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Survival Analysis Of Nfl Concussions During The 2014 And 2015 Regular Seasons

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ABSTRACT

Prior to the 2015 season, the National Football League reported that regular season in-game concussions had fallen 35% from 2012 to 2014. However, the number of concussions suffered during the 2015 regular season increased to 182, the highest total since the league implemented a standardized protocol for diagnosing and treating concussions after the 2011 season. To determine whether this large increase likely represented an increase in actual incidence or simply an increase in diagnosed injuries, survival analysis was used to compare the risk of injury between the 2014 and 2015 seasons. To show that the risk environment of the game did not differ significantly between the seasons, the total plays and points scored per team as well as overall yards per play were tested across the seasons. To test the risk of injury by a metric other than concussions, knee injury totals were compared to see if those numbers differed between the seasons. For the primary analysis of concussions, no significant difference in the survivor function was detected ($\chi^2 = 0.08$; $p = 0.774$).

INTRODUCTION

Baseball may retain the moniker "America's Pastime," but football is undoubtedly America's passion. Quantifying the degree to which people *care* about something based on how much they spend on it may seem crass, but it is illuminating. Major League Baseball took in about $9 billion of revenue in 2014 [1]. By comparison the NFL, in roughly one tenth as many games, brought in $12 billion [2]. However, this obsession faces an existential threat: concussions. Mild traumatic brain injuries (MTBI) and their potential long-term consequences have garnered a great deal of attention from both the media and the scientific community. The possible health detriments have not dissuaded crowds from watching other people's children play football, but it might be dissuading them from allowing their own sons to play it. From 2010- 2012, there was 9.5% drop in participation on Pop Warner youth teams, which represents a reduction of more than 23,000 children participating in organized tackle football [3]. If substantial numbers of parents refuse to let their sons play football for fear of the unknown long-term risks of brain injuries, the survival of football is anything but secure.

Chronic traumatic encephalopathy (CTE), a degenerative brain disease caused by repeated forcible blows to the head [4-9], has an alarmingly high incidence in former football players [10] whose brains have been donated to the increasingly famous Center for the Study of Traumatic Encephalopathy at Boston University. Whatever their motivations and whether the risk can be minimized to a degree that people can agree is acceptable, the NFL has taken steps to make the game safer.

Prior to the start of the 2015 season, the NFL reported a 35% reduction in regular season in-game[1] concussions from 2012-2014 [11]. The league credited this reduction to rules changes, improved enforcement of those rules, stricter injury protocols, and "improved equipment as well as players and coaches embracing culture change"[11]. In terms of raw numbers, reported brain injuries dropped from 173 in 2012 (0.66 injuries/game) to 115 in 2014 (0.45 injuries/game). In 2015, however, the concussions numbers rose startlingly to 182 (0.71 injuries/game) [12], an increase of 58%, despite ongoing efforts to

[1] For all of the years in question the NFL regular season comprises 256 games, with all teams playing the same number of games (16). Each team is also scheduled a week off, i.e. a bye week, so the 16 games occur within a 17 week span.

improve player safety, injury reporting and risk signaling procedures. The league compiles these numbers from the medical reports that each team provides. Even if the *New York Times* had not recently published a story that summarized how suspect the league-reported concussion statistics have been in the past due to selection bias resulting from reporting practices that varied from team to team [13], these numbers would be suspect due to reporting bias and under diagnosis. Beyond the history of "cherry-picking" data and outright fraud described by the *NYT* article and more thoroughly documented in print and documentary form by *League of Denial,* getting an accurate accounting of brain injuries is difficult. Concussions are notorious for being an under reported injury at all levels of athletics [14, 15]. Incidence rate estimates also vary wildly, from 2.8% to 25% of high school football players [16].

Even allowing that it is all but impossible for the NFL, or any other athletic organization for that matter, to report the incidence of concussion with a similar level of accuracy that can be expected with other injuries, the league presents their concussion data with very little context to permit meaningful analysis. The only information provided beyond cause and total number is the number of injuries suffered in practice or in games and whether the injury occurred in the preseason or regular season. Players' names are not made public within the official summary reports the NFL issues even though the names of injured players, type of injury, and likelihood the player will be able to play[2] are made public each week in the team injury report. The league does not break down the injuries by week, game or even team. Neither do they provide the number of players who suffered multiple concussions.[3] As a consequence of this constricted form, one has to do a lot of work to try to make the NFL's concussion information actually *informative*.

In response to questions about the increase in brain injuries in 2015, Richard Ellenbogen, the chairman of the NFL's Head, Neck and Spine Committee claimed that "these are good trends. They're expected" and were due to the league "lower[ing] the threshold for diagnosing concussions" [17]. The

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[2] Injured players are classified as out, questionable or probable for that week's game.

[3] It may seem strange to belabor the fact that this is deidentified medical data. As mentioned, though, the information is in fact made public. The NFL releases public injury reports so that bookmakers can set betting lines, meaning that NFL players do not work under the same privacy protections common to most workplaces.

claim that the threshold has been lowered is a completely false one; the diagnosis criteria have been in place and unchanged since 2011. In 2011, the league standardized concussion diagnosis and treatment protocols for all teams, mandating the use of a standardized assessment, which is virtually identical to many widely-used sideline concussion assessments, and instituting the recovery protocol [18]. The NFL's assessment is administered during the preseason to establish baseline measurements of the quantity and severity of physical symptoms[4] and cognitive function[5] [18]. When administered during a game, the degree to which those measurements have changed factors into the diagnosis. However, it is possible the player may pass all of the neurocognitive testing even if an injury has been incurred. Because the assessment is not sensitive enough to identify every injury, the NFL stresses the "importance of knowing the athlete and the subtle deficits in their personality and behavior that can occur with concussive injury" [18]. The concussion assessment can be administered serially, approximately every 30 minutes, over the course of several hours if an injury is suspected [18], but, unlike most injuries, there is not a different type of test or medical scan that will yield a definitive diagnosis if the neurologist or team doctor continues to suspect MTBI.

Prior to 2011, each team's physicians — usually orthopedic surgeons — and athletic trainers were responsible for screening, diagnosing and treating all team injuries, including concussions. Not only were the assessment procedures standardized in 2011, an effort was made to identity more instances of possible injuries occurring. Trained "spotters," who watch for and report signs of concussion, were placed in the press box, which offers a less obstructed field of view than the doctors or trainers have from the sideline. Because concussions do not necessarily present with outwardly visible symptoms, the spotters also look for blows to the head that might cause injury even if the player appears unharmed. In

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[4] In addition to asking questions about symptoms commonly associated with concussion such as headaches, blurred vision, etc., there are also questions that are important in establishing physical and emotional baselines, such as whether or not someone ever experiences anxiety, sadness or difficulty falling asleep.

[5] Cognition on these types of assessments is generally measured in terms of orientation and memory/concentration. Common orientation questions would be along the lines of "What city are we in?" The memory/concentration portion would require the player to repeat a short list of words or numbers or a similar task.

2013, unaffiliated neurotrauma consultants (UNC)[6], neurologists contracted specifically to diagnose and treat head injuries, were added to the medical personnel on each team's sidelines. Having more trained people looking specifically for head injuries leads inevitably to more players being screened, but an increase in screening does not change the actual threshold for diagnosis. The number of players screened is not reported so there is no way to determine if the predictive value of the NFL's concussion assessment has remained relatively stable since 2011. Delayed onset of symptoms compounds the difficulty of gauging the performance of the assessment. How many players were diagnosed after the game after initially passing the assessment during the game? How many were administered the test in sequential fashion over the course of several hours before a significant change from baseline was detected? Without answers to these questions, it is not possible to quantify the effectiveness of the assessment.

Another issue that certainly contributes to the number of diagnosed concussions is the nebulous one of "culture change." Presumably the culture changes to which the league referred to in the 2015 preseason report [11] entail players and coaches taking a more evolved and cautious approach to dealing with injuries. Measuring something as subjective as culture change is certainly more difficult than measuring the sensitivity of the concussion assessment, but the issue of culture change also suffers from a lack of data. For instance, knowing how many players were diagnosed as a result of self-reporting would likely indicate changing attitudes, but this is unfortunately more information that is not available. Given that true culture change is likely to take more than 3 years, expecting concussion incidence to continue to fall or remain at 2014 levels while maintaining a qualitatively similar risk environment seems truly naïve. In attributing the decline in concussions to their efforts — rule changes, more and better staff and player education, specially trained and independent doctors — the NFL set an expectation and then failed to meet it.

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[6] The neurologists are considered independent because they are not paid by the team, which theoretically decreases conflicts of interest when diagnosing and treating players. Technically, the team physician has the authority to "overrule" the diagnosis of the UNC and medically clear a player to return to play, but no reported instances of this actually happening or even being hinted at were found.

To reiterate, the diagnosis standard *did not change* between 2014 and 2015. However, there was a rule change in 2015 that should expedite the process of getting a player who might have suffered an injury off the playing field to be screened by the neurologist on the sideline. Prior to 2015, the spotters, independent certified athletic trainers (ATC), monitored the game from the press box and would alert medical personnel on the sideline if they suspected a player needed to be evaluated either because the player had visible symptoms or simply because the player suffered a blow to the helmet. The rule change now allows the ATCs to bypass notifying sideline personnel and to instead signal the head referee directly down on the field to stop the game [19]. Allowing the spotters to stop the game should reduce instances of visibly staggered players remaining in a game, as wide receiver Julian Edelman did in Super Bowl XLIX while the Patriots ran their hurry-up offense [Appendix A #1]. This rule was praised in theory but was ridiculed when it failed in practice, such as when the ATCs failed to stop a game despite St. Louis Rams' quarterback Case Keenum writhing on the field clutching his helmet after taking a blow to his head [20, 21, Appendix A #2]. This rule change did not impact the on-field risk of incurring a brain injury. It simply expedited addressing potential brain injuries by getting them into the screening process as quickly as possible.[7]

In terms of addressing the risk of incurring an injury only one rule change made between 2014 and 2015 aimed to improve player safety. The league expanded the definition of a "defenseless player" [Appendix A #3] to include the intended offensive receiver on a pass resulting in an interception [19], meaning *any* contact with the receiver's head or neck area, not just illegal helmet-to-helmet contact, would draw a penalty [Appendix A #4]. The defenseless player rule is designed to protect players from blows to the head by disincentivizing them with a15-yard penalty. The expansion of the defenseless player rule may slightly reduce the number of injuries incurred, although the number of plays to which this applies is so small that it would be impossible to quantify its effect in a single season.

If the risk of injury changed in 2015, perhaps some disparities in game statistics might explain it. For instance, a large increase in the total number of plays would inevitably lead to more injuries of every

[7] See Appendix B for a more detailed explanation of the entire concussion protocol.

kind. By the numbers, there were certainly some huge changes that occurred from 2014 to 2015. The Carolina Panthers were much better in 2015 (+ 0.469 win %) and Peyton Manning, the recently-retired quarterback of the Super Bowl Champion Denver Broncos, was much worse (- 30.16 QBR) [22, Appendix A #5]. Wild statistical swings of fortune for a few teams and players from year to year give Cleveland Browns fans hope and make for good storylines, but they are belied by the overall statistical and qualitative similarities of NFL football from year to year. To determine that play did not change significantly from 2014 to 2015 in terms of overall volume and outcome, initial analyses were of total plays, points and yards/play [Appendix A #6]. While far from comprehensive, observed similarities would suggest that the game environment remained largely unchanged from 2014 to 2015.

Was football somehow more dangerous in 2015? The difference in concussion incidence between 2014 and 2015 suggests so. Certainly, football players suffer many types of injuries of varying degrees so knee injuries as a comparison might seem rather limited. However, without access to full medical data from every team, knee injuries are probably the best option to capture some sense of the overall physical risk for a few reasons. 1) They are generally serious enough as to require medical attention, which serves to obviate the risk of underreporting. 2) They can be accurately diagnosed with an MRI, meaning they are not prone to misclassification.[8] 3) They occur more frequently than many other injuries that can also be definitively diagnosed with a medical test or scan such as broken arms so year-to-year variability is less likely to significantly change the total number of knee injuries.

If certain broad measures fail to indicate a significant difference in game play or injury risk between 2014 and 2015, additional analyses must be performed to attempt to identify other factors that explain the sharp increase in concussions. This paper posits that risk of injury was essentially the same in 2014 and 2015 and the difference likely represents an increase in diagnoses, not in actual incidence, due to increased screening. Admittedly, it is not possible to conclusively prove this. However, it is a

[8] While an MRI does not preclude the severity of an ACL or MCL injury being misread, it does prevent the gross misclassification of such injuries.

potentially more informative way to examine the NFL's concussion numbers than simple year-to-year addition or subtraction.

For the purposes of this paper, analysis was limited to knee injury and concussion data from the 2014 and 2015 season. During these two years the rules, in-game spotting procedures, diagnostic tools and post-injury protocols were essentially the same except for the previously mentioned expansion of the spotters' power to call for a stoppage of play, which only changes how quickly a player is sent to the sideline to be screened by the UNC. These two years are also of interest because of the sharp increase in 2015 after a period of declining totals of reported concussions.

DATA COLLECTION

The first step was to identify the players who suffered concussions during the regular season. All players with "concussion" or "head" injuries listed on the public injury reports available on NFL.com were identified starting with week 2 and continuing through week 17 of the 2014 and 2015 seasons. Injury reports are issued prior to the game so week 1 reports would have identified players injured in the preseason, which were not included in the analysis. Week 17 injury reports would include injuries suffered in week 16, i.e., the 15th game for all teams.

Because the game circumstance in which the injury occurred were of interest, the on-line game logs[9] of CBS Sports and Fox Sports of the previous week's games were searched for the play on which the injuries occurred. The game logs act as running box score that summarize each play in a line of text. Injuries that did not cause game stoppages were not usually noted in the game logs. For injuries that were listed in the game logs, the quarter and time of the play on which the injury occurred were noted for when studying the film of each injury began. For unlisted injuries, the PBS *Frontline: Concussion Watch* website, which includes a brief synopsis of the information known, if any, about the circumstances of the injuries, was checked first to obtain pertinent information. *Frontline* often did not provide any additional

[9] A screen shot of part of the game log for Super Bowl 50 is included in Appendix C for reference as to what these look like and what information they contain.

details about the injury, which is a function of how little information is released about some injuries. In that event, a Google search was used to attempt to verify if the injury did in fact occur during the game and to attempt to pinpoint the time it happened. After the first 10-15 such instances, the following search criteria were determined to attempt to narrow the scope of film viewing: "Player name + team + 'concussion' + opponent" limited to the one month after the date of the game and the first 3 pages of search results. This process seemed to be a good balance of information yield, information reputability and speed. The month time limit mitigated the redundancy of stories that occurred for divisional opponents,[10] i.e. results were less likely to include mentions of an injury incurred during the first meeting of teams in preview stories about an upcoming meeting.

Often, either national sports media or local media coverage provided the exact circumstances of the injury or sufficient information to drastically narrow the film search, e.g. noting that the player left the game after making a tackle during the first possession of the 2nd quarter. In the event that national or local media quoted the player or head coach as indicating it was unknown if the injury occurred in practice or in the previous game, that injury was not considered as being an in-game concussion and was excluded. All injuries that were definitively reported as having occurred in practice were also omitted.

After checking the game logs, *Concussion Watch* and Google search results, no information was found for 97 of 275 concussions as to when during the game the injury occurred. In those cases, footballoutsiders.com was used to identify how many and what type of plays the player participated in during that game to narrow the scope of the search when watching film. To document the game circumstances of each injury, the network broadcast was watched. Since the broadcast version of a game is meant to optimize appeal for the viewer, the "All 22" coaches' film, which provides a higher, wider view of all 22 players on the field, was used if the broadcast version did not provide sufficient angle or a sufficient field of view to see the potential source of injury. This was often the case on punts and kickoffs when a great deal of contact occurs away from the main action of the ball between the blockers of the

[10] Teams within the same division play each other twice per season, with the remaining ten games of the regular season split between intra-conference and inter-conference opponents. There are two conferences, each with four divisions of four teams.

kick receiving team and the players of the kicking team attempting to reach the ball carrier to attempt to make a tackle.

Generally, the offending play was immediately identifiable, with the player remaining on the turf before being removed from the game, staggering after getting up or some similar indication of a head injury. Given the unpredictable nature of symptom onset [23] and the fact that most players endure multiple collisions during a game, the force of which does not necessarily correlate with injury [24], identifying the play on which a concussion occurred necessitated allowing for a somewhat heuristic process if the play was not immediately evident. In a few cases, such as Eric Reid of the 49ers, the player only participated in one play that involved contact beyond hand checking or grabbing [Appendix A #7], in which case that single play was considered the play of record. If the player participated in many plays involving significant contact *and* there were no media reports from the team to clarify when the injury occurred, three people independently watched and re-watched the plays in which the player participated. If two of the three identified the same play and agreed that there was some visible symptom of injury that play was the play that was included for analysis. Visible symptoms were considered to be: staggering or stumbling; grabbing and holding one's helmet; and shaking one's head as if to "clear the cobwebs." Many players either remained asymptomatic until after the game or were not observed to be symptomatic during the course of the game. 49 injuries could not be identified due to either limited angles/field of view in the available film or simple lack of recognition. In these cases, cause was classified as "unknown" and pertinent game situation variables were left as missing. Six injuries that were not observed on film were categorized as occurring on special teams plays because those were the only types of plays that the injured players participated in during that game per footballoutsiders.com. In identifying the specific play that caused the injury, Fleiss' κ for inter-rater agreement for three raters was 0.845.[11]

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[11] Ratings were changed for four injuries to reflect unanimous agreement. Not all raters had access to the same level of technology, i.e. large high definition televisions, which provided a wide enough field of view to see evidence of injury in three cases. The rating for the fourth case was changed after two raters initially agreed a player staggered badly after a blow to the helmet but the third rater astutely pointed out he had also been kicked in the groin.

The cause of the injury was never attributed to a single hit, no matter how violent it appeared on film, if the player did not exhibit any symptoms. Allowing for delayed or extremely subtle symptoms, the cause could be retroactively attributed to a big hit if that the player did not suffer significant contact subsequently. For example, if a receiver jumped quickly to his feet after suffering what seemed to be a particularly hard tackle and remained in the game, that tackle was counted only if that was the last play in which the player endured any violent impacts or twisting. Often there were multiple points of contact with the head during the play on which the injury occurred. Cause was always attributed to whatever body part or playing surface first made contact with the injured player's head. Making that distinction often required multiple viewings in slow motion, but it was possible though meticulously watching all the available angles. Two common instantiations of multiple contacts were the shoulder pads making contact a fraction of a second before the helmet or an initial blow to the head during a tackle followed by the tackled player's head making contact with the ground. Often the second impact *looked* more violent, but instead of making qualitative arguments about which of sometimes several impacts seemed to be the worst, it was decided to simply attribute cause to the first impact. For injuries a play of record was determined ($n = 226$), Fleiss' κ was 0.947, with most disagreements resulting from contacts perceived to be simultaneous. One injury was identified by play, but the cause could not be determined because there were too many players involved to discern what collided with the helmet.

The data collected were the name, position and team of the player; the number of games the team and the player had participated in up to and including the one in which the injury occurred; down; difference in team and opponent points at the time of injury; quarter; line of scrimmage; the number of players other than the injured one that were involved in the contact; the distance from the line of scrimmage that the contact occurred; the cause of injury, e.g. another helmet, a knee, the ground, etc. The end of season winning percentages of the team and opponent were also recorded as a crude measure for overall team quality.

Only data from the first 15 games of the regular season was analyzed for two primary reasons. 1) In terms of data gathering, preseason games typically are not covered by the same number of cameras,

thus reducing the number of replay angles from which an injury can be detected and evaluated. In terms of data quality, preseason games cannot be considered representative of football as it is played during the regular season and playoffs. They include many players that that will not make teams' 53 man rosters or even the practice squads. They serve as fully officiated, televised scrimmage for surefire 1st stringers and an intensely competitive tryout for marginal prospects. Play calling and player substitutions aim to keep starters healthy and to evaluate the other players who will fill out the final roster. 2) After week 17, the week in which all 32 teams play their final regular season game, the injury reporting system differentially changes. NFL injury reports are public primarily to set betting lines so the 20 teams whose seasons end do not file any additional injury reports. Some data might be available for concussions that are reported in-game, but due either to team policy on not commenting on injuries during the game or to the time it takes to actually assess whether or not a player has suffered head trauma, concussions are often not reported during the game. As the playoffs continue, the losing half of teams that play each week will not report injuries; after the Super Bowl, neither team will. Additionally, the top 2 seeds in each conference earn an additional bye week at the beginning of the playoffs, with yet another for the teams that earn a trip to the Super Bowl. Since teams do not file injury reports on bye weeks, a player who experiences concussion symptoms after the game could be placed in the concussion protocol and recover sufficiently to pass out of it without ever appearing on a public injury report. Bye weeks are scheduled beginning in week 4, and all teams have had an off week before the last 4-5 games of the season so in week 16 of the season all teams play their 15th game. The number of games a team had played determined the at-risk intervals, not the week of the season. To distinguish between those players whose injuries in week 15 caused a loss of playing time and those whose injuries did not, observation time continued to the 16th game of the season.

ANALYSIS

To test for differences in play outcome and volume across the two seasons means analyses were performed on total number of plays and points scored per team. ACL and MCL injuries were used as

proxies for physical risk. Pearson's chi-squared test was used to determine if the numbers of knee injuries per play differed significantly between the seasons.

To compare the risk of concussion in 2014 to 2015, survival analysis was the method chosen, essentially treating the year as a binary condition, for which a difference in failure times might be expected. Granted, this is a strange view to take. Yet, survival analysis is appropriate to test Ellenbogen's claim that the threshold for diagnosis has been substantively lowered. Because the player must test at baseline levels at each stage of the recovery protocol [Appendix B], lowering the threshold for diagnosis would necessarily raise the threshold for returning to play, which should result in more injured players missing more games due to concussion. If analyses fail to reveal differences in the "survival" experience from year to year, that relative continuity between seasons bolsters the theory that the baseline risk of incurring a concussion during an NFL game remains fairly stable from year to year. By employing survival analysis, the time to injury, multiple injuries per player, risk intervals of different length, as well as multiple intervals of risk per player within the season can be accounted for and compared between the two seasons. If such a large increase in reported concussions represented an increase in actual incidence, it would likely have some proportional effect on the injury survival curve.

The analysis of hazard was by year. All concussed players were included in the risk set for all the games in which they played. If a player exited the risk set for any reason other than a concussion, it was considered a censoring event. Any player still at-risk after game 15 was considered to be censored just prior to the start of game 16. To account for multiple events and multiple at-risk intervals per player, each player was analyzed as his own cluster to account for increased correlation. Kaplan-Meier and cumulative hazard plots included all players who suffered in-game concussions. To protect against the disproportional impact innate variability might have with only two years of data, the log-rank test and the Renyi Type test, a modified log-rank test that is robust in cases of non-proportional hazards, were pre-specified to test for difference

Independent covariates were tested in a Proportional Hazards Cox model one-by-one for significance and included: position type, cause, the type of action the player in which was engaged, the

number of other players involved in the contact, difference in winning percentage of the teams, point differential at the time of injury, quarter during which the injury occurred, down, and distance from the original line of scrimmage the contact occurred. All other numeric variables were categorized. Because it was not possible to make the categories within all the variables both meaningful in terms of football and similarly sized, each variable was checked across all categories and with the categories collapsed as a single variable.

As several of the categorical variables had more than two levels, to be maximally inclusive of potentially important variables, a p-value less than 0.2 was designated as the cut-off for single covariate models to be included in an initial multivariate model. Due to the relative dearth of data, interactions were not considered for the model. In univariate models, identifying the play that caused the injury may not be important in assessing the hazard, for example, the hazard of offensive players compared to defensive players. Conversely, it is necessary to identify the instance of injury when comparing something like run plays versus pass plays. In the event that both identification-independent and identification-dependent variables qualify for testing in a multivariate model, the identification-independent variable(s) would be re-checked while restricted only to injuries that could be attributed to specific plays.

Analyses were carried out using Stata/SE 14.1 software.

RESULTS

Plays, Yards and Points

Over the course of the 2014 regular season teams ran a total of 32,779 plays (64.02 plays per game) for an average of 5.43 yards/play (SE = ± 0.0742) and scored a total of 11,565 points. In 2015 there were 32, 976 plays (64.41 plays per game) for an average of 5.48 yards per play (SE = ± 0.0507) and 11,680 total points scored [22]. The difference between the team with the highest total point differential and the lowest point differential was 354 points in 2014 and 347 points in 2015. The total number of plays by each team over the course of the season was not significantly different 2014 (mean =

1024.3; SE = ± 8.443) and 2015 (mean = 1030.5; SE = ± 8.478; t = -0.515; p = 0.609). Furthermore, in the aggregate, the yield of those plays was not significantly different in terms of yards per play (t = -0.479 ; p = 0.634) and total points scored per team (2014: mean = 361.4; SE = ± 12.55; 2015: mean = 365; SE = ± 10.77; t = -0.217 ; p = 0.829).

Knee Injuries

Using the reported in-game concussion totals for the 16 game regular seasons (115 in 32,779 plays in 2014; 182 in 32,976 plays in 2015), the difference was highly significant (χ^2 = 14.71; p =0.00013). However, using knee injuries as an alternative measure of physical risk, which are typically more costly in terms of playing time lost, there is no evidence that 2015 was riskier than 2014. MCL injuries went up from 98 to 110 in 2015 [12], but the difference was not statistically significant (χ^2 = 0.630; p = 0.427). There were slightly fewer ACL injuries in 2015 compared to 2014, 24 down from 27 [12], but this did not represent a significant change either (χ^2 = 0.192; p = 0.661).

Concussions

Total time at risk for 99 players concussed in 2014 was 1148.2 weeks with a median survival time of 9 games (SE = ± 1.0426); three players suffered two injuries for a total of 102 concussions. The average number of games at risk was 11.52 per player. In 2015, the 164 concussed players were at-risk for a total of 1870.2 weeks with a median survival time of 10 games (SE = ± 0.5413). Seven players suffered two concussions and one player had three for a total of 173 concussions. The average number of games at-risk was 11.40 per player. Decimals resulted from subtracting 0.1 from the start of risk intervals that only included a single game since observations in which failure/censoring occur simultaneous to becoming at-risk would have been omitted. Figure 1 shows the Kaplan-Meier plot of the survival analysis of the players who suffered concussions during the 2014 and 2015 seasons. Figure 2 is the smoothed hazard function by year. Despite the curves crossing, hypothesis testing did not indicate a significant

difference between the two years (log-rank p-value = 0.774; Reyni p-value = 0.873). Assuming a standard deviation of 0.5, 256 events would have been sufficient to detect a hazard ratio of 1.5 at $\alpha = 0.05$ with 90% power under a Cox Proportional Hazards model. However, the Cox model by year showed a non-significant increase in hazard of less than 5% from 2014 to 2015 (HR = 1.044; SE = ± 0.0701; χ^2 = 0.41; p = 0.523).

The right-most columns of Table 1 provide the NFL's reported totals based on 256 regular season games per year. The left portion of table 1 shows data taken from 240 total regular seasons games in both 2014 and 2015. P-values are from log-rank tests for year stratified by cause; position group; type of play; the type of action the player was engaging in at the time of injury; classification as an offensive, defensive or special teams player at the time of the injury.

In comparing this data to the NFL's reported injury statistics, the most glaring discrepancy in the number of concussions attributed to impact with another helmet. For the 2014 and 2015 seasons, the NFL list helmet as the impact source in 58 and 92 injuries respectively, compared to just 25 and 53 here. Using totals from a slightly truncated season and not having access to medical records, firsthand accounts or even the names of players hurt in practice versus those hurt in games probably accounts for many of the smaller discrepancies in attributable cause. The huge difference in injuries attributed to impact from another helmet could be due to the special attention the league devotes to attempting to reduce helmet-to-helmet contact. Watching for and penalizing illegal helmet-to-helmet contact is perpetually a "point of emphasis" for game officials. Based on that concern, perhaps, the trainers opt for "helmet" when multiple impacts occur at the league's instruction. It is also difficult to know how these numbers might be affected by the report form the league uses, which is not publicly available.

More than half of the concussions with an identifiable cause resulted from plays that involved only one other player in addition to the injured one (n = 131). There were 63 plays that involved two other players, 20 that involved 3, and 11 that involved another number of players (ranging from 0 to 8). Due to severe imbalances, 8 instances in which the action was categorized as "diving" were recategorized as either "getting tackled" (n = 4) for offensive players or "tackling" (n = 4) for defensive players. Of

these plays, 6 involved players diving to make a reception/interception. The final 2 were plays in which quarterbacks were sliding after attempting to rush for a first down; in both cases a defender hit the quarterback illegally and was penalized.

Counts of NFL Regular Season In-game Concussions and Log-rank Tests by Year Stratified by Select Variables

Table 1

					NFL Totals	
	2014	**2015**	χ^2	**p-value**	**2014**	**2015**
Total	*102*	*173*	*0.08*	*0.774*	*115*	*182*
Cause*	n (%)	n (%)	**2.17**	**0.141**		
Leg	14 (13.73)	18 (10.40)	1.12	0.290	17	20
Arm	23 (22.55)	25 (14.45)	0.06	0.813	14	24
Helmet	25 (24.51)	53 (30.64)	0.35	0.552	***58***	***92***
Ground	10 (9.80)	30 (17.34)	0.02	0.881	16	29
Torso	14 (13.73)	14 (8.09)	1.27	0.261	N/A	N/A
Unknown	16 (15.68)	33 (19.08)	0.40	0.526	10	17
Position Group			**0.08**	**0.782**		
Defensive Back	36 (35.29)	53 (30.64)	3.11	0.078		
Defensive Line	6 (5.88)	16 (9.25)	0.20	0.656		
Linebacker	12 (11.76)	22 (12.72)	0.52	0.471		
Offensive Line	17 (16.67)	26 (15.03)	1.41	0.235		
Backs†	12 (11.76)	18 (10.40)	0.01	0.924		
Tight End	9 (8.82)	16 (9.25)	0.05	0.829		
Wide Receiver	10 (9.80)	22 (12.72)	0.18	0.675		
Play Type			**1.73**	**0.189**		
Special Teams‡	23 (22.55)	45 (26.01)	1.01	0.316		
Run	26 (25.49)	36 (20.81)	0.87	0.351		
Pass	38 (37.25)	64 (36.99)	0.03	0.863		
Unknown	15 (14.71)	28 (16.18)	0.53	0.467		
Player Action**			**1.72**	**0.189**		
Blocking	19 (18.63)	19 (10.98)	0.77	0.379		
Tackling	38 (37.25)	64 (36.99)	0.07	0.794		
Getting Blocked	8 (7.84)	23 (13.29)	1.94	0.164		
Getting Tackled	21 (20.59)	36 (20.81)	0.08	0.776		
Unknown	16 (15.69)	31 (17.92)	0.45	0.503		
Position Class††			**0.12**	**0.726**		
Offense	29	49	0.34	0.561		
Defense	39	60	0.44	0.507		
Special Teams	23	45	1.01	0.316		

* Leg included foot (n = 3), thigh (n = 6) and knee (n = 23). Arm included forearm (n = 6), elbow (n = 6) and shoulder (n = 36). Torso was considered from hips (n = 12) to chest (n = 9) and included back (n = 3), ribs (n = 2) and buttocks (n = 2).

† Running backs (n = 33) and Quarterbacks (n = 19) combined.

‡ Special teams (n = 44) and "broken" plays combined. Special teams plays included all Field Goal/ Point After Touchdown/ 2 Point Conversion attempts, punts and kickoffs. "Broken" plays included turnovers (n = 11), quarterback sacks (n = 5) and quarterback scrambles (n = 8).
** Indicates intended action, not necessarily completed/successful attempt.
†† Category totals do not sum to yearly totals due to missingness.

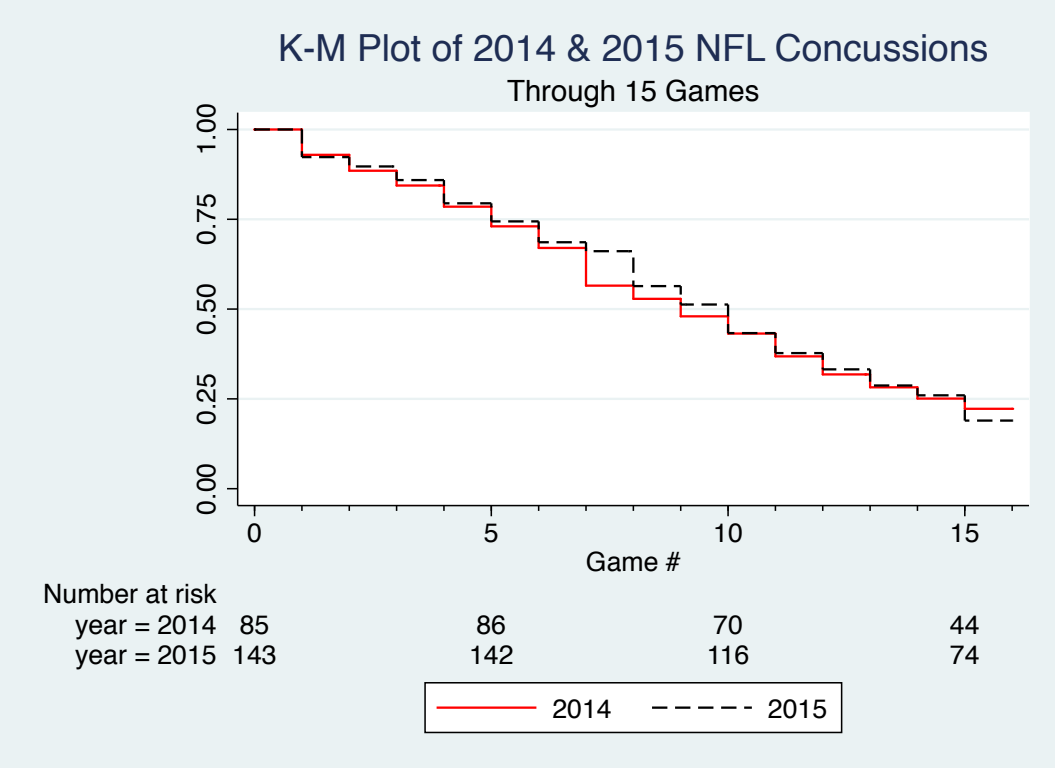

Figure 1

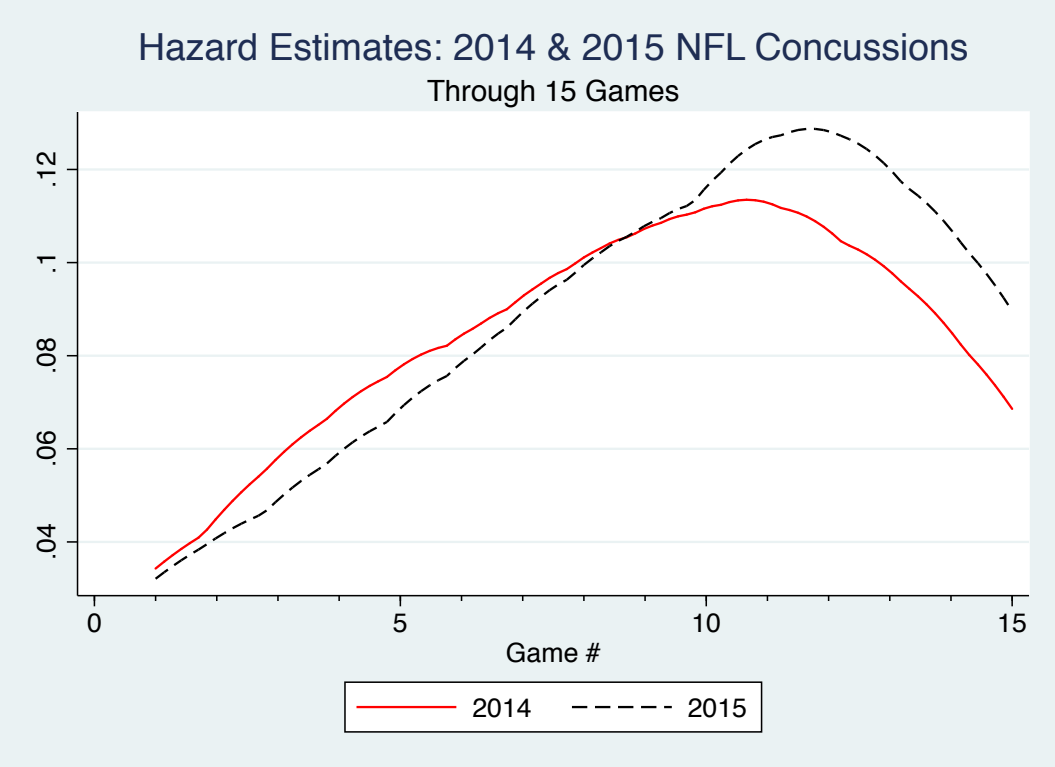

Figure 2

Due to the fact that so many plays were not identified on film (17.8%), testing Cox proportional hazards models of game variables was abandoned. Without more complete data of a comparable type, this degree of missingness would not likely yield meaningful results.

As a post-hoc analysis, an endogenous variable was created to distinguish injuries incurred by offense, defense, and special teams players because the binary offensive/defensive player classification obscures the risks of special teams players. A player who only participates in special teams plays is assigned an offensive or defensive position, which misrepresents the actual role he fills when he takes the field. Distinguishing between these three phases of the game is also useful because special teams plays, especially kickoffs, have recently been subjected to rule changes aimed at improving player safety. Three versions of this variable were tested. 1) When the instance of injury was unknown and the injured player participated in both defensive or offensive plays and special teams plays during that game,[12] a missing value was re-entered. This resulted in only 30 missing values despite being unable to identify 49 injuries

[12] As taken from footballoutsiders.com snap count totals.

on film. 2) All missing values were replaced with the injured player's position status as either an offensive or defensive player. 3) All missing values were classified as special teams. As Table 1 shows, the broad play category of "special teams" includes "broken" plays (sacks, scrambles and turnovers). Within this variable, injuries occurring on sacks or quarterback scrambles were classified based on the injured player's status. However, turnovers were counted as special teams plays. This served to avoid exacerbating the imbalance in the size of the categories. More importantly, a turnover essentially inverts the relationship between offense and defense, rendering listed positions just as meaningless as they are for the players who only play on special teams.

The first version of the offense/defense/special teams variable proved highly significant ($\chi^2_2 = 47.10$; $p < 0.0001$) with offensive (HR = 0.472; SE = ± 0.0551; $p < 0.001$) and defensive plays (HR 0.479; SE = ± 0.0562; $p < 0.001$) both showing significantly less risk of injury than special teams plays. The results were similar when missing values were replaced with the player's offensive or defensive classification ($\chi^2_2 = 44.63$; $p < 0.0001$), with both offensive (HR = 0.485; SE = ± 0.0555; $p < 0.001$) and defensive (HR 0.492; SE = ± 0.0563; $p < 0.001$) plays showing significantly lower hazard ratios compared to special teams plays. Only when all of the missing values for the original variable were coded as special teams did the hazard ratios rise above 0.5 ($\chi^2_2 = 26.09$; $p < 0.0001$), though both offensive HR 0.600; SE = ± 0.0645; $p < 0.001$) and defensive plays (HR 0.608; SE = ± 0.0667; $p < 0.001$) continued to have significantly lower risk than special teams plays. Weighing this based on either the typical proportion of special teams plays per game or based on the proportion of special teams plays a player participated in based on his total number of plays that game would have been preferable. Unfortunately, Stata does not allow for weights to be applied within its survival analysis regression commands when using the clustering effect within each player as had been done for all other analyses.

The Weibull distribution offered a slightly better fit than the Cox model. Figure 3 shows the Weibull estimate ($\chi^2_2 = 45.48$; $p < 0.0001$) of the survivor function for the second version of the variable in which missing values were simply replaced with the player's offense/defense designation. In this

version the distribution of injuries by play category is most similar to what the distribution of plays by category would be in an actual game. 55 injuries were attributed to special teams plays (20.0%); 102 were attributed to offensive plays (37.1%); and 118 were attributed to defensive plays (42.9%). The Weibull model also showed both offense (HR = 0.500; SE = ± 0.0547; $p < 0.001$) and defense (HR = 0.504; SE = ± 0.0551; $p < 0.001$) as having about half the risk of concussion as special teams plays.

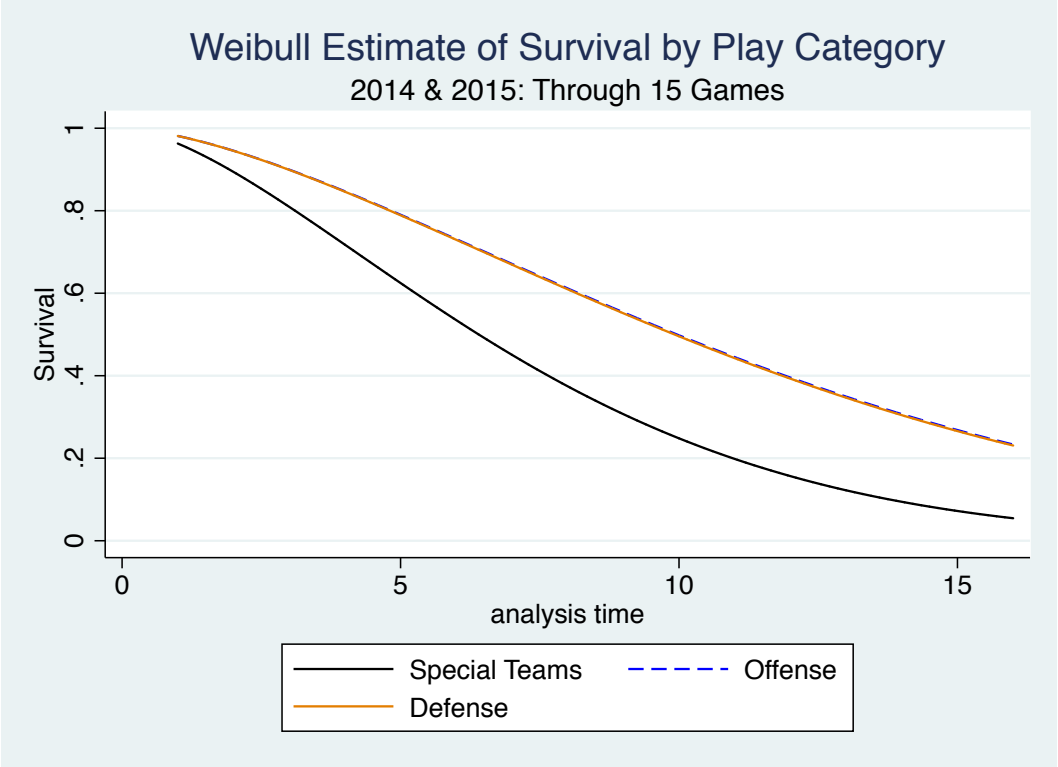

Figure 3

To illustrate the unsettled nature of the NFL's concussion numbers, in the less than 6 months between the Health & Safety Committee's preseason report and the pre-Super Bowl data release, 3 additional concussions were added to the 2014 total, which was only 112 in the report released prior to the start of the 2015 regular season [11]. So, even with the benefits of high cost health care, electronic medical records and a high medical personnel to player ratio, a few injuries were not originally listed. It is very difficult to discern where discrepancies might be occurring because whatever standardization there has been to the medical reporting of concussions, teams are free to comment or not comment as they see fit. Beyond mandating that a concussed player appear on the public injury report, the team has no

obligation to release any information. Furthermore, there does not seem to be a mandate to attempt to identify the cause of injury in the event a player experiences delayed symptoms. While it was unfortunate to not be able to build a better model to explain the game circumstances of concussions, knowing the game in which the injury occurred and what games a player participated in during the course of the season is revealing nonetheless. As an another post hoc comparison, the in-game concussions (n = 148) and risk intervals for players during the 2013 regular season were recorded to see how that season would compare to the 2014-15 data. The resulting survival plots (figure 4) and hazard curves (figure 5) suggest that the risk of concussion was remarkably similar across all 3 seasons despite differences in the number of reported injuries.

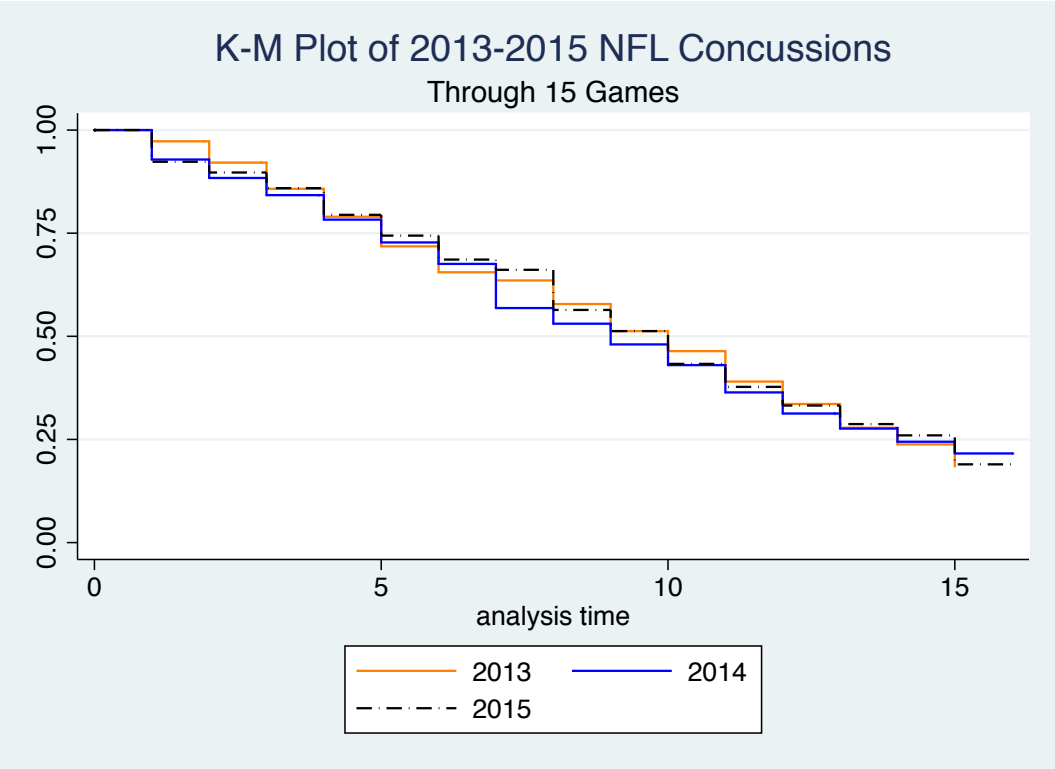

Figure 4

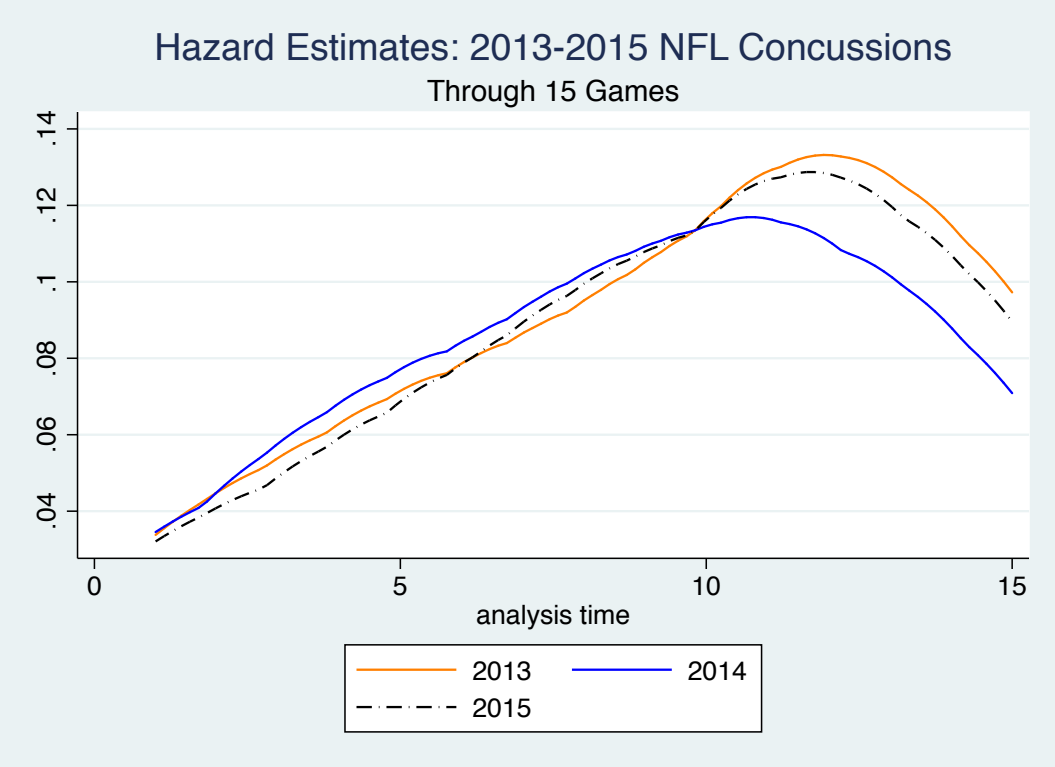

Figure 5

DISCUSSION

It seems that NFL officials believed that concussion numbers would either continue to fall or remain around the low 2014 level. However, in explaining the drop during the 2014 season, the league actually lists factors that should pull in the numbers in opposite directions. Yes, better helmets and rule changes should lower injury rates. Conversely, "culture change" and better screening protocols should drive the numbers up. Changing rules to increase player safety is logical and noble, but believing that changing rules to limit blows to the head will substantially lower the number of injuries presumes that most blows to the head are made with intent. Football is a violent sport in which players inevitably are hurt, but it is rare to watch a game and become convinced that a certain player is maliciously trying to injure another player. Regardless of how the numbers fluctuate over the next few years, the baseline risk of concussion is not likely to change substantially. Despite significantly different concussion rates in 2014 and 2015, the survival curves are virtually identical. It is certainly possible with only two years of

data that there was a true increase in incidence and the survival curves mirrored each other due to chance. However, the survival curve for 2013 hews closely to the other two years, which is additional evidence that large changes to the number of reported concussions are not likely due to large changes in risk.

The count discrepancies between this data and the NFL's public data, require a few additional comments. As previously discussed in the results section, the criteria used to assign cause are not known. They have 3 different ways of classifying source that ultimately mean that the source is unknown: "Body, location unknown;" "AT selected 'unknown;'" and "AT did not select source" [12]. What sources are listed as options? For example, the NFL numbers do not list any body part that could be understood as being part of the torso. What guidelines does the league provide about determining the impact source? Did medical staff or anyone from the league offices watch film to visually confirm what is in the medical reports? Is the injured player's account of the circumstances of the injury considered reliable enough to put on the concussion reporting form? Is there some sort of evaluation of the quality of the reports coming in from the 32 teams? Is there a medical reason that "helmet" might be cited as the cause even when some other part of the body made contact first? These questions are not meant as belligerent challenges to the validity the injury report totals or classification of the source, but they do recall the earlier criticism that the league numbers are not overly transparent.

To compare the overall totals from this dataset to the NFL's totals, the *Frontline: Concussion Watch* website was search for injuries that occurred during the last week of the season. In 2014, 5 concussions were reported in the last week, which would bring this total to 107 for 2014. For 2015, 3 concussions were reported in the last week, bringing the total to 175. Comparing these totals to the NFL's numbers yields a $\chi^2 = 0.826$ with a non-significant p-value of 0.363. Considering the previously discussed issues of the public injury reports, this seems like an acceptable difference. It is doubtful that all 15 missing injuries occurred during the last week of the season to teams who failed to make the playoffs and thus did not have to report the injuries. It could also be due to players not appearing on the injury report due to retirement or being cut from the team. Given the 3 injuries that were added to the 2014 total, it is possible that the injuries were retroactively diagnosed.

The attempt to model the risk of concussion based on in-game variables was unsuccessful due to the failure to identify such a high proportion of injuries on film. Beyond that, many variables had extremely unbalanced categories that either could not modified or had to be modified in ways that suppressed differences that are meaningful in terms of football. The only variable of interest that was not affected by the number of identified plays was player position. However, player position is not necessarily informative. It can even be misleading. Roster positions do not reflect temporary position changes, such as an offensive guard playing tackle for a single game. Listed positions also do not capture the differences in how teams utilize players at each position. With additional years of data and a greater proportion of definitively identified injuries, more of these variables might prove useful in a hazard model, but for this analysis they were superfluous.

The previously mentioned difficulties of diagnosing concussions coupled with the culture surrounding all injuries in the NFL make assessing the true incidence of MTBI difficult. In addition to the natural underreporting that occurs because of bye weeks, self-reporting concussion symptoms is still not the norm. While the league may be able to incrementally change the "tough guy" elements of the culture that encourage players to "shake it off," what it cannot eliminate is self-interest. A Super Bowl-winning quarterback such as Pittsburgh's Ben Roethlisberger, who has made tens of millions of dollars playing football and whose roster spot is secure, may feel comfortable self-reporting symptoms to medical staff [25], while a marginal player who is likely to be released if he cannot perform his special teams duties probably does not. For that type of player, the risk of a self-reporting a concussion and possibly losing out on the opportunity to make several hundred thousand dollars probably far outweighs whatever risk he perceives in suffering further injury. Over time it will be interesting to explore if increases in the league salary cap correlate with increases in player self-reporting possible injuries.

Even if players begin to self-report symptoms regularly, their diagnosis may be based on a faulty assessment. Players have admitted that they intentionally do poorly on the baseline exam when it is administered during the preseason so they will be more likely to pass the exam during a game [26, 27]. The designer of the ImPACT assessment, a computerized test that measures attention, memory and

reaction time, that the NFL uses to help establish baseline functioning, claims that it is difficult to "fool" the baseline exam [28]. The attention and short-term memory questions on these assessments typically require a player to repeat back a series of words or numbers, which seem like easy targets for a player wishing to depress his baseline score. While there are some recent studies suggesting moderate test-retest reliability for the ImPACT assessment with ICCs ranging from 0.43-074 across five metrics [29], other studies suggest only minimal reliability across some, not all, scales (ICC: 0.21-0.79) [30] or generally poor reliability on all scales (ICC: 0.15-0.39) [31]. Yet another study showed that over a third of subjects registered as false positives [32]. Casting more dubious light on the ImPACT system is the fact that the initial studies of its efficacy were published by the CEO of the company that developed it, Mark Lovell [33]. When the accuracy of the ImPACT assessment was publicly questioned, Dr. Lovell likened the reliability of ImPACT to the reliability of blood pressure, heart rate and EEG [34]. A recent study measured ImPACT's sensitivity at only 55% [35]. The Mayo Clinic endorses the King-Devick test, a measure of eye movement, which has both test-retest and inter-rater reliability of 90% or better [36, 37] and can also be used effectively by people without special training [38], meaning any member of the medical, training or coaching staff could within minutes determine if a player warranted further evaluation from the sideline neurologist.

Several issues create doubt about the accuracy of concussion data. There is not a definitive diagnostic test. There is not a definitive course for the symptoms. The sources of potential bias are legion. Unfortunately, the NFL recently abandoned a program to embed accelerometers in helmets to measure the force of impacts [39], which would have been a source for objective data that could be used when assessing in occurrence of MTBI during games. Under the auspices of garbage in/garbage out axiom of data, the league claimed the accelerometers were not accurate unless they were hit "squarely [39]. The fact that this type of data does not exist speaks to systemic dysfunction between the people who actually play the game and the people who legislate it. The players union also supported the removal of the accelerometers, not because they thought the data were of low quality, but because they were worried that teams would use those data against them [40]. Most players are not irreplaceable franchise

cornerstones. Most are replaceable cogs so the fear that a franchise would eschew signing a player with a few years of experience who had absorbed what they deemed to be an inordinate number of hard hits is a real one. Some college football teams use the accelerometers that the NFL abandoned [24, 39]. While they agree that the devices are less accurate when the helmet is not hit squarely, they disagree that the output is so inaccurate as to be worthless [24, 39]. Furthermore, diagnosing the inaccuracies and variability in a device and subsequently accounting for them is easier than diagnosing and accounting for the inaccuracies and variability of every game situation that results in a concussion in a game with 22 active participants on the field for each of those plays.

Ultimately, there is only so much that can be done to make a game based on large, strong men running into each other at full speed safe in the same way tennis or even basketball are safe. There are ways to make it safer and to be more honest about the risks, but there needs to be an accurate risk assessment before that can occur. Accurately assessing risk while rejecting pertinent data is not only impossible, it is dishonest.

There is certainly a moral argument that the NFL has a responsibility to the players to make the as safe as possible. Beyond that, though, making football safer is in football's own interest. Parents from Troy Aikman, who was forced to retire after several serious concussions, to President Obama have said they would not allow their sons, if they had one, to play football [41, 42]. If the trend of parents funneling their children away from football and to other sports, the pool from which the NFL draws its talent will become smaller. Having fewer great athletes will undoubtedly affect the quality of the on-field product, but more important it is likely to negatively impact player safety. What one comes away with after watching thousands of hits in slow motion is awe at the supreme athleticism that players display in making split-second adjustments to their body positioning in attempts to keep from hurting themselves or others. Whereas, there are certainly players that launch themselves helmet-first like a human missile, that is not true in the majority of cases. Players from a diminished talent pool likely will not lack size, strength or speed; they will lack that fraction of ineffable athleticism that allows them to adjust their bodies at the last second to somewhat mitigate the danger of running into another large man at full speed.

This analysis reveals nothing new about concussions in the NFL. Nor does it suggest anything definitive about the circumstances in which they occur. The analyses were also carried out on data that are suspect for a number of reasons. However, imperfect information is not the same as no information at all, which is just one of many things about concussions Roger Goodell needs to start believing.

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Appendix A

1. After being tackled during the Super Bowl Edelman got up and staggered quite badly. However, the Patriots were running a "hurry-up" type of offense. In a hurry-up, the players do not huddle, they simply go to where they are supposed to be for the next play. A coach uses hand signals or the quarterback verbally shouts the play call. It is called the "hurry-up" because it designed to minimize the time between the end of one play and the beginning of the next. Even though the ATC (and millions of Super Bowl viewers) noticed Edelman's injury, he was not immediately removed from the game because there was not enough time for the ATC to call down to the Patriots' sideline, and for the sideline personnel to then signal for the coach to remove him between plays. The ability of the ATC to directly communicate to the head referee obviously improves this process.

2. Keenum's injury was an egregious failure. He remained on the ground holding his helmet after being hit. The ATC obviously missed this. However, the ATC is not the only or final authority on who should be examined. None of the Rams coaching or medical staff intervened, and Keenum remained in the game for a few more plays and the game ended.

3. A "defenseless player" is a player considered to be in the midst of an act that precludes him from protecting himself. The most common example of this is a receiver attempting to catch a pass. The actions required to make a catch make it impossible to simultaneously brace oneself for an impact, as such the "defenseless player" rule is designed to provide a modicum of protection to players while they are particularly vulnerable.

4. A great deal of helmet-to-helmet contact is completely unavoidable and also completely within the rules because most of it occurs between offensive and defensive linemen when the ball is first snapped and the offensive line starts blocking. Broadly speaking, though, some types of helmet-to-helmet contact are always forbidden and will draw a penalty. In attempting to tackle someone, if the first contact of the defensive player with the offensive player is helmet-to-helmet, that will draw a penalty. Any time any player initiates contact on a member of the opposite team with the crown of his helmet, whether he is blocking, running or tackling, that is illegal. The defenseless player rule makes more types of contact to the head or neck illegal.

5. QBR is a statistical measure of how "good" a quarterback is based on how much they contributed to the team scoring points and how much they contributed to the team's win probability. It ranges for 0 to 100, and 50 represents what an average quarterback contributes to his team's success. It is a proprietary statistic that ESPN developed. Even though no one knows how QBR is formulated, it has become widely used and is thus included.

6. A play is any instance of a team trying to move the line of scrimmage, which is essentially the starting line for each play. The most common type starts with the center, an offensive lineman, snapping the ball from the line of scrimmage between his legs back to the quarterback. Play totals also include punts, kickoffs, point-after-touchdown (PAT) kicks and two-point conversion attempts when a team runs a play from the 2 yard line with its usual group of offensive players to attempt to get 2 points after a touchdown, instead of the usual 1 point from a kick. Plays in football are typically much more scripted than plays in sports like basketball or soccer. "Snap" can be used interchangeably with play in many circumstances. Snap also refer the action the center, who is the middle person in the offensive line, snapping the ball between his legs to the quarterback.

7. When a ball is run right up the middle of field, where the majority of large offensive and defensive linemen are, often receivers and corner backs are not particularly involved in the play. They still typically grab or shove each other a little bit after the ball is snapped.

Appendix B

1. Potential injury sighted by the ATC or sideline medical/coaching personnel; or player self-reports symptoms to team physician/UNC.

2. Initial screening with Maddocks-type questions that are commonly used in concussion screening tests. Examples include questions like “What team are you playing?”

3. Based on this initial screening, the player is either cleared to return to play or is removed from the sideline and taken to the locker room for more extensive test of cognitive function and balance.

4. Player cleared to return to play or placed in the concussion protocol.

5. Protocol as follows:

    Step 1: Rest & Recovery

    Step 2: Light Aerobic Exercise

    Step 3: Introduction of Strength Training

    Step 4: Football Specific Work

    Step 5: Full Football Activity

Player must be deemed symptom-free by an independent neurologist at each stage prior to proceeding to the next step.

Appendix C

Denver Broncos at 09:19	
1-10-DEN25	(9:19) (Shotgun) P.Manning pass short left to E.Sanders to DEN 32 for 7 yards (L.Kuechly). Caught at DEN 24. 8-yds YAC
2-3-DEN32	(8:44) C.Anderson left tackle to DEN 34 for 2 yards (L.Kuechly, T.Davis).
3-1-DEN34	(8:08) (Shotgun) P.Manning pass short left to C.Anderson to DEN 34 for no gain (T.Davis; R.McClain). Caught at DEN 34. 0-yds YAC
4-1-DEN34	(7:34) B.Colquitt punts 50 yards to CAR 16, Center-A.Brewer. T.Ginn to CAR 15 for -1 yards (K.Webster).
Carolina Panthers at 07:23	
1-10-CAR15	(7:23) (Shotgun) C.Newton pass incomplete deep middle to J.Cotchery (D.Stewart). Carolina challenged the incomplete pass ruling, and the play was Upheld. The ruling on the field stands. (Timeout #1 at 07:16.)
2-10-CAR15	(7:16) (Shotgun) J.Stewart up the middle to CAR 15 for no gain (D.Wolfe). CAR-J.Stewart was injured during the play.
3-10-CAR15	**(6:34) (Shotgun) C.Newton sacked at CAR 4 for -11 yards (V.Miller). FUMBLES (V.Miller) [V.Miller], RECOVERED by DEN-M.Jackson at CAR -1. TOUCHDOWN. V.Miller credited with 15-yd sack.**
Denver Broncos at 06:27	
B.McManus extra point is GOOD, Center-A.Brewer, Holder-B.Colquitt.	
CAR 0 DEN 10	
Denver Broncos at 06:27	
B.McManus kicks 68 yards from DEN 35 to CAR -3. J.Webb to CAR 21 for 24 yards (C.Nelson).	
Carolina Panthers at 06:21	
1-10-CAR21	(6:21) (Shotgun) F.Whittaker left end pushed ob at CAR 36 for 15 yards (T.Ward).