)	0 (0)	0 (0)	0 (0)	5 (83.3)	0 (0)	1 (14.3)
Men	6 (46.2)	0 (0)	0 (0)	0 (0)	0 (0)	1 (16.7)	1 (100)	6 (85.7)
Field hockey	7 (2.1)	3 (42.9)	0 (0.0)	1 (14.3)	2 (28.6)	2 (28.6)	3 (42.9)	4 (57.1)
Women's lacrosse	7 (2.1)	4 (57.1)	0 (0.0)	0 (0.0)	2 (28.6)	6 (85.7)	1 (14.3)	4 (57.1)
Women's swim/dive	7 (2.1)	1 (14.3)	0 (0.0)	0 (0.0)	1 (14.3)	1 (14.3)	1 (14.3)	2 (28.6)
Baseball	6 (1.8)	2 (33.3)	0 (0.0)	0 (0.0)	2 (33.3)	3 (50.0)	1 (16.7)	3 (50.0)
Golf	4 (1.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (25.0)	1 (25.0)	2 (50.0)
Women	1 (25)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	0 (0)	1 (50)
Men	3 (75)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (100)	1 (50)
Not listed	3 (0.9)	1 (33.3)	1	0 (0.0)	1 (33.3)	1 (33.3)	1 (33.3)	1 (33.3)
Total, N (%)	335 (100)	108 (32.2)	19 (5.7)	38 (11.3)	112 (33.4)	214 (63.9)	103 (30.7)	156 (46.6)

^aData presented as n (%). Three respondents did not report sport.

instruments had identical questions, and there were no differences ($P > 0.05$) in any of the primary dependent variables between questionnaire administration methods.

To identify the total number of concussions, 4 dependent variables were calculated, including: (1) self-reported

concussion rate, (2) acknowledged unreported rate, (3) potentially unrecognized concussion rate, and (4) "any concussion," which would include participants who were included in any of the 3 prior groups. An "acknowledged unreported concussion" refers to a respondent indicating they

Table 2. Reported, unreported, and unrecognized concussion rates

	Rate, % (n/total)
Reported concussions	32.2% (108/335)
Unreported concussions	11.3% (38/335)
Reasons for not reporting concussion ^a	
1. Did not want to be removed from future games	65.8% (25/38)
2. Did not want to be removed from current game	60.5% (23/38)
3. Did not want to let down teammates	50.0% (19/38)
4. Did not think the injury was serious	47.4% (18/38)
5. Did not know it was a concussion	36.8% (14/38)
Potentially unrecognized concussions	33.4% (112/335)
Unrecognized concussion symptoms ^a	
1. Knocked silly/seen stars	29.6% (99/335)
2. Loss of consciousness	9.3% (31/335)
3. Memory loss	7.8% (26/335)

^aParticipants were instructed to select all that apply, and therefore, these were not mutually exclusive. “Any concussion” rate (reported, unreported, or unrecognized) was 46.3% (155/335).

believe they suffered a concussion but did not report the injury to a health care professional, whereas a “potentially unrecognized concussion” refers to the respondent acknowledging a common concussion symptom (eg, loss of consciousness, memory loss, etc) but did not indicate this was diagnosed as a concussion.^{27,34} Three dependent variables were calculated to identify the number of lower extremity injuries: (1) ankle sprain rate, (2) knee injury rate, and (3) muscle extremity muscle strain rate (eg, pulled, torn, or strained muscle) in which the participant self-reported a lower extremity (hip or distal, but not including lumbar area) injury. Chi-square analyses were performed to identify the association between each of the 4 concussion variables (reported, unreported, potentially unrecognized, and any concussion) and lower extremity variables (ankle sprain, knee injury, muscle strain). Absolute rates were calculated by sport and sex (see Table 1), but no statistical tests were performed due to the small sample size of many of the sports.

RESULTS

Concussions and lower extremity injury rates are provided by sport in Table 1. Concussion rates (reported, unreported, and unrecognized) are provided in Table 2.

There were significant associations between any concussion and lateral ankle sprain ($P = 0.012$), knee injury ($P = 0.002$), and lower extremity muscle strain ($P = 0.031$). There were also

significant associations between reported concussions and knee injury ($P = 0.003$), unreported concussions and knee injury ($P = .002$), and unrecognized concussions and lateral ankle sprain ($P = 0.001$) and lower extremity muscle strains ($P = 0.006$). The odds ratios for the relationships ranged between 1.61 and 2.87 (Table 3).

DISCUSSION

There is emerging evidence that concussions are associated with musculoskeletal injuries, particularly in soccer and football.^{9,11,28,36,39} The primary finding of this study was a positive association between concussion history and lower extremity injuries, including lateral ankle sprains, knee injuries, and muscle strains, among student-athletes at the conclusion of their intercollegiate athletic careers. Similar to recent reports, the odds ratios were elevated by 1.6 to 2.9 times risk of lower extremity injury among respondents who suffered a collegiate concussion.^{28,36,39} Among respondents who acknowledged a concussion, the only association was a 2.1 times elevated risk of knee injury; however, when unreported and potentially unrecognized concussions were included in the analysis, there was an elevated risk for all lower extremity injuries (ankle sprain, knee injury, muscle strain), which further highlights the importance of accurate concussion identification. This finding furthers the existing literature by expanding across multiple sports and intercollegiate athletic seasons as well as considering

Table 3. Association between concussion history and lower extremity injury

	Lateral Ankle Sprain (N = 214)			Knee Injury (N = 103)			Muscle Strain (N = 156)		
	χ^2	P Value	Odds Ratio	χ^2	P Value	Odds Ratio	χ^2	P Value	Odds Ratio
Reported concussion (N = 108)	0.95	0.329	—	8.93	0.003	2.08	2.47	0.116	—
Unreported concussion (N = 38)	0.10	0.922	—	9.64	0.002	2.87	0.63	0.426	—
Unrecognized concussion (N = 112)	10.52	0.001	2.29	2.71	0.099	—	7.56	0.006	1.90
Any concussion (N = 155)	6.28	0.012	1.79	10.04	0.002	2.13	4.65	0.031	1.61

reported, unreported, and potentially unrecognized concussions. This study design, similar to that by Pietrosimone et al,³⁹ was unable to ascertain a directional or causative relationship; however, these findings may assist clinicians in targeting and developing injury prevention programs to reduce musculoskeletal injuries after concussion.¹⁹

Retrospective questionnaires and chart reviews are not capable of identifying the underlying mechanisms for the identified relationships; however, multiple rationales have been suggested. Lynall et al²⁸ argued that postconcussion impairments in motor and/or postural control, known predictors of lower extremity injuries, may predispose athletes to subsequent injury.^{20,38,41} Lingering impairments in the motor cortex and supplementary motor areas may inhibit planning and integration of efficient motor programs.³⁹ Transient alterations in neurocognitive function, which may be exacerbated postconcussion by psychological stress and inadequate sleep, may contribute to elevated injury risk.¹⁹ Postconcussion changes in cerebral functioning including prolonged deficits in attentional resource allocation and cognitive processing speed adversely affects postural control beyond the acute injury phrase.³ There may be an elevated risk of injury both prior to and after a concussion, suggesting these individuals could be injury prone or partake in higher risk activities, which elevates the likelihood of all injuries.^{9,36} As this study was unable to identify a directional relationship between injuries, it is possible individuals sustained the lower extremity injury first, which adversely affected their motor control thereby elevating the risk of subsequent concussion, or that these individuals are simply more injury prone overall.^{9,36}

The neurological components essential to healthy postural control include the somatosensory, motor, and cognitive systems, which allow the successful integration of the individual, task, and environment.⁴³ Clinical measures of postural control typically suggest recovery within 3 to 5 days postconcussion, but these tests are known to have limitations.^{8,14,31,42} Not surprisingly, sophisticated measures of

postural control including gait, gait termination, and quiet stance have consistently identified lingering deficits for weeks or months postinjury despite apparent recovery on typical clinical measures.^{6,15,30,37,45} Gait involves widespread supraspinal control mechanisms involving the cerebral cortex, basal ganglia, motor cortex, supplementary motor areas, cerebellum, and brainstem.⁴³ Supraspinal disintegration may disrupt descending pathways, thus impairing the nervous system's ability to appropriately anticipate, prepare, and respond to postural challenges, thereby elevating the risk for injury.^{28,39} Motor cortex inhibitions, including longer cortical silent period duration and increased long interval intracortical inhibition, may persist for at least 9 months postconcussion.¹² Deficits and alterations in supraspinal control, specifically in the supplementary motor area and motor cortex, have been identified in individuals with both ankle and anterior cruciate ligament (ACL) injuries.^{40,41}

A concussion involves transient alteration in mental status, and acute cognitive deficits are a common concussion sign.³³ Current concussion management best practice models, largely adhered to by collegiate athletic trainers, incorporate both baseline and postinjury neurocognitive assessments that require athletes to achieve premorbid performance prior to return to participation.^{4,23,33} However, 122 respondents herein endorsed an unreported or potential concussion and likely continued participating despite the probable cognitive deficits typically associated with a concussion. Altered neurological function has been identified despite apparent recovery on clinical neurocognitive tests, and poorer performance on these tests has been associated with elevated injury risk.^{44,45} Swanik et al⁴⁶ reported poorer performance across all measures of neurocognitive testing in athletes with subsequent noncontact ACL injuries. Similarly, poorer reaction time may be a predictor of lower extremity strains and sprains in collegiate football players.⁴⁷ After a concussion, neurocognitive functioning may be further challenged by psychological stress and inadequate sleep, which are both known consequences of concussion.^{19,22,29} Interestingly, 38% of professional rugby players failed to achieve

valid postconcussion neurocognitive test performance, which potentially elevates their injury risk.¹¹ Thus, residual deficits in neurocognitive functioning, despite apparent clinical recovery or because of nonreporting of potential concussions, could be a contributing factor in the elevated risk of postconcussion subsequent musculoskeletal injury.

Concussion reporting remains a substantial challenge for sports medicine clinicians, and the results herein indicate that both intentionally unreported and potentially unrecognized concussions remain prevalent among NCAA student-athletes.^{5,26,27,32} Indeed, 36.4% (122/335) of respondents had either an unreported or potentially unrecognized concussion, independent of reported concussions, during their intercollegiate athletic careers. This disturbing lack of reporting persisted despite 95.5% (316/331) of respondents indicating they had a good relationship with their athletic trainer; however, the role of the coach was not assessed, which may have played a larger role in reporting decisions.^{1,10} Interestingly, 35% of all ankle sprains were also unreported to athletic trainers by respondents, but most (82.2%, 176/214) completed rehabilitation programs.

Overall, nearly half of all respondents (46.3%, 155/335) in this study reported suffering either a reported, acknowledged unreported, or potential concussion during their intercollegiate athletic career. Furthermore, of the individuals who self-reported diagnosed concussions, 17.6% indicated 3 or more concussions—a number frequently associated with multiple later-life neuropathologies.^{16,17} These results are particularly concerning when considering that less than half (42%) of respondents played sports generally considered to be high risk for concussion (eg, football, soccer).

The primary concern with failure to report a suspected concussion is typically the risk of second-impact syndrome; however, these results agree with the recent findings that these individuals may also be at risk for subsequent musculoskeletal injuries.^{9,11,28,36,39} It is noteworthy that this pattern continues herein, with a population of over 60% being female participants and only 42% participating in “high-risk” concussion sports. If further prospective controlled studies confirm the elevated risk identified recently, the potential exists for preventative strategies to reduce overall musculoskeletal injury rates. For example, ACL injuries are particularly problematic as they frequently require surgery and lengthy rehabilitation programs that strain the sports medicine staff and increase health care expenditures. Herein, the majority of participants with ACL injuries also reported a concussion (reported, unreported, or potentially unrecognized), which provides the opportunity for sports medicine providers to intervene with established ACL prevention programs to potentially reduce ACL injury risk.²⁰

The most substantial limitation to this study is the inability to establish causation or identify an order effect between concussion and lower extremity injury, and therefore, the extrapolation should not exceed an association between pathologies.³⁹ However, the results and odds ratios are highly consistent with the limited previous findings relating concussion

and subsequent musculoskeletal injury.^{9,11,28,36,39} Concussion self-report is inherently limited by the honesty and accuracy of the respondents but has previously demonstrated moderate to high reliability.^{24,32} The instrument herein has been previously utilized and demonstrated high test-retest reliability (0.92), but the study is limited by the presumption of accurate responses and interpretation of the questions.²⁷ It is also important to note that potentially unrecognized concussions in this study were termed “potential,” as other conditions (eg, dehydration, fatigue) could account for these common concussion symptoms; however, these terms have been frequently used in the literature along with the colloquialisms “bell ringer” and “ding.”³⁴ Furthermore, data were collected through 2 different protocols (pen/paper and online), but no differences were identified in the primary dependent variables between protocols. Nonetheless, this is a potential limitation. These results are specific to collegiate student-athletes at the conclusion of their intercollegiate athletic experiences and should not be extrapolated to other populations. Finally, there is a potential selection bias in the respondents who agreed to participate in the study, which may be reflective of student-athletes who have higher injury rates or better relationships with their athletic trainers. Future studies could aim to investigate this correlation in randomized samples or consecutive patient populations.

CONCLUSION

The primary finding of this study was a 1.6 to 2.9 times elevated risk of lower extremity musculoskeletal injury in student-athletes who suffered a concussion during their intercollegiate athletic careers. Furthermore, these results extend prior work by including diverse sports (baseball, basketball, cheerleading, field hockey, football, golf, lacrosse, soccer, softball, swim/dive, tennis, track and field, and volleyball) and predominately female participants. If the neurological mechanisms underlying this elevated risk can be established, concussion protocols can be adapted to reduce the risk of subsequent injuries either through clinically plausible improved testing paradigms or the implementation of established injury prevention programs.

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