Risk of Knee and Ankle Sprains under Various Weather Conditions in American Football

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ABSTRACT

ORCHARD, J. W., and J. W. POWELL. Risk of Knee and Ankle Sprains under Various Weather Conditions in American Football. *Med. Sci. Sports Exerc.*, Vol. 35, No. 7, pp. 1118–1123, 2003. **Purpose:** Previous studies have found conflicting relationships between type of playing surface and injury in American football but have not taken into account possible variations in the surface conditions of outdoor stadiums due to changing weather. **Methods:** A total of 5910 National Football League team games between 1989 and 1998 inclusive were studied to determine associations between knee and ankle sprains, playing surface, and the weather conditions on the day of the game. **Results:** There was reduced risk of significant ankle sprains (at least 7-d time loss) for games in natural grass stadiums compared with domes (indoor stadiums using AstroTurf) (RR 0.69, 95% CI 0.58–0.83). There was also reduced risk of significant knee sprains on grass compared with domes (RR 0.77, 95% CI 0.66–0.91), although most of this reduction was related to cold and wet weather on grass (RR 0.66, 95% CI 0.47–0.93 compared with hot and dry weather on grass). In open (outdoor) AstroTurf stadiums, cold weather was associated with a lower risk of significant ankle sprains (RR 0.68, 95% CI 0.51–0.91), significant knee sprains (RR 0.60, 95% CI 0.47–0.77) and ACL injuries (RR 0.50, 95% CI 0.31-0.81) compared with hot weather in the same stadiums. Weather did not have any significant effects on the injury risk in domes. The ACL incidence rate was lower during the later (cooler) months of the season in open stadiums (both AstroTurf and natural grass) but not in domes. **Conclusion:** Cold weather is associated with lower knee and ankle injury risk in outdoor stadiums (both natural grass and AstroTurf), probably because of reduced shoe-surface traction.
Key Words: KNEE INJURIES, ANKLE INJURIES, SHOE-SURFACE TRACTION, ARTIFICIAL TURF

The National Football League (NFL) has been conducting its injury surveillance system since 1980, which is thought to be longer than any other professional sporting competition in the world (20,22). Risk factors for injury can be divided into intrinsic (player-related) and extrinsic (environment-related). Many of the documented intrinsic risk factors for injury are nonreversible, such as player age, sex, and past history of injury. A potential extrinsic risk factor of interest within the sports medicine community has been the playing surface (1,3,5–7,9,11,12,14,19,20,22,26,27). Injury causation is complex, with potential interactions between surface type and other extrinsic (e.g., weather, type of play) and intrinsic (e.g., player position, age, injury history, and shoe selection) variables.

Many studies in the 1970s and 1980s compared the injury rates between artificial surfaces, such as AstroTurf (Southwest Recreation Industries, Leander, TX), and natural grass. (In this study AstroTurf and artificial turf will be used interchangeably, as this report covers a time period when AstroTurf was the only type of artificial surface used in the NFL.) There have been conflicting conclusions from the results of these studies. Many studies have found that artificial turf and grass have a similar overall injury rate (12,14,20–22,25,26). Injuries to the foot and ankle have been reported as slightly more common on AstroTurf than grass (3,20–22,26). Injuries to the knee have been reported as either not related to the playing surface or slightly more common on artificial turf (3,20–22,26). The relative risk for injuries on AstroTurf compared with natural grass has varied when the data were controlled for player position and type of play (22).

Surface characteristics (such as hardness) of AstroTurf and particularly natural grass are quite variable (11). Natural grass varies widely in soil moisture content, soil type, and species of turfgrass. Previous studies that have compared injury rates on natural grass and artificial turf have generally not assessed the condition of either surface, which could be a reason for the conflicting conclusions from these studies.

The aim of this study was to describe the association between weather conditions and knee and ankle sprains for natural grass and AstroTurf surfaces in the NFL for the 10 seasons 1989–1998, as weather conditions are responsible for some of the variation in surface characteristics in outdoor stadiums.

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METHODS

Injury surveillance. Athletic trainers at each NFL club collected injury data for this study over the years 1989–1998 as part of the NFL Injury Surveillance System. The injury definition for this surveillance system was "any injury that caused cessation of an athlete's customary participation throughout two participation days after the day of onset." There were further aspects to the NFL survey definition of an injury, but these related to concussions and fractures, which were not analyzed as part of this study. Only those injuries that occurred during a game were considered. Player details were not exported from the NFL Injury Surveillance system for this study.

Knee sprains (ligament injuries) were subdivided into: 1) ACL sprains; 2) MCL sprains; and 3) other knee sprains (such as PCL, LCL, and nonspecific ligament sprains) based on their primary diagnosis (that is, the diagnosis considered by the recording athletic trainer and physician to be primarily responsible for the time loss). Ankle sprains were subdivided into: 1) inversion sprains; 2) eversion sprains; and 3) other sprains, based on their primary diagnosis. Inversion sprains included lateral ligament sprains and anterior capsule sprains, whereas eversion sprains included medial ligament and distal tibiofibular sprains. Knee and ankle sprains had the severity of injury calculated, based on time loss. A category of "significant injuries" was created for injuries that missed at least 7 d of practice and/or game time.

The games under consideration were those occurring in seasons 1989–1998 inclusive, in either the preseason, regular season, or postseason, played at the regular home stadiums of NFL teams (Table 1). With respect to playing conditions, the stadiums were grouped as either being: 1) A natural grass surface with an open roof (grass), 2) an artificial turf surface with an open roof (open turf), or 3) an artificial turf surface with a closed roof (dome).

For the time period under consideration, there were no games played on natural grass surfaces in closed stadiums. Some open stadiums changed from artificial surfaces to natural grass surfaces over the time of study, and some teams moved their home stadium during this period to another with different conditions, even though it may have been in the same city. Some teams relocated from one city to another. All of these changes were taken into account, so that the data for each stadium reflected the ground and roof type on the documented days.

Weather data. Weather information was obtained through the National Climatic Data Center (NCDC) web site http://www.ncdc.noaa.gov/. Daily information of precipitation and maximum temperature over the period July 1988–January 1999 was obtained for each station. The closest station to each stadium that had data for the entire study period was used. Anaheim (LA Rams) and Los Angeles (LA Raiders) were considered distinct locations, as were Baltimore and Washington, DC. A station was available for every city with an NFL team except for Foxboro (New England Patriots), for which the nearby town of Brockton was used. The vast majority (well over 95%) of the weather-related variables were available, although there were occasional missing data. Because the weather variables were to be converted to binary categorical data (hot and cold days; rain and no rain), it was decided to approximate the missing values. Where the downloaded data had missing elements, the following procedures were used to complete the data set:

1) For missing temperature elements of 1–2 d duration, the same temperature reading from the previous or following day (depending on which was closest to the median for that time of year) was taken.

2) For missing rainfall elements, or temperature elements that were missing in blocks of greater than 2 d, the readings from the closest other city was used; for example, if New York had 1 wk of missing temperature readings, then these were imported from the Philadelphia data set over the same dates to complete the set.

Using this procedure, every venue had a complete daily data set for precipitation and maximum temperature for all calendar dates (July 1988–January 1999 inclusive). Categorical variables from the continuous weather data were created to allow discrete stratified analysis. For rainfall this was based on presence or absence of any precipitation ("wet days" or "dry days"). For maximum temperature, this was based on whether the temperature was equal to or greater than 70°F (21°C) (referred to in the analysis as "hot days") or less than 70°F (referred to as "cold days"). This cut-off

TABLE 1. Stadiums and cities in the analysis (1989–98 seasons).

Surface	City	Stadium
AstroTurf (domes)	Atlanta	Georgia dome
	Detroit	Pontiac Silverdome
	Houston	Astrodome
	Indianapolis	RCA (Hoosier) dome
	Minneapolis	Metrodome
	New Orleans	Superdome
	Seattle	Kingdome
	St. Louis	TransWorld dome
AstroTurf (open roof)	Buffalo	Ralph Wilson (Rich)
	Cincinnati	Cinergy Field (Riverfront)
	Dallas	Texas Stadium
	East Rutherford, NJ	Giants Stadium
	Nashville	Vanderbilt
	Philadelphia	Veterans Stadium
	Pittsburgh	Three Rivers Stadium
	St. Louis	Busch Stadium
Mixed (open roof)	Chicago	Soldier Field
	Foxboro, MA	Foxboro Stadium
	Kansas City	Arrowhead Stadium
Natural grass	Atlanta	Fulton County Stadium
	Anaheim	Anaheim Stadium
	Baltimore	Memorial Stadium
		PSINet Stadium
	Charlotte	Clemson Stadium
		Ericsson Stadium
	Cleveland	Cleveland Stadium
	Denver	Mile High Stadium
	Green Bay	Lambeau Field
	Jacksonville	Alltel Stadium
	Los Angeles	LA Coliseum
	Memphis	Liberty Bowl
	Miami	Pro Player (Joe Robbie)
	Milwaukee	Milwaukee County
	Oakland	Alameda County Stadium
	Phoenix	Sun Devil Stadium
	San Diego	Qualcomm (Jack Murphy)
	San Francisco	3Com (Candlestick) Park
	Tampa Bay	Houlihan's
		Raymond James
	Washington, DC	RFK/Jack Kent Cook

TABLE 2. Comparison of incidence rates for various injuries on different surface types.

Injury Type	No. of Injuries	Incidence Rates (Injuries/Team Season)				Relative Rates (95% CI)		
		All	Dome	Open Turf	Grass	Open Turf: Dome	Grass: Dome	Grass: Open Turf
Knee sprains	1609	5.5	6.2	6.0	4.8	0.97 (0.83–1.13)	0.78 (0.68–0.90)	0.81 (0.71–0.93)
Significant knee sprains	1140	3.9	4.4	4.1	3.4	0.93 (0.78–1.11)	0.77 (0.66–0.91)	0.83 (0.71–0.97)
MCL sprains	932	3.2	3.6	3.4	2.8	0.95 (0.79–1.15)	0.79 (0.66–0.93)	0.82 (0.70–0.97)
ACL sprains	252	0.9	0.9	0.9	0.8	0.96 (0.69–1.36)	0.82 (0.60–1.12)	0.85 (0.63–1.15)
Ankle sprains	1518	5.1	6.4	5.6	4.3	0.87 (0.74–1.01)	0.67 (0.58–0.78)	0.78 (0.68–0.89)
Significant ankle sprains	773	2.6	3.3	2.7	2.3	0.83 (0.68–1.02)	0.69 (0.58–0.83)	0.83 (0.70–1.00)
Ankle inversions	625	2.1	2.5	2.4	1.8	0.97 (0.78–1.20)	0.71 (0.58–0.87)	0.73 (0.60–0.89)
Ankle eversions	713	2.4	3.0	2.6	2.1	0.87 (0.71–1.07)	0.70 (0.58–0.85)	0.80 (0.67–0.97)

temperature was selected because it was the mean maximum daily temperature for all game days.

Data analysis. Injury incidence was calculated as a unit of injuries per team season (injuries per 20 team games). Injury rates were compared between different stadium types (dome/open, AstroTurf/grass) and then within stadium types for different weather conditions (hot/cold and wet/dry) on the day of the game.

The reference stadium type when comparing stadiums was domes (therefore, risk for open AstroTurf and grass is expressed relative to domes). The reference weather conditions were hot days, dry days, and hot & dry days. Therefore, on grass, for example, risk on a cold day is expressed relative to risk on a hot day, and risk on a hot & wet day is expressed relative to risk on a hot & dry day. Multivariate analysis considering both stadium conditions and weather conditions in the same equation was not performed, as outside weather conditions would not have had a comparable effect on different stadium types. This is because domes are shielded from the outside weather, and even in outdoor stadiums, the effect of weather conditions on AstroTurf compared with natural grass is likely to be very different.

The 95% confidence intervals (95% CI) for relative risks were calculated using a Taylor series expansion (17,24).

RESULTS

There were 5910 team games and of these, there were 2910 games on natural grass (all in the open air) and 3000 on artificial turf, with 1624 of these played in the open and 1376 in a domed stadium. There were 40 venues analyzed in 35 distinct locations (Table 1).

There were 1609 knee sprains over the period of study that occurred in games in those stadiums under consideration. The knee sprains represented 13% of all injuries. There were 1518 ankle sprains in the same games (12% of all injuries). The breakdown of knee and ankle injuries is shown in Table 2.

Games in domes had a similar risk for all injury types on wet days compared with dry days, and on hot days compared with cold days. This was expected, as domes are shielded from the outside weather conditions. However, in open AstroTurf and grass stadiums there were weather conditions that showed significantly different injury risk compared with other weather conditions on the same surface, as shown in Tables 3 and 4.

Table 2 shows a reduced risk of significant knee sprains on grass compared with domes (RR 0.77, 95% CI 0.66–0.91). Table 3 reveals that most of this reduction was related

TABLE 3 (a). Comparison of incidence rates for various injuries in different weather conditions on natural grass.

Injury	No. of Injuries	Incidence Rates (Injuries/Team Season)				Relative Rates (95% CI)	
		Hot	Cold	Dry	Wet	Cold:Hot	Wet:Dry
Knee sprains	703	5.0	4.6	4.8	4.9	0.93 (0.78–1.10)	1.01 (0.83–1.22)
Significant knee sprains	499	3.8	2.9	3.5	3.4	0.77 (0.63–0.94)	0.98 (0.78–1.22)
MCL sprains	409	2.8	2.8	2.9	2.6	0.98 (0.79–1.21)	0.91 (0.71–1.16)
ACL sprains	113	0.9	0.6	0.7	1.0	0.69 (0.47–1.03)	1.46 (0.98–2.18)
Ankle sprains	627	4.5	4.1	4.6	3.5	0.92 (0.77–1.11)	0.76 (0.61–0.94)
Significant ankle sprains	329	2.4	2.2	2.3	2.1	0.92 (0.72–1.16)	0.93 (0.71–1.21)
Ankle inversions	257	1.7	1.9	1.9	1.4	1.11 (0.85–1.43)	0.77 (0.56–1.05)
Ankle eversions	301	2.2	1.9	2.2	1.7	0.83 (0.65–1.06)	0.75 (0.56–1.00)

TABLE 3 (b). Comparison of incidence rates for various injuries in different weather conditions on natural grass.

Injury Type	Incidence Rates (Injuries/Team Season)				Relative Rates (95% CI)		
	Hot & Dry	Hot & Wet	Cold & Dry	Cold & Wet	Hot & Wet: Hot & Dry	Cold & Dry: Hot & Dry	Cold & Wet: Hot & Dry
Knee sprains	4.8	5.5	4.8	4.3	1.14 (0.88–1.48)	0.99 (0.81–1.21)	0.88 (0.67–1.15)
Significant knee sprains	3.6	4.4	3.2	2.4	1.22 (0.91–1.62)	0.87 (0.69–1.10)	0.66 (0.47–0.93)
MCL sprains	2.9	2.8	2.9	2.5	0.98 (0.70–1.37)	1.03 (0.81–1.32)	0.87 (0.62–1.21)
ACL sprains	0.8	1.3	0.6	0.7	1.74 (1.05–2.86)	0.74 (0.45–1.21)	0.93 (0.51–1.70)
Ankle sprains	4.6	4.0	4.7	3.0	0.88 (0.66–1.17)	1.02 (0.83–1.25)	0.65 (0.48–0.88)
Significant ankle sprains	2.3	2.4	2.2	2.0	1.00 (0.70–1.44)	0.95 (0.73–1.25)	0.83 (0.57–1.21)
Ankle inversions	1.7	1.6	2.1	1.3	0.95 (0.62–1.45)	1.25 (0.94–1.68)	0.75 (0.48–1.17)
Ankle eversions	2.3	1.9	2.1	1.4	0.82 (0.55–1.21)	0.88 (0.67–1.17)	0.62 (0.41–0.94)

TABLE 4 (a). Comparison of incidence rates for various injuries in different weather conditions on artificial turf in open stadiums.

Injury	No. of Injuries	Incidence Rates (Injuries/Team Season)				Relative Rates (95% CI)	
		Hot	Cold	Dry	Wet	Cold:Hot	Wet:Dry
Knee sprains	485	7.1	5.1	5.9	6.1	0.71 (0.58–0.88)	1.02 (0.81–1.29)
Significant knee sprains	336	3.8	3.2	4.2	4.0	0.60 (0.47–0.77)	0.96 (0.74–1.25)
MCL sprains	277	3.6	3.3	3.3	3.7	0.92 (0.71–1.19)	1.13 (0.86–1.50)
ACL sprains	74	1.3	0.6	1.0	0.6	0.50 (0.31–0.81)	0.61 (0.34–1.09)
Ankle sprains	451	6.0	5.2	5.5	5.7	0.86 (0.69–1.07)	1.04 (0.82–1.31)
Significant ankle sprains	220	3.3	2.3	2.7	2.8	0.68 (0.51–0.91)	1.03 (0.75–1.40)
Ankle inversions	196	3.1	1.9	2.4	2.3	0.61 (0.45–0.82)	0.96 (0.69–1.33)
Ankle eversions	209	2.4	2.7	2.6	2.5	1.11 (0.83–1.49)	0.94 (0.68–1.30)

TABLE 4 (b). Comparison of incidence rates for various injuries in different weather conditions on artificial turf in open stadiums.

Injury Type	Incidence Rates (Injuries/Team Season)				Relative Rates (95% CI)		
	Hot & Dry	Hot & Wet	Cold & Dry	Cold & Wet	Hot & Wet: Hot & Dry	Cold & Dry: Hot & Dry	Cold & Wet: Hot & Dry
Knee sprains	7.0	7.8	5.0	5.3	1.12 (0.78–1.60)	0.71 (0.55–0.92)	0.76 (0.56–1.02)
Significant knee sprains	5.4	5.1	3.1	3.5	0.95 (0.64–1.43)	0.57 (0.43–0.76)	0.65 (0.46–0.91)
MCL sprains	3.5	4.0	3.1	3.6	1.14 (0.72–1.79)	0.89 (0.65–1.22)	1.04 (0.73–1.49)
ACL sprains	1.4	0.7	0.7	0.6	0.46 (0.18–1.18)	0.45 (0.26–0.79)	0.43 (0.21–0.87)
Ankle sprains	6.0	6.2	5.0	5.5	1.03 (0.70–1.52)	0.84 (0.65–1.09)	0.91 (0.68–1.23)
Significant ankle sprains	3.2	3.6	2.2	2.4	1.10 (0.69–1.77)	0.67 (0.48–0.95)	0.74 (0.50–1.11)
Ankle inversions	3.1	3.2	1.8	2.0	1.02 (0.63–1.68)	0.60 (0.42–0.86)	0.64 (0.41–0.98)
Ankle eversions	2.5	2.2	2.8	2.6	0.90 (0.51–1.59)	1.11 (0.79–1.57)	1.04 (0.69–1.57)

to cold weather (RR 0.77, 95% CI 0.63–0.94, compared with hot weather on grass) and particularly cold and wet weather on grass (RR 0.66, 95% CI 0.47–0.93, compared with hot and dry weather on grass). Table 4 shows that for open AstroTurf stadiums, there was a lower risk of significant knee sprains in cold weather (RR 0.60, 95% CI 0.47–0.77), and particularly cold and dry weather (RR 0.57, 95% CI 0.43–0.76).

Table 2 shows that the overall injury incidence for ACL injury between stadium types was not significantly different. Table 5 shows that the incidence of ACL sprains fell in the later (cooler) months in open stadiums (both AstroTurf and grass) but not in domes. Table 4(a) shows that the reduction in ACL injury risk for open AstroTurf stadiums in cold weather was statistically significant (RR 0.50, 95% CI 0.31–0.81). There were only mild associations between stadium and weather conditions and knee MCL sprains. There was a slightly lower risk of MCL sprains on natural grass compared with domes, but the risk for knee MCL sprain on grass was almost identical under the various weather conditions.

Table 2 shows that ankle sprains of all types were less likely on natural grass compared with AstroTurf. The effect of weather conditions on ankle injuries in open stadiums was generally less than the effect of weather conditions on knee injuries. However, in open AstroTurf stadiums, cold weather was associated with a lower risk of significant ankle sprains (RR 0.68, 95% CI 0.51–0.91). In grass stadiums, cold and wet weather was associated with a lower risk of all ankle sprains (RR 0.65, 95% CI 0.48–0.88). The injury incidences listed give an indication of the magnitude of injury reductions. For example (Table 2), a team playing its entire season schedule in domes would have suffered an average of 6.4 ankle sprains for the season, whereas a team playing its entire schedule on natural grass would have suffered an average of 4.3 ankle sprains for the season. With respect to significant ankle sprains, the difference would have been only one injury per team per season (3.3 in domes compared with 2.3 on natural grass).

DISCUSSION

This study reports that in the NFL knee and ankle sprains are generally less likely in outdoor stadiums (both natural grass and AstroTurf) when the temperature is cooler. Overall, there were significantly lower rates of ankle sprain in games on grass compared with those in AstroTurf stadiums, and lower rates of most types of knee sprains, which were statistically significant except for ACL sprains. The injury rates for open AstroTurf stadiums were lower than domed AstroTurf stadiums, which may have been due to domed stadiums not being exposed to the apparent protective effect of cold weather. There was no statistically significant difference between the overall ACL incidence rate and stadium

TABLE 5. ACL Injury Incidence by time of season.

	Team Games			ACL Injuries (*N*)			Incidence: Injuries/Team Season (*N*/20 Team Games)		
	Season	July–Oct	Nov–Jan	Season	July–Oct	Nov–Jan	Season	July–Oct	Nov–Jan
Dome	1376	780	596	65	36	29	0.9	0.9	1.0
Open turf	1624	898	726	74	53	21	0.9	1.2	0.6
Grass	2910	1636	1274	113	70	43	0.8	0.9	0.7
All	5910	3314	2596	252	159	93	0.9	1.0	0.7

or surface type (under all conditions). However, the ACL incidence rate was lower on cold days and during the later (cooler) months of the season in open stadiums (both AstroTurf and natural grass) but not in domes.

It is possible that there are factors other than weather and surface conditions that may change over the course of a season that would have an effect on injury rates (e.g., player fitness) (16). In general, football competitions that are played over a fall to winter season show higher injury rates early in the season, whereas summer football competitions and indoor sports such as basketball do not (16).

The findings of this study expand on, but are very consistent with, the findings of Powell and Schootman (20,22) for the NFL over the period 1980–1989, where it was found that:

- There was an increased incidence of ankle sprains on AstroTurf compared with natural grass (Incidence density ratio (IDR) 1.34, 95% CI 1.17–1.53) (20).
- There was a slightly increased incidence of knee sprains overall on AstroTurf than grass (IDR 1.13, 95% CI 1.00–1.27), although this relationship varied as the data was controlled for player position and type of play (22).
- There was no overall difference in injury rates for ACL injury between artificial turf and natural grass (IDR 1.10. 95% CI 0.73–1.54) (22).
- The only specific circumstances under which ACL injuries were more likely on AstroTurf than grass were for special teams play (IDR: 2.96, 95% CI 1.59–5.52) (22).

The knee and ankle sprain injury rates between the NFL studies during the 1980s (20–22) and this study of the 1990s were very similar. The only injury that appeared to increase in incidence between the two eras was ACL sprains. The true incidence of ACL sprain may have been underestimated during the early 1980s, before the widespread use of arthroscopy and magnetic resonance imaging scans.

Surface characteristics that may relate to injury in football include hardness (the effect that the surface has on absorbing impact energy) and traction (the type of footing a playing surface provides) (23). AstroTurf has been consistently shown to be harder than grass (4,11,27). The greater hardness on AstroTurf results in faster running speeds for players, which has been hypothesized as a mechanism for higher injury rates (27). The exception to this is when natural grass becomes frozen, where the surface is at least as hard as AstroTurf (11). By contrast, the results with respect to traction have varied considerably (2,8,27,28). It is difficult to make presumptions about the "traction" provided by a surface without considering the shoes that each player is wearing. Whether the surface is wet or dry is also relevant (8). One recent study has shown that shoe-surface traction on artificial turf increases with increasing ambient temperature (29). This observation, together with our finding that the ACL injury incidence is significantly associated with increasing temperature in games played in open stadiums on AstroTurf, suggests that shoe-surface traction is a risk factor for ACL injury.

Recent studies from the professional Australian Football League (AFL), which plays exclusively on natural grass, has found ACL injuries are more likely under conditions that will tend to make the playing surface drier, such as low rainfall and high temperature and water evaporation (15,18,19). Other studies involving American football have reported findings that are consistent with the trend that there are more injuries when the grounds may be drier. Bramwell et al. (5) found a higher rate of injury on AstroTurf than grass over the season, with the difference occurring later in the season, when the grass surfaces (in Seattle) presumably became softer due to climatic conditions. Andresen et al. (1) found that injuries on muddy or wet surfaces (grass) were less frequent than on good or hard surfaces in Wisconsin. Scranton et al. (25) found that the surface was described as good or dry for the vast majority of noncontact ACL injuries in the NFL, although no direct measurement of ground hardness was made. All of these studies, along with other studies of soccer, rugby union, and rugby league, have shown findings consistent with the idea that knee and ankle sprain injuries are more likely when the ground surface is warmer, drier, and harder (16). These conditions may lead to greater shoe-surface traction and contribute to the risk of injury. Most of these studies are generally limited by the indirect or subjective measurement of ground conditions.

Natural grass species and shoot density are potential risk factors for both knee and ankle injuries. Natural grass venues in the northern United States generally use Kentucky bluegrass (*Poa pratensis* L.). Southern venues generally prefer Bermuda grass (*Cynodon dactylon* L.), which has a higher shoot density than other grass species (30). This is thought to potentially create greater shoe-surface traction (13,15). However, many venues using Bermuda grass will oversew with perennial ryegrass (*Lolium perenne* L.) during late fall or winter. Ryegrass is likely to create lower shoe-surface traction (16). Because records of grass mix at all venues were not taken prospectively, an analysis of risk of injury on the different species could not be performed.

Other factors that are potential confounders of the association between weather conditions and injury are player shoe selection, ankle taping, and the overall speed of the game (which may decrease on wet and cold days). The proportion of plays (rush/pass/punt/kick) may possibly alter in cold weather to a mix that is associated with fewer injuries. The wearing of shoes with longer and more peripheral cleats has been associated with an increase in ACL injuries (10). The practice of spatting the ankle (taping on the outside of the boot) may affect the risk of ankle injuries and requires further analysis (25).

CONCLUSION

For both outdoor AstroTurf and natural grass stadiums, knee and ankle sprains are less likely when temperatures are cooler. Shoe-surface traction has been previously shown to directly correlate with ambient temperature on artificial turf,

and this is the likely mechanism for the effect we observed with AstroTurf. The explanation for natural grass is more complex, as the predominance of different grass species, shoot density, ground hardness, and player shoe selection all change over the course of a season. Further prospective study is recommended in which surface characteristics are directly measured and correlated with injury.

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