Concussion in National Football League Athletes Is Not Associated With Increased Risk of Acute, Noncontact Lower Extremity Musculoskeletal Injury

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Concussion in National Football League Athletes Is Not Associated With Increased Risk of Acute, Noncontact Lower Extremity Musculoskeletal Injury

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**Background:** Impaired neuromuscular function after concussion has recently been linked to increased risk of lower extremity injuries in athletes.

**Purpose:** To determine if National Football League (NFL) athletes have an increased risk of sustaining an acute, noncontact lower extremity injury in the 90-day period after return to play (RTP) and whether on-field performance differs pre- and postconcussion.

**Study Design:** Cohort study, Level of evidence, 3.

**Methods:** NFL concussions in offensive players from the 2012-2013 to the 2016-2017 seasons were studied. Age, position, injury location/type, RTP, and athlete factors were noted. A 90-day RTP postconcussive period was analyzed for lower extremity injuries. Concussion and injury data were obtained from publicly available sources. Nonconcussed, offensive skill position NFL athletes from the same period were used as a control cohort, with the 2014 season as the reference season. Power rating performance metrics were calculated for ±1, ±2, and ±3 seasons pre- and postconcussion. Conditional logistic regression was used to determine associations between concussion and lower extremity injury as well as the relationship of concussions to on-field performance.

**Results:** In total, 116 concussions were recorded in 108 NFL athletes during the study period. There was no statistically significant difference in the incidence of an acute, noncontact lower extremity injury between concussed and control athletes (8.5% vs 12.8%; P = .143), which correlates with an odds ratio of 0.573 (95% CI, 0.270-1.217). Days (66.4 ± 81.9 days vs 45.1 ± 69.2 days; P = .423) and games missed (3.67 ± 3.0 vs 2.9 ± 2.7 games; P = .470) were similar in concussed athletes and control athletes after a lower extremity injury. No significant changes in power ratings were noted in concussed athletes in the acute period (±1 season to injury) when comparing pre- and postconcussion.

**Conclusion:** Concussed, NFL offensive athletes did not demonstrate increased odds of acute, noncontact, lower extremity injury in a 90-day RTP period when compared with nonconcussed controls. Immediate on-field performance of skill position players did not appear to be affected by concussion.

**Keywords:** concussion; lower extremity; NFL; football; performance; injury

Concussions in the National Football League (NFL) occur at the highest rate in professional sports. With concussions occurring at a rate of around 150 per season, the NFL has long been the model for concussion research. In the NFL, the majority (67.7%) of concussions result from helmet-to-helmet contact with another player. From the 1996 to 2007 seasons, 56.5% of reported concussions were the result of a tackle and 32.2% resulted from blocking. Tight ends and quarterbacks are the most frequently concussed players throughout the league, with estimated rates from the 2002 to 2007 seasons of 1.45 and 1.20 concussions per 100 games at position, respectively. In addition, these positions had the greatest odds for repeat concussion after returning to play. Although the epidemiology of concussions in the NFL is well-documented, much needs to be learned about the lasting effects on the musculoskeletal system and on-field performance.

Concussive events present with varying effects, such as headache, confusion, amnesia, and other cognitive deficits. In most cases, these acute symptoms regress in days to weeks with proper cognitive rest. While most symptoms resolve in days to weeks, lingering deficits in cognition,
conduct, and motor function can result from repetitive concussive events.\textsuperscript{31} In addition to the cerebral effects, changes in proprioception, reaction time, and gait pattern have been documented in athletes after concussion.\textsuperscript{4,8,17,29} There has been recent evidence to suggest that these deficits increase the risk for a musculoskeletal injury, especially to the lower extremity.\textsuperscript{2,7,32} This phenomenon has been demonstrated in several different demographics, including National Collegiate Athletic Association (NCAA) Division I collegiate athletes across several men’s and women’s sports as well as military personnel returning to combat after a concussion.\textsuperscript{7,9} Recently, increased odds of lower extremity musculoskeletal injury after a concussion were demonstrated in National Basketball Association (NBA) athletes; however, it remains to be seen if this phenomenon is generalizable across all professional sports.\textsuperscript{9}

Lower extremity injuries plague the NFL athletes on a yearly basis; however, it is not known to what extent concussions contribute to these numbers. This study sought to find out if there were increased odds for lower extremity injury within the 90-day return-to-play (RTP) period after a concussion and whether lingering concussive effects altered on-field performance. We hypothesized that concussed NFL athletes would not be at greater risk for a lower extremity injury and would have no change in on-field performance postinjury.

METHODS

Data on all concussions sustained by professional offensive skill players (quarterback, halfback, wide receiver, tight end) in the NFL from the 2012-2013 to the 2016-2017 seasons were collected using publicly attainable injury reports and postgame reporting using methods validated by previous studies.\textsuperscript{10,16,17,23} Specific online sources for data acquisition included the official sports websites of ESPN (ESPN.com), CBS (CBSsports.com), NBC (NBCsports.com), and Fox (FoxSports.com) as well as a transactional sports database (prosportstransactions.com). Team websites, local game reports, and media guides were then used to further cross-reference and verify concussions. The NFL mandates that teams quickly and accurately disseminate injury information to the league office, opponents, local and national media, and the league’s broadcast partners. Alongside each concussion, primary position, date of injury, season year, athlete age, lower extremity injury within 90 days of RTP, injury type, and RTP date were also recorded. Injury locations were broadly categorized as hip, groin, thigh, knee, shin, ankle, or foot. Injuries were further classified by type: acute fracture, muscle strain and/or tear, or ligament sprain and/or tear. A 90-day analysis was chosen because previous literature showed an increased risk of lower extremity injury in this timeframe.\textsuperscript{2,7} This study was exempt from institutional review board approval given the nature of the publicly available data used.

All offensive skill players who returned to regular season NFL play for at least 1 play after their documented concussion were included in this analysis. The number of days and games missed were calculated for each player, referenced from the RTP date. To assess on-field performance, the offensive power rating (PR) metric shown in Figure 1 was used to monitor players’ offensive productivity before and after the concussion. Performance was analyzed for each player using offensive metrics including games played, total yards (receiving or rushing), and touchdowns. From these variables, the offensive PR was calculated for each athlete. The offensive PR was previously described and has been proven reliable and validated for use as an outcome instrument in the orthopaedic literature.\textsuperscript{10,19,22,33} In the PR equation shown in Figure 1, yards and touchdowns are weighted by dividing by 10 and multiplying by 6, respectively. PRs were calculated for \pm 1, \pm 2, and \pm 3 seasons, if applicable, in which a null value was recorded if a player did not participate in 1 of those seasons.

A matched-cohort analysis of all nonconcussed NFL offensive skill position athletes (quarterback, halfback, wide receiver, tight end) from the 2012-2013 to 2016-2017 seasons was gathered to compare the incidence of lower extremity injury. The 2014-2015 NFL regular season was used as the reference period for control players. Adhering to previously used methodology, an age-, body mass index–, and NFL experience–matched control group consisting of all halfbacks and wide receivers that did not sustain a documented concussion in their professional career and completed the 2012 NFL season was assembled.\textsuperscript{5,11,23,24} Any control player who had a previous concussion was removed from the control. The incidence of

\[ \text{Power rating} = \left( \frac{\text{Total yards}}{10} \right) + (6 \times \text{Touchdowns}) \]

Figure 1. Power rating metric used to assess on-field performance of offensive National Football League players.
lower extremity injury in the 90-day RTP period and PRs for ±1, ±2, and ±3 seasons were compared between the control and concussed groups.

Statistical Analysis

For continuous variables, group comparisons were performed using 1-way analysis of variance. For categorical variables, group comparisons were performed using chi-square tests when expected cell counts were >5 and Fisher exact tests when expected cell counts were <5. For comparing pre- and postperformance, paired *t* tests were performed if the differences between the variables were normally distributed, and Wilcoxon signed-rank test were used when differences were nonnormally distributed. All differences were calculated by subtracting preinjury values from postinjury values. Statistical significance was set at *P* < .05. All analyses were performed using SAS 9.4 (SAS Institute).

RESULTS

A total of 116 concussions were recorded in 108 NFL offensive skill players. Concussed players had a mean age of 26.7 ± 3.0 years. Athletes who sustained a concussion were most often wide receivers (33%), followed by tight ends (27%). Concussed athletes with lower extremity injuries showed similar trends, as 56% were wide receivers and 33% were tight ends (Table 1). Injury specifics are reported in Table 2. In the concussed group, 9 athletes sustained a noncontact lower extremity injury within the 90-day RTP period. There was no statistically significant difference in the incidence of an acute, noncontact lower extremity injury between concussed athletes and the control (8.5% vs 12.8%; *P* = .143), correlating with an odds ratio of 0.573 (95% CI, 0.270-1.217). In comparing time and games missed after an acute lower extremity injury, there was no statistically significant difference between the concussed and control groups in days missed (66.4 ± 81.9 days vs 45.1 ± 69.2 days; *P* = .423) or games missed (3.67 ± 3.0 games vs 2.9 ± 2.7 games; *P* = .470).

### TABLE 1

| Athlete and Return-to-Play Data of Concussed NFL Athletes With LE Injuries and Nonconcussed Control NFL Athletes<sup>a</sup> | Nonconcussed (n = 328) | Concussed Without LE Injury (n = 107) | Concussed With LE Injury (n = 9)<sup>b</sup> | *P* Value |
|---|---|---|---|---|
| Age, y | 26.27 ± 3.28 | 26.66 ± 2.96 | 24.88 ± 1.4 | .206 |
| Body mass index | 28.86 ± 2.10 | 29.17 ± 2.17 | 28.44 ± 2.43 | .326 |
| Primary position | | | | |
| Quarterback | 32 (10) | 18 (17) | 0 (0) | .112 |
| Wide receiver | 130 (40) | 35 (33) | 5 (56) | | |
| Halfback | 98 (30) | 25 (23) | 1 (11) | | |
| Tight end | 68 (21) | 29 (27) | 3 (33) | | |
| Days missed after LE injury | 45.13 ± 69.18 | 66.44 ± 81.85 | .423 |
| Games missed after LE injury | 2.93 ± 2.71 | 3.67 ± 3.00 | .470 |

<sup>a</sup>Data are reported as mean ± SD or n (%). Univariate 2-group comparisons. LE, lower extremity; NFL, National Football League.

<sup>b</sup>One player with a concussion and subsequent LE injury was excluded because the LE injury occurred outside of the 90-day postconcussive window.

### TABLE 2

| Injury Characteristics for Concussed NFL Athletes With LE Injuries and Nonconcussed Control NFL Athletes<sup>a</sup> | Nonconcussed With LE Injury (n = 43) | Concussed With LE Injury (n = 9) | *P* Value |
|---|---|---|---|
| Injury location | | | .786 |
| Hip | 2 (5) | 0 (0) | | |
| Groin | 4 (9) | 0 (0) | | |
| Thigh | 14 (33) | 2 (22) | | |
| Knee | 2 (5) | 1 (11) | | |
| Shin | 2 (5) | 1 (11) | | |
| Ankle | 9 (21) | 2 (22) | | |
| Foot | 10 (23) | 3 (33) | | |
| Injury type | | | .401 |
| Acute fracture | 1 (2) | 0 (0) | | |
| Muscle strain/tear | 24 (56) | 3 (33) | | |
| Ligament sprain/tear | 18 (42) | 6 (67) | | |
| Multiple LE injuries | 13 (30) | 2 (22) | .697 |

<sup>a</sup>Data are reported as n (%). Univariate 2-group comparisons. LE, lower extremity; NFL, National Football League.
incidence of lower extremity musculoskeletal injuries in 2011. This study reached similar conclusions, with a higher evaluated 73 Division I collegiate athletes across men's football
ence in our findings. In a similar study, Herman et al7 eval-
NFL, we suspect that we have a decreased sample size of
from 2011 to 2014. Because of the contact nature of the
basketball, wrestling, and volleyball at a single institution
spective study of 87 concussion cases in 75 NCAA Division I
play. Brooks et al1 displayed this phenomenon in a retro-
lower extremity musculoskeletal injury after returning to
sions increase the risk of sustaining an acute noncontact
quality of play in the acute setting after initial recovery
may not experience additional risks to injury or changes in
Moreover, decreased maximal muscle activation and motor
phased potentials likely equate to lower muscle force production and activation, correlating to less severe
injuries in concussed athletes and similar RTP times when
compared with nonconcussed controls.
As our understanding of concussions in the NFL continues
to evolve, the potential long-term consequences are well-
documented, but much is to be learned about the immediate
effect on athlete performance and well-being. Our study
suggests that there is not an increase in the odds of an acute noncontact lower extremity musculoskeletal injury in
offensive NFL players in a 90-day RTP period postconcus-
ion. In addition, we found that there was no immediate
decline in play after a concussion to an NFL athlete as
compared with controls when 3 seasons pre- and postinjury.
These findings suggest that although severe long-term
repercussions from concussions are evident, NFL players
can not experience additional risks to injury or changes in
quality of play in the acute setting after initial recovery from
a concussive event.
Several previous studies have suggested that concus-
sions increase the risk of sustaining an acute noncontact
lower extremity musculoskeletal injury after returning to play. Brooks et al1 displayed this phenomenon in a retro-
spective study of 87 concussion cases in 75 NCAA Division I
collegiate athletes across football, soccer, hockey, softball,
basketball, wrestling, and volleyball at a single institution
from 2011 to 2014. Because of the contact nature of the
NFL, we suspect that we have a decreased sample size of
noncontact injuries, potentially contributing to the differ-
cence in our findings. In a similar study, Herman et al2 eval-
uated 73 Division I collegiate athletes across men's football
and women's basketball, soccer, and lacrosse from 2006 to
2011. This study reached similar conclusions, with a higher
incidence of lower extremity musculoskeletal injuries in
concussed athletes when compared with nonconcussed con-
trols.7 However, this study did not isolate injuries as noncon-
tact in nature and also included multiple sports.
Without identifying injuries as noncontact, it may be diffi-
cult to correlate injury causality with changes in neuromus-
cular function or due to direct physical blow, altering
biomechanics, especially in football. When compared with
other professional sports, such as basketball, we suspect
that increased rest time between games (6 days vs 2-3 days)
also contributes to lower rates in NFL athletes. In addition,
NFL players have up to 60 minutes of in-game play time per
week, in comparison with NBA athletes, who could have up
to 144 minutes of play time in a 3-game week. This phe-
nomenon has been documented in NBA athletes, showing
increased odds of injury by 2.67% (P < .001) for each 96
minutes played. It was also found that in the context of
constant game load and fatigue level found in the NBA, the
odds of injury increase by 3.03% for each year played in the
NBA.15 Increased play time over the 90-day RTP in NBA
athletes could result in a higher prevalence of the previ-
ously stated phenomenon regarding lower extremity inju-
rpies. Recent discoveries of sports-related concussions
affecting gait pattern, reaction times, and proprioception
are suspected to account for an increased risk of lower extremity injury in previous studies.1,8,18,29 A decline in
neuromuscular function could affect the odds of sustaining
a lower extremity injury and could play a role in recovery
protocols to assess an athlete’s readiness for RTP.
Along with increased risk for injury, Herman et al7 hy-
thesized that concussed athletes would sustain more
severe lower extremity injuries, leading to prolonged RTP
periods. However, their findings showed that there was an
insignificant difference in RTP times after lower extremity
injury between concussed athletes and controls. In a previ-
ous study on the incidence of lower extremity injuries in
concussed NBA athletes reciprocating these results, Jildeh
et al20 found no significant difference in days or games
missed between concussed NBA athletes and nonconcussed
controls after a noncontact lower extremity injury. The cur-
rent study further supports previous work, as we found
no significant difference in days (66.4 ± 81.9 vs 45.1 ± 69.2;
P = .423) or games (3.67 ± 3.0 vs 2.93 ± 2.71; P = .470) missed
when comparing concussed NFL athletes and nonconcussed
controls after a lower extremity injury. We support the pre-
vious hypothesis that the mechanism of these findings stems
from changes in specific neuromuscular function persisting
long after acute recovery from a concussion.20 Specifically,
decreased maximal muscle activation and motor evoked
potential amplitudes likely equate to lower muscle force
production and activation, correlating to less severe
injuries in concussed athletes and similar RTP times when
compared with nonconcussed controls.
There have been several studies on the performance of
NFL athletes after concussion. Kumar et al14 studied 131
concussion cases in 124 NFL players using ProFootball-
Focus performance scores and found that scores were sim-
ilar pre- and postconcussion for players missing no games
and those missing at least 1 game. Reams et al20 performed
a similar study using Football Outsiders’ defense-adjusted
yards above replacement (DYAR) metric. They assessed

### TABLE 3

| Power Rating | Nonconcussed (n = 328) | Concussed Without LE Injury (n = 107) | Concussed With LE Injury (n = 9) | P Value |
|--------------|------------------------|--------------------------------------|----------------------------------|---------|
| 3 seasons preinjury | 60.41 ± 131.72 | 65.24 ± 123.24 | 9.84 ± 21.85 | .4629 |
| 2 seasons preinjury | 73.40 ± 135.69 | 74.47 ± 133.28 | 27.69 ± 33.01 | .5937 |
| 1 season preinjury | 81.14 ± 135.61 | 82.05 ± 119.29 | 39.09 ± 35.98 | .6295 |
| 1 season postinjury | 75.82 ± 131.14 | 72.97 ± 105.34 | 46.36 ± 46.02 | .7734 |
| 2 seasons postinjury | 61.53 ± 127.53 | 65.82 ± 126.62 | 31.79 ± 46.55 | .7345 |
| 3 seasons postinjury | 48.84 ± 109.06 | 31.99 ± 78.13 | 19.03 ± 39.06 | .2497 |

*Data are reported as mean ± SD. Univariate 2-group comparisons. LE, lower extremity; NFL, National Football League.
140 concussed NFL players from 2007 to 2010 and found no significant change in DYAR in concussed athletes when compared with controls with head and neck injuries other than concussion. In a study utilizing the PR metric to assess the on-field performance of NFL running backs and wide receivers pre- and postconcussion, Jildeh et al⁹ found that the change of PR in both the acute (±1 year from injury) and chronic (±3 years from injury) settings was similar in concussed and nonconcussed control athletes. Our current study further echoes these findings, as we found no significant differences in change of PR when comparing groups of concussed athletes with lower extremity injury, concussed athletes without lower extremity injury, and controls in the acute (7.27 ± 46.11 vs –9.08 ± 136.81 vs –5.32 ± 104.38) setting (±1 year from injury). We did find there to be a significant difference in the PR of concussed athletes without lower extremity injuries ±3 years from the injury with a mean difference of –33.25 ± 128.83 (P < .01). However, since this is a 6-year period and there are no significant differences in the ±1-year and ±2-year metrics, we suspect this difference is due to natural career progression rather than concussive effects. These findings suggest that, while the long-term ramifications of concussions are well-documented, they do not appear to affect immediate off-field performance in NFL athletes.

In a prospective cohort study of 76 Division I collegiate football players, Wilkerson³⁴ found that decline in neurocognitive reaction time appears to increase risk for ligament sprains/tears. Wilkerson assessed reaction time using the Immediate Post-Concussion Assessment and Cognitive Testing and found slower reaction times in starters who sustained a lower extremity strain or strain when compared with uninjured starters, contributing to a relative risk of 2.17 (90% CI, 1.40-4.30) for sustaining a lower extremity strain or strain in athletes with a prolonged reaction time (≥0.545 s). Herman et al⁷ corroborated this finding, showing a 3.39 greater risk of sustaining a ligament sprain/tear or muscle sprain/tear in the 90-day RTP period after a concussion. Jildeh et al⁹ found that the most common acute injury in NBA athletes after concussion was ligament sprains/tears (64%). The current study, although showing no increased risk for lower extremity injury after concussion, found that the most common injury type in concussed athletes was ligament sprains/tears (67%) compared with muscle strains/tears (56%) in nonconcussed controls. To explain this phenomenon, a decline in maximum muscle activation has been demonstrated in anterior cruciate ligament injury and chronic ankle instability.¹³,²⁶,²⁷ Concussive effects on the motor cortex are suspected to contribute to altered muscle activation, creating joint laxity and increased susceptibility to these injuries.⁵ Knee injuries are the most common injury in the NFL (24%), most often being ligamentous in nature (anterior cruciate or medial cruciate ligament).¹² The prominence of lower extremity injuries in the NFL makes them a crucial area of investigation for player safety. Establishing clear risk factors for acute noncontact lower extremity injuries after concussive events can help team physicians treat athletes with new preventative guidelines to promote athlete well-being.

Limitations

This study has several limitations. Potential inaccuracies could exist in publicly available injury information; however, the NFL authorizes each organization to accurately report records pertaining to injuries, illness, or rest each game day, so a fair amount of accuracy can be expected. Furthermore, each potential concussion or lower extremity injury was cross-referenced with team websites and NFL game summaries/media guides to confirm time missed and documented reasons for injury. In addition, there was no way to control for athletic exposure in regard to minutes and plays per game. This could account for some inaccuracy in an athlete’s risk for injury, as higher exposure likely increases risk for injury. Players injured late in the season were likely not participating in games for the full 90-day period. The postconcussive period of documented athletic exposure could underestimate the number of lower extremity injuries after concussion. Nonetheless, the current study reports data of professional athletes who are returning to an elite level of competition after a concussion.

With a specific focus on offensive NFL football players, these findings may not be generalizable to the entire NFL or other sports, although similar results have been shown in different demographics.²⁷,²¹ On-field performance was assessed with a single PR metric, which fails to account for other aspects of athletic performance (speed, strength, size, etc.), leading to a potential oversimplification. History of concussion was not accounted for in this study, which could have left some players more at risk for lower extremity injury than others. Furthermore, more severe or recurrent concussions may lead to more severe neuromuscular and cognitive deficits, which may have implications on RTP and lower extremity injury risk; however, determination of concussion severity is challenging and more rarely reported. Therefore, stratification of risk by severity was not performed in this study. Finally, concussions may be underestimated because of reliance on athletes self-reporting their symptoms and varying standards between organizations.⁶

CONCLUSION

Concussed offensive NFL athletes appeared to have no increased risk for acute noncontact lower extremity injury in a 90-day RTP period when compared with nonconcussed controls. Increased time between games and fewer minutes played per week as compared with noncontact professional sports may contribute to this assumption. Concussed players did appear to sustain a higher percentage of ligamentous sprains/tears when compared with nonconcussed controls. Concussed NFL athletes had no apparent change in performance pre- and postconcussion, suggesting that production longevity can be maintained after a concussion.

REFERENCES

1. 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;44(3):742-747.
2. Casson IR, Viano DC, Powell JW, Pellman EJ. Repeat concussions in the National Football League. Sports Health. 2011;3(1):11-24.

3. De Beaumont L, Mongeon D, Tremblay S, et al. Persistent motor system abnormalities in formerly concussed athletes. J Athl Train. 2011;46(3):234-240.

4. Eckner JT, Kutcher JS, Broglio SP, Richardson JK. Effect of sport-related concussion on clinically measured simple reaction time. Br J Sports Med. 2014;48(2):112-118.

5. Erickson BJ, Ahn J, Chalmers PN, et al. Reasons for retirement following ulnar collateral ligament reconstruction among Major League Baseball pitchers. Orthop J Sports Med. 2017;5(12):232596717745021.

6. Gilbert FC, Burdette GT, Joyner AB, Llewellyn TA, Buckley TA. Association between concussion and lower extremity injuries in collegiate athletes. Sports Health. 2016;8(6):561-567.

7. Herman DC, Jones D, Harrison A, et al. Concussion may increase the risk of subsequent lower extremity musculoskeletal injury in collegiate athletes. Sports Med (Auckland, NZ). 2017;47(5):1003-1010.

8. Howell DR, Beasley M, Vopat L, Meehan WP III. The effect of prior concussion history on dual-task gait following a concussion. J Neurotrauma. 2017;34(4):839-846.

9. 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. Arthroscopy: J Sports Med Rehabil. 2020;3(1):e219-e225.

10. 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(11):2717-2722.

11. Keller RA, Steffes MJ, Zhuo D, Bey MJ, Moutzouros V. The effects of medial ulnar collateral ligament reconstruction on Major League pitching performance. J Shoulder Elbow Surg. 2014;23(11):1591-1598.

12. Kluczynski MA, Kelly WH, Lashomb WM, Bisson LJ. A systematic review of the orthopaedic literature involving National Football League players. Orthop J Sports Med. 2019;7(8):232596719864356.

13. Kuenze CM, Hertel J, Weltman A, et al. Persistent neuromuscular and corticormotor quadriceps asymmetry after anterior cruciate ligament reconstruction. J Athl Train. 2015;50(3):303-312.

14. 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(9):2050-2055.

15. Lewis M. It’s a hard-knock life: game load, fatigue, and injury risk in the National Basketball Association. J Athl Train. 2018;53(5):503-509.

16. Marshall NE, Jildeh TR, Okoroha KR, et al. Implications of core and hip injuries on Major League Baseball pitchers on the disabled list. Arthroscopy. 2018;34(2):473-478.

17. Marshall NE, Jildeh TR, Okoroha KR, et al. Performance, return to play, and career longevity after ulnar collateral ligament reconstruction in professional catchers. Arthroscopy. 2018;34(6):1809-1815.

18. Martini DN, Sabin MJ, DePessa SA, et al. The chronic effects of concussion on gait. Arch Phys Med Rehabil. 2011;92(4):585-589.

19. McHale KJ, Rozell JC, Milby AH, Carey JL, Sennett BJ. Outcomes of Lisfranc injuries in the National Football League. Am J Sports Med. 2016;44(7):1810-1817.

20. Myer GD, Smith D, Barber Foss KD, et al. Rates of concussion are lower in National Football League games played at higher altitudes. J Orthop Sports Ther. 2014;44(3):164-172.

21. 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(19):1447-1450.

22. Nwachukwu BU, Bedi A, Premkumar A, Draovitch P, Kelly BT. Characteristics and outcomes of arthroscopic femorocacetabular impingement surgery in the National Football League. Am J Sports Med. 2019;47(1):144-148.

23. Okoroha KR, Kadri O, Keller RA, et al. Return to play after revision anterior cruciate ligament reconstruction in National Football League players. Orthop J Sports Med. 2017;5(4):2325967117698788.

24. Okoroha KR, Taylor KA, Marshall NE, et al. Return to play after shoulder instability in National Football League athletes. J Shoulder Elbow Surg. 2018;27(1):17-22.

25. Pellman EJ, Powell JW, Viano DC, et al. Concussion in professional football: epidemiological features of game injuries and review of the literature—part 3. Neurosurgery. 2004;54(1):81-96.

26. Pietrosimone BG, Gribble PA. Chronic ankle instability and corticospinal excitability as predictors of disability after anterior cruciate ligament reconstruction. J Shoulder Elbow Surg. 2013;22(1):1-6.

27. Powers KC, Cinelli ME, Kalmar JM. Cortical hypexcitability persists beyond the symptomatic phase of a concussion. Brain Inj. 2014;28(4):465-471.

28. Powers KC, Kalmar JM, Cinelli ME. Dynamic stability and steering control following a sport-induced concussion. Gait Posture. 2014;39(2):728-732.

29. Reams N, Hayward RA, Kutcher JS, Burke JF. Effect of concussion on performance of National Football League players. Int J Sports Physiol Perform. 2017;12(8):1100-1104.

30. Stern RA, Riley DO, Daneshvar DH, et al. Long-term consequences of repetitive brain trauma: chronic traumatic encephalopathy. PM R. 2011;3(10)(suppl 2):S460-S467.

31. Swank CB, Covassin T, Steamer DJ, Schatz P. The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. Am J Sports Med. 2007;35(6):943-948.

32. Tran A, Kappa J, Smith E, et al. The effect of turf toe injuries on player performance in the National Football League. Iowa Orthop J. 2019;39(2):35-39.

33. Wilkerson GB. Neurocognitive reaction time predicts lower extremity sprains and strains. Int J Athl Ther Train. 2012;17(6):4-9.