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Risk for Lower Extremity Injury After Concussion: A Matched Cohort Study in Soldiers

The rate of lower extremity musculoskeletal injuries is reportedly higher in collegiate and professional athletes following concussions.[3,13,18] The increased risk for lower extremity injury following concussion was 1.47 to 2.48 times greater within 90-day follow-up.[3,13,18] Increased risk of injury within 1 year varied considerably between studies, from 1.64 to 4.07 times greater risk.[13,18]

It is hypothesized that this increased risk for lower extremity injury is due to the persistence of postconcussive symptoms or neuromotor deficits. Multiple studies give merit to this hypothesis through reports of lingering effects on cognition,[7,15] postural control,[4,9,10,27] and gait deviations[5,8,20,22] following concussions. Diminished postural stabilization[4,10,27] and altered stability,[8,19,20,24] sway,[21] speed,[21] and response to perturbations[5] during gait are some of the deficits that have been reported in people considered clinically recovered from a concussion.

BACKGROUND: Rates of lower extremity musculoskeletal injury are reportedly higher in professional and collegiate athletes following concussions. However, there is a paucity of evidence on this relationship in individuals who are not high-level athletes.

OBJECTIVES: To examine the risk of acute lower extremity musculoskeletal injury in soldiers within 2 years of an incident concussion, compared to matched nonconcussed soldiers.

METHODS: This was a matched-cohort study that used the medical encounter and personnel data of active-duty US Army soldiers from 2005 to 2011. Incident concussions were identified using International Classification of Diseases-Ninth Revision codes in medical encounter data of all soldiers from 2005 to 2009. One nonconcussed soldier in the US Army during the same month was matched by age, sex, rank, length of service, deployment status, and military career field to each concussed soldier. Hazard ratio (HR) and 95% confidence interval (CI) were calculated for the risk of lower extremity injury within 2 years of the incident concussion. Monthly HRs were compared to identify differences in injury rates between the groups, and an HR for the period of greatest difference was also calculated.

RESULTS: A total of 23 044 individuals (11 522 concussed and 11 522 nonconcussed) were included in the study. Within 2 years of concussion, the hazard of lower extremity injury was 38% greater in concussed compared to nonconcussed soldiers (HR, 1.38; 95% CI: 1.30, 1.46), while the 15-month hazard was 45% greater (HR, 1.45; 95% CI: 1.36, 1.56).

CONCLUSION: The rate of lower extremity musculoskeletal injury among this population of physically active adults is higher following concussion, and the risk remains elevated for more than a year following injury.

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When more dynamic activity was examined during jump landing, alterations in joint stiffness of the lower limbs were also detected between people who sustained a concussion and matched controls.[6] Specifically, increased dynamic hip joint stiffness and decreased knee and ankle joint stiffness were seen, which may represent an altered proprioceptive processing or neuromotor response during more dynamic activities.

It is plausible that a concussion could be associated with increased risk for musculoskeletal injuries during activities in which these injuries commonly occur, such as athletic events. That potential relationship is supported by the evidence that athletes have higher injury rates following a concussion and by lingering cognitive and postural control impairments or gait deviations after clinical recovery from a concussion. However, there is a

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paucity of research examining concussion as a risk factor for musculoskeletal injury in individuals who are not high-level, traditional athletes.

Because military service members represent an occupational population that experiences high rates of musculoskeletal injury, examining concussions as a risk factor for musculoskeletal injury in soldiers may provide evidence that is applicable to other physically active occupations or adults who exercise regularly. The purpose of this study was to examine the risk of acute lower extremity musculoskeletal injury in soldiers following concussion, compared to matched nonconcussed soldiers. The time to lower extremity injury was also examined between the groups.

METHODS

This study used data from the Total Army Injury and Health Outcomes Database, a data repository of medical encounters and personnel data for all active-duty US Army soldiers, which have been used to conduct epidemiologic research within the US Army. This matched-cohort study design involved matching participants based on exposure event (concussion) and examining risk of lower extremity outcomes over a 2-year period after the event. These methods contrast those of a case-control design, which matches participants based on outcome (lower extremity injury) and examines risk factors, such as concussion, as predictors of outcome. This study was approved by the Institutional Review Board of the US Army Research Institute of Environmental Medicine. The investigators have adhered to the policies for protection of human subjects, as prescribed in Department of Defense Instruction 3216.02, and the research was conducted in adherence with provision 32 of Code of Federal Regulations Part 219.

Participants

The population for this study comprised US Army soldiers on active duty from January 1, 2005 through December 31, 2009. Study participants were followed for 2 years, potentially until December 31, 2011. To minimize confounding bias due to prior history of head injuries or lower extremity injuries, soldiers with International Classification of Diseases-Ninth Revision (ICD-9) codes for concussions, traumatic brain injuries, and related head injuries (skull fractures or intracranial injuries) listed in the Barell Injury Diagnosis Matrix,[2] or lower extremity injuries at any time in their military medical records prior to enrollment in the study, were excluded. Both the concussed and nonconcussed cohorts were selected from soldiers with no history of these injuries prior to enrollment in the study.

Individuals with medical encounters for concussions were identified using ICD-9 codes 850.0, 850.1, 850.5, 850.9 (concussions with loss of consciousness of less than 1 hour), or 310.2 (postconcussive syndrome). Concussed soldiers with concomitant diagnoses of skull fractures or intracranial injuries that could potentially be associated with more severe brain injuries[2] were excluded from the study. If a lower extremity injury was noted within the same medical encounter as the concussion, then those individuals were excluded from the study, as those injuries likely occurred at the same time as the concussion, not following the concussion.

The matched (unexposed) cohort, or nonconcussed group, was selected from soldiers with no medical encounters for a head injury or concussion during the study period. Soldiers were matched on age, sex, rank, length of service, deployment status, and military career field (as described in Department of Defense Occupational Conversion Index, March 2001, DoD 1312.1-1) with nonconcussed soldiers on active duty during the same month that a concussed soldier was identified. All soldiers were followed from time of incident concussion or time of matching until the first of (1) a lower extremity injury, (2) loss to follow-up, or (3) the end of the 2-year follow-up period.

Acute lower extremity injuries were identified by ICD-9 codes in soldiers' medical encounter data, as referenced using the Barell Injury Diagnosis Matrix[2] regional designations: hip, upper leg and thigh, knee, lower leg and ankle, foot and toes, and other and unspecified (ie, defined as having ICD-9 codes for fractures, sprains, and strains of the lower extremity without a specific anatomical structure or segment identified). Continuous variables and military rank were stratified into the following groupings: years of age (less than 20, 20-29, 30-39, 40 or greater), years of service (1 or less than 1, greater than 1 to 3, greater than 3 to 5, greater than 5 to 7, greater than 7 to 10, greater than 10), and ranks (E1-E4, E5-E6, E7-E9, Warrant Officer, Commissioned Officer). Person-time was calculated from entry into the study until (1) a lower extremity injury, (2) loss to follow-up, or (3) the end of the 2-year follow-up period.

Statistical Analyses

A Cox proportional-hazards regression stratified by matching criteria and adjusted for race, education level, and marital status was used to evaluate the hazard of lower extremity injury between the concussed group and nonconcussed group. Additionally, the mean time to lower extremity injury was compared between the groups using a *t* test. A life table was created to estimate the unadjusted probability of an incident lower extremity injury for each monthly interval, conditional on soldiers continuing service to the start of the interval. The effective sample size was calculated by subtracting half of the number of subjects censored during the interval from the number of subjects at risk at the start of the interval.[1] Probabilities were calculated by dividing the number of injuries by the effective sample size. Visual examination of the life table was performed to estimate the time frame following concussion in which injury probabilities between the cohorts showed the greatest difference. Additionally, hazard ratio (HR) was calculated for each month of follow-up as an additional tool to find the period of greatest injury difference between the study groups.

Following qualitative and quantitative determination of the potential period of greatest risk, a Cox proportional-hazards regression was performed to calculate the HR for lower extremity injury during this period. Chi-square analyses with Bonferroni-corrected alpha (.008) were performed to examine injury rates between the groups by lower extremity region to determine whether a particular region drove increased hazard. All statistical tests were performed using SAS Version 9.3 (SAS Institute Inc, Cary, NC), with the level of significance set at $\alpha = .05$.

RESULTS

From 2005 through 2009, there were 29 758 incident concussions identified in active-duty soldiers (n = 905 095). **FIGURE 1** provides a flow diagram depicting the application of inclusion and exclusion criteria within the study sample. After excluding soldiers with skull fractures and intracranial wounds that could represent more severe head injuries (n = 3873) and those with a prior history of lower extremity injuries (n = 14 359), a total of 11 526 individuals with an incident concussion remained. Of the concussed soldiers, 4 could not be matched to nonconcussed soldiers, so the final number of concussed soldiers was 11 522, with an equal number of matched nonconcussed soldiers (total n = 23 044). Soldiers with concussions contributed 187 379 person-months of follow-up, while the matched cohort contributed 214 789 person-months of follow-up. **TABLE 1** shows the demographic characteristics of the study for the matched variables. **TABLE 2** shows the demographic information for variables that were not matched between the cohorts. Within the group that sustained concussions, 2551 soldiers (22.1%) experienced a lower extremity injury within 2 years of incident concussion, while 2114 (18.3%) nonconcussed soldiers experienced a lower extremity injury within 2 years of enrollment.

Soldiers who sustained a concussion showed a 38% increased hazard of lower extremity injury over the 2-year follow-up period compared to those without a concussion (HR = 1.38; 95% confidence interval [CI]: 1.30, 1.46). The survival curve for the 24-month study period is shown in **FIGURE 2**. When lower extremity injury risk was examined separately in men and women, the trend for increased hazard of lower extremity injury remained. However, the confidence bounds around the female HR were wide, spanning a range that included the overall estimate and crossed zero (male HR = 1.39; 95% CI: 1.31, 1.48; female HR = 1.19; 95% CI: 0.95, 1.49).

There was a significant difference (t = 6.13, P<.001) in mean time to injury between the concussed group (mean ± SD, 9.1 ± 6.7 months) and the nonconcussed group (mean ± SD, 10.3 ± 7.1 months). Visual examination of the injury rates from the life table (**FIGURE 3**) showed that the greatest difference between the 2 groups occurred within the first 15 months post concussion. The HRs showed injury rates between the groups to be significantly different for all but 1 (month 12) of the first 15 months of follow-up, while the 95% CIs around the HRs for months 16 to 24 indicated no significant difference between groups.

On examination of lower extremity injury risk within 15 months of concussion, the hazard for lower extremity injury in concussed soldiers was 45% greater than in those who had not sustained a

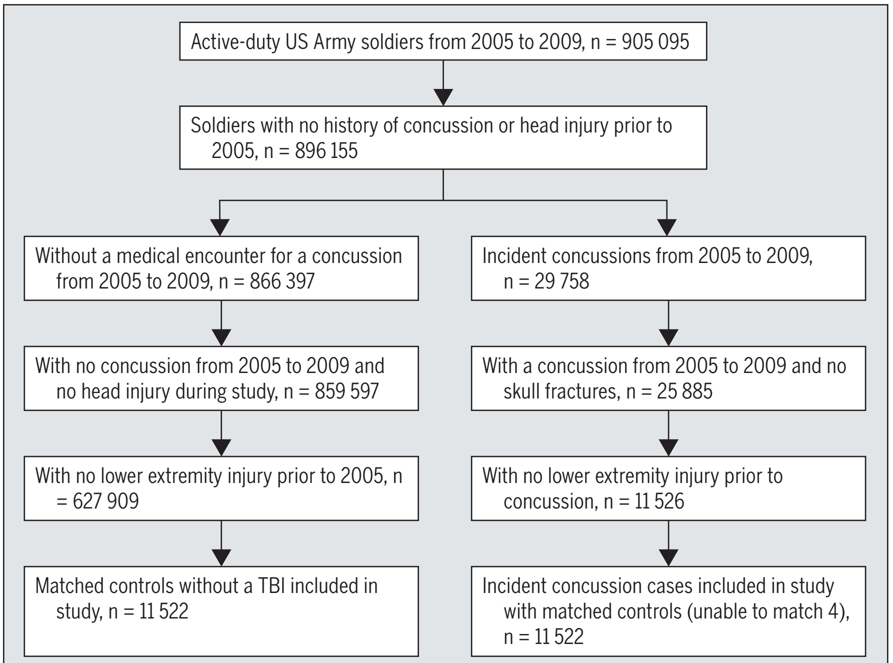

FIGURE 1. Development of study data set. Nonconcussed soldiers were matched to concussed soldiers at the time of incident concussion, based on age, sex, time in service, rank, career management field, and deployment status at time of injury. Abbreviation: TBI, traumatic brain injury.

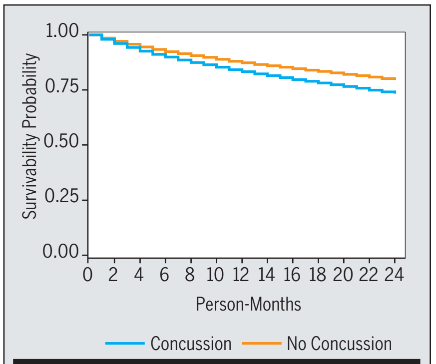

FIGURE 2. Survival curve for incident lower extremity musculoskeletal injury over the 24-month study period. The hazard ratio for lower extremity injury in concussed soldiers compared to nonconcussed soldiers was 1.38 (95% confidence interval: 1.30, 1.46).

concussion (HR = 1.45; 95% CI: 1.36, 1.56). The same trend was also seen for men and women as for the sex-specific analyses for the 24-month interval. Both sexes showed elevated hazard for lower extremity musculoskeletal injury during the 15-month period following concussion, but the female HR did not maintain statistical significance (male HR = 1.48; 95% CI: 1.38, 1.59; female HR = 1.14; 95% CI: 0.89, 1.45).

Frequency counts of injuries within 2 years following concussion, grouped by region, are available in **FIGURE 4**. All regions showed statistically significant differences in injury frequencies between groups for the 15-month analysis ($P \le .002$), while all regions were statistically different ($P \le .006$), except for the lower leg and ankle ($P = .045$) and the hip ($P = .009$) in the 2-year analysis (Bonferroni-corrected $\alpha = .008$).

DISCUSSION

THE PRIMARY FINDINGS OF THIS large population-level study showed an increased rate of lower extremity injury following an incident concussion among US Army soldiers. Neither the concussed nor the nonconcussed group had a medical history of concussion or lower extremity injury in military medical records prior to entry into this study, increasing the likelihood that the findings are attributable to the aftereffects of the concussion or to intrinsic factors of an individual that lead to greater risk of musculoskeletal injury following a concussion.

The incident lower extremity musculoskeletal injuries occurred sooner following a concussion compared to matched, nonconcussed soldiers, and the differences in injury rates appeared greater for more than a year following concussion. These findings suggest that musculoskeletal injury risk is greater following a concussion and diminishes over time. As the frequency of injury for all lower extremity regions was significantly greater during the 15 months following concussion, the risk of lower extremity musculoskeletal injury may be generally elevated and not driven by susceptibility to a particular lower extremity injury.

Several previous studies have reported an increased risk of lower extremity injury following concussion in collegiate and professional athletes.[3,13,18] Specifically in comparison to the current study, a previous study in collegiate athletes found a similar trend of higher risk of lower extremity musculoskeletal injury following a concussion, with lower risk as the time interval after injury increased from 3 months, to 6 months, and up to 1 year.[13] A study in professional soccer players reported the opposite trend, with a progressive increase in the hazard of musculoskeletal injury in general (not limited to the lower extremity) as the time interval after concussion increased up to 1 year.[18] Differences in the study populations, methodology, and inclusion/exclusion criteria likely figure into differing results between studies.

The primary difference between the previously published work and the current study is that individuals with prior history of concussion or lower extremity injury were excluded from this study to reduce confounding from injury history. This is important, because it has been documented that prior injury history is associated with future injury risk,[11] and the effects of multiple concussions may be associated with an injury risk different from that of a single concussive event.

The current study was also conducted in a population of adults who may be more representative of active adults

TABLE 1 PARTICIPANT CHARACTERISTICS FOR MATCHED VARIABLES (N = 23 044)

Variable	Distribution*
Age, y	
<20	13.5
20-29	68.5
30-39	14.5
>40	3.5
Time in service, y	
≤1	17.3
>1-3	33.8
>3-5	21.9
>5-7	10.0
>7-10	6.8
>10	10.3
Sex	
Female	6.1
Male	93.9
Deployed status	
Yes	9.4
No	90.6
Rank	
E1-E4	64.0
E5-E6	27.0
E7-E9	4.5
Commissioned Officer	4.1
Warrant Officer	0.4

Abbreviation: E, enlisted.
**Values are percent.*

within the general population, as military service members are recruited from the general population and participate in a variety of physical training, sports, and occupational activities. This contrasts with the high-level sport-specific activities of collegiate and professional athletes. Therefore, the results of this study may represent injury risk that could generalize to recreationally or occupationally physically active adults across the general population.[25,26,28]

The current study demonstrated that the increased risk for lower extremity injury following a concussion may occur closer to the time of injury and diminish over time. This adds to the literature by providing evidence on the temporal patterns of injury following a concussion that can be considered in conjunction with previous work on lingering neurocognitive or neuromotor deficits in people who have sustained concussions. The neurocognitive deficits from a concussion are thought to resolve within a week to 10 days in most cases,[16,17] although prolonged recovery (greater than 10 days) is thought to occur in 10% to 15% of cases[14] and may result in postconcussive syndrome, with persistent cognitive deficits lasting several weeks or longer.[7,15]

Even in patients thought to have clinically recovered from a concussion, neuromotor alterations may persist for a longer period. There are reports of altered postural control in athletes for up to 3 months after a concussion.[4,9,10,27] Additionally, alterations in dynamic stability during gait have been noted for several days and up to 4 to 6 weeks following a concussion.[5,8,19,20,22,24] When a more dynamic task of jump landing was examined in collegiate football players, alterations in hip, knee, and leg stiffness were observed between preseason and postseason testing in athletes who sustained a concussion during the season.[6] These findings support the hypothesis that alterations in neuromotor control persisting for several months after concussive injury may be related to increased injury risk. However, additional work is needed to directly link specific neuromotor alterations to injuries or injury risk.

A previous study[13] in collegiate athletes (n = 102) examined differences in risk for lower extremity injury before and after documented concussion. The study reported an increased risk for musculoskeletal injury in athletes after

TABLE 2 PARTICIPANT CHARACTERISTICS FOR NONMATCHED VARIABLES*

Variable	Concussion (n = 11 522)	No Concussion (n = 11 522)	*P* Value
Lower extremity injury	2551 (22.1)	2114 (18.3)	<.001
Race			<.001
White	8248 (71.6)	7720 (67.0)	
Black	1320 (11.5)	1755 (15.2)	
Hispanic	1291 (11.2)	1345 (11.7)	
American Indian/Alaskan Native	143 (1.2)	106 (0.9)	
Asian/Pacific Islander	400 (3.5)	495 (4.3)	
Other	108 (0.9)	94 (0.8)	
Education			.064
Did not graduate high school	474 (4.1)	407 (3.5)	
High school graduate	8142 (70.7)	8142 (70.7)	
College	2729 (23.7)	2746 (23.8)	
Advanced degree	134 (1.2)	159 (1.4)	
Marital status			.014
Single	6077 (52.7)	6295 (54.6)	
Married	5044 (43.8)	4854 (42.1)	
Other†	401 (3.5)	373 (3.2)	

*Values are n (%).
†Includes divorced, widowed, or separated.*

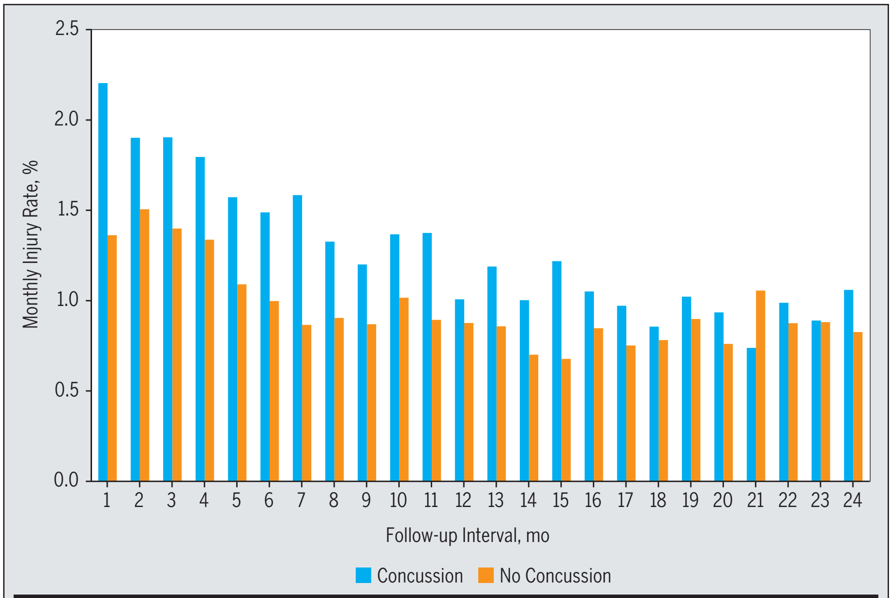

FIGURE 3. Rates of lower extremity injury for each month during the 2-year follow-up period. Survival is assumed to be constant during each 1-month interval (ie, matching strata or other hazards are not considered). The monthly hazard ratios were significantly different between the groups for months 1 to 15, except for month 12. There was no statistically significant difference in hazard ratio between the groups for months 16 to 24.

concussion compared to before, but a limitation of the study was that it did not control for prior injury. That could allow for confounding of the results due to injury history. A self-report survey of former National Football League players found that concussion injuries were associated with higher rates of musculoskeletal injury,[23] but the study did not capture the temporal relationship of the injuries (whether concussion or musculoskeletal injury occurred first). Another study has suggested that athletic injuries in general may affect cognition, as neurocognitive impairments were present in athletes following musculoskeletal injury, as well as concussion, when compared to uninjured athletes.[12] Therefore, the possibility exists that neurocognitive and neuromotor changes occur after injuries in general, which may affect injury risk.

Further information regarding injury risk following musculoskeletal injuries was summarized in a recent systematic review.[11] That review reported evidence supporting the contribution of overall alterations in motor control and function following lower extremity musculoskeletal injuries to an increased risk for subsequent injuries. The review also cited the need for further exploration of direct relationships of these alterations to injuries. Thus, it is important to consider whether the risk relationships between concussions and musculoskeletal injuries involve multiple environmental and intrapersonal factors and similar mechanisms of injury that make the risks for these injuries reciprocal in nature.

Because neuromotor alterations are present and risk of musculoskeletal injuries appears greater following a concussion, future research is warranted to determine whether skilled intervention from rehabilitation professionals may help to mitigate injury risk following a concussion. Though neurocognitive and neuromotor deficits following concussion may place people at greater risk for musculoskeletal injury, exploration of additional modifiable or nonmodifiable risk factors common to both concussion and musculoskeletal injury may help in the development of potential risk-mitigating interventions for both injuries.

It is possible that the relationship between concussion and musculoskeletal injury includes environmental factors and factors innate to individuals that predispose them to both injuries. This possibility is supported by the study by Nordström et al,[18] which reported that professional male soccer players who sustained incident concussions were generally more prone to injury both before and after the concussion. As the groups within the current study were matched based on military career field, rank, and time in service, environmental exposures were likely similar between the concussed and nonconcussed groups. However, intrapersonal factors that influence injury risk, such as risk-taking behavior or individual movement strategies, are difficult to control for, and the size of this study and the use of administratively collected data did not allow for control of these factors.

This study examined only incident lower extremity musculoskeletal injuries and did not account for multiple injuries within the same individual. As a result, it is possible that individuals who were more susceptible to lower extremity injury following a concussion contributed to the elevated hazards seen closer to the time of concussion. Those who were at lower risk might have sustained injuries later, until the difference between the groups was no longer significant. This may indicate that some people are at greater risk for musculoskeletal injury after a concussion than others, and sustain injuries sooner after a concussion. Another possible explanation is that the risk for musculoskeletal injury may diminish as time since concussion increases. Either of these scenarios raises the question of whether rehabilitative intervention can modify the risk for musculoskeletal injury following a concussion. Treatment following a concussion may help to decrease risk for injury or may allow for identification of individuals with greater risk profiles who might benefit from longer or more targeted intervention.

The current study has several limitations that must be noted as the results are interpreted. Intrapersonal factors that influence injury risk are difficult to control for in any study, and that type of control for this study was not possible due to its

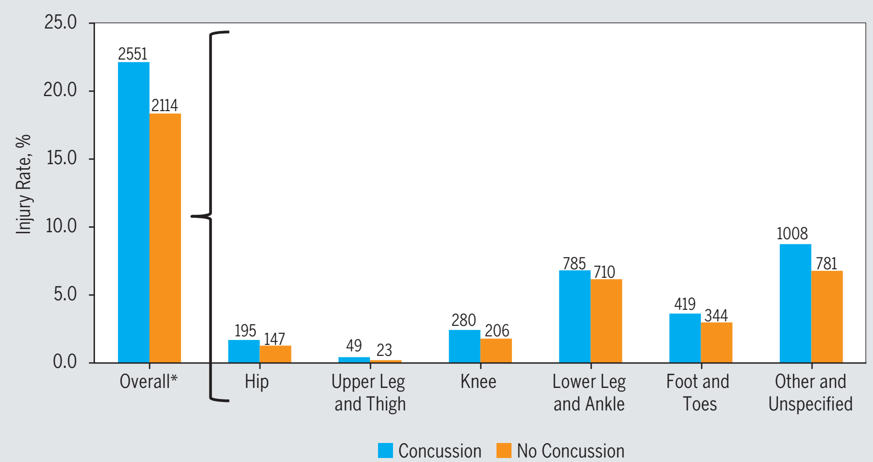

FIGURE 4. Overall number of soldiers with lower extremity injuries and lower extremity injuries by region during the 2-year follow-up period. Regional classifications for injuries are the same as those used in the Barell Injury Diagnosis Matrix.[2] The category of "other and unspecified" includes International Classification of Diseases-Ninth Revision codes for lower extremity injuries that did not specify a limb segment or joint. Comparisons using a Bonferroni-corrected alpha of .008 showed that all categories were statistically different ($P \leq .006$), except for the hip ($P = .009$) and lower leg and ankle ($P = .045$). *The regional injuries total a larger number than the overall number of soldiers with injuries because some soldiers were coded with multiple injuries on the incident visit.

size and the use of administratively collected data. Because only military medical encounter data were available, the current study excluded individuals with prior head or lower extremity injuries during their military service time, but could not control for these injuries if they were sustained prior to military service.

The medical encounter data also have limitations, as neither mechanism of injury nor information on clinical exam findings or injury severity was available, aside from the diagnosis code. Additionally, the diagnostic criteria for concussion were likely different across providers for the 11 522 concussed soldiers examined in this study, creating a heterogeneous sample. However, this is reflective of clinical practice and helps to produce findings that are generalizable to the clinical environment.

Another limitation is that the time to clinical recovery from concussion was not captured in this study, so the timing of injury related to a return to duty after injury was not captured. This limitation is also common to other studies that have examined musculoskeletal injury following concussion and may be an issue to resolve in future work that looks at injuries after concussions. It must also be noted that only 6.1% of participants in this study were female, and even though the same trend was seen in both sexes, the generalizability of the overall study results to women may be somewhat limited.

CONCLUSION

This study shows that a physically active adult population, as represented by US Army soldiers, has an increased risk for lower extremity musculoskeletal injuries following a concussion diagnosis. The injuries occur sooner following concussion when compared to nonconcussed soldiers, and the elevated injury risk may persist for more than a year following concussion. Taken together, these findings suggest that lower extremity musculoskeletal injury risk is elevated following a concussion and may diminish over time. ◉

KEY POINTS

FINDINGS: There was an elevated risk for lower extremity musculoskeletal injury in soldiers following a concussion, compared to nonconcussed controls.
IMPLICATIONS: Adults who are physically active, occupationally or recreationally, may be at increased risk for lower extremity injuries following a concussion.
CAUTION: While groups were matched on several key factors, this study did not control for intrapersonal factors (eg, risk-taking behavior or individual movement strategies) that affect injury risk or susceptibility.

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