

Influence of Extrinsic Risk Factors on National Football League Injury Rates

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Background: The risk of injury associated with American football is significant, with recent reports indicating that football has one of the highest rates of all-cause injury, including concussion, of all major sports. There are limited studies examining risk factors for injuries in the National Football League (NFL).

Purpose: To identify risk factors for NFL concussions and musculoskeletal injuries.

Study Design: Case-control study; Level of evidence, 3.

Methods: Injury report data were collected prospectively for each week over the 2012-2013 and 2013-2014 regular seasons for all 32 teams. Poisson regression models were used to identify the relationship between predetermined variables and the risk of the 5 most frequent injuries (knee, ankle, hamstring, shoulder, and concussion).

Results: A total of 480 games or 960 team games (TGs) from the 2012-2013 and 2013-2014 regular seasons were included in this study. A trend to an increasing risk of concussion and TG ankle injury with decreasing mean game-day temperature was observed. The risk of TG concussion (incidence rate ratio [IRR], 2.16; 95% CI, 1.35-3.45; $P = .001$) and TG ankle injury (IRR, 1.48; 95% CI, 1.10-1.98; $P = .01$) was significantly greater for TGs played at a mean game-day temperature of $\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$) compared with a mean game-day temperature of $\geq 21.0^{\circ}\text{C}$ ($\geq 69.8^{\circ}\text{F}$). The risk of TG shoulder injury was significantly increased for TGs played on grass surfaces (IRR, 1.36; 95% CI, 1.02-1.81; $P = .038$) compared with synthetic surfaces. The risk of TG injury was not associated with time in season, altitude, time zone change prior to game, or distance traveled to a game.

Conclusion: This study evaluated extrinsic risk factors for injury in the NFL. A hazardous association was identified for risk of concussion and ankle injury with colder game-day temperature. Further research should be conducted to substantiate this relationship and its potential implication for injury prevention initiatives.

Keywords: National Football League; NFL; concussion; injury prevention; temperature; epidemiology

The risk of injury associated with American football is significant, with recent reports indicating that football has one of the highest rates of all-cause injury, including concussion, of all major sports.²⁰ The National Football League (NFL) has attempted to reduce the injury burden of its athletes through the introduction of numerous rule

changes,² implementation of a novel concussion-screening program and management protocols,³ and the development of an educational campaign for injury awareness.¹⁵ The NFL is concomitantly exploring league-wide restructuring with proposals to increase the number of games played per season¹² and expand the geographic borders by increasing the number of games played outside the United States.¹³ These changes would increase volume of competition and travel requirements for players, despite limited information on the effect these variables will have on injury risk.

The impact of existing modifiable and nonmodifiable variables on injury risk within the NFL should be assessed to provide guidance for future injury prevention and general league-restructuring strategies. One accepted approach to inform injury prevention initiatives involves a 4-stage strategy, which includes (1) establishing the incidence and frequency of injuries within a particular sport, (2) identifying risk factors for injury, (3) introducing injury prevention strategies targeting the identified modifiable risk factors, and (4) evaluating the efficacy of the implemented interventions.⁴³

It has been previously documented that within the NFL, the knee is most frequently injured, followed by the ankle,

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hamstring, shoulder, and the head/concussion.²⁰ There are limited data documenting risk factors associated with injury in the NFL, with previous studies focusing on the relationship between injury incidence and type of playing surface^{16,30} and the altitude at which games are played.²⁶ Recently, Teramoto et al⁴¹ identified an association between the style of play and risk of concussion in the NFL. Broadening the search for factors associated with adverse injury outcomes remains one of the primary strategies for informing targeted player safety initiatives and can provide insight into the potential influence of prospective plans for league expansion on injury risk. Thus, the purpose of this study was to investigate the relationship between extrinsic risk factors (game, scheduling, and meteorological variables) and injuries in the NFL.

METHODS

National Football League Injury Reports

Official NFL injury reports are published weekly online by all 32 teams on each team's official website as well as on the official NFL league-wide website. The NFL regular season includes 16 games per team, played over a period of 17 weeks. Injury reports are published prior to each game and therefore reflect injuries sustained in the previous week's game or in the current week's practices. Injury data pertaining to the final regular-season game (week 17) are only available for the 12 teams that advance to the playoffs and are not available for the 20 teams that are eliminated and are no longer required to publish injury data. Injured players who are not immediately available to participate may be reported as being on the "injured reserve list" as opposed to the weekly injury report. The injured reserve list for each team is available online and is updated daily.⁸

Injury reports and the injured reserve list include the following information of all players on the roster diagnosed with an injury or illness by a team physician: player name, position, anatomic area injured (eg, ankle, knee, hip, shoulder, toe, head), practice status of a player for 3 practices during the week (eg, did not practice, limited participation, full participation), and game status (eg, probable to play, doubtful to play, out).

Data Collection

All injury report and injured reserve data were collected prospectively for each week over the 2012-2013 and 2013-2014 regular seasons for all 32 teams. An *injury* was defined as any reported injury that was not documented on the injury report 1 week immediately prior to the index injury week. A *concussion* was defined as any injury reported as a concussion or a head injury. The 5 most prevalent injuries in the NFL were previously documented and include knee, ankle, hamstring, and shoulder injuries as well as concussions.²⁰ Injury reports do not identify the situational context (ie, game vs practice) in which the injury occurred; however, previous reports have documented that the majority of injuries during a football and NFL

season occur during games.^{7,22,24} Therefore, all injuries were assumed to occur during games for data analysis and modeling.

Additional situational and contextual data for each team-game (TG) were collected retrospectively to identify factors for an increased risk of TG injury. A TG was defined as a team exposure to a game and, consequently, for each game played there are 2 TGs. The included variables were selected based on previous reports of their association with hazardous outcomes in other sports and levels of play. The predictor variables included the following: game altitude,^{26,37} playing surface material,^{4,16,30,31,40} time in season,^{21,29,39} time zone change prior to a game,³⁵ distance traveled to game,¹⁴ air temperature,^{29-31,34} game outcome,¹¹ game importance,²⁵ and time between games.¹⁰

Scheduling Variables. The following scheduling variables were collected for each TG:

1. The number of days between the index TG and the previous TG were classified as a short week (TGs played <5 days after the previous TG), a normal week (6-8 days), or a long week (10-15 days).
2. The distance traveled to a TG was calculated manually using the Google Maps "measure distance" function. The distance a team traveled for a TG was defined as the distance between the center of their home stadium to the center of the stadium in which the TG was played. TGs were tertiled based on distance traveled, resulting in TGs with no distance traveled (0 km [0 miles]), a short distance traveled (108.28-1009.14 km [67.28-627.05 miles]), and a long distance traveled (≥ 1012.52 km [≥ 629.15 miles]).
3. The time-in-season describes the week in which the TG was played and was analyzed in quartiles (weeks 1-4, 5-8, 9-12, and 13-16).
4. Time zone (TZ) change prior to a TG describes the absolute change in TZ between a team's home TZ and the TZ in which the game was played. The change in TZ was categorized as ≥ 3 TZ compared with ≤ 2 TZ to examine the maximal change in TZs (and greater) a team may experience when playing within the United States.

Game Variables. Information pertaining to game-specific data was collected and included the following:

1. The outcome (win, loss, or tie) of a TG, in which TGs resulting in a win or tie were compared with a loss.
2. The identification of TGs played against divisional opponents compared with TGs not played against divisional opponents.
3. The playing surface type (grass, artificial turf, or a hybrid grass/turf surface) available on each stadium's official website. Both turf and hybrid surfaces were amalgamated and compared with natural grass surfaces during the modeling analysis.

Meteorological Variables. Meteorological data were also collected for each TG and included the following:

1. The mean game-day temperature was retrospectively collected for each game from an online meteorological archive (wunderground.com). The mean game-day temperature was quartiled for analysis resulting in TGs played at $\geq 21.0^{\circ}\text{C}$ (69.8°F), 16.9°C to 20.8°C (62.4°F to 69.4°F), 10.0°C to 16.7°C (50.0°F to 62.1°F), and $\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$). For all indoor stadiums and stadiums with retractable roofs, a mean game-day temperature of 21.1°C (70°F) was assumed, representing “room” temperature.
2. The altitude of each stadium was obtained manually from an elevation-approximation map (<http://www.daftlogic.com/sandbox-google-maps-find-altitude.htm>), which measures elevation based on coordinates relative to sea level. The center of each stadium was used as the point of reference for elevation data. The altitude of the games played were quartiled, resulting in TGs played at ≤ 5.18 m (16.99 feet), 5.87 to 121.02 m (19.26-397.05 feet), 142.03 to 216.34 m (465.98-709.78 feet), and ≥ 220.59 m (≥ 723.72 feet) above sea level. Altitude cut-offs in each quartile were similar to previous reports.²⁶

Statistical Analysis and Ethics

In addition to descriptive statistics, Poisson regression models were performed for each of the 5 most prevalent TG injuries, including concussion, knee, ankle, hamstring, and shoulder. Outcomes were analyzed at the level of the TG as the included variables theoretically uniformly influence all players on a given team for each TG. A full model including all variables was used for each outcome model based on a priori hypotheses. Data for TGs played on week 17 were not included as week 17 injury data were only available for 12 of the 32 TGs on week 17. A variance inflation factor (VIF) was calculated to estimate multicollinearity of the included variables. The mean VIF of the variables in the model was 1.12 (range, 1.02-1.25), suggesting minimal correlation between predictor variables.²⁸ To control for variable multiplicity in the regression models, a significance level adjustment was performed using false discovery rate (FDR) control to calculate a new rejection criterion.⁵ All variables identified with an initial significance level of $\alpha < .05$ were subjected to FDR significance level adjustment. All statistical analyses were performed using STATA Data Analysis and Statistical Software version 13.1 (StataCorp LP). An institutional review board deemed this study exempt from requiring ethics approval, as all included data were available in the public domain.

RESULTS

A total 512 regular season games, or 1024 TGs, were played during the 2012-2013 and 2013-2014 regular seasons, of which 480 games or 960 TGs (93.8%) from weeks 1 through 16 were included in this study (Table 1).

TABLE 1
Demographic Data of Included Team Games (N = 960)^a

Variable	Team Games, n (%)
Time in season	
Weeks 1-4	252 (26.3)
Weeks 5-8	224 (23.3)
Weeks 9-12	228 (23.8)
Weeks 13-16	256 (26.7)
Time between index and previous team game ^a	
Short (4 days)	27 (3.0)
Normal (6-8 days)	798 (89.1)
Long (10-15 days)	71 (7.9)
Game outcome	
Win	478 (49.8)
Loss	478 (49.8)
Tie	4 (0.4)
Opponent: divisional rival	320 (33.3)
Change in time zone prior to team game	
≤ 2 time zones	900 (93.8)
≥ 3 time zones	60 (6.3)
Distance traveled to game	
None (0 km [0 mi])	461 (48.0)
Short (108.28-1009.14 km [67.28-627.05 mi])	178 (18.5)
Long (1012.52-8619.12 km [629.15-5355.67 mi])	321 (33.4)
Altitude of game	
≤ 5.18 m (≤ 16.99 ft)	238 (24.8)
5.87-121.02 m (19.26-397.05 ft)	248 (25.8)
142.03-216.34 m (465.98-709.78 ft)	242 (25.2)
≥ 220.59 m (≥ 723.72 ft)	232 (24.2)
Playing surface	
Grass	610 (63.5)
Turf	350 (36.5)
Mean game-day temperature:	
$\geq 21.0^{\circ}\text{C}$ ($\geq 69.8^{\circ}\text{F}$)	232 (24.2)
16.9 - 20.8°C (62.4 - 69.4°F)	249 (25.9)
10.0 - 16.7°C (50.0 - 62.1°F)	233 (24.3)
$\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$)	246 (25.6)

^aTeam games do not total 960, as week 1 and bye-week data were not included in this variable.

A total of 4133 all-cause injuries were identified in 1654 athletes. The most frequent injuries occurred to the knee (n = 746), followed by ankle (n = 519), hamstring (n = 367), and shoulder (n = 357); concussions were the next most prevalent injury (n = 296) (Table 2).

Concussion

A total of 296 concussions were identified in 249 TGs (25.9%), while 711 TGs (74.1%) were concussion free (Table 2). A trend to an increasing risk of concussion with decreasing mean game-day temperature was observed (Figure 1A). The risk of TG concussion was significantly greater for TGs played at a mean game-day temperature of $\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$) compared with a mean game-day temperature of $\geq 21.0^{\circ}\text{C}$ ($\geq 69.8^{\circ}\text{F}$; incidence rate ratio [IRR], 2.16; 95% CI, 1.35-3.45; $P = .001 < \text{FDR}$) after controlling for injury week, length of week, TG outcome,

TABLE 2
Frequency of National Football League Injuries
According to Team Game

Injuries per Team Game	Team Games, n (%)
Concussion (n = 296)	
0	711 (74.1)
1	208 (21.7)
2	35 (3.6)
3	6 (0.6)
Knee injury (n = 746)	
0	460 (47.9)
1	316 (32.9)
2	136 (14.2)
3-6	48 (5.0)
Ankle injury (n = 519)	
0	569 (59.3)
1	291 (30.3)
2	77 (8.0)
3-5	23 (2.4)
Hamstring injury (n = 367)	
0	670 (69.8)
1	219 (22.8)
2	65 (6.8)
3	6 (0.6)
Shoulder (n = 357)	
0	677 (70.5)
1	220 (22.9)
2	54 (5.6)
3-4	9 (0.9)

divisional opponent, TZ change prior to TG, altitude of the game, and playing surface (Figure 1). Risk of TG concussion was not associated with injury week, length of week, TG outcome, divisional opponents, TZ change prior to TG, altitude of the game, or playing surface.

Knee Injuries

A total of 746 knee injuries were identified in 500 TGs (52.1%) (Table 2), with multiple knee injuries occurring in 184 TGs (19.2%) and 0 knee injuries occurring in 460 TGs (47.9%). The risk of TG knee injury was not associated with injury week, length of week, TG outcome, divisional opponents, TZ change prior to TG, altitude of the game, playing surface, and mean game-day temperature (Figure 1B).

Ankle Injuries

A total of 519 ankle injuries were identified in 391 TGs (40.7%), with multiple ankle injuries occurring in 100 TGs (10.4%) (Table 2). The risk of TG ankle injury was significantly greater for TGs played at a mean game-day temperature of $\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$) compared with a mean game-day temperature of $\geq 21.0^{\circ}\text{C}$ ($\geq 69.8^{\circ}\text{F}$; IRR, 1.48; 95% CI, 1.10-1.98; $P = .01$ <FDR) after controlling for all other covariates (Figure 1C). Risk of TG ankle injury was not associated with injury week, "length" of week, TG outcome, divisional opponents, TZ change prior to TG, altitude of the game, and playing surface. To note, the risk of TG ankle injury for TGs

with ≥ 3 TZs change prior to the TG (IRR, 0.58; 95% CI, 0.35-0.95; $P = .032$ <.05) failed to reach significance after FDR adjustment.

Hamstring Injuries

A total of 367 hamstring injuries were identified in 290 TGs (30.2%), with multiple hamstring injuries occurring in 71 TGs (7.4%) (Table 2). The risk of TG hamstring injury was not associated with injury week, length of week, TG outcome, divisional opponents, TZ change prior to TG, altitude of the game, playing surface, and mean game-day temperature (Figure 1D).

Shoulder Injuries

A total of 357 shoulder injuries were identified in 283 TGs (29.5%), with multiple shoulder injuries occurring in 63 TGs (6.6%) (Table 2). The risk of TG shoulder injury was significantly increased for TGs played on grass surfaces (IRR, 1.36; 95% CI, 1.02-1.81; $P = .038$ <FDR) compared with TGs played on turf surfaces after controlling for all other covariates (Figure 1E). Risk of TG shoulder injury was not associated with injury week, length of week, TG outcome, divisional rival opponents, TZ change prior to TG, altitude of the game, and mean game-day temperature. To note, there was a trend to a reduced risk of TG shoulder injury for TGs with ≥ 3 TZs change prior to the TG (IRR, 0.57; 95% CI, 0.30-1.06; $P = .074$); however, this association failed to reach significance.

DISCUSSION

This study identified risk factors associated with the 5 most prevalent injuries in the NFL over 2 regular seasons from 2012 to 2014. We identified an increased risk for concussion and ankle injuries during games played at colder temperatures and an increased risk of shoulder injuries for games played on a grass surface. The risk of injury at any of the included anatomic locations was not related to the time in season, distance traveled to a game, change in TZ prior to a game, game outcome, division opponents, and the altitude at which the games were played.

We identified a greater risk of concussion for games played at a mean game-day temperature of $\leq 9.7^{\circ}\text{C}$ ($\leq 49.5^{\circ}\text{F}$) and a trend of an increasing risk with decreasing temperature. There is limited evidence examining the effect of climatic temperature on concussion incidence. Orchard et al³¹ examined the incidence of soccer injuries in warmer compared with cooler climates in 3 professional soccer leagues, and no significant association between climatic temperature and concussion incidence was identified. Discussion surrounding the underlying etiology of climatic temperature and concussion risk is speculative at this time; however, we present several hypotheses. We recognize that at lower temperatures, materials within the playing environment (ie, the equipment and playing surface) have a lower elastic potential and higher yield stresses,³³ which may generate greater impulse potentials

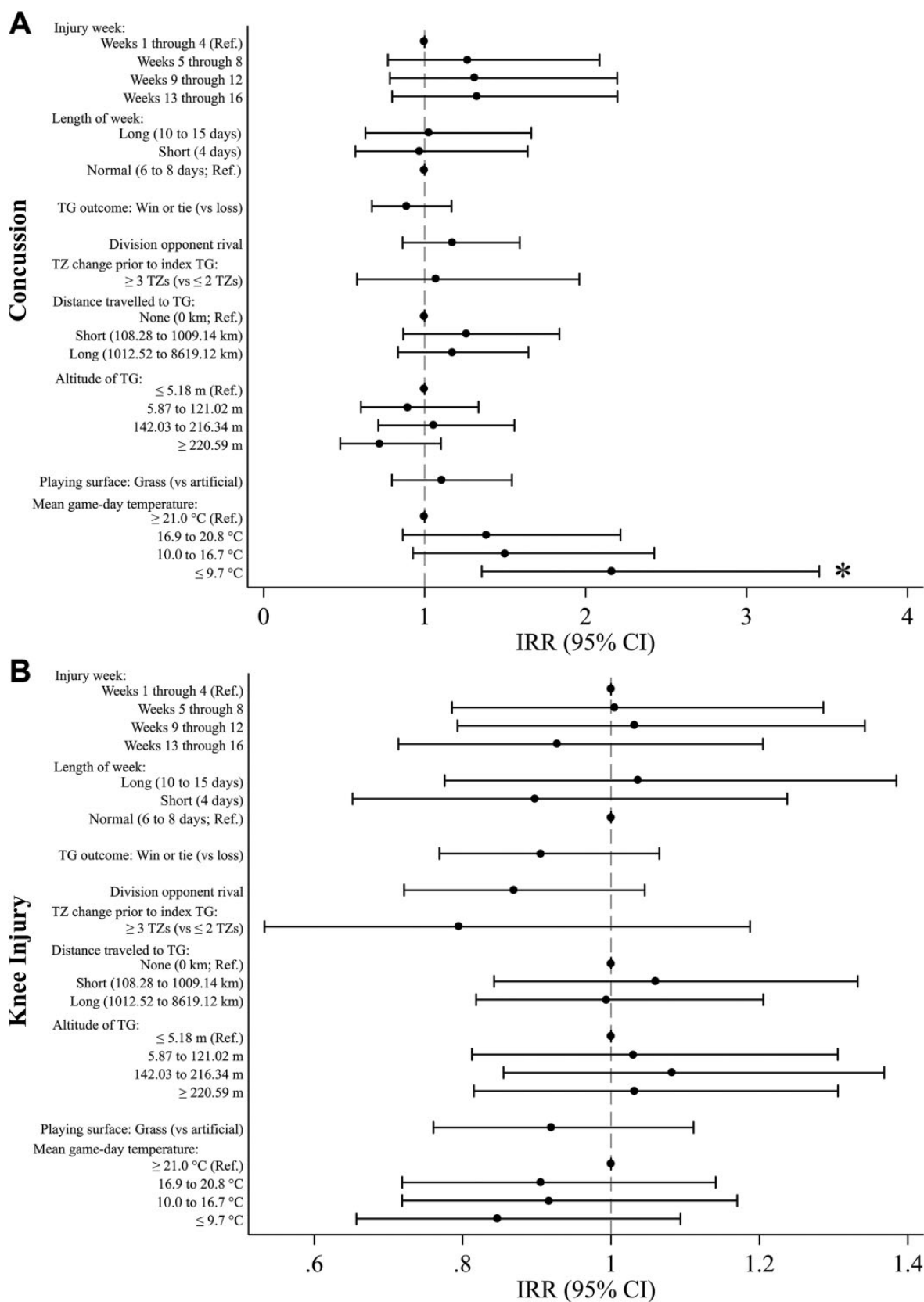


Figure 1. Results of Poisson regression models identifying the risk factors for the 5 most prevalent injuries in the National Football League: (A) concussion, (B) knee injury, (C) ankle injury (the significance of the risk of ankle injury associated with time zone [TZ] change was $P < .05$; however, this failed to reach significance after false discovery rate [FDR] adjustment), (D) hamstring injury, and (E) shoulder injury. IRR, incidence rate ratio; Ref, reference; TG, team-game. *Variables with $P < .05$ and $< \text{FDR}$.

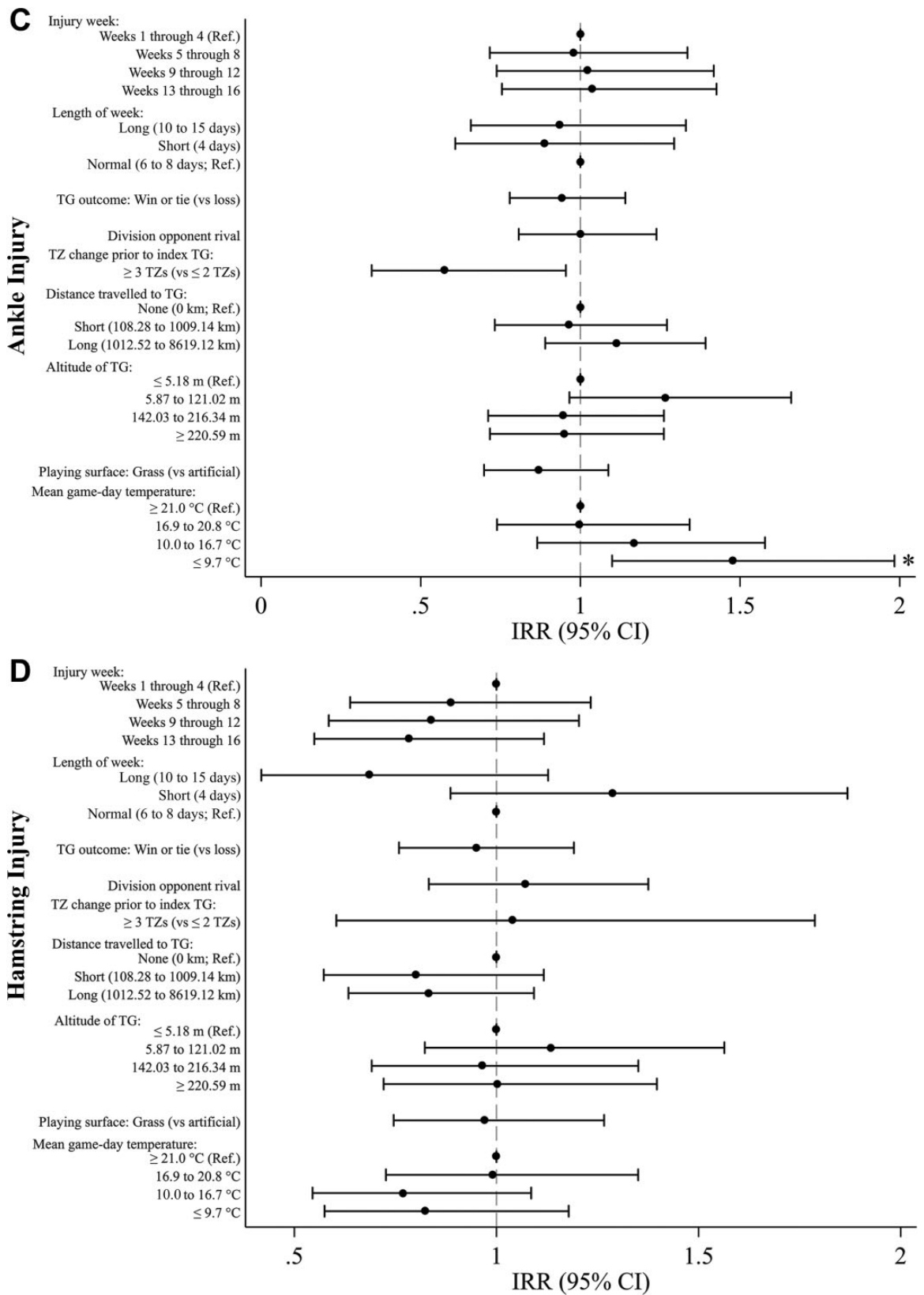


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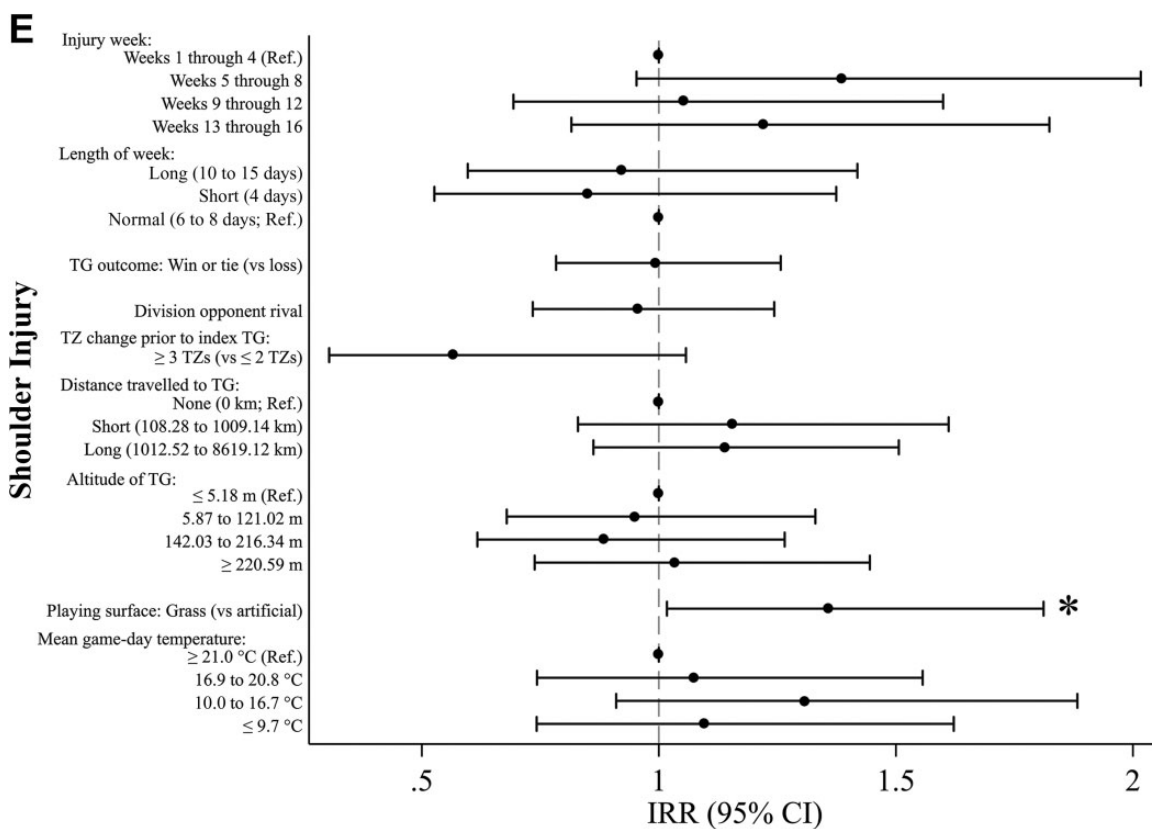


Figure 1. (continued)

during impacts and collisions. However, the change in the properties of sports equipment and playing surfaces at lower temperatures has not been well documented. Additionally, the observed relationship between concussion and temperature may be attributed to changing athlete behaviors at lower game-day temperatures, although not previously documented. Colder temperatures can increase the use of warming devices and equipment on the sideline (eg, sideline coats, hand warmers, warm drinks).⁶ Access to these devices may increase the likelihood of interaction with athletic training and medical personnel and may facilitate earlier recognition of an injured athlete. Furthermore, an athlete’s motivation to ascertain and achieve a warmer milieu may be more conducive to earlier symptom self-recognition through less distraction on the sidelines. Conversely, concussion symptomatology is nonspecific and can share a common presentation with heat-related illness (in the context of symptom onset during a collision sport). In warmer temperatures, players may attribute concussive symptoms to heat-related conditions (such as heat exhaustion, dehydration, etc) and underreport concussion symptomatology in warmer temperatures. The relationship between climatic temperature and concussion incidence should be studied further prior to proposing modifying game-day environment.

Additionally, there is a paucity of evidence documenting the relationship between climatic temperature and

musculoskeletal injuries. Orchard et al³⁰ identified a protective influence of colder temperatures on the risk of ankle and knee injuries in the NFL over a 9-year period from 1989 to 1998. The authors attribute this protective influence of colder temperatures to a lower shoe-surface traction with decreasing temperature, with a greater influence on Astro-Turf surfaces compared with natural grass. Discordantly, we observed an increased risk of ankle injury for games played at lower temperatures and no influence of temperature on the incidence of knee injury. This disparity may be attributed to a shift away from using AstroTurf to more natural synthetic and grass surfaces, which likely do not undergo as significant a reduction in shoe-surface traction at lower temperatures. We suggest that the hazardous effect of colder temperature on ankle injuries is related to intrinsic factors, as supported by literature suggesting that reflexive responses, such as the Hoffman reflex, are diminished in cooler temperatures.^{9,18}

No association between the risk of injury and the number of days off between games was identified. This does not support previous literature that documented an association between myofascial injuries and both muscle fatigue and overtraining.^{17,19,23,32} Furthermore, anecdotal evidence from players and media reports suggest a shortened week reduces preparation time and increases injury risk.^{38,42} Additionally, some media reports suggest that the “Thursday Night Football” television scheduling,

which requires teams to play on a shortened week, is associated with an increase in injury rates.³⁶ The large discrepancy in the reporting of the influence of the time between NFL games and injury risk warrants further investigation.

The results of this study failed to document an association between the risk of concussion and the altitude at which a game is played. Two previous studies reported a reduced risk of concussions for games played at higher altitudes. Myer et al²⁶ documented a protective influence of altitude on concussion risk in NFL athletes over the same time period as the current study, while Smith et al³⁷ observed the same relationship in all high school sports and football, specifically. Both studies attribute the protective influence of increasing altitude to physiological adaptations that increase cerebral blood flow, venous engorgement, and subsequently intracranial pressure resulting in a reduction in intracranial compliance^{26,37}; however, the validity of this theory has been challenged.^{44,45}

This study identified a small but increased risk of shoulder injuries for games played on grass surfaces compared with artificial turf. There was no relationship between lower extremity injury and game surface material. There is a large body of literature investigating the influence of grass and synthetic surfaces on lower extremity injuries with varying results.^{4,16,29,40} However, there is limited evidence linking surface type to upper extremity injuries. New synthetic surfaces have improved shock-absorbing properties and may be more forgiving to direct impacts to the shoulder. Furthermore, anecdotal evidence and player reports suggest poor footing on newly sodded soft grass surfaces²⁷ potentially increasing the risk of falls and shoulder impacts. The relationship between surface material and upper extremity injury should be investigated further.

The results of the current study demonstrated no influence of distance traveled to games and TZ change prior to games on injury outcomes. These results provide no impetus to censure NFL restructuring proposals to expand the geographic borders of the league, which would require teams to travel greater distances to games; however, strategies for ongoing evaluation of these variables should be implemented.

This study has several limitations. First, the source of data utilized for this study involved team-reported injury data. The potential for discrepancy in reporting practices between teams is large, and teams have previously been investigated for improper reporting practices.¹ Furthermore, injury data, apart from concussions, were limited to anatomic location, and information regarding the diagnosis or injury severity was not available. In addition, the injury history of the athletes was not available and, therefore, identifying recurrent and repeat versus new injuries was not possible. The precise date of the injuries included in this study was not available, and the timing of the injuries was limited to the week in which the injury occurred. As such, to calculate incidence rates we assumed all injuries occurred during games, as previous reports indicate that the majority of injuries in an NFL season occur during games compared with practices.

CONCLUSION

This study evaluated risk factors for injury in the NFL and identified a hazardous association between colder game-day temperature and the risk of concussion and ankle injury. Application of this information may aid in implementing injury prevention strategies in the NFL. Preventative measures to further explore and mitigate the risk of injury in the NFL are warranted.

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