Publisher: Taylor & Francis & Informa UK Limited, trading as Taylor & Francis Group

Journal: *The Physician and Sportsmedicine*

DOI: 10.1080/00913847.2022.2080515

Concussion is Not Associated with Elevated Rates of Lower Extremity Musculoskeletal Injuries in National Football League Players.

Thomas A. Buckley,[1,2] Ed.D., ATC, Steven Brown,[3] MS, ATC, Katherine J. Hunzinger,[4] Thomas W. Kaminski,[1,2] Ph.D., ATC, Charles. Buz Swanik,[1,2] Ph.D., ATC

1. Department of Kinesiology and Applied Physiology, University of Delaware, Newark, DE. USA.
2. Interdisciplinary Program in Biomechanics and Movement Science, University of Delaware, Newark, DE. USA.
3. Department of Intercollegiate Athletics, University of Delaware, Newark, DE. USA.
4. Department of Epidemiology, Biostatistics, and Informatics, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA. USA.

Corresponding Author;

Thomas A. Buckley, Ed.D., ATC
Associate Professor
Department of Kinesiology and Applied Physiology
University of Delaware
349 STAR Tower
100 Discovery Blvd
Newark, DE. 19716
p: 302-831-4783
f: 302-831-3693
TBuckley@udel.edu
ORCID: 0000-0002-0515-0150

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

Abstract

Objective: Emerging evidence has identified an ~2x elevated risk of musculoskeletal (MSK) injury in the year following a concussion. Most of these studies have examined a single college/university athletic department and may lack generalizability to professional sports. Therefore, the purpose this study was to assess the odds of post-concussion MSK injury utilizing publicly available National Football League (NFL) injury reports.

Methods: Concussions were identified through review of published NFL injury reports during the 2015, 2016, and 2017 regular seasons. Concussed players were matched by team and position and injuries were tracked for both groups for the remainder of the season. A chi-square analysis compared the frequency of MSK injury in both groups and a Cox Proportional Hazard model calculated the risk of sustaining a subsequent MSK injury.

Results: There were 322 concussed NFL players who meet inclusion criteria and were successfully matched. From the time of concussion through the remainder of the season, 21.4% of the concussed players were injured and 26.4% of control participants were injured. There was no difference in MSK injury rates (p=0.166) and the relative risk ratio was (0.90) for subsequent injury in the concussion group. There was no difference in the time to event for subsequent MSK between the two groups (p=0.123).

Conclusion: The primary finding of this study was no elevated risk of post-concussion MSK in NFL football players.

Keywords: Injury Risk Reduction, Mild Traumatic Brain Injury, Professional Athletics.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

Introduction

Sport related concussions are a complex neurophysiological injury which involves deficits in cognition, postural control, autonomic, visual, oculomotor, and sleep which manifest numerous symptoms.[1-7] While concussions occur across all sports, they are particularly common in American football with National Football League (NFL) players experiencing about 200 concussions per season in the last half decade.[8] While the acute effects of concussions have been well documented,[7] increased concern has focused on the long term neurodegenerative effects of multiple concussions with numerous adverse outcomes in former NFL players.[9] However, emerging research has identified an intermediate concern – an elevated rate of musculoskeletal (MSK) injuries in the year following a concussion.[10, 11]

In the NFL, MSK injuries are commonplace with single season risks of approximately 41% per player.[12] It is critically important to understand sports injury risk factors and identify those conditions which elevate individuals risks above the universal risk of injury from sport participation.[13] While recurrent injury to the same body part is a known risk factor, most injuries occur to a different body part with a different mechanism.[13] However, an emerging trend is an ~2x elevated rate of post-concussion MSK injuries.[10, 11] This finding has consistently been identified in intercollegiate student-athletes,[14-22] high school and adolescent-age athletes,[23-25] community members and recreational athletes,[26-28] and military populations.[29, 30] Likely due to diverse methods, important determinants remain to be elucidated with inconsistent findings related to sex differences,[17, 22, 23, 27] elevated injury rates prior to the concussion,[15, 17, 18, 23, 26, 31, 32] timing of the subsequent MSK,[14, 16, 17, 32] and subsequent MSK mechanisms and classifications.[15, 21, 23, 29, 31] Large

databases in high risk concussion sports may further elucidate these factors and assist in identifying athletes at elevated risk of post-concussion MSK.

Professional sports leagues, including the NFL, pose unique challenges to sports medicine research given their limited injury transparency.[33, 34] Injury data can be acquired from publicly available sources, (e.g., NFL.com) however injury reports are only released twice a week and only during the regular- and post-season. In contrast to the consistent findings in amateur athletics, professional sports studies on concussion and subsequent MSK have had mixed results with both increases [31, 32, 35] and no differences[36-38] identified. Retired NFL players had a dose-response relationship whereby prior concussion history was associated with elevated self-reported serious MSK injuries.[39] Specific to the NFL, there have been mixed findings with offensive "skill" players not having an elevated MSK risk within 90 days of a concussion.[40] Conversely, when matched to uninjured controls, post-concussion players had a 2.35x elevated risk of MSK, but no difference from prior MSK injured players.[37] Both the tight matching and limited time window of the study resulted in only 13% of the concussions being analyzed. Thus, the larger question on the risk of post-concussion subsequent MSK remains to be elucidated in NFL players.

There is a clear relationship between concussion and subsequent MSK injury in collegiate student-athlete populations[10, 11] and football specifically, however less is known about professional athletes. Therefore, the purpose this study was to assess the odds of post-concussion MSK injury utilizing publicly available NFL injury reports. We hypothesized that there would an elevated odds of injury sustained over the remainder of the season in NFL players who experienced a concussion.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

Materials and Methods

Participants

All data were collected by reviewing the NFL.com injury reports during the 2015, 2016, and 2017 seasons which included player status for that respective week and the injured body part. The concussion group (CONC) was collected first by identifying players reported to have a concussion on an injury report during the regular season, cross referenced on the PBS Frontline concussion database,[41] and were on the roster for at least one week. Once the CONC group was determined, non-concussion (Control) players were identified by matching to a teammate of the same position with no reported injury prior to the matching (e.g., if the concussion player suffers their concussion in Week 5, the control participant would not have been on the injury report prior to Week 5). Position matching was narrowly defined initially (e.g., middle linebacker), but in the event a matched control could not be identified then a broader definition (e.g., linebacker) was used based on position listed on the NFL.com website. All CONC participants were successfully matched to a teammate to reduce the influence of coaching, team exposure, and concussion treatment processes to minimize extraneous circumstances. As all data collected during this study was publicly available, the university's institutional review board deemed the project exempt from informed consent.

Procedures

Only concussions which occurred during the regular season, except for Week 17, and returned to play in at least one game following their concussion were utilized in this study. Pre-season concussions were not assessed because injuries are not uniformly disclosed until the first week of the season. Week 17, the last week of the season, was not included because players

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

seasons may have ended after that game. Post-season concussions were not assessed to maintain equal exposure for all potential participants as less than half of the teams qualify for the playoffs. If a player experienced more than one reported concussion during the season, only the first concussion was utilized in the analysis. If a player experienced multiple concussions across multiple seasons, then the first concussion within each season was used.

Specifically, each week during the regular season each NFL team is required to provide a publicly available injury report and the research team reviewed these reports on the NFL.com website. For the purpose of this study, "injury" was defined as appearing on an injury report independent of participation in a game. The rationale for this decision was the game day active roster (46 players) is smaller than the team's overall roster (53 players) and therefore a player on the injury list could be withheld from the game either due to injury or to "coaches' decision" and no reliable metric is available to differentiate. An additional rationale for this approach is that players may experience an injury which does not limit game participation. Consistent with the preponderance of findings to date, this study focused exclusively on subsequent lower extremity MSK (foot, ankle, leg, knee, or hip) injuries and did not include trunk, spine, upper extremity, neck or head injuries. The MSK injuries were tracked from the time of return to play from the concussion to the end of the season for both groups (e.g., if the concussion occurred in week 5 and the player returned in week 6, both players, CONC and matched control, were tracked from week 6 through week 17).

Statistical Analysis

Descriptive statistics were reported for all groups and all variables and were classified as categorical (injured or not injured). Participants were classified as injured if they appeared on the injury list at any time following the concussion return to participation for either group.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

To address the odds of post-concussion MSK injury, a chi-square analysis was performed to compare the expected vs observed frequency of reported injury in the CONC and Control groups. Secondly, a Cox proportional hazard model was used to determine the risk of sustaining a lower extremity MSK injury after the initial concussion time point.

Results

Over the three years of the study, there were 397 concussions reported during the NFL regular season between weeks 1 and 16. From these, 75 were excluded either due to being a regular season-ending concussion (N=41) or they were a subsequent concussion in the same season (N=34) leaving a total of 322 concussions for analysis. All 322 CONC participants were successfully matched. (Table 1) The concussions typically occurred around mid-season (mean: week 9.2; median: week 10) leaving 6 – 7 games of exposure. [Table 1 near here]

In the CONC group, there were 69 MSK injuries (21.4%) in the remainder of the season and the Control group had 85 injuries (26.4%). There was no significant relationship (p=0.166) identified in the Chi-Square analysis and the Risk Ratio was 0.90 (95% CI: 0.69 – 1.19) for a subsequent MSK in the CONC group.

There was no difference in time to event in the Cox Proportional model for subsequent MSK injury between the two groups (p=0.123). (Figure 1) [Figure 1 near here]

Discussion

An elevated risk of post-concussion MSK injury has been routinely identified in a diverse sample of athletes including collegiate football players.[10, 11] Herein, we evaluated the odds of post-concussion MSK injury, as defined by appearing on the injury report, in NFL football

players by utilizing publicly available injury reports over three seasons. The primary finding of this study was no elevated risk of post-concussion MSK identified in professional football players. This finding stood in contrast to our hypothesis and prior studies and raises interesting questions as to why NFL players would have different outcomes than previously reported.

The results of this study further the mixed findings identified in professional athletic league studies and stand in contrast to amateur sports findings despite both the NFL and NCAA having similar formal concussion management policies. Herein, no elevated risk of post-concussion MSK injury was identified (Risk Ratio: 0.90) which is consistent with Jildeh who found an non-significant decreased odds (Odds Ratio: 0.57) in NFL offensive skill players in the 90 days following a concussion.[40] In this study, the concussions occurred around midseason (median: week 10) which yielded less than 90 days of exposure time, on average, for a subsequent injury to occur. Conversely, Wittrup identified an elevated rate of MSK injury (2.35x) when comparing concussed players to non-injured players, but not previously injured players.[37] However, Wittrup had a longer exposure window of at least 8 weeks following the concussion and most players in this study (63.0% [203/322]) had less than 8 weeks of post-concussion exposure. The exposure issue may be critical as an exclusively college football player study found no elevated risk prior to 12 months, but a 3.2x elevated risk beyond 12 months.[20] This would be difficult to replicate in the NFL given the considerable roster turnover which occurs annually. After retirement, NFL players did demonstrate a dose-response whereby those with more career concussions had higher rates of "serious" injuries[39] and later life osteoarthritis[42] suggesting longer temporal windows need to be investigated. These NFL findings are similar to a professional ice hockey study which failed to find an elevated post-concussion MSK injury risk,[38] however elevated rates of post-concussion MSK injuries have

been identified in both professional soccer/futball and rugby.[31, 32] In professional soccer, the hazard ratio increased over time following the concussion (4.1x for >6 months as opposed to 1.6x for <3 months).[31] In professional rugby, Cross followed the players for two years; however substantial groups differences were present within 50 days following the concussion.[32] Taken together, future research on professional sports injury risk needs to consider longer exposure windows despite the inherent challenge of considerable annual roster turnover.

The majority of the prior studies on post-concussion subsequent MSK injuries have investigated collegiate athletic populations with the research team typically having access to the medical records of the participants.[14-20] Professional sports leagues often lack transparency on reporting injuries[33, 34] and it is plausible that injury reports are not accurate reflections, either over or under-reporting, of actual injuries experienced by NFL players. For example, Tom Brady was infamously listed as "probable – right shoulder" 116 times between 2000 and 2017 despite never missing a game for a shoulder injury. Conversely, a review of ACL injuries in NFL players found that publicly available data only identified 66% as compared to data reported to the private NFL Injury Surveillance System.[33] Herein, the combined MSK injury rate was 23.9% which below the internal NFL health record rate of ~41%, but this injury rate only reflects the time from the concussion/matched on for the remainder of the season which likely explains the lower rate.[12] It should be noted there was no *a-priori* reason to believe that these injury reporting discrepancies would differ between players who did or didn't previously experience a concussion, nonetheless this limitation must be considered. Indeed, players who with higher plays per game prior to their concussion had less time off prior to returning post-concussion which would suggest higher and quicker in-game exposure.[43] Moving forward, more

transparent injury reporting by professional sports league could facilitate both improved sports injury research and sports health care at younger age levels.

The differences between professional and amateur post-concussion MSK injury outcomes defies obvious neurophysiological explanation beyond the exposure issue. Previously, it was argued that NFL players respond differently to concussion than amateur athletes and, if true, could explain the lack of elevated risk in NFL football players; however, that previous report was heavily criticized.[44] If persistent neurophysiological deficits are present in professional athletes in collision sports, it is interesting to note that no performance differences from pre- vs post-concussion have been identified despite analysis of diverse statistical metrics.[45-49] While no single mechanism to explain the elevated rate of post-concussion MSK injury has been identified, lingering neurophysiological deficits beyond clinical recovery has received the most attention. Unfortunately the typical clinical concussion battery is not predictive of post-concussion subsequent MSK injury.[17] Deficits in dual-task gait (completing a cognitive task while walking) has been linked to elevated post-concussion MSK injury rates in both adolescent collegiate student-athletes.[50-52] Another proposed mechanisms is an altered perception action coupling which persists following a concussion.[53] An encouraging recent pilot study has provided evidence that a neuromuscular training program may reduce the risk of post-concussion MSK injury in adolescent athletes, although it is unknown how this would translate to collegiate or professional athletes.[54]

The major limitation of this study was the utilization of public injury reports from the NFL as opposed to the team specific health records; however, this data is generally not available to external sources.[33, 34] Nevertheless, this approach has been recently utilized by researchers examining professional sports injuries including concussions.[31, 32, 37, 40, 45-47]

Additionally, beyond the exposure of weeks to months post-concussion, the specific within-game exposure was not assessed and it's possible that players had less on-field time in games or practices thereby reducing their risk of injury. Similarly, the team's status (e.g., playoff contender) could have influenced coaches to increase or decrease a player's on-field time which could influence these results. The players history of prior concussion or MSK injuries prior the season in question was not controlled for as availability of accurate data is limited (e.g., high school or college injuries). Finally, player honesty in reporting injuries, either concussion or MSK, is an inherent limitation of this research approach. Many of these limitations could be addressed by increased transparency by professional sports leagues as related to injury.

Conclusion/Summary

In contrast to numerous findings in collegiate student-athletes, the NFL players in this study between 2015 and2017 seasons did not have an elevated rate of same season post-concussion MSK injury (Risk Ratio: 0.90). This finding continues the trend whereby professional sports athletes may not have the same elevated risk as amateur athletes.[36-38] If these findings persist in future studies, an understanding of the neurophysiological mechanisms limiting the risk should receive further exploration to see if training programs could be adapted to decrease MSK risk in amateur athletes.

Conflict of interest statement

The authors report there are no competing interests to declare.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

REFERENCES

1. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus Statement on Concussion in Sport - the 5th International Conference on Concussion in Sport held in Berlin, October 2016. *Br J Sports Med.* 2017; 51: 838-57.

2. Dobson JL, Yarbrough MB, Perez J, et al. Sport-Related Concussion Induces Transient Cardiovascular Autonomic Dysfunction. *Am J Physiol Regul Integr Comp Physiol.* 2017; 312: R575-84.

3. Whitney SL, Eagle SR, Marchetti G, et al. Association of acute vestibular/ocular motor screening scores to prolonged recovery in collegiate athletes following sport-related concussion. *Brain Inj.* 2020; 34: 840-5.

4. Turner S, Langdon J, Shaver G, et al. Comparison of Psychological Response Between Concussion and Musculoskeletal Injury in Collegiate Athletes. *Sport Exerc Perform Psychol.* 2017; 6: 277-88.

5. Buckley TA, Oldham JR, Caccese JB. Postural control deficits identify lingering post-concussion neurological deficits. *J Sport Health Sci.* 2016; 5: 61-9.

6. Weber ML, Lynall RC, Hoffman NL, et al. Health-Related Quality of Life Following Concussion in Collegiate Student-Athletes With and Without Concussion History. *Annals Biomed Eng.* 2019; 47: 2136-46.

7. Broglio SP, McAllister T, Katz BP, et al. The Natural History of Sport-Related Concussion in Collegiate Athletes: Findings from the NCAA-DoD CARE Consortium. *Sports Med* 2021; 52(2): 403 - 415.

8. Mack CD, Solomon G, Covassin T, et al. Epidemiology of Concussion in the National Football League, 2015-2019. *Sports Health.* 2021; 13: 423-30.

9. Manley G, Gardner AJ, Schneider KJ, et al. A systematic review of potential long-term effects of sport-related concussion. *Br J Sports Med.* 2017; 51(12): 969- - 977.

10. McPherson A, Nagai T, Webster K, Hewett T. Musculoskeletal Injury Risk After Sport-Related Concussion: A Systematic Review and Meta-analysis. *Am J Sports Med.* 2018; 47: 1754-62.

11. Howell DR, Lynall RC, Buckley TA, Herman DC. Neuromuscular Control Deficits and the Risk of Subsequent Injury after a Concussion: A Scoping Review. *Sports Med.* 2018; 48(5): 1097-115.

12. Mack CD, Kent RW, Coughlin MJ, et al. Incidence of Lower Extremity Injury in the National Football League: 2015 to 2018. *Am J Sports Med.* 2020; 48: 2287-94.

13. Stares JJ, Dawson B, Peeling P, et al. Subsequent Injury Risk Is Elevated Above Baseline After Return to Play: A 5-Year Prospective Study in Elite Australian Football. *Am J Sports Med.* 2019; 47(9): 2225 - 2231.

14. Brooks MA, Peterson K, Biese K, et al. Concussion Increases Odds of Sustaining a Lower Extremity Musculoskeletal Injury After Return to Play Among Collegiate Athletes. *Am J Sports Med.* 2016; 19: 742-7.

15. Fino PC, Becker LN, Fino NF, et al. Effects of Recent Concussion and Injury History on Instantaneous Relative Risk of Lower Extremity Injury in Division I Collegiate Athletes. *Clin J Sport Med.* 2019; 29: 218-23.

16. Harada GK, Rugg CM, Arshi A, et al. Multiple Concussions Increase Odds and Rate of Lower Extremity Injury in National Collegiate Athletic Association Athletes After Return to Play. *Am J Sports Med* 2019; 47: 3256-62.

17. Buckley T, Howard C, Oldham J, et al. No Clinical Predictors of Postconcussion Musculoskeletal Injury in College Athletes. *Med Sci Sports Exerc.* 2020; 52: 1256-62.

18. Lynall RC, Mauntel TC, Padua DA, Mihalik JP. Acute Lower Extremity Injury Rates Increase following Concussion in College Athletes. *Med Sci Sports Exerc.* 2015; 47: 2487-92.

19. Herman D, Jones D, Harrison A, et al. Concussion Increases the Risk of Subsequent Lower Extremity Musculoskeletal Injury in Collegiate Athletes. *Clin J Sports Med.* 2013; 23: 124.

20. Krill ML, Nagelli C, Borchers J, et al. Effect of Concussions on Lower Extremity Injury Rates at a Division I Collegiate Football Program. *Orthop J Sports Med* 2018; 6.

21. Gilbert FC, Burdette GT, Joyner AB, et al. Association Between Concussion and Lower Extremity Injuries in Collegiate Athletes. *Sports Health* 2016; 8: 561-7.

22. Houston MN, Hoch JM, Cameron KL, et al. Sex and number of concussions influence the association between concussion and musculoskeletal injury history in collegiate athletes. Brain Inj 2018; 32: 1353-8.

23. Biese KM, Stamm JM, Wichman DM, et al. Association of lower extremity injuries and injury mechanism with previous concussion history in adolescent athletes. *Phys Ther Sport* 2021; 48: 76-82.

24. Lynall R, Mauntel T, Pohlig R, et al. Lower Extremity Musculoskeletal Injury Risk Following Concussion Recovery in High School Athletes. *J Athl Train.* 2017; 52: 1028-34.

25. Wilson JC, Carry PM, Daoud AK, et al. Single season re-injury risk after concussion and lower extremity injury among male, collision sport, high school athletes. *J Sci Med Sport* 2021; 24(11): 1105 - 1109.

26. Burman E, Lysholm J, Shamim P, et al. Concussed athletes are more prone to injury both before and after their index concussion: a data base analysis of 699 concussed contact sports athletes. *BMJ Open Sport Exerc Med* 2016; 2: e092.

27. Hunzinger KJ, Costantini KM, Swanik CB, Buckley TA. Diagnosed concussion is associated with increased risk for lower extremity injury in community rugby players. *J Sci Med Sport* 2020; 28: 30804-5.

28. McPherson AL, Shirley MB, Schilaty ND, et al. Effect of a Concussion on Anterior Cruciate Ligament Injury Risk in a General Population. *Sports Med* 2020; 50: 1203-10.

29. Hunzinger KJ, Radzak KN, Costantini KM, et al. Concussion history is associated with increased lower-extremity injury incidence in Reserve Officers' Training Corps cadets. *BMJ Mil Health* 2020.

30. Kardouni JR, Shing TL, McKinnon CJ, et al. Risk for Lower Extremity Injury After Concussion: A Matched Cohort Study in Soldiers. *J Orthop Sports Phys Ther* 2018; 48: 533-40.

31. Nordstrom A, Nordstrom P, Ekstrand J. Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players. *Br J Sports Med* 2014; 48: 1447-50.

32. Cross M, Kemp S, Smith A, et al. Professional Rugby Union players have a 60% greater risk of time loss injury after concussion: a 2-season prospective study of clinical outcomes. *Br J Sports Med* 2015; 50: 926-31.

33. Inclan PM, Chang PS, Mack CD, et al. Validity of Research Based on Public Data in Sports Medicine: A Quantitative Assessment of Anterior Cruciate Ligament Injuries in the National Football League. *Am J Sports Med*. 2021.

34. Dreyer NA, Mack CD, Anderson RB, et al. Lessons on Data Collection and Curation From the NFL Injury Surveillance Program. *Sports Health* 2019; 11: 440-5.

35. Jildeh TR, Meta F, Young J, et al. Concussion Is Associated With Increased Odds of Acute Lower-Extremity Musculoskeletal Injury Among National Basketball Association Players. *Arthrosc Sports Med Rehabil* 2021; 3(1): e219-e25.

36. Jildeh TR, Meta F, Young J, et al. Concussion in National Football League Athletes Is Not Associated With Increased Risk of Acute, Noncontact Lower Extremity Musculoskeletal Injury. *Orthop J Sports Med* 2021; 9.

37. Wittrup EM, Fox LA, Breedlove KM, et al. Evaluation of Musculoskeletal Re-Injury Occurrence in Previously Concussed National Football League Athletes. *Open Access J Sports Med* 2020; 11: 169-76.

38. Nyberg G, Mossberg KH, Lysholm J, Tegner Y. Subsequent Traumatic Injuries After Concussion in Elite Ice Hockey: A Study over 28 Years. *Curr Res: Concussion* 2015; 2: 109-12.

39. Pietrosimone B, Golightly YM, Mihalik JP, Guskiewicz KM. Concussion Frequency Associates with Musculoskeletal Injury in Retired NFL Players. *Med Sci Sports Exerc* 2015; 47: 2366-72.

40. Jildeh TR, Meta F, Young J, et al. Concussion in National Football League Athletes Is Not Associated With Increased Risk of Acute, Noncontact Lower Extremity Musculoskeletal Injury. *Ortho J Sports Med* 2021; 9.

41. Public Broadcasting Services. Concussion Watch. 2015.

42. Lynall R, Peitrosimone B, Kerr Z, et al. Osteoarthritis Prevalence in Retired National Football League Players With a History of Concussion and Lower Extremity Injury. *J Athl Train* 2017; 52: 518-25.

43. Heintz EC, Breaux L, Lewis A, Foreman JJ. Determinants of Missed Games Following Concussions in the National Football League. *Front Sports Act Living* 2020; 2.

44. Pellman EJ, Viano DC, Casson IR, et al. Concussion in professional football: Players returning to the same game - Part 7. *Neurosurgery* 2005; 56: 79-90.

45. Van Pelt KL, Lapointe AP, Galdys MC, et al. Evaluating Performance of National Hockey League Players After a Concussion Versus Lower Body Injury. *J Athl Train* 2019; 54: 534-40.

46. Buckley TA, Bryk KN, Van Pelt KL, et al. Concussion and National Hockey League Player Performance: An Advanced Hockey Metrics Analysis. *J Athl Train* 2019; 54: 527-33.

47. Baker HP, Kahn AJ, Rosenberg S, et al. NFL total quarter back rating (QBR) is not decreased following sport related concussion injury. *Sport Sci Health* 2021; 17: 535-41.

48. Jildeh TR, Okoroha KR, Taylor KA, et al. Effect of Concussions on the Performance of Running Backs and Wide Receivers in the National Football League. *Am J Sports Med* 2019; 47: 2717-22.

49. Kumar NS, Chin M, O'Neill C, et al. On-Field Performance of National Football League Players After Return From Concussion. *Am J Sports Med* 2014; 42: 2050-5.

50. Oldham JR, Howell DR, Knight CA, et al. Gait Performance is Associated with Subsequent Lower Extremity Injury Following Concussion. *Med Sci Sports Exerc* 2020; 52: 2279 - 85.

51. Howell D, Buckley T, Lynall R, Meehan W. Worsening dual-task gait costs after concussion and their association with subsequent sport-related injury. *J Neurotrauma* 2018; 35: 1630-6.

52. Buckley TA, Murray NG, Munkasy BA, et al. Impairments in Dynamic Postural Control Across Concussion Clinical Milestones. *J Neurotrauma* 2021; 38: 86 - 93.

53. Wilkerson GB, Bruce JR, Wilson AW, et al. Perceptual-Motor Efficiency and Concussion History Are Prospectively Associated With Injury Occurrences Among High School and Collegiate American Football Players. *Orthop J Sports Med* 2021; 9.

54. Howell DR, Seehusen CN, Carry PM, et al. An 8-Week Neuromuscular Training Program After Concussion Reduces 1-Year Subsequent Injury Risk: A Randomized Clinical Trial. *Am J Sports Med* 2022; 21.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

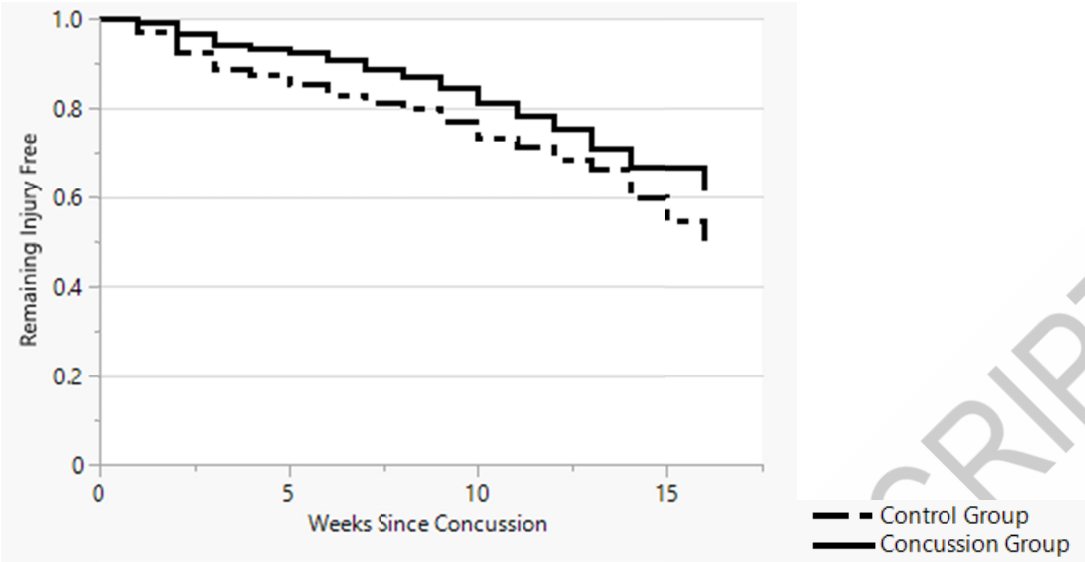

Figure 1. Cox Proportional Hazard Model. There was no difference between groups for post-concussion MSK over time. The 'Weeks Since Concussion" refers to the number of weeks between the concussion or matched control participant and the subsequent LE MSK.

Accepted Manuscript
Version of record at: https://doi.org/10.1080/00913847.2022.2080515

NFL Season (Conc Week)	CONC	Control
2015 (9.17)	117 (36.3%)	117 (36.3%)
2016 (9.30)	90 (28.0%)	90 (28.0%)
2017 (9.19)	115 (35.7%)	115 (35.7%)
Player Positions		
Offensive Line	57 (17.7%)	57 (17.7%)
Wide Receivers	39 (12.1%)	39 (12.1%)
Tight Ends	28 (8.7%)	28 (8.7%)
Running Backs	27 (8.4%)	27 (8.4%)
Quarterbacks	16 (5.0%)	16 (5.0%)
Total Offensive Players	167 (51.9%)	167 (51.9%)
Defensive Lineman	27 (8.4%)	27 (8.4%)
Linebackers	40 (12.4%)	40 (12.4%)
Defensive Backs	88 (27.3%)	88 (27.3%)
Total Defensive Players	155 (48.1%)	155 (48.1%)

Table 1. Participant Demographics. The CONC participants were matched by Control participants within season by position. There was no difference between seasons for which week the concussion occurred within.