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Exploring the Associations of Playing Surface and Lower Extremity Injuries Among National Football League Players

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Bachelor of Science
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2021

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Abstract

Exploring the Associations of Playing Surface and Lower Extremity Injuries Among National Football League Players

By Juliana Y. Bushnell

Introduction: Lower extremity injuries make up a large proportion of injuries experienced by football players. There is limited literature on the specific role playing surfaces have on injury rates.

Methods: We conducted analyses of the association between playing surfaces and visiting team missed-game lower extremity (LE) injury rates per team game of the 2018-2021 National Football League regular season. Our data included 2,593 LE injuries resulting in at least one missed game. We compared the IRs of playing surface as a binary, trinary, and an eight-level category (artificial turf models and natural grass types specified) variable. Finally, we used a Poisson mixed model with a log link function to estimate the association between playing surface and LE injury rates. This model was selected as our outcome is count data (# of injuries) and it allowed us to control for stadium and club-year as random effects. We ran three versions of this model with our three different surface variables.

Results: For the binary surface variable, the LE injury rate was 1.42 (95% CI 1.31-1.53) and 1.31 (95% CI 1.21-1.40) respectively. When divided into three categories (Artificial sit film, natural grass, other artificial) we found that slit-film had the highest injury rate per team game (1.49 95% CI 1.32-1.65) compared to other artificial (1.36 95% CI 1.22-1.51). When artificial and grass types are specified, A-Turf has the lowest IR (1.07 95% CI 0.69-1.45). Bermuda and Kentucky Bluegrass had an injury rate of 1.30 (95% CI 1.20-1.41) and 1.34 (95% CI 1.10-1.57) respectively. The highest injury rate was UBU/Turfnation with an IR of 2.04 (95. % CI 1.70-2.39). Our model output also showed that Artificial slit-film has the highest injury rate ratios (1.14 95% CI 0.97-1.32). The two major slit-film models, UBU/TurfNation and MomentumTurf, had the highest IRR's for the octonary surface model ran (UBU: 1.33 95% CI .92-1.94, MT: 1.31 95% CI 0.91-2.01).

Discussion: In our data, artificial slit-film had the highest injury rates followed by other artificial models then natural grass. We recommend that artificial slit-film be prohibited as a playing surface for both competition and practice fields moving forward.

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1 Corinthians 15:57

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Background

Football

American Gridiron Football is the most viewed sport in the United States.[2] In a traditional game of football, 11 men from opposing teams take the field. A football field is 100 yards long with hash marks at every yard. At every 5 yards, a line extends across the field, and there are numbers at every 10 yards. The playing field width is 55.3 yards wide. When teams are on offense, the goal is to move the ball into the endzone to score 6 points. Offensive players must advance the ball at least 10 yards in four plays or downs. The ball moves "down" the field through running or passing plays. Once the offense successfully moves the ball across the 10th-yard line, the down count restarts and they have four more chances to move forward another 10 yards. If they are successful in crossing into the end zone, the scoring team has the opportunity to either kick the ball into the upright from the 15-yard line (or two-yard line in NCAA football) for one extra point or once again get the ball into the end zone in a single try from the two-yard line for two extra points.[3]

In North America, there are a handful of football leagues. The National Football League (NFL) is the biggest and most prominent league. The NFL was founded in 1920 and went through a few decades of instability. It was not until the 1950s when the NFL started airing games on TV regularly that football became a major mainstream sport. In the 1960s, 10 American Football League (AFL) teams merged with three NFL teams to create the American Football Conference (AFC), and the other 13 NFL teams formed the National Football Conference (NFC), and thus, the NFL that we know and love today was officially born.[4]

Population

There is no 'official' number of football participants, but through reports of various age groups, it is evident that millions participate annually. [5,6] Some reports have stated that there were 2.2 million participants between the age of 6-14 in 2015.[5] Other research groups estimate over 5.2 million participants over the age of 6 (including all of high school, college, and professional) in 2018.[6] Governing bodies have more accurate estimates of participation by level. According to the National Federation of State High School Associations, which serves 19,500 high schools, 1.2 million athletes participate in football at the high school level.[7] The National Collegiate Athletic Association (NCAA), which serves 1,100 schools and over 500,000 student-athletes, reports 73,712 football participants at the collegiate level.[8] Each professional NFL team is allowed to have a 53-man roster. With 32 teams, that means there are 1,696 professional NFL players (excluding practice squad-only players).

While there are mixed reports of how many people play football, what is understood is that the participation rate has changed within the past few decades.[9] At the high school level, between the mid-90s through the 2000s annual participation increased approximately 12% per year.[10] In 2009, participation in tackle football at the high school level reached its all-time high (1,112,303). Every year since then, participation on the high school level has decreased.[11] For children aged 6-12, tackle football has also declined by almost 30% between the years 2016-2021. The fear of brain injury among parents is theorized to contribute to this decline.[9]

NFL Demographics

The age within the NFL ranges between roster. In the 2022 season, the average age of within the league was 26 years, 5 months, and 12 days. The youngest roster were the Cleveland Browns with the average age of 25 years, 4 months, and 11 days. The oldest average roster age

belonged to the Tampa Bay Buccaneers with the average age of 27 years, 5 months, and 13 days.[12] In the 2021 season, 70% of the players in the NFL were people of color. 58% were black, 25% are white, 0.7% were Hispanic/Latino, 1.9% were Asian, Pacific Islander/Hawaiian, or Alaska Natives.[13]

Injury Reporting

Youth Leagues Through College

Youth injuries are more widely reported and studied in academic journals. Smith et al. reported that in 2015 there were over 2 million emergency room visits related to youth sports. 1.1 million were related to tackle football. Among the study population, 46 (43.2%) had trauma to their upper extremities and 487 (32.6%) to their lower extremities.[5] Lykissas et al. did a similar study examining trends in pediatric sports-related injuries using the National Electronic Injury Surveillance System (NEISS) database. While injuries in other sports and recreational activities decreased overall, football injuries increased by 22% in 2010. Participation in football led to the most injuries than any other activity and had the highest number of total injuries among pediatric populations.[14]

There have been some investigations regarding football injuries on the high school and collegiate levels. Tyler et al. showed that previous ankle injury and high BMI were independent risk factors for sustaining a non-contact ankle sprain among high schoolers playing football. The combination of these risk factors resulted in a 19 times higher injury incidence compared to players with no previous ankle sprain and was of normal weight.[15]

The McCunn 2017 study investigated how playing experience and position influenced injury risk among college football players. This study showed that within the cohort, the incidence of injury was 7.1 injuries per 1000 training hours (compared to rugby with an

incidence rate of 3 injuries per 1000 training hours).[16] Playing experience and position were shown to influence risk of injury as well. However, "the strength of relationship varied between years of experience, positions, and whether training or games were considered." Interestingly, sophomore and junior players were at the highest risk of sustaining time loss injuries compared to freshmen. Because game exposure was accounted for within their statistical analysis, it is unclear why there is an increased injury risk among sophomore and juniors but not seniors. The researchers theorized that perhaps seniors had better technique and strength that protected them from injury. Fitness mitigates physical fatigue and has been reported as protective against injury within rugby. Between positions, WR had the highest risk of injuries and the greatest risk for non-time loss injury. RBs were at the greatest risk for time loss injury during training among this cohort.[16]

Finally, the Shankar et al. study compared the injury rates of the two populations by studying injury data from 100 nationally representative high schools and 55 colleges (DI, DII, and DIII). The researchers showed that the rate of injury in college football was higher than high school football in both practice and competition. The difference was the greatest in competition (IRR 3.34).[10] However, most of these studies on are relatively outdated which shows a need for further investigation at these levels. There have been many rule changes (such as the 2019 implementation of targeting penalty), improved surveillance and assessment techniques, and safety equipment advancements in the past 20 years which may have changed the distribution of injury. Furthermore, many of these studies have smaller sample sizes and only focus on a select few programs.

NFL

The NFL and NFLPA currently partner with a third-party company (IQVIA) to analyze the league's injury data. Every year, IQVIA reports the incidences of reported ACL, MCL, and concussions reported during the preseason and regular season. There was a total of 187 concussions, 71 ACL tears, and 129 MCL tears in the 2021 pre- and regular season.[17] Unfortunately, the NFL injury surveillance system "has not been used for broad-based investigation into injury risks and rates."[18]

Injury Location

There is some age variation among the distribution of injuries among youth. The Smith et al. study noted that lower extremity trauma was highest in the oldest studied age groups (33.0% and 33.6%, respectively), compared with the younger age groups.[5] The Shankar 2007 study compared the distribution of high school and NCAA football injuries. Among High school players, fractures represented a larger proportion of injuries. Concussions were more frequent in high school as well. The percentage of lower extremity injuries were 54% for college players and 46% for high school players.[10] While these differences seem subtle, it does indicate that level of play and possibly age may change the risks of certain injuries.

NFL ISS data has been used primarily to focus on specific injury types[19-22]. Like mentioned earlier, IQVIA does do some injury surveillance but is extremely selective in releasing their results. Using Harvard law school data in which they counted overall injuries in the NFL ISS, There were 75 injuries per 1,000 athlete exposures in game and 2.8 injuries per 1,000 AE during regular season practice (specifically excluding any pre- and off-season activities).[18,23] Other known official numbers show that over 15 seasons, there were 20,639 injuries in games and over 3,000 injuries in practices.[24]

Since official injury data in the NFL is kept confidential for a multitude of legal and business reasons, researchers tend to use official injury reports as a source of injury data.[18] The League mandates that all teams must release a report publicly of any player with an injury [25] Some limitations of the data source include the definition of injury is unclear and the actual information is vague: limited to likelihood of playing in the next game, practice status, and injury location.[25] The details provided differ from team to team and do not provide any specifics that epidemiologists are generally interested in such as injury history, severity, or where the injury occurred (practice vs games).[25]

Another study by Lawrence et. al noted studied the 5 most common injuries (knee, ankle, hamstring, shoulder, and concussion) stratified by many game level data variables across 480 games from the 2012-13 and 2013-14 season.[26] There were 4133 injuries among 1654 athletes with most frequent injury location being the knee (n=746). The study noted that as temperatures lowered, ankle injuries were more common. Hamstring injuries, conversely, were less common in colder games and at away games. Shoulder injuries were more common on grass than artificial turf.[26]

Playing Surfaces

Natural Grass

"Kentucky" Bluegrass

Kentucky bluegrass (*Poa pratensis*) is considered a cool-season grass.[27] Being a cool-season grass, it is particularly good for northern latitude fields. It is spread throughout cool and humid parts of the US and like other cool-season grasses, it grows most vigorously during the fall and spring. However, despite its name Kentucky bluegrass most likely did not originate in Kentucky.[28,29] While there is some controversy whether or not KBG is native to North America,

the general consensus is that early colonists brought KBG seeds to the US and mixed it into the native grass.[29] In the southeast, KBG is limited to North Carolina, Tennessee, northern Arkansas to panhandle of Texas and Oklahoma. On the west coast, KBG must be grown with irrigation. Much of KBG's pattern of growth has more to do with day length rather than temperature.[28] Due to the extensive ribosome activity, the sod produced is extremely dense and has strong tensile strength. This strength is a contributing factor to why many growers will blend it with other, less dense grass types in order to create a stronger hybrid field.[29]

Ryegrass

There are many species of ryegrass (*Lolium* spp.), but only two are used in the United States - Italian ryegrass (L. multiflorum) and perennial ryegrass (L. perenne). Typically, perennial ryegrass (used for athletic playing surfaces) are distinguished due to the absence of awns.[30] Perennial ryegrass was 'released' in the United States as turfgrass in the early 1960s. It has been prominent in the Pacific Northwest. Like KBG, it is a cool-season grass and is best in northern to mid regions. While it is a perennial (meaning it does not need to be reseeded every year), its roots are annual so the roots are naturally replaced every year – usually in the spring when it undergoes its flush growth period. Compared to all other cool-season turfgrasses, ryegrass has the least amount of thatch – some grass experts theorize that this is due to the grass thinning out during the winter months. One of its biggest draws is that it is easy to establish compared to other grass types.[31]

Tall Fescue

Tall Fescue (*Lolium arundinaceum)* is a third cool-season grass and is popular globally. It was introduced in the 1800s in North America by Europeans. The best environment for tall fescue are moist, low-lying pastures. While it is a cool-season grass, it has adapted well to

transition zones of the US where traditional cool-season grasses and warm-season grasses are unable to thrive year round.[32] Compared to all cool-season turfgrasses, TF has the deepest roots (approximately 2-3' deep) and are extremely drought tolerant.[33]

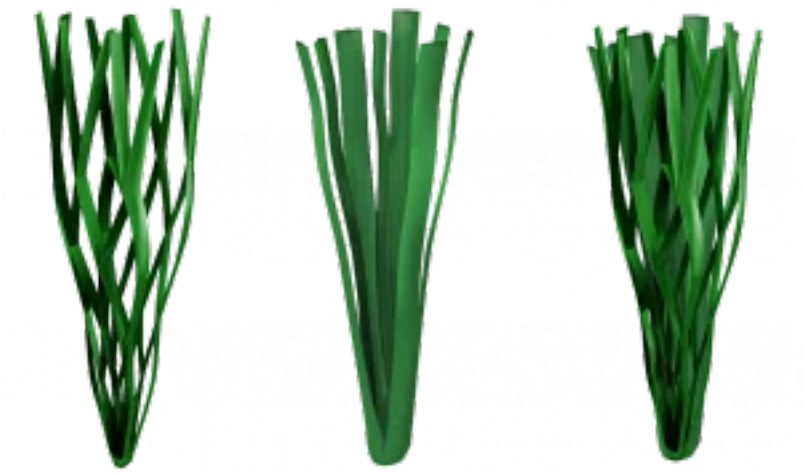
Bermuda Grass

Bermudagrass (*Cynodon* spp.) is one of the most prominent turf species for sport fields globally. *C. dactylon* is the most common species in the United States and was introduced from Africa. While it is extremely successful as a sport field surface, it is a destructive and invasive species for many crops globally garnering names such as "devil's grass" in India. It has destroyed countless corn, sugarcane, cotton, and vineyards globally and is difficult to eradicate due to its deep rhizomes. Bermudagrass thrives in areas where the average temperature is 75F+ but will stay green in locations where the average temperature is 50F+. It is a warm-season grass, but grass experts have developed cold-tolerant cultivars. However, if bermudagrass is exposed to temperatures below freezing, the leaves and stems will die. Dense bermudagrass recovers from damage quickly and tolerates wear. However, it must get full sunlight which is why it is hard for bermudagrass to grow further north.[34]

Artificial

The primary types of synthetic athletic fields are slit film, monofilament fiber, and dual fiber (Figure 1). Slit-film are flat blades that are created by taking a thin sheet of plastic and adding slits to it. Monofilament fibers are blades that stand upright and are dimensional. Dual fiber are a blend of slit film and monofilament blades. [1]

Slit film surfaces are able to sustain significant activity. Twenty-Four/Seven is the most common brand for flit-film football fields. The structure of slit-film fibers as it gets broken in encapsulates infill which reduces maintenance. Generally, monofilament fibers are not used for football fields. Dual fiber is popular for multipurpose fields where durability is the priority.[1]



Three types of artificial turf fibers. Slit-film, Monofilament, and Dual Fiber[1]

AstroTurf was the original artificial surface. It was invented in 1966 and had little to no padding or flexibility.[35] Essentially, short abrasive nylon fibers were glued onto concrete with no infill. This resulted in many injuries. The second generation of turf was created in the 70s by using short polypropylene fibers with sand infill.[36] However, they were longer and thicker than the first generation of AstroTurf and the infill provided a reduction in stiffness.[37] Third and fourth generation turfs are exclusively used now and use softer polyethylene fibers with sand and rubber infill for the third generation and sand and natural infill for the fourth generation.[36]

Distribution of field types - NFL

Natural grass fields are more difficult to maintain, but have less heat retention and are more comfortable for athletes. Bermudagrass is the primary natural grass playing surface in Southern states where it does not get too cold in the winter months. The other three grass types mentioned previously (Bluegrass, Ryegrass, and tall fescue) are found in northern and

transitional states. Third and fourth generation turf are generally used now.[38] In the NFL, only Bermuda and Kentucky Bluegrass are used.

Natural - Bermuda	State Farm Stadium (ARI), M&T Bank Stadium (BAL), TIAA Bank Field (JAX), Arrowhead Stadium (KC), Allegiant Stadium (LV), Raymond James Stadium (TB), Nissan Stadium (TEN), FedExField (WAS), Hard Rock Stadium (MIA)
Natural – Kentucky Bluegrass	Soldier Field (CHI), FirstEnergy Stadium (CLE), Empower Field at Mile High (DEN), Heinz Field (PIT)
Natural – Mix	Levi's Stadium (SF) - Bermuda/Perennial Ryegrass Mixture
Artificial – Field Turf (Revolution, Revolution 360, Classic HD)	Bank of America Stadium (CAR), Gillette Stadium (NE) – FieldTurf Mercedes-Benz Stadium (ATL), - Revolution Ford Field (DET) – FieldTurf Classic HD Caesars Superdome (NO), Lumen Field (SEA) – FieldTurf Revolution 360
Artificial – Hellas Matrix Turf	AT&T Stadium (DAL), NGR Stadium (HOU), SoFi Stadium (LAR, LAC),
Artificial – UBU	Paul Brown Stadium (CIN), MetLife Stadium (NYG, NYJ), U.S. Bank Stadium (MIN)
Artificial – A-Turf Titan 50	Highmark Stadium (BUF)
Artificial – Shaw Sports Momentum Pro	Lucas Oil Stadium (IND)
Hybrid – Desso GrassMaster	Lambeau Field (GB), Lincoln Financial Field (PHI)

Practice facility turf is rarely reported on.

Injury Rates & Turf Type

There have been multiple studies on injuries and playing surface for football players. Natural grass is particularly difficult to study as an exposure due to variation of grass type, soil composition, and other environmental factors.[39] Among literature, this difficulty is shown with contrasting study results, even within the same population. One study conducted within the Australian Football League showed that "low water evaporation and high rainfall significantly lower the risk of ACL injuries."[40] Another study by the same author did not find a significant

correlation between the ground hardness and ACL incidence.[41] When conditions are wet/slippery, there were lower rates of injury on grass, most likely due to decreased friction.[42] Species of grass also has been shown in literature to be associated with different injury rates. Among AFL players, ACL tears occurred "up to 2.13 times more on Bermuda grass than on ryegrass." The researchers theorized that this may be due the thick thatch of Bermuda grass increasing traction.[43]

Increased friction between shoe and surface and stiffness of turf found among synthetic surfaces has been shown in literature to increase risk of lower extremity injuries among football players.[37,44-46] In a systematic review of the relationship between ACL injuries and synthetic turf, researchers found that among American football cohorts, synthetic turf increased risk of ACL injury.[47] Authors of a 2012 study examined the injury rates among playing surfaces (natural grass vs FieldTurf). Results showed that there was no difference in MCL injuries, but higher rates of ACL injuries and knee sprains [44] Other studies found that among college players, those who played on artificial turf were twice as likely to have a big toe injury than a football player who played on grass.[48] The previously mentioned Lawrence et. al study compared natural grass to artificial surfaces. It showed that there were higher rates of shoulder injuries, but lower rates of ankle and knee injuries on natural grass.[26] Other older studies have shown that the rate of knee spraints is around 20% lower on natural grass than artificial turf.[49] However, due to the technological advances in artificial turf over time, it is better to only evaluate the newer studies.[26]

Limitations and Gaps in Literature

Currently, there are very few studies done looking specifically at LE football injuries in the National Football League. Most literature are general surveillance within other leagues or levels of play – particularly pediatric and college populations. Furthermore, there are fewer

recent studies evaluating the association between playing surface and lower extremity injuries. Because of the various advances in grass care, artificial turf technology, and equipment, the relationship between injury and playing surface should be re-evaluated often. Currently, there is also relatively little investigations on various types of artificial turf. Studies generally compare all artificial turf with all types of natural grass. Furthermore, quality and consistent injury reporting is rare in every league. For both privacy and legal reasons, leagues, teams doctors, and player associations keep official injury data protected. Publicly available data (such as databases based on injury reports) have significant limitations.

Unfortunately, finding out the particular turf type and how old surfaces are is difficult as teams and leagues do not frequently report on it. Furthermore, there is very little publicly available data regarding practice surfaces. Most professional and D1 CFB football teams have multiple practice fields, as well as their main field. There is no standard for reporting the precise brand and model, and installation year information from manufacturers is also inconsistent and in some cases confidential.

Manuscript Title: Exploring the Associations of Playing Surface and Lower Extremity Injuries Among National Football League Players

Manuscript

Introduction

American football is a popular and physically demanding sport that requires players to have high levels of physical fitness, strength, and agility. However, it also poses a significant risk of injury to players. Among the primary North American sports (Soccer, Football, Hockey, Basketball, Baseball), football has the highest rate of injuries.[14] With millions of individuals participating annually, it is essential to understand variables contributing to injuries to implement far-reaching injury prevention strategies.[6]

Currently, most football-related health research focuses on preventing concussions and CTE. Lower extremity injuries are common among American football players, and they can significantly impact a player's ability to perform and continue their career. The lower extremity accounts for 3 of the top 5 injury locations. These injuries can range from minor sprains and strains to more severe injuries, such as fractures and tears of the ligaments and tendons. Given the physical demands of the sport and the frequency of these types of injuries, there is a need for a better understanding of the factors that contribute to lower extremity injuries in American football players.

One such factor that has gained attention in recent years is the playing surface. American football is played on a variety of surfaces, including natural grass, artificial turf, and hybrid surfaces. Each surface has its own unique characteristics that can affect the biomechanics of the athlete's movements and increase the risk of lower extremity injuries. Certain types of playing surfaces may increase the risk of lower extremity injury due to differences in surface hardness,

traction, and other factors. Natural grass is the traditional playing surface for football, providing a natural cushioning and impact-absorbing surface that can help reduce the risk of lower extremity injuries. However, natural grass can be challenging to maintain and may be impacted by weather conditions, leading to inconsistencies in surface quality that can increase the risk of injuries. Furthermore, natural grass is both challenging and expensive to maintain, particularly in harsher climates. The rising popularity of domed stadiums also creates challenges to maintaining natural grass fields.

Artificial turf has gained popularity due to its durability and consistent playing surface. While initially invented in the 1960s, the artificial turf technology has increased rapidly. There are four main types of modern artificial turf: monofilament, dual-fiber, slit-film, and hybrid. Monofilament fibers are blades that stand upright and are dimensional. Slit-film are flat blades that are created by taking a thin sheet of plastic and adding slits to it. Dual fiber are a blend of slit film and monofilament blades and hybrid surfaces combine natural grass and synthetic fibers.[1] While the advancement in the base and fibers have decreased injury rates and ware on the body, some studies have still found associations between artificial turf and higher rates of lower extremity injuries, particularly in the knee and ankle. The increased friction between the artificial turf and the player's cleats can lead to increased twisting and torsional forces on the lower extremities, increasing the risk of ligament sprains and tears.

Several studies have investigated the association between playing surface and lower extremity injury among American football players, but the results have been inconsistent.[5] Some studies have reported a higher incidence of lower extremity injury on artificial turf than natural grass, while others have found no significant difference between the two surfaces.[40,41]

Understanding the relationship between playing surface and lower extremity injury is vital for developing injury prevention strategies and improving player safety.

Almost every football season in recent memory, there is some discussion about playing surfaces. In the 2021 season, Odell Beckham Jr. tore his ACL in the Super Bowl, and immediately there was outcry by fans, players, and coaches regarding artificial turf contributing to injuries. In the 2022 season, the Super Bowl was in Arizona at State Farm Stadium. Unlike the previous year, the playing surface was a specially grown grass. However, it was clear that players were struggling through the entire game to gain traction. Fans, players, and coaches again were in an uproar about playing surfaces. Some literature shows that there is a significantly lower injury rate playing on natural grass vs artificial, particularly slit film, turf. However, based on literature this is not always a consistent finding across various leagues, ages, and levels.

By studying the association between playing surface and lower extremity injuries, we can gain valuable insights into the factors that contribute to these injuries and develop strategies to reduce the risk of injury and improve player safety. This information can also inform decisions regarding the choice of playing surface in different settings, such as professional versus amateur leagues, and could potentially impact the design and maintenance of playing surfaces to optimize athlete safety and performance.

In this study, we aim to investigate and describe the association between different types of playing surface and lower extremity injury among American football players, using a retrospective analysis of injury data controlling for team and non-turf stadium effects. We also investigated if there were any major remaining variations in injury rates across stadiums once accounting for turf type and discuss the implications for injury prevention and player safety.

Methods

Data Source

The injury data were collected from a database maintained by the website Football Outsiders (FO, 2007-2021 Seasons)[50]. Every week before a team plays, teams are required to publish an injury report. This injury report lists out the identity of the player, their injury, how much they participated in practice, and the likelihood of their participation in that game that week. [25,51] This database is updated throughout the regular season for all teams without a bye and through the playoffs up until the Super Bowl. This set indicates which week the injury occurred and when the player returned. If necessary, injury severity could be roughly estimated by the number of weeks a player was ruled too injured to play or how long they were on the injury report. Each injury also has its own unique injury id.

Game data were taken from Pro-Football-Refrence.com (PFR). PFR is a sports statistics website maintained by Sports Reference[52]. It was founded in 2003 and contains football information dating back to 1920. Throughout the years, it has been used as a credible source by prominent news sites such as the New York Times, ESPN, and Forbes among others. In this dataset, each game is listed twice (one line for the home team of that game, one line for the away team). It includes the result, day of the week, date, as well as things such as location, surface, roof, and in some cases the temperature. The more detailed playing surface specifications were manually added from online resources, inquiries to turf manufacturers, and other media reports. The dataset queried from this site has games spanning from the 2007 season through the 2021.

Measures

In our dataset, injuries were reported and included location (ie: ankle, hip, knee) and in some cases the specified description (ie: sprain, tendon tear, ACL partial tear). The condensed

injury type standardized this to include “other” for specified description if it was not given initially. The injury type variable listed specifics of injury (if reported) such as “dislocation,” “tear,” “bruise.” This was further simplified to an injury location variable that included 39 general categories including. In some cases, players had multiple injuries. These injury columns were repeated for a second injury, if applicable.

The second primary dataset contains game data. The main measures of this dataset used are the game, teams, and surface. The surface variable contains categories of playing surface including various brands of artificial and hybrid surfaces. This dataset spans the 2007 to the 2021 season.

Exposure

For this study, the exposure is playing surface. While there are many types of natural grass playing surfaces with various geographical distribution, thatch, root density, and hardiness, as outlined in the background, for the purpose of this study all natural grass surfaces are grouped into one category. Artificial turf was categorized into 7 general categories: fieldturf, a_turf, momentumturf, matrixturf, hybrid (dessograss+sisgrass), ubu/turfnation, and actglobal. A binary and trinary surface variable was also created - Artificial Turf/Natural Grass & Natural Grass/Artificial Slit-Film/Other Artificial respectively.

Outcome

The outcome is lower extremity injury. For the purposes of this study, lower extremity injury is described as any reported injury in these locations: groin, knee, ankle, Achilles, thigh, foot, hip, hamstring, pelvis, quadriceps, leg, calf, buttocks. Previous renditions of this study only included events where the reported injury location variable matched “knee” “ankle” or “foot.” Literature shows how a vast majority of lower extremity injuries include sprains and strains. The

literature review also showed that previous injury of any severity (ie: strain, tear etc) was a risk factor for future injury which is why the author decided to expand LE injury to include more specified locations in the data.

Injury Definition

In epidemiology, definitions are important in order to ensure proper classification. In sport injury studies, there have been many established definitions of what an injury is. A study focused on injuries among NFL kickers using the NFL's ISS defined injuries as "significant and reportable if it resulted in premature cessation of at least 1 practice, game, or training event. Additionally, football injuries that were treated in a delayed fashion, even if not associated with premature cessation of play, were also reported."[53] Another study that used the NCAA's ISS defined injuries as "one that (1) occurred as a result of participation in an organized intercollegiate practice or competition and (2) required medical attention by a team certified athletic trainer or physician and (3) resulted in restriction of the student-athlete's participation or performance for 1 or more calendar days beyond the day of injury. If an off day followed the injury event, athletic trainers were asked to assess whether the injured athlete would have been able to participate…include[s] any dental injury occurring in an organized practice or game, regardless of time loss." [54] The data set used for this study came from weekly seasonal injury reports as referenced earlier. The NFL's definition for injuries that are included in the report is wordy, yet unclear and leaves much up to the interpretation of the teams:[51]

> All players with significant or noteworthy injuries must be listed on the report, even if the player takes all the reps in practice, and even if the team is certain that he will play in the upcoming game. This is especially true of key players and those players whose injuries have been covered extensively by the media. … A player who misses a game due to injury or a player who does not finish a game due to injury must be included on the Injury Report each day of the following week…

This open ended definition has led to many issues surrounding the reliability of injury report based data. Firstly, there have been multiple instances of injury report manipulation.[25,55] There is also questions about the reliability of publicly available injury data. A systematic review investigated how reliable studies using publicly available NFL injury data were. In this review, investigators found that included publicly obtained data studies captured around 70% of the concussions that were reported by NFL medical staff to the official NFL injury database.[56] Moreover, it is not reported if the injury is contact or non-contact. It is also unknown where this injury occurred. We have no knowledge of if it occurred during games, during drills in practice, or in training sessions. The dataset does not show the severity as well, only the location (or in some cases, simply lists 'illness'). Of the 37626 injuries reported in these weekly reports between 2007-2021, 547 (1.5%) were designated as unknown. There is some variation between teams, but overall this is a only a small percentage of all injuries reported.

Data Transformation

All cleaning, transformation, and analysis were done in RStudio. The code can be found on Github. Due to privacy and non-disclosure agreements, the injury data used is only available upon request and approval of FO. Please contact the primary author (JYB) to request access.

The first step of the analysis process was to clean then join the two datasets. The game dataset had non-standard team abbreviations. For example, the New Orleans Saints were abbreviated as NOR instead of the league standard NO. Similarly, three teams changed locations during the timeframe of the dataset (the Chargers, Raiders, and Rams). The initial cleaning stage ensured that before the year 2017, the charger were "SD" and 2017 and after, the Chargers has "LAC" designation. The Rams last season in St. Louis was 2015, so from 2016 and after STL changed to LAR. "OAK" and "LVR" changed to simply "LV" after the year 2019 in this mutate

stage as well. These mutation steps were applied to both the Tm variable and Opp variable in the games dataset.

Due to weather, Buffalo's proximity to Canada, and the league's business interest in Europe, some games were played in locations that were not the traditional home stadium of either team competing. From 2007-2021, approximately 41 games fit this description and were played in 6 different locations: Detroit (Ford Field), London (Wembley, Twickenham, Tottenham) Mexico City (Estadio Azteca), and Toronto (Rodgers Center). Between 2007-2021, the domed Ford Field in Detroit was used twice (2010 and 2014) due to bad weather at the originally scheduled stadium. Between 2008-2013, the Buffalo Bills and Rodgers Telecommunication company had an agreement for the Bills to play at least 1 regular season game per year at the Rodgers Centre and three exhibition games. Notably, this is the only international series that was directly negotiated by the team instead of the head league office. The Toronto contract was eventually cancelled in 2014. Between 2018 and 2021, 10 regular season games were played internationally. Using the left join function, the nontraditional location was merged with the game data and matched on Year and Week variable.

Teams do not always stay in the same stadiums even if they stay in the same city. While the Chicago Bears have famously played at Soldier Field since 1924, other franchises have built new stadiums to house their home team. For example, before 2017 the Atlanta Falcons played in the Georgia Dome then played in Mercedes Benz stadium since the 2017 season. The Minnesota Vikings also played in the Hubert H Humphrey Metrodome until 2014 when it was torn down to build the US Bank Stadium. During the two year build process, the Vikings played at Huntington Bank Stadium, home of the University of Minnesota football team. Other teams have also made similar moves which are accounted for in the data. Using the mutate function and searching

through public documentation and reporting of new stadium builds and upgrades, the location variable in the games dataset accounts for these field/stadium changes.

The UBU and Turfnation Brand were combined into one surface category as Turfnation owned the rights to the "UBU" title until 2017. In 2018, ActGlobal bought the rights to the "UBU" title. Both of these models are slit-film. Dessograss and sisgrass were also combined into a hybrid category. A binary and trinary variable was created at this point to the game dataset. In this step, the surface variable was categorized into either Natural Grass or Artificial turf (binary), or Natural Grass, Artificial Slit Film, or Other Artificial (trinary variable) from the general surface variable. A final category variable was made for surface where all the artificial turf brands and natural grass species were specified.

The injury dataset was filtered down to only include regular season games (week 1-16 before the 2020 season, and week 1-17 the 2021 season and after) between the year 2018 through 2021 (our study period). We also only included injuries that resulted in at least one missed game. The game dataset and the injury dataset were joined via the Team, Year, and Week variable. Teams that shared a field (New York Jets and New York Giants and the LA Rams and LA Chargers during and after the 2020 season) were combined in their location.

Analysis

We calculated visiting team injury rates using injury count as the numerator and team games played as the denominator. We used visiting team reported injuries as to not over account for a home teams particularly healthy/unhealthy rosters and training staff quality. By using visiting team injuries, turf types that are less frequent (such as hybrid fields), will not over count home specific home-team attributes. Each observation in our data represented 1 team-game. We compared crude injury rates across all playing surface categories (7 artificial, 1 natural), binary

surface category (artificial vs natural), and trinary surface category (artificial slit film, other artificial, and natural) using Poisson point estimates and confidence intervals. We used similar methods to investigate if there were differences in rude injury rates for visiting teams across different stadiums; we used visiting teams to control for home team factors that may influence stadium injury rates.

We used a Poisson mixed model with a log link function to estimate the association between playing surface and lower extremity injury rates. This model was selected as our outcome is count data (# of injuries) and it allowed us to control for stadium and club-year (e.g. 2021 Seattle Seahawks) as random effects. Our model is as follows:

$$log(LE.Inj.Rate_{T,G,S}) = \beta_0 + \beta_1 Surface_{G,S} + b_0 ClubYears_{G,S} + b_1 Stadium_S + \epsilon_{T,G,S}$$

Our subscripts T,G, and S correspond to Team, Games, and Stadium variables. The outcome for our model was lower extremity injury rate. Our exposure is playing surface. We ran three different models with differing playing surface variables: one where playing surface was a nine category variable (all artificial turf brands and natural grass species specified), one with playing surface as a binary variable (natural grass, artificial turf), and one as a trinary variable (slit film, other artificial, and natural grass). We included two random effects for club-year and stadium as each of those is correlated with turf type but likely to have independent effects on lower extremity injuries due to differences in surface age, grounds crew and maintenance procedures, coaching and training staffs, roster construction, and other differences.

We used random effects for these variables because of their large number of levels and the small amount of data in some strata making partial pooling and shrinkage desirable. Because of the variability between club-years (i.e. changes to coaching staff, schedule, roster, once-in-a-lifetime pandemics etc.) and the fact that club-year levels will never be repeated, random effects

are also more conceptually appropriate for making inferences beyond the team years we have in our study.[57] Because we used the Poisson mixed model with the log link, we can exponentiate the regression coefficient for each level of our exposure in order to get the rate ratio. These ratios represent the ratio of the expected count of the outcome variable for each level of the exposure variable, relative to the reference level.

Results

During our study period (2018-2021 regular season games), there were 2,593 lower extremity injuries resulting in at least one missed game reported. The three most common injury locations were knee (29.3%), ankle (21.5%), and hamstring (16.2%) (Table 1). The average number of career games played by those in the study population was 65. The average week of injury was 8 and on average, players missed four games. Offensive players made up a slightly higher percentage of injuries than defensive players (49.6% vs 48.9%). Of the 976 games in our dataset, 513 (53%) were played on natural grass. 22% of games were played on artificial slit film, and 26% were played on other artificial surfaces (Table 2).

We calculated injury rate per team game using away games only. When divided into two categories (Artificial turf vs Natural Grass), the injury rate per team game was 1.42 (95% CI 1.31-1.53) and 1.31 (95% CI 1.21-1.40) respectively (Figure 1a). When divided into three categories (Artificial sit film, natural grass, and other artificial) we found that slit film had the highest injury rate per team game (1.49 95% CI 1.32-1.65) compared to other artificial (1.36 95% CI 1.22-1.51) and natural grass (1.31 95% CI 1.21-1.40) (Figure 1b). When all artificial and grass types are specified, A-Turf has the lowest IR (1.07 95% CI 0.69-1.45) followed by Hybrid (1.24 95% CI 0.93-1.56), Momentum Turf (1.30 95% CI 1.02-1.58), Bermuda Grass (1.30 95% CI 1.20-1.41), Kentucky Bluegrass (1.34 95% CI 1.10-1.57), FieldTurf (1.43 95% CI 1.24-1.62), MatrixTurf (1.56 95% CI 1.20-1.82), and finally Ubu/Turfnation (2.04 95. % CI 1.70-2.39) (Figure 1c).

We also compared injury rates by stadium (n=35) (Figure 1d). The injury rates were also per team game using the visiting team injuries only. Of the 35 stadiums, 3 are international (London-Tottenheime, London Wembly, and Mexico). Three are no longer in use as of 2022, but

were in use during some point of the study period (Oakland, LA-Dig, and LA-Col). The stadiums with the lowest injury rate are LA-Dig, Bermuda grass, (0.71 95% CI 0.27-1.16), San Francisco 49ers Levi Stadium, Bermuda Grass (0.87 95% CI 0.54-1.20), and the LA Colosseum, Bermuda grass (0.92 95% CI 0.40-1.45). The Houston Texan's NGR Stadium with matrixturf had the median IR (1.41 95% CI 0.98-1.85). AT&T Field in Dallas had the highest missed game IR (1.77 95% CI 1.31-2.24).

We also explored the yearly injury rates by year and turf type to see if there were differences over time (Figure 2). When surfaces are divided into three categories (natural grass, artificial slit-film, and other artificial), we see overall that in 2019, 2020, and 2021, slit film has the highest overall injury rates (1.55 95% CI 1.21-1.98;1.63 95% CI 1.29-1.98; 1.52 95% CI 1.20-1.84). In 2018 and 2021, natural grass fields had the lowest injury rates (1.15 95% CI 0.97-1.33; 1.33 95% CI 0.99-1.53). In 2019, artificial non-slit film fields had the lowest injury rate (1.14 95% CI 0.85-1.41) and in 2020 artificial non-slit film fields and natural grass fields essentially had the same injury rate, with natural grass having a slightly narrower 95% confidence interval (Artificial: 1.50 95% CI 1.21-1.79; Natural: 1.49 95% CI 1.27-1.71).

Model Outcome

We ran 3 models. Each model had a different surface category – 2 category (natural, artificial), 3 category (slit film, other artificial, natural grass), and all surface variable (A-Turf, Hybrid, ActGlobal, MatrixTurf, Bermuda Grass, FieldTurf, Kentucky Bluegrass, Ubu/Turfnation, and Momentum Turf). Our model ran with the 3 category surface variable had the lowest intercept p-values. While none of the fixed effect estimates had significance, the models still shows an important relationship. Our model output generally follows the trends of our data (Table 3-5). Artificial slit-film has the highest injury rate ratios (1.14 95% CI 0.97-

1.32). The two major slit-film models, UBU/TurfNation and MomentumTurf, had the highest IRR's for the all surface model ran (UBU: 1.33 95% CI .92-1.94, MT: 1.31 95% CI 0.91-2.01). These results continue to show us that overall, slit-film fields will tend to have higher injury rates than other types of surfaces (Figure 3a-c).

Discussion

American Football is a full-contact sport and is inherently dangerous. The results of this study contribute to the existing body of literature examining risk factors, notably environmental variables, of lower extremity injuries among professional football players. Some studies have examined variables such as position, player weight, and career length, while other studies have, like this study, examined playing surface.[14-16] The results of our study suggest an association between playing surface type and lower extremity injury rates among NFL players. Specifically, artificial slit film fields tend to have the highest injury rates, followed generally by other artificial turf (monofilament, dual filament, and hybrid surfaces), then natural grass. Results from an internal IQVIA study also support these results.[58] This finding is important because it highlights the role of playing surface in injury incidents in the NFL and beyond.

There are numerous implications for these results. Moving forward, NFL teams & their owners should prioritize player health and protect their investments in individual players by removing all slit film turf from competition and practice fields. Switching to natural grass is generally the better option; however, some stadiums and practice facilities are not set up to realistically house a grass field and maintain it at a high level. In cases where it is virtually impossible to have a natural grass field, other artificial or hybrid fields should be installed. Other sports organizations, particularly football leagues such as the NCAA, AFL, and XFL, should consider these findings and implement similar changes to their practice and competition fields to minimize the risk of lower extremity injuries to players. Moreover, as future stadiums are built, they should be designed to allow for the installation and maintenance of natural grass fields. However, in leagues with less money and the ability to maintain natural grass fields, non-slit film artificial turf may be the better alternative.

Various limitations to our study should be taken into account. Firstly, the injury data was compiled from weekly injury reports from individual teams. These injury reports are often vague; as stated earlier, there is no specific definition for what constitutes an injury.[51] There have also been multiple recorded instances of injury report manipulation, and teams have willfully reported injuries in a way to give themselves a tactical advantage.[25,55] While these teams had to pay fines, these inaccuracies contribute to this data's limitations. Furthermore, injury reports do not give us a location/time of injury, so we do not know if the injury occurred in game or during practices. Finally, our data is limited because we do not know the severity of injuries. This can be difficult for our results because natural grass may have fewer injuries overall, but the injuries may be more severe. The data only shows us the location of the injury.

Another limitation of this study is that we only focus on the NFL. There are many levels of football spanning a multitude of age ranges and fitness levels. Our literature review highlighted differences in injury rates among NCAA players of different ages. These results suggest that age may play a more significant role, and some ages may also have lower injury rates on different field surfaces. Moreover, NFL competition fields have large maintenance crews and are preserved pristinely. There may be less money to invest into playing surfaces at lower levels of play, such as recreation leagues or D3 schools. Natural grass can be challenging to maintain well throughout an entire season of football and during the off-season. This study does not consider how a lack of maintenance of fields can contribute to injury rates, making it less generalizable.

While our study provides valuable insights into the relationship between playing surface type and lower extremity injuries among NFL players, many unanswered questions warrant further research. Players have different recovery times for injuries, and it would be useful to

explore the impact of playing surface on injury severity and recovery time. Our data did include weeks missed but did not give us any official indication of injury severity. A more detailed data collection method would need to be employed with the cooperation of all 32 teams to compile a robust public dataset to help answer this line of inquiry. While this study focused on the incidence of lower extremity injuries, it did not examine how the playing surface affected the severity of these injuries. Future research could investigate whether certain surfaces are associated with higher rates of more severe injuries or longer recovery times. Literature also shows that previous injury is a risk factor for re-injury, so it would be interesting to see if certain players are more susceptible to injuries on specific fields.[59]

Another interesting future direction could be to investigate the role of individual player characteristics, biometrics, and playing styles in modifying the relationship between playing surface and injury rates. Specific players and positions may have different movement strategies that could affect their risk of injury on different playing surfaces. Likewise, players with prior injury histories could be more or less sensitive to certain playing surfaces. Another potential direction for future research would be to examine the playing surface's impact on NFL players' long-term health outcomes. This study focused specifically on the relationship between playing surface and lower extremity injury rate in the short term. Other studies could explore the possibility that repeated exposure to certain surfaces or injuries sustained on specific surface types could have cumulative effects on joint and muscle health. Furthermore, studies could also investigate the impact of factors such as weather, field maintenance, and cleat design on the relationship between playing surface and lower extremity injuries.

This study provides valuable insights into the relationship between playing surface and lower extremity injuries among NFL players. However, more research is needed to fully

understand the complex relationship between playing surface, injury, and long-term health outcomes for athletes. By working to understand better the impact of playing surfaces on athlete health, we can help ensure that sports continue to be a safe and enjoyable activity for players at all levels of play. The findings of future studies can inform injury prevention and management strategies, as well as the design and construction of professional sports facilities.

Appendix: Figures & Tables

Table 1: Characteristics of Injury Data

Lower Extremity Injuries	**N = 2,593**[1]
Injury Location	
Achilles	56 (2.2%)
Ankle	558 (21.5%)
Calf	133 (5.1%)
Foot	229 (8.8%)
Groin	182 (7.0%)
Hamstring	421 (16.2%)
Hip	97 (3.7%)
Knee	760 (29.3%)
Leg	31 (1.2%)
Quadriceps	88 (3.4%)
Thigh	38 (1.5%)
Career Games	65 (45)
Side	
Defense	1,267 (48.9%)
Offense	1,287 (49.6%)
ST	39 (1.5%)
Week Occured	8 (5)
Games Missed	4 (3)

[1] n (%); Mean (SD)

Table 2: Playing Surface Characteristics

Games	**N = 976**[1]
All Surface	
a_turf	29 (3.0%)
actglobal	22 (2.3%)
Bermuda	420 (43.0%)
fieldturf	150 (15.4%)
Hybrid	36 (3.7%)
Kentucky Bluegrass	92 (9.4%)
Kikuyu	1 (0.1%)
matrixturf	91 (9.3%)
momentumturf	63 (6.5%)
ubu/turfnation	72 (7.4%)
Binary Surface	
Artificial Turf	463 (47.4%)
Natural Grass	513 (52.6%)
Trinary Surface	
Artificial Slit-Film	213 (21.8%)
Natural Grass	513 (52.6%)
Other Artificial	250 (25.6%)

[1] n (%)

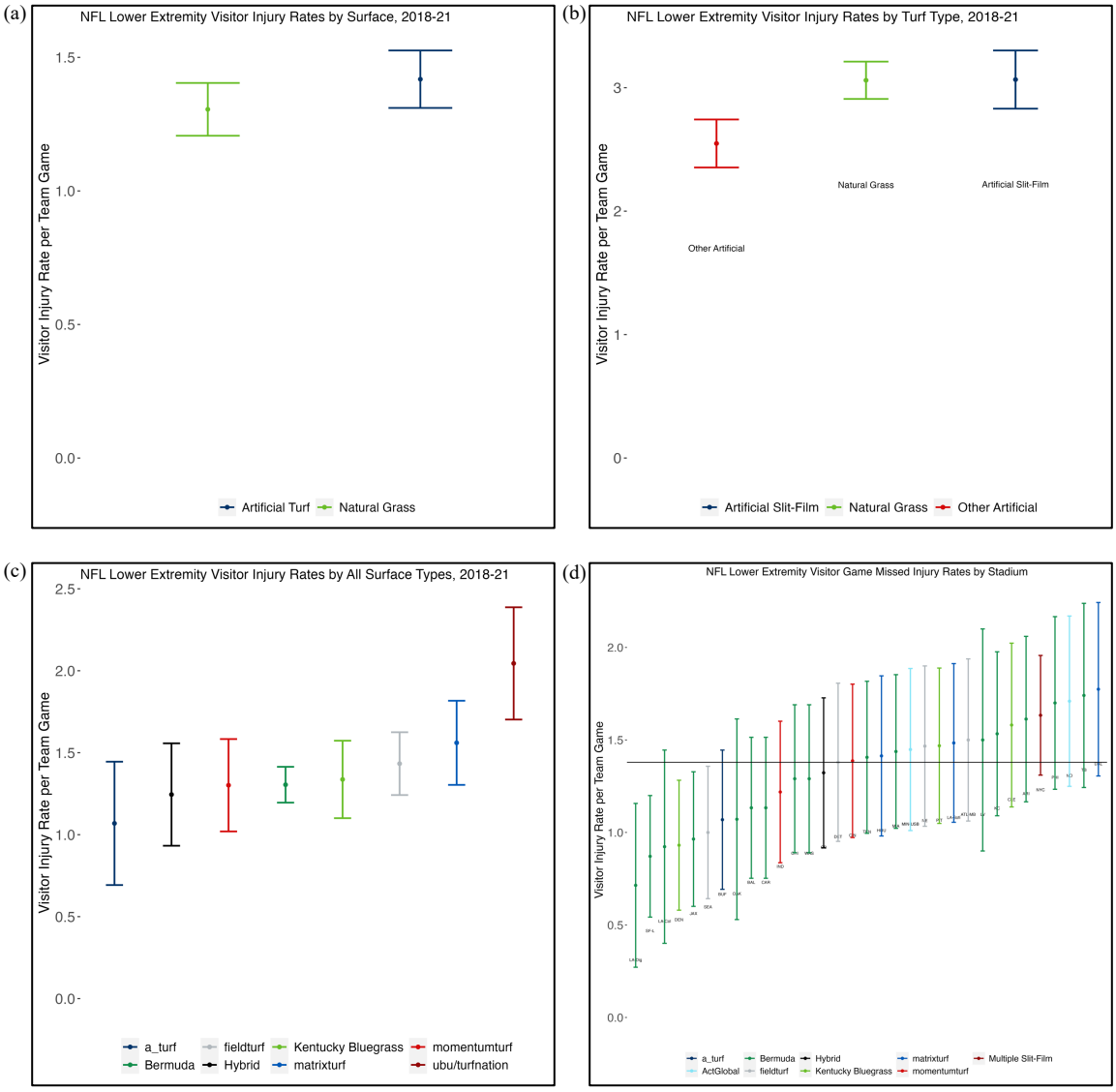


Figure 1: Visitor Injury Rates per Team Game for Binary Surface Category (a), Trinary Surface Category (b), All Surfaces (c), and by Stadium (d)

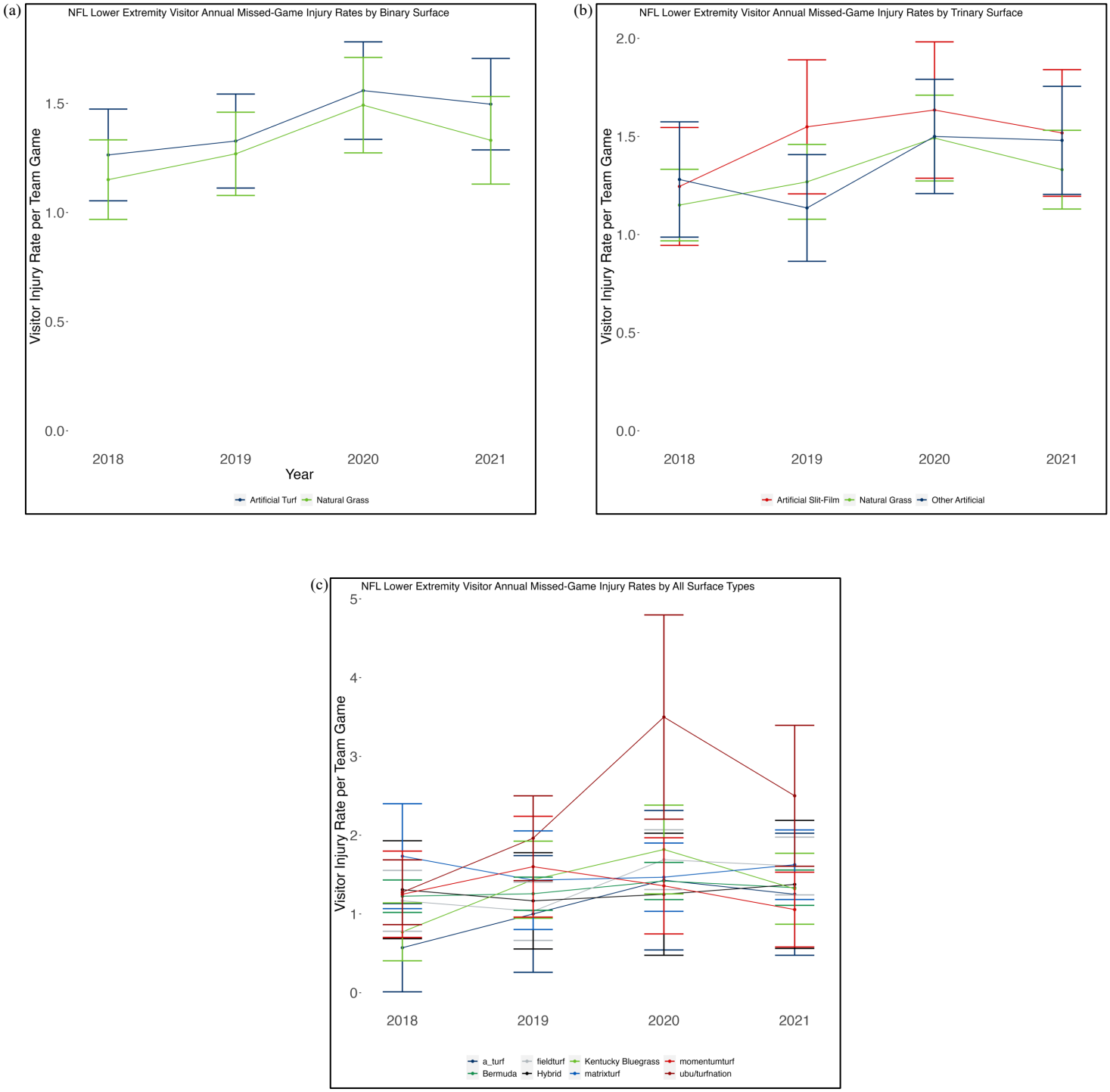


Figure 2: Lower Extremity Visitor Injury Rates per Team Game for Binary Surface Category (a), Trinary Surface Category (b), All Surfaces (c) – by Year

(a)

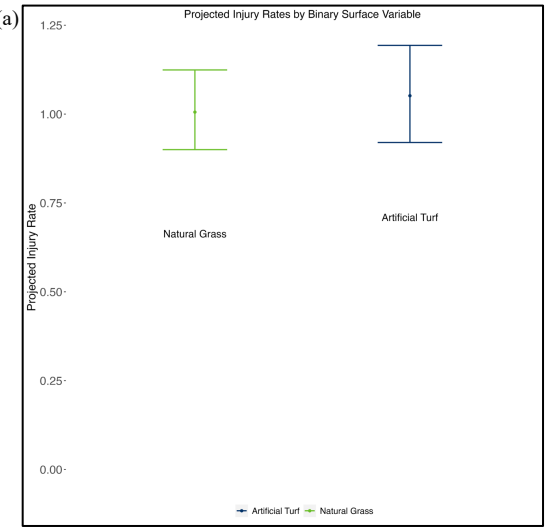


Table 3: Model Binary Surface Category Output

	Estimates	LL	UL
Natural Grass	1.01	0.90	1.12
Artificial Turf	1.05	0.92	1.19

(b)

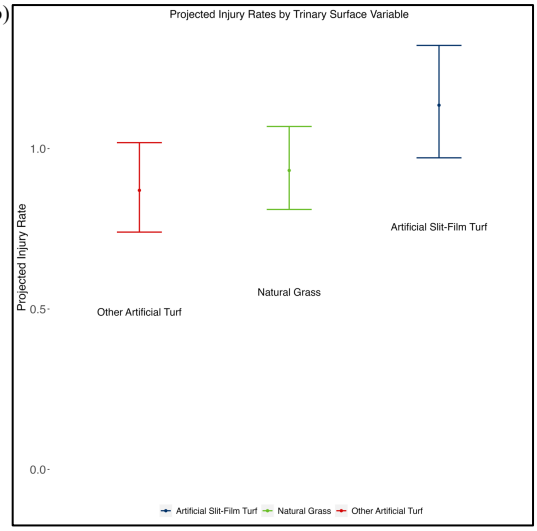


Table 4: Model Trinary Surface Category Output

	Estimates	LL	UL
Other Artificial Turf	0.87	0.74	1.02
Natural Grass	0.93	0.81	1.07
Artificial Slit-Film Turf	1.14	0.97	1.32

(c)

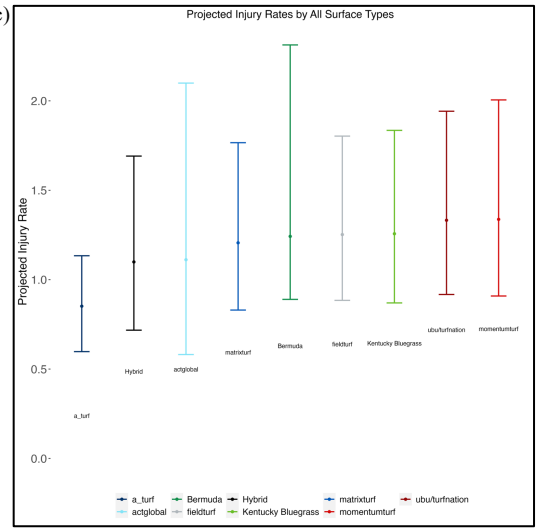


Table 5: Model All Surface Category Output

	Estimates	LL	UL
a_turf	0.85	0.60	1.13
Hybrid	1.10	0.72	1.69
actglobal	1.11	0.58	2.10
matrixturf	1.21	0.83	1.77
Bermuda	1.24	0.89	2.31
fieldturf	1.25	0.88	1.80
Kentucky Bluegrass	1.26	0.87	1.83
ubu/turfnation	1.33	0.92	1.94
momentumturf	1.34	0.91	2.01

Figure 3: Model Projections for binary (a), trinary (b), and all surface (c) exposure category.

Public Health Implications

Football is the most popular sport in America – both as a spectator and participant.[7,9,60-62] With millions playing recreationally, we as public health practitioners must take steps to ensure that injury prevent is prioritized. In 2015 there were over 2 million emergency room visits related to youth sports and 1.1 million were related to tackle football.[5] Among the study population, 46 (43.2%) had trauma to their upper extremities and 487 (32.6%) to their lower extremities.[5] Studies using the National Electronic Injury Surveillance System (NEISS) database confirm these results. Even though injuries in other sports have been consistently decreasing, football injuries increased by 22%.. Participation in football generally leads to the most injuries than any other activity and pediatric populations are shown to be the most vunerable.[14] In a modern world where physical activity has been continually dropping, recreational sport injuries, especially at a young age, can lead to longer term health consequences.

Football players who participate at a high level (both college and professional) are at high risk for injuries during their career. However, most players suffer from long term consequences of playing such an intensive sport that drastically affects both their physical and mental health as well as their interpersonal relationships. 40% of retired NFL players under 60 years old suffer from arthritis. In the general population, only 11% of males under 60 suffer from arthritis.[63] 48% of retirees report difficulty with pain and almost 15% suffer from some form of depression. Both of these are correlated with relationship problems, exercise/fitness problems, financial difficulties and sleeping problems.[64] These long term consequences show that injury prevention must be at the forefront of decision making at all levels of play.

Research in football injuries have been increasing greatly and the NFL has provided a lot of money and attention towards research and injury prevention programs.[65] With as many

participants as it has, football focused injury prevention will impact millions annually. Future research should continue examining various parts of the Haddon's injury prevention matrix as it relates to football. Host factors has been studied extensively. We know that weight, position, previous injury, and career length contributes to future injury. Being able to study football players at every level will help create demographic specific injury prevention measures. Coaches and trainers should also be trained extensively on injury prevention for the demographic that they work with the most. Environmental factors, such as playing surface, also needs to be examined more in order to create the safest playing environment possible. Furthermore, rule changes and safety equipment can help decrease injuries as well. We know now through research that the chop-block ban the NFL implemented in 2016 has decreased injuries. Other agent factors such as equipment and other rule changes need to be studied at every level in order to ensure that football continues to grow safer every year.

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