

Evolving The Punt Play

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Reducing Injuries while maintaining the integrity of the game

The NFL Punt Analytics Competition is being held by the NFL to elicit the public's proposal for rule modifications to punt rules. The goal being to reduce injuries.

Submissions will be judged by the NFL on the following criteria:

- **Solution Efficacy** - Have you clearly demonstrated, through your data analysis, that you have an understanding of what play features may be associated with concussions and how your proposed rule change(s) will reduce these injuries? Your kernels should be easy to understand and the analysis should be reproducible.
- **Game Integrity** - Is your proposal actionable by the NFL? Could they implement your rule change and still maintain the integrity of the game? Have you considered the way your proposed changes to game dynamics could introduce new risks to player safety? Strong submissions will demonstrate an understanding for the game overall.

High Level Overview

Punt plays have the potential to be some of the most exciting and game changing moments in football. Specialized positions like punters and punt returners have worked to hone their craft and are an essential part of football. As part of our preparation for this challenge we were able to interview College Football Hall of Fame coach Frank Beamer, known for his innovative approach to special teams at the college level. He was adamant the punt plays have the potential to be the most exciting part of the game and the integrity of the game needs to be considered when implementing rule changes. We agree with Frank Beamer and our approach attempts to minimize the number of unnecessarily dangerous plays while keeping the integrity of the game. Football is a dangerous sport, and removing all risk is impossible, but by focusing on plays that are not pivotal to the game (like short punt returns).

Our kernel is organized similar to our overall analytical approach to the problem:

Kernel Outline

- Section I. **High Level Analysis of All Punts**
 - What are the types of results for punt plays and how common are each of them?
 - What the distribution of return yards on punts?
 - What are the common formations for punts and punt returns?
- Section II. **Focused Analysis of Punts resulting in concussions**
 - Which players are commonly involved in injuries?
 - What are the types of returns which result in injuries?
 - Clustering similar types of punt plays resulting in concussions.
 - What are the speed and velocity of players hurt?
 - Look at common trends with players changing direction prior to impact.
- Section III. **Analysis of Fair Catch vs. Returned**
 - What are the players positions on the field at the time of fair catch / return
 - What are the distances at which the coverage team is from the punt returner during fair catches?
- Section IV. **Exploration of the routes run by role types**
 - Plot all routes by position, highlighting injury players to see if we can identify trends.

- What routes do punt returners tend to take?
- Section V. **Using Physics to calculate play and player risk**
 - Calculate a heuristic which captures the risk of each pair of players in a given play.
 - Aggregate risk to the play level to rank reach play's risk.
 - Look for trends in the risk associated with certain types of plays.
- Section VI **Our proposed rule changes**
 - Incentivize the fair catch.
 - Expand the definition of defenseless player to include punting team players in pursuit of the returner.
 - Restrict double teaming gunners to balance the starting position of opposing players starting positions.
- Section VII **Solution Efficacy and impact on Game Integrity**
 - Explanation of how these proposed rule changes would reduce the type of plays associated with concussions.
 - Details about how the integrity of the game will remain intact with these changes.
 - Possible negative impacts of these proposed rule changes.

Setup and Data Prep

Code
Code
Code
Code
Code

Section I - High Level Review of Punting Plays

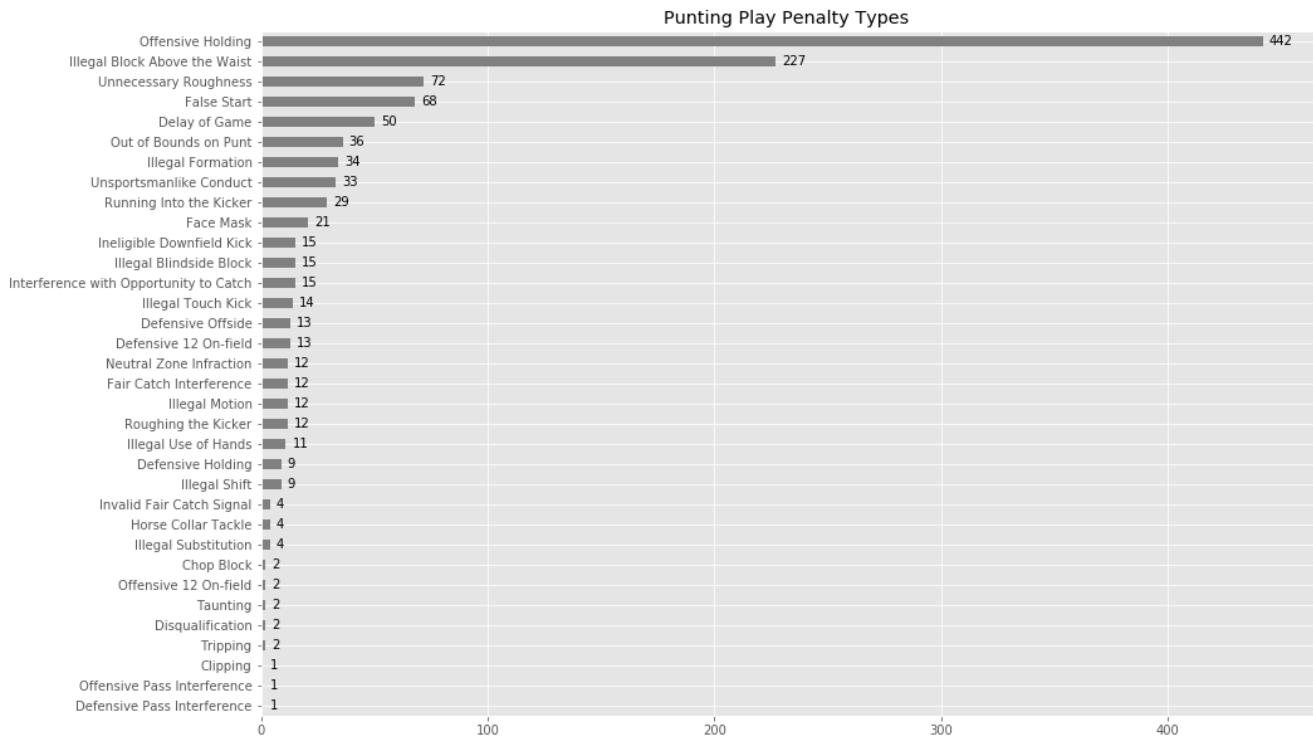
We were provided data from 6681 different punt plays from 2016 and 2017 NFL Pre, Regular and Post-Season games.

Penalties

We can look at some of the common penalties that occur during punt plays. This may not impact our final analysis but we will gain insights to what type of penalties already occur.

- 1077 Plays with Penalties (16.1%)
- 1038 plays have 1 type of penalty, 38 have 2 types of penalties, and 1 play has 3 types of penalties.
- Most common penalty is **Offensive Holding** 442 of plays (6.6% of all punting plays) result in **Offensive Holding**
- **Illegal Blocking Above the Waist** is second most common penalty with 227 (3.39% of all punting plays)
- 243 plays (3.63% of punting plays) ended up not actually counting - ie a No Play
- 16 Plays were reviewed and had the call of field REVERSED
- 99 penalties declined
- There was a punting play with 5 total penalties! <https://www.ninersnation.com/2017/8/19/16175124/referee-laughs-five-penalties-49ers-broncos-punt-pete-morelli> (<https://www.ninersnation.com/2017/8/19/16175124/referee-laughs-five-penalties-49ers-broncos-punt-pete-morelli>)

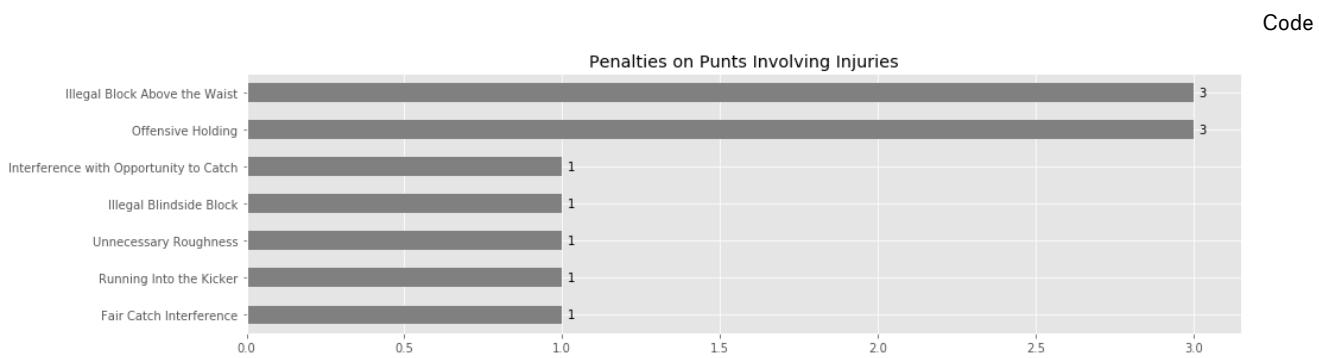
Code



1.b Penalties on plays involving concussions

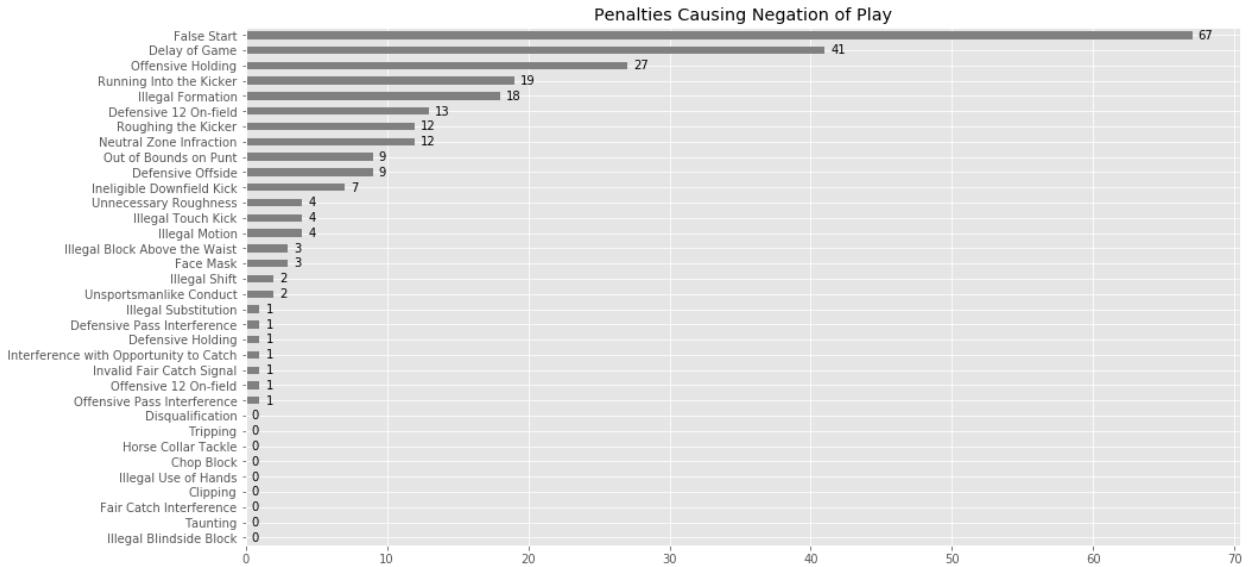
Insights:

- Surprisingly only one play involved a penalty for unnecessary roughness.
- Offensive holding and illegal blocking above the waist are the most common penalties (3 each) that occur during concussion plays. These penalties are also common for non-injury plays.



Punt plays where the punt did not count

- 243 plays resulted in No Play meaning that a snap never occurred or the penalty negated the play. Of these 67 were false starts and 41 were delay of games.



Reviewed / Reversed Plays

Many of the punt plays were reviewed. These reviews can occur because of a coaches challenge or by the replay official.

- 41 Punting plays had some sort of review. 23 of the reviews were by challenge. 18 plays reviewed by the Replay Official
- 52.1% of challenged plays were reversed
- 22.2% of reviewed by Replay Official reversed

Out[9]:

	Upheld	Reversed
Challenged		
True	11.0	12.0
False	14.0	4.0

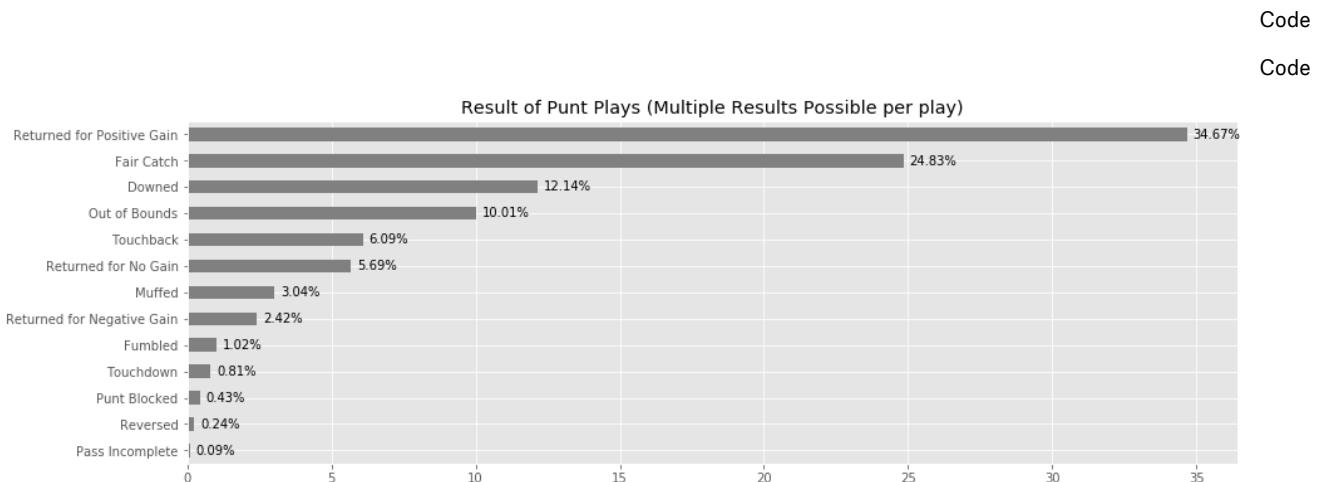
Result of Punt Plays

Punt plays open the potential for many different things to happen. That's part of what makes them such an exciting part of football. We wanted to look at an aggregate level view of punt plays and how they resulted.

- Potential outcomes of a punt:
 - Punt Kicked out of Bounds - (play stops when out of bounds and ball is spotted at the point where it leaves the field of play).
 - Touchback - The returning team is awarded the ball at the 20 yard line.
 - Fair Catch - Punt returner indicates a fair catch
 - Punt downed by punting team - Ball spotted at the point it was downed
 - Muffed Catch (Could also be a fair catch)
 - Punt Blocked
 - Punt Returned for No Gain
 - Punt Returned (positive or negative gain)
 - Punt Returned and Fumbled
 - Trick play (pass or run) - Pass could be incomplete
 - *Other possible outcomes we did not see in the sample of punt plays like a fumbled snap by the punter - or a snap over the punters head*

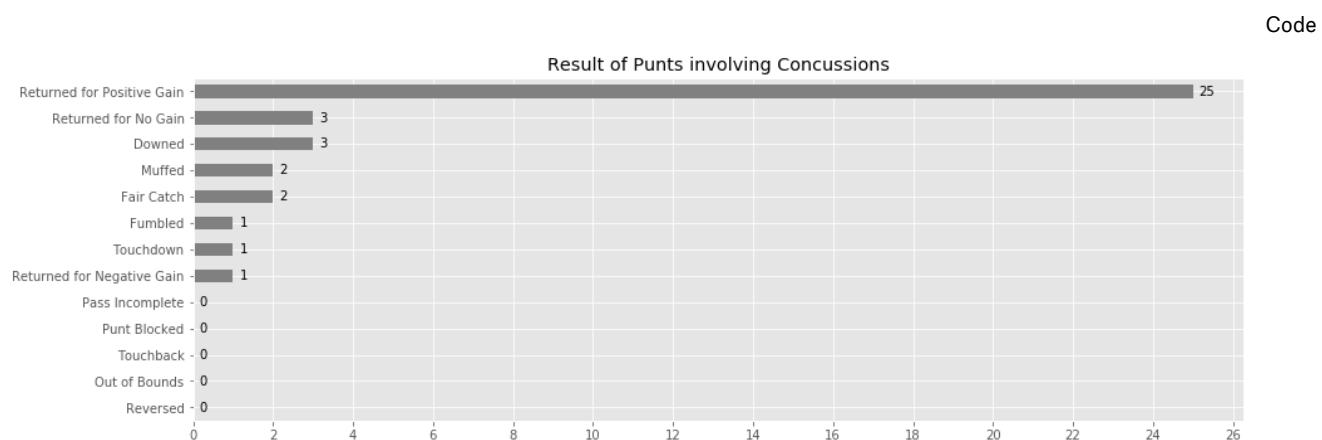
Using the `play description` provided for each play we were able to pull

1. Punt return yards for plays with returns.
2. Punt distance. (unless a fake)



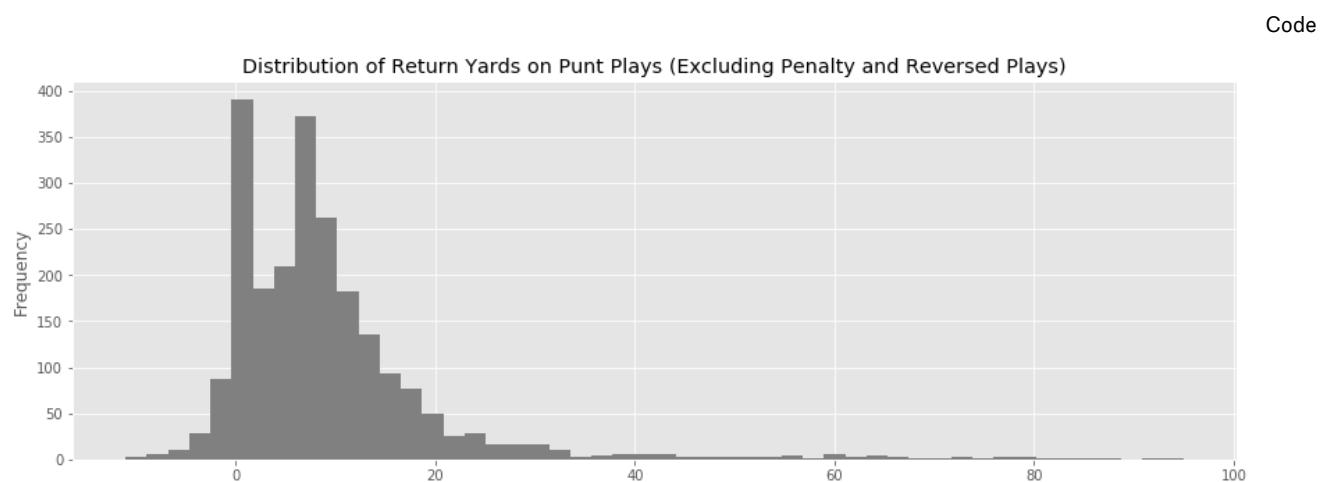
When looking at the results of an average punt, the majority of the time the punt is returned for positive gain with 34.67%. It still is surprising that 2.42% of punts are returned for a negative gain and 5.69% of plays are returned for no gain - almost as many punts as result in a touchback! Many of these type of plays are not exciting for the fans and yet put the players at what we believe to be an unnecessary risk. 24.83% of plays result in a fair catch, but seeing that many result in negative or no gain - this number should be higher.

Next we look at the results of plays that resulted in a concussion. With a sample size this small it is hard to make any conclusions about the result correlating with the injury - but we do note that most were returned for a positive gain. Three were returned for no gain and three were downed.



Distribution of Return Yards

Next week looked at the distribution of return yards for all the plays provided. We've excluded plays that resulted in a penalty that reversed the call on the field. We can see there is a fairly normal distribution, except for the large number of returns for no gain (0 yards). This is possibly due to the fact that returners can be tackled almost right after they receive the punt- but if they managed to dodge the first tacklers (gunners) they tend to make around a 7 or 8 yard gain.

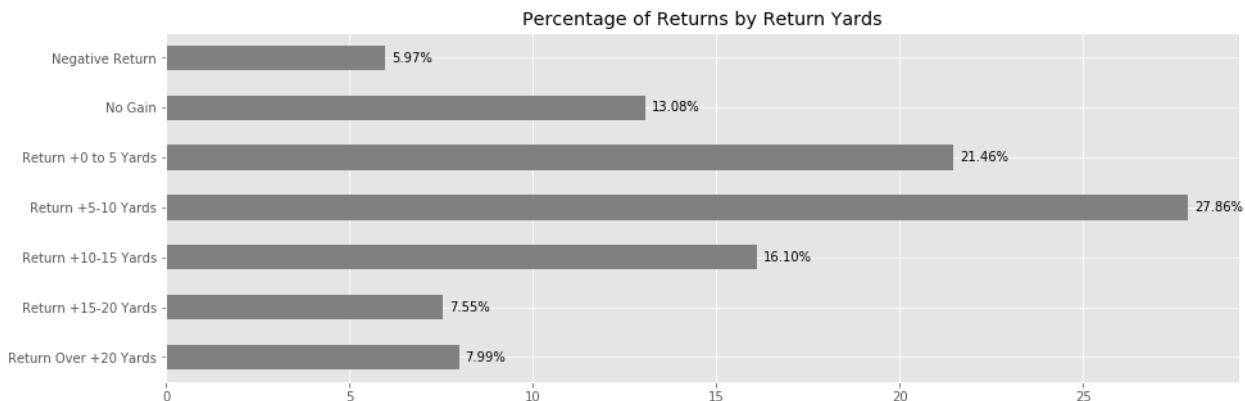


Median return excluding penalty and reversed plays is for : 7.00 yards
Mean return excluding penalty and reversed plays is for : 9.10 yards

Code

The same information is shown below, but as a percentage of all plays involving a return. We see the majority of returns (27.86%) are for 5-10 yards followed by returns over 0-10 yards (21.46%). Big returns of 20+ yards are rare (7.99%) but still occur often enough to make punts an exciting play to watch. Our team believes that we do not want to diminish these "exciting" plays since they are so integral to the integrity of football. Still, the median return of a punt play is for 7 yards- which is not a game changer compared to a typical offensive play.

Code

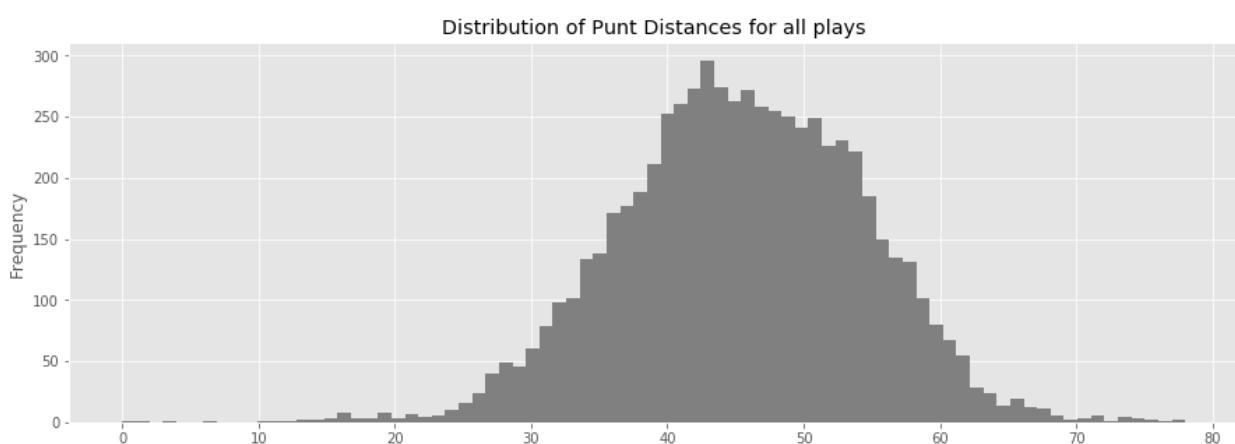


Review of Punting Distances

Next we look at the punting distance for each play. Longer punts are not always better, in situations where there is a potential for a touchback- and when the punter can "out-punt" his coverage unit. We can see that from all the punt data, the distribution of punts is fairly normal with a mean around 45.5 yards.

Code

Code

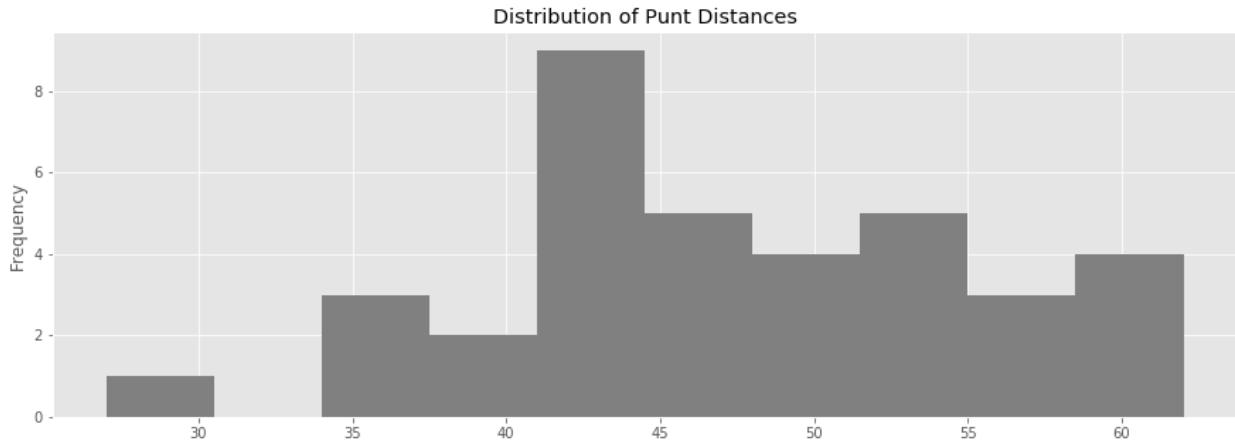


Code

The mean distance of a punt is 45.52 yards
The median distance of a punt is 46.00 yards

When we look only at plays where concussions occurred the mean punt distance is slightly longer 47.4, but the distribution visually we can see is skewed towards longer punts. This may or may not be significant but is important to note.

Code



Code

The mean distance of punts involving a concussion is 47.36 yards
The median distance of punts involving a concussion is 46.00 yards

Section II - Focused Analysis of Punts resulting in concussions

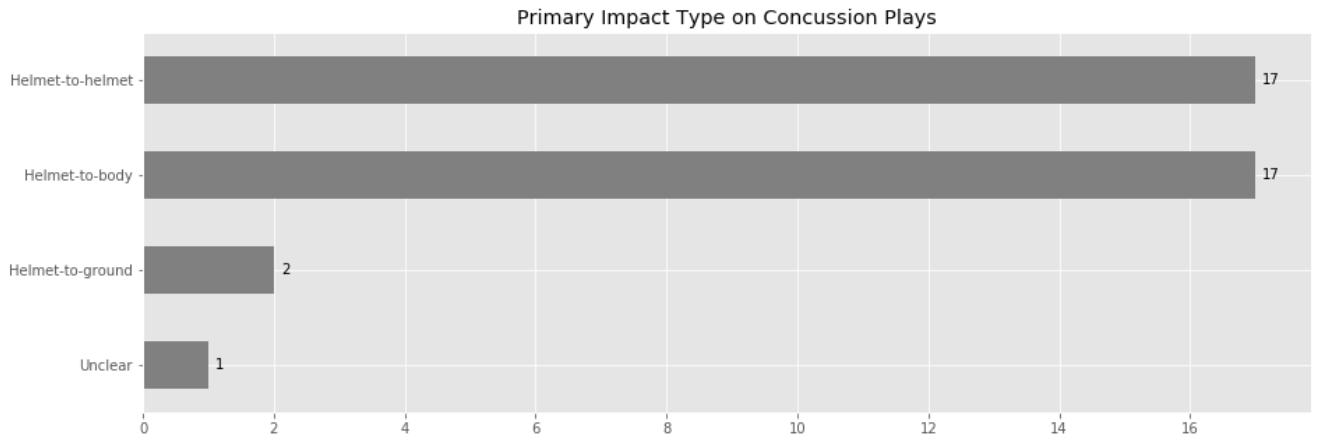
It's important to have a full understanding of which plays resulted in injury, and gathering intuition for the causes of these injuries. We reviewed all 37 punt plays involving a concussion extensively. This included analyzing video footage- taking notes of the type of situations that caused the injury. We also plotted each play out reviewing player positions and direction of the play. Additionally we reviewed the individual player speed and direction components of the NGS play noting trends in the direction of players especially prior to impact. Of course we also took note of the outcome of the play (fair catch, return, fake, etc).

Code

Injury Play Details

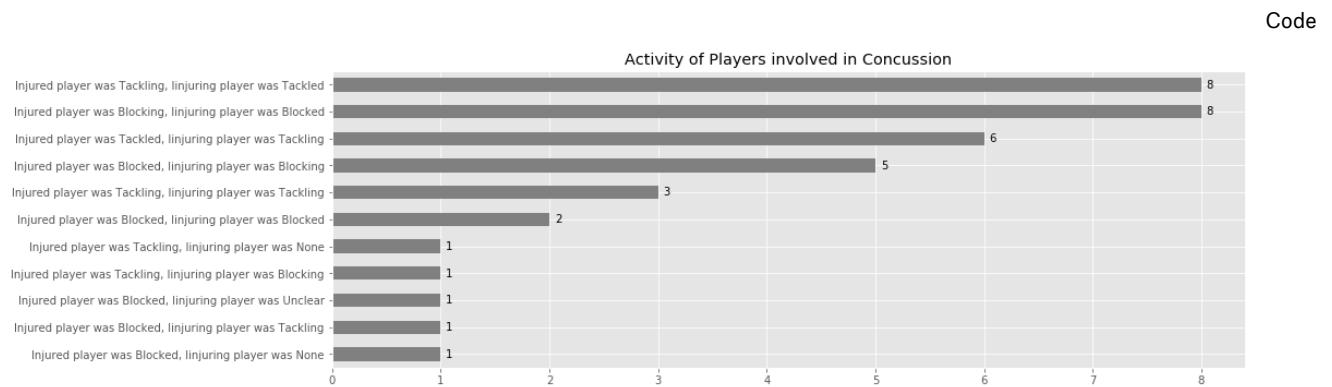
We can see that the top primary impact is balanced between helmet-to-ground and helmet-to-body impact causing the concussion. Helmet to ground occurred twice. As we know, the NFL has rules in place to leading with the helmet, but it is surprising that helmet to body contact is on par with helmet to body concussions.

Code



The activity of the players involved in a concussion play shows us that the most common actions are **concussion from tackling another player** and **concussed while blocking another player** followed by **concussed while being tackled**.

We found it interesting that the top two actions show that the player receiving the concussion was the one initiating the action (tacking or blocking not being blocked or tacked).



Generalizing the Player Roles

To help generalize the player positions, we've taken the player roles and defined them as either punting or receiving. We've generalized the positions below and believe this allows us to better aggregate trends between plays:

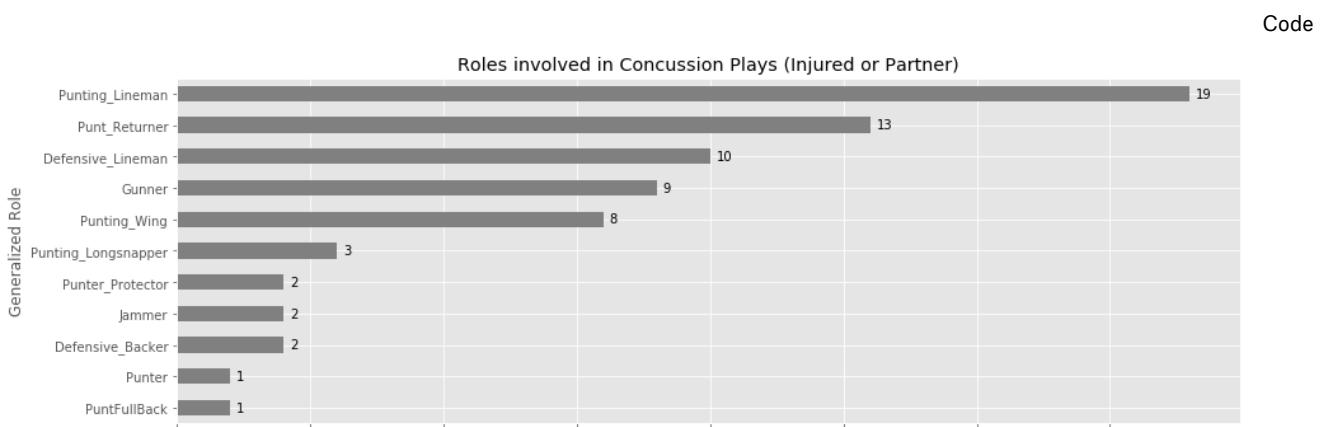
1. Punting Team or Returning Team
2. General Position
 - Linemen
 - Wing
 - Longsnapper
 - Punter Protector
 - Punter
 - Punt Fullback (Returner Protector)
 - Jammer
 - Gunner
 - Defensive Backer

Some main takeaways from this data are:

- Punting team players have more occurrences of concussions than the returning team. Returning team more commonly the primary partner but only slightly (.
- There are 3 cases of friendly fire- all involving the punting team.
- Punting Team's linemen top the role that suffered concussions.



Contrary to our assumptions going into this analysis. The top player involved in punting play concussions is not the punt returner or gunners, but instead punting team linemen. Punt returners are still high on the list, followed by defensive linemen.



Common Pairing of Player Roles involved in Injuries

Some observations:

- Most common pairing is to the punting lineman when making contact with the punt returner and NOT with gunners.
- Defensive linemen making contact with Punting Wing and Punting Linemen is common.
- Gunner / Punt Returner combination only occurs 3 times.

Code

Out[28]:

	Injured Player	Primary Partner	count
0	Punting_Lineman	Punt_Returner	4
1	Punting_Wing	Defensive_Lineman	3
2	Punting_Lineman	Defensive_Lineman	3
3	Punting_Wing	None	2
4	Gunner	Punt_Returner	2
5	Punting_Lineman	Punting_Wing	2
6	Punt_Returner	Punting_Lineman	2
7	Defensive_Backer	Gunner	1
8	Punter_Protector	Punting_Lineman	1
9	Punting_Longsnapper	Punt_Returner	1
10	Punting_Longsnapper	Defensive_Lineman	1
11	Punting_Lineman	Punting_Lineman	1
12	Punting_Lineman	None	1
13	Punting_Lineman	Gunner	1
14	Punter	Jammer	1
15	Defensive_Lineman	Punting_Lineman	1
16	Punt_Returner	Punter_Protector	1
17	Punt_Returner	None	1
18	Punt_Returner	Gunner	1
19	PuntFullBack	Punting_Lineman	1
20	Jammer	Punting_Lineman	1
21	Gunner	Gunner	1
22	Gunner	Defensive_Lineman	1
23	Gunner	Defensive_Backer	1
24	Defensive_Lineman	Punting_Longsnapper	1
25	Punting_Wing	Punt_Returner	1

Code

Injury Play Analysis - Plotting all 37 Plays

Plotting these plays was essential in allowing us to see diverse these 37 plays are. No immediate trends show themselves when looking at all plays. It's also important that our sample size is relatively small and we should not try to confuse correlations with causation for the punt types and cause of concussions.

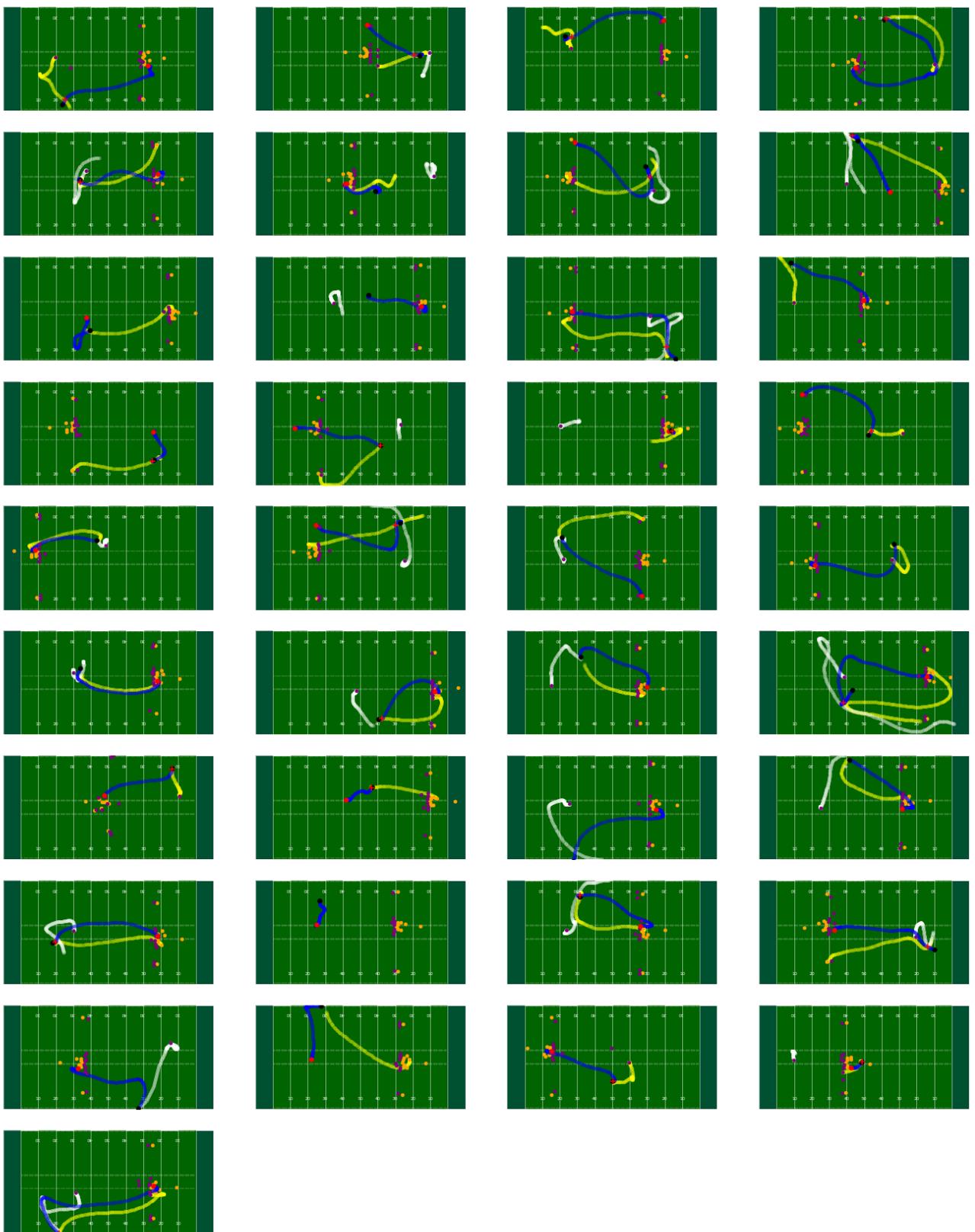
Interpreting our Punt Play Plots

- **Blue Line:** Indicates the path of the player who suffered a concussion.
- **Yellow Line:** Indicates the path of the player who was listed as the primary partner in the injury.
- **White Line:** If the punt returner is not involved in the injury this shows his path
- **Orange Circles:** Punting team formation at time of the snap
- **Purple Circles:** Returning Team formation at time of snap
- **Red Circle** - Starting position of injured player
- **Red +** - The approximate location where the injury occurred (calculated at the point where the injured player and primary partner were at the closest distance)

We've also removed any NGS data points from before the snap and after the play has ended to allow us to only focus on moments of action. There were a few plays where the impact occurred slightly after the end of the play.

Code

Code



Preprocessing for this section was completed in this kernel : <https://www.kaggle.com/robikscube/nfl-punt-data-preprocessing-ngs-injury-plays/output> (<https://www.kaggle.com/robikscube/nfl-punt-data-preprocessing-ngs-injury-plays/output>)

We identified some trends in the type of plays resulting in a player suffering a concussion:

- **Direct Hit on Punt Returner** - This was the most common type of play, where the punt returner was tackled soon after catching the ball.
- **Player hit while in pursuit of punt returner** - This was also a common trend. These types of plays typically had the punt returner avoiding the first round of tacklers (gunners) and making their way upfield. We noticed that a common trend was players from the punt return team turning their momentum 180 degrees to follow the punt returner. This then opened the possibility for these players to engage in high velocity collisions with players still running upfield.
- **Injury Near Line of Scrimmage** - These plays were less common (3 in total) - all occurred near the line of scrimmage-usually on the punting teams side. They were mostly the result to linemen contacting other linemen,
- **Player injured by a non-contact / fall** - A few injuries appeared to be the result of either a missed tackle or fall where the player suffered a concussion due to hitting their head on the ground. These appear to be less likely to avoid since they were mostly non-contact.
- **Friendly Fire by players attempting to tackle the punt returner from opposing angles.** - This was less common, but observed in 2 cases where the punting gunners collided with each other near where the punt returner caught the ball.
- **Other: Trick play, unique, or unclear from video footage** - There were other plays, like the Seahawks trick play, and other injuries where the cause was either not clear on film, or what seemed to be a fluke injury.

Next we will show some plots with examples of each type of play. We only plot the path for one of the plays, but the rest are commented out in the code. You can view them by uncommenting for a specific play.

Closer Look: Play where concussion a result of direct hit on punt returner (13 Plays)

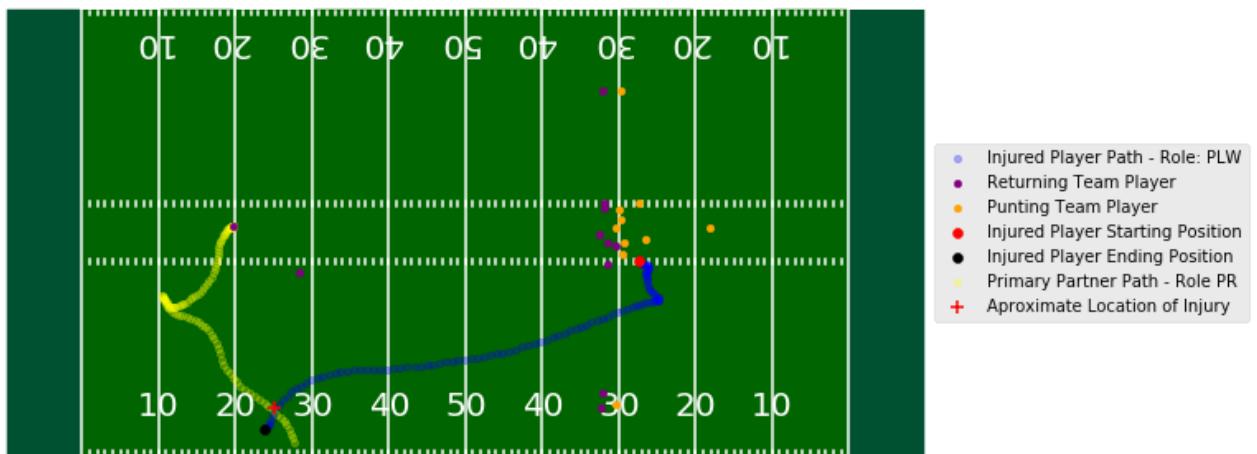
The most common type of play we see from the 37 concussion plays are where the punt returner is directly hit. Either the tackling or punt returner are injured. On the example below the PLW on the punting team suffered a concussion after running upfield and contacting the returner.

Code

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153233/Kadeem_Carey_punt_return-Vwgfn5k9-20181119_152809972_5000k.mp4)

Injured player number 25, 25o was injured while Tackling with primary impact Helmet-to-body

Season 2016 - Gamekey 5 - Playid 3129



Closer Look: Play where concussion a result of hit while in pursuit of returner (9 Plays)

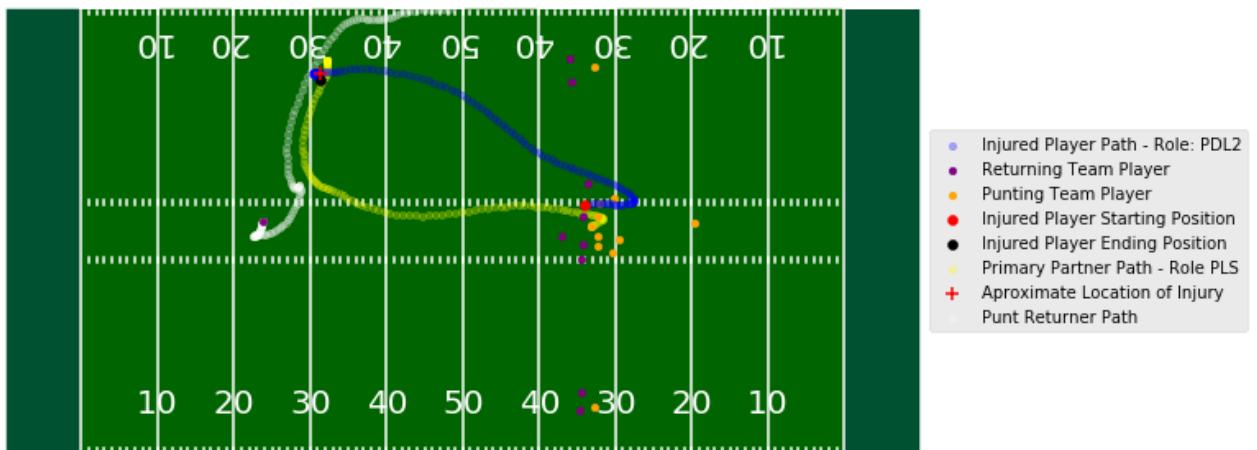
Second most commonly we see plays where one player is in pursuit of the punt returner and they are contacted by another player, either from their own team or another. We see a trend with these types of plays where the punt returner has passed the first line of the coverage team (gunners) therefore causing players to reverse direction that they are running to pursue. This appears to be when many of these types of injuries occur.

In the example below you can see that the PDL2 position player returned upfield to protect the punt returner who was running towards the sideline. The punting team's long snapper (PLS) was then brutally blocked by the PDL2 player while he was in pursuit of the returner. Even though the longsnapper took the brunt of the hit, the PDL2 player was the one who incurred a concussion.

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153280/Wing_37_yard_punt-cPHvctKg-20181119_165941654_5000k.mp4)

Injured player number 48, 62d, 62 was injured while Blocking with primary impact Helmet-to-helmet

Season 2017 - Gamekey 553 - Playid 1683



Plays where injury occurs near the line of scrimmage (3 Plays)

These injuries occurred near or at the line of scrimmage. They did not involve players moving at high velocity. In the example below the coverage team's PLW (left wing) was pushed backwards and hit his head on the ground after being contacted by the returning team's PDR2 role moments after the snap. This can be seen in the video.

Code

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153326/Sanchez_27_yd_punt-r51JAWPm-20181119_174359780_5000k.mp4)

Injured player number 85, 86 was injured while Blocking with primary impact Helmet-to-head

Season 2017 - Gamekey 607 - Playid 978



Injury due to player falling and hitting head on ground (2 Plays)

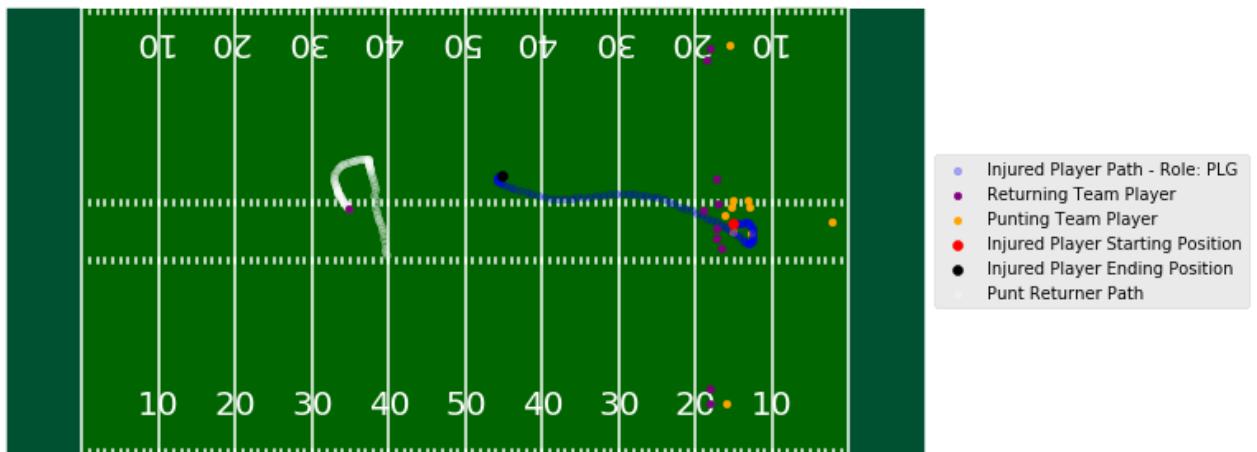
- Players hit head on ground when attempting to tackle or being blocked

Code

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153243/Punt_by_Brett_Kern-p3udGBnb-20181119_15513915_5000k.mp4)

Injured player number 89 was injured while Blocked with primary impact Helmet-to-ground

Season 2016 - Gamekey 218 - Playid 3468



Injury plays as a result of friendly fire where gunners hit each other. (2 plays)

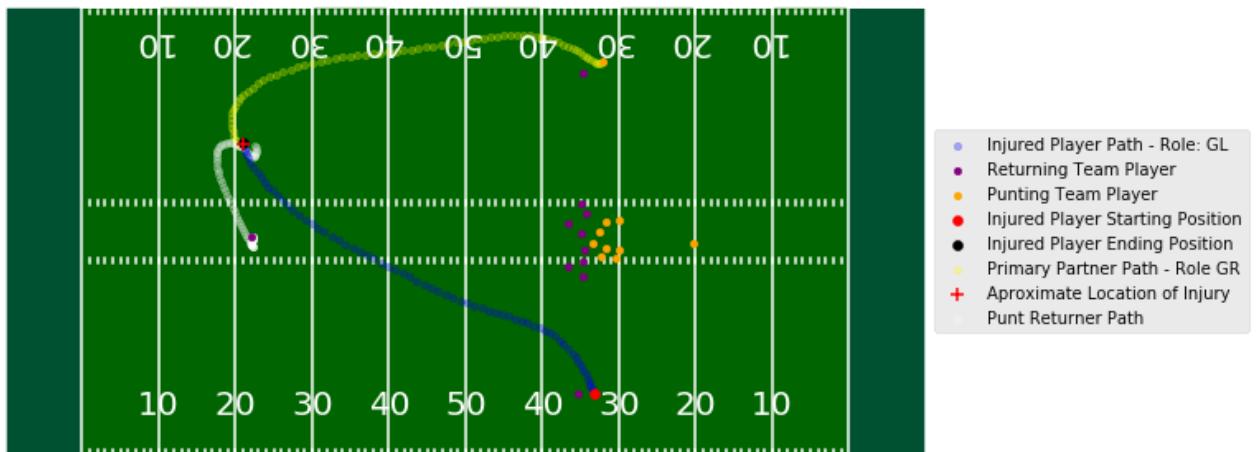
We see this occur on two plays where gunners hit each other when attempting to tackle the punt returner.

Code

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153249/Punt_by_Brett_Kern-KYTnoH51-20181119_161310312_5000k.mp4)

Injured player number 36 was injured while Tackling with primary impact Helmet-to-helmet

Season 2016 - Gamekey 296 - Playid 2667



Other types of plays (Fake punt, unclear, etc.)

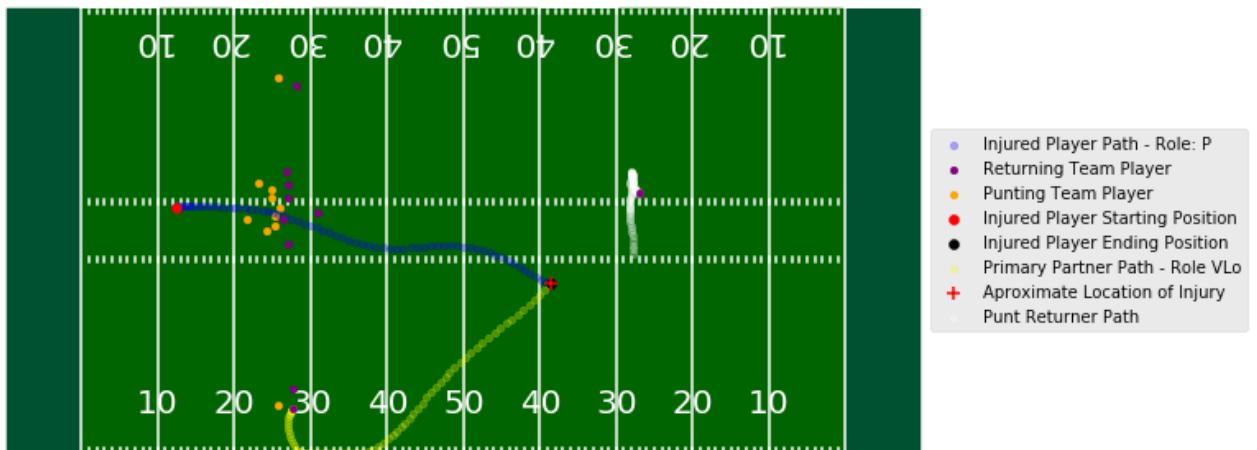
The rest of the plays were either unique situations where the concussion occurred or were not clear to identify given the video footage.

Code

Play-Video-Link (http://a.video.nfl.com//films/vodzilla/153248/Rush_by_Jon_Ryan-Csg9PS77-20181119_160437472_5000k.mp4)

Injured player number 9 was injured while Tackled with primary impact Helmet-to-helmet

Season 2016 - Gamekey 274 - Playid 3609



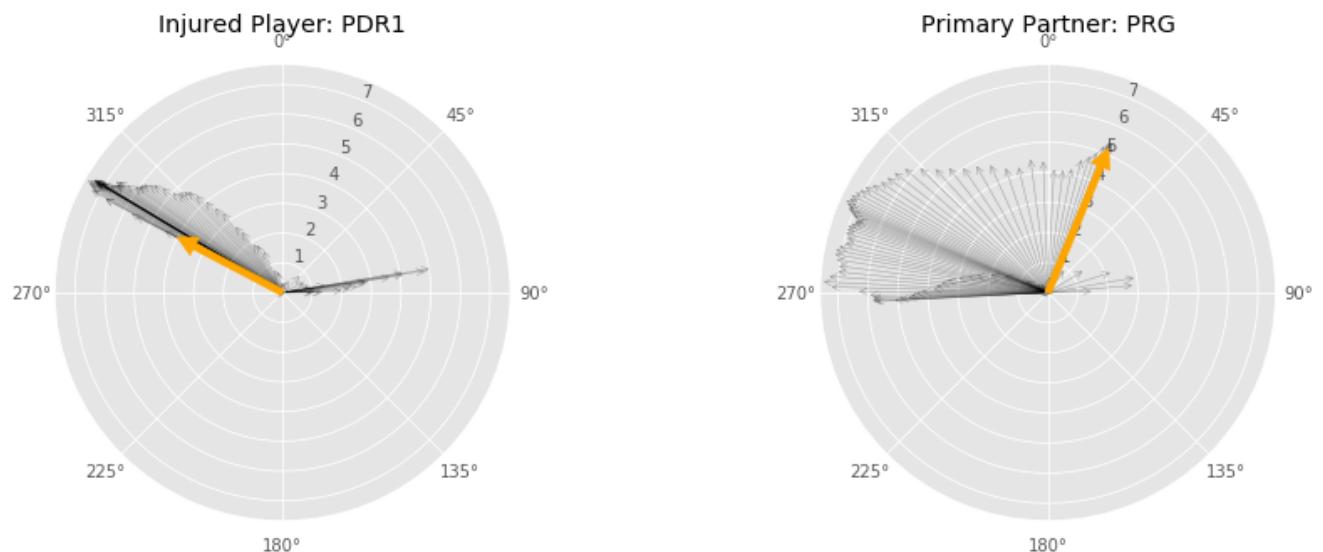
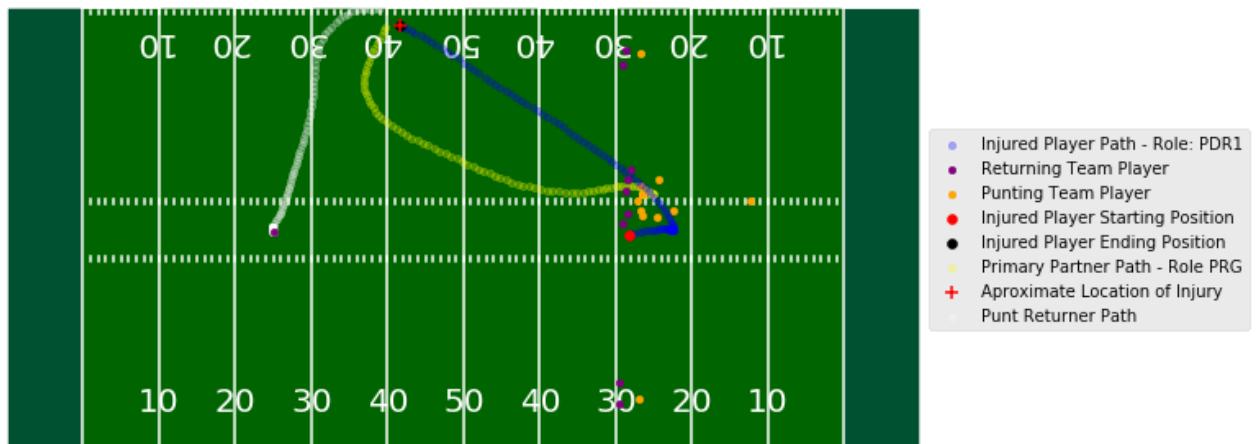
Velocity and Direction of Players During Injury Plays

By plotting out the direction and velocity that the two players involved in an injury were moving we can visually see some trends. The players commonly are changing direction, in order to follow the punt returner when they contact the punt returner. Some thing we've observed from reviewing all the play's velocity and direction, is that players often suddenly change their direction prior to impact. In the compass plots:

- Velocity is measured in meters per second
- Orange Arrow indicates the approximate moment when the injury occurred.

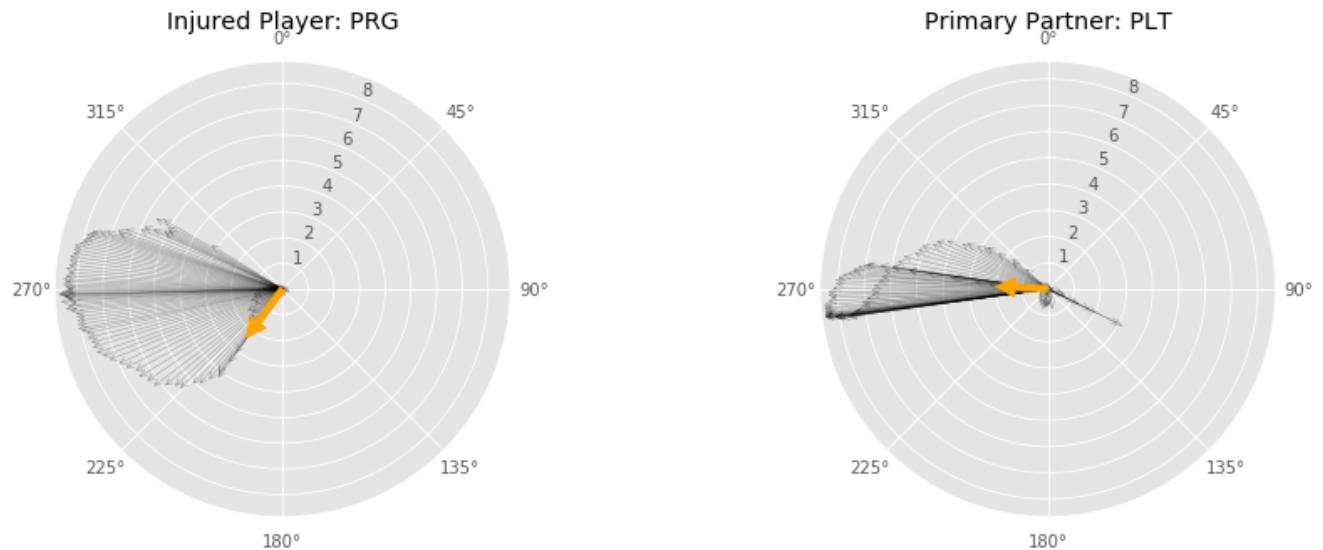
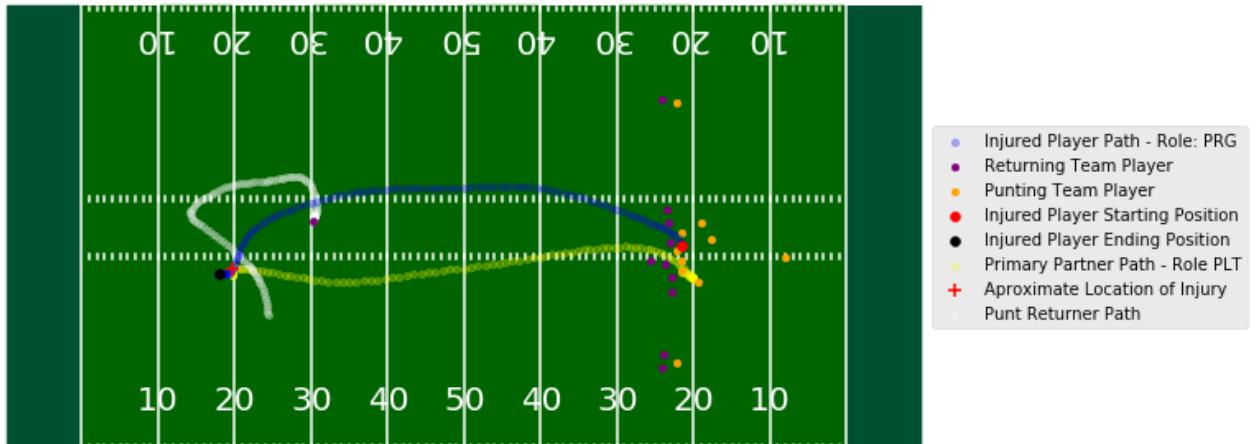
In this first example we can see the punt returner went towards the left sideline upon receiving the punt. The injured player (PDR1) had a pretty straight path towards the punt returner after his initial blocker. The primary partner however, was moving upfield for the majority of the play and then made a sharp turn to block prior to impact. This same trend was observed a number of times when reviewing each injury play.

Season 2017 - Gamekey 448 - Playid 2792



In this example we can see the punt returner retreated slightly and then ran to his right. The injured player (PRG) and the primary partner (PLT) both were moving directly upfield at high velocity. The injured player changed direction just prior to impact.

Code



Section III - Analysis of Fair Catch vs. Returned Punt

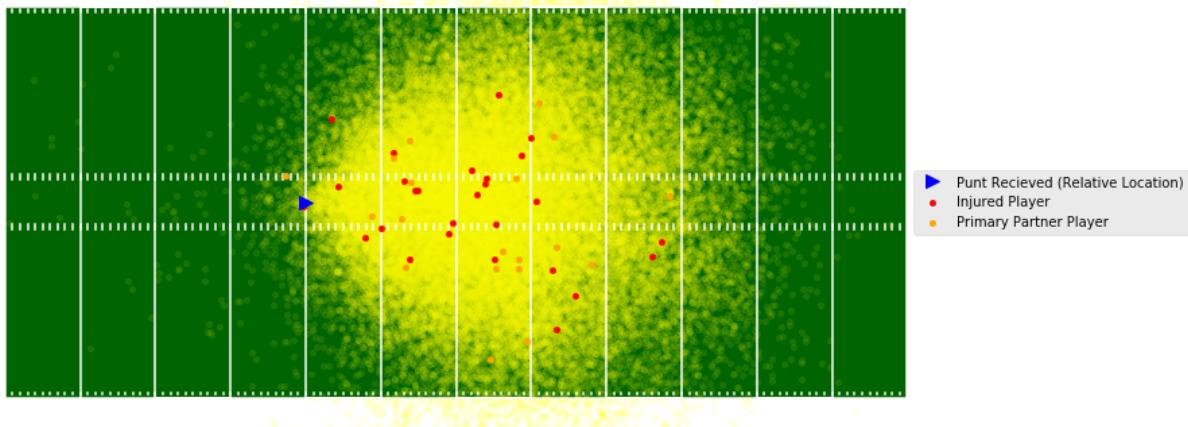
In order to analyze how and when punt returners decide to fair catch, we've taken every play and normalized the data such that we have each players position in relation to the punt returner. This allows us to visualize the general distance from the punt returner when he decides to fair catch or try and return.

Punting Team Relative Position to Punt Returner (Fair Catch vs. Return)

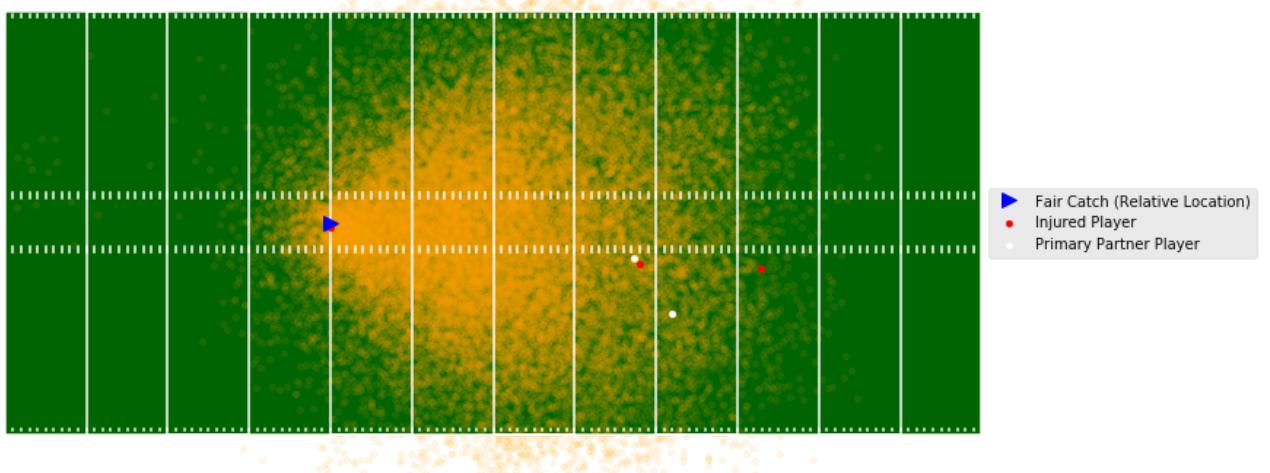
In these two plots we can see that fair catches occur more commonly when the opposing team is closer (and in some cases behind) the punt returner. This is expected. The distance of injured players and primary partners in injuries appear to be distributed throughout the relative locations. One main observation of this plot is that the location of injured players on punt returns (relative to the punt returner at time of catch) varies quite a bit. Some are almost on top of the punt returner and others are 30+ yards down field. The number of injuries on fair catches is much less, but we do see that these injuries occur relatively far away from the returner.

Code

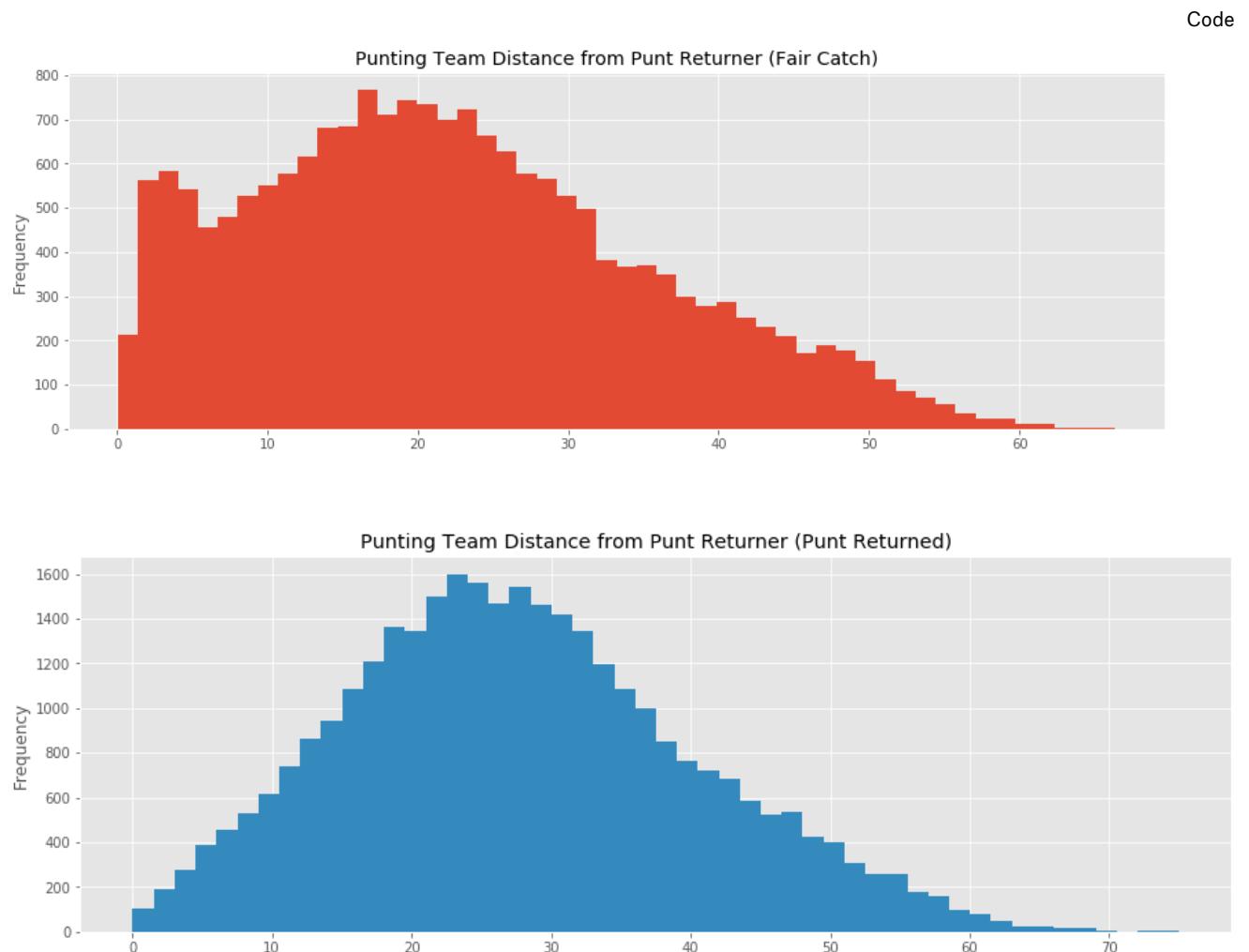
Gunners Relative to Punt Returner (Injury Colored)



Gunners Relative to Punt Returner (Injury Colored)



We can look at the distribution of the punting team in relation to the punt returner. On a fair catch there is a noticeable spike in the number of player 2-5 yards from the returner- presumably these are gunners who have reached the returner and are waiting near by. On returned punts however the distribution of players is much more normally distributed. On returns the gunners have not reached the returner or have overshot the returner.

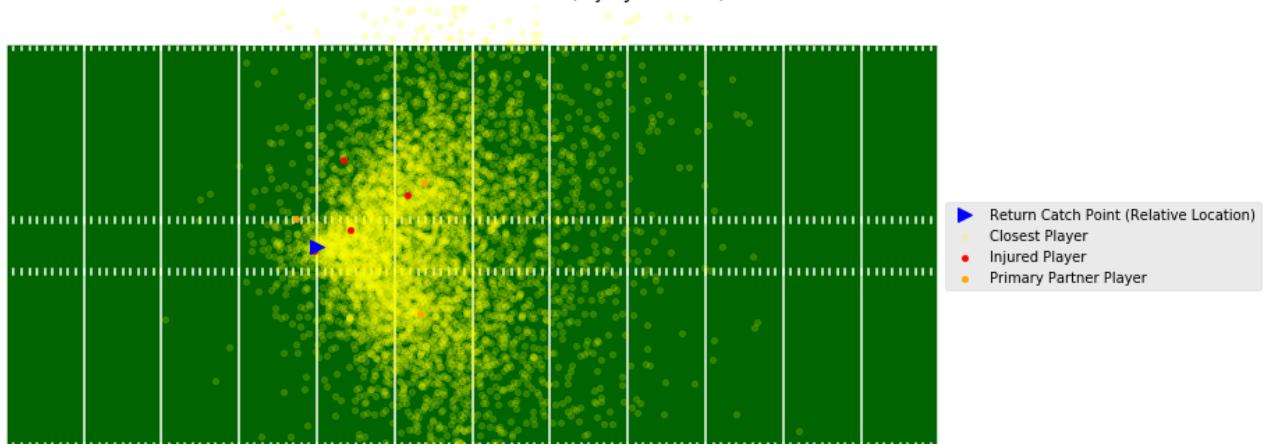


Distribution of Closest Player (Gunner) Distance from Punt Returner

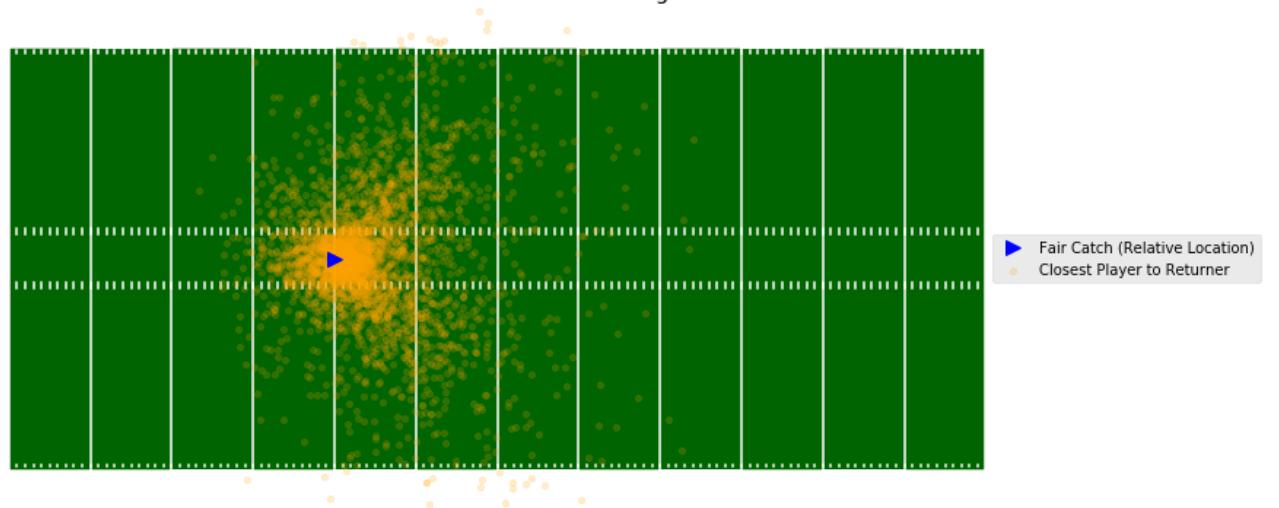
Next we look at the closest player to the punt retuner from the punting team at the time of punt or fair catch. Surprisingly this is overwhelmingly the left gunner - 99.28% on fair catches and 98.6% of the time on returned punts. We also see the median distance of the closest player on a fair catch is much less than that of a return (3.19 yards for a fair catch vs 10.03 on a return). From this we can conclude that fair catches are usually only made when the opposing player is very close distance to the punt returner. This makes sense as returners currently have no incentive to try and return if they think they can at least make a gain. Gunners involved in concussion plays are close by the returner on return plays. No concussions involved gunners on fair catch plays.

Code

Gunners Relative to Punt Returner (Injury Colored)

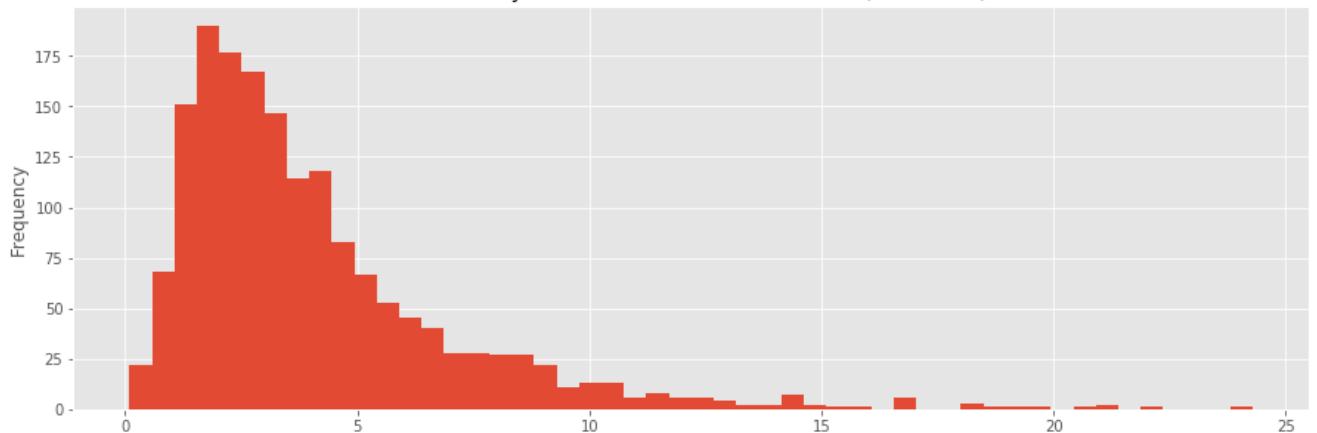


Gunners Relative to Fair Catch Punting Team

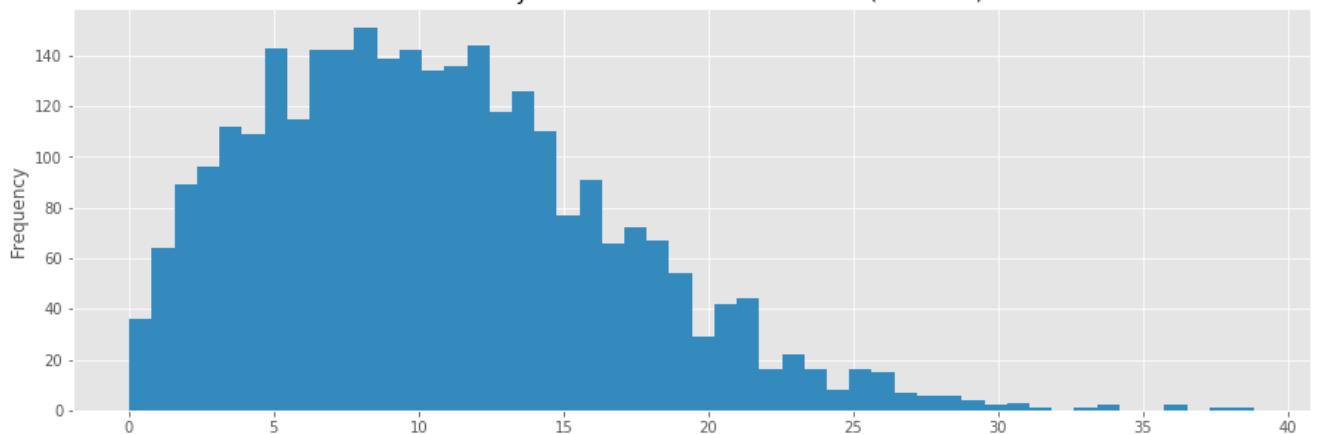


Code

Closest Player Distance from Punt Returner (Fair Catch)



Closest Player Distance from Punt Returner (Returned)



Code

Median closest player to punter returner on a return is 10.03 yars

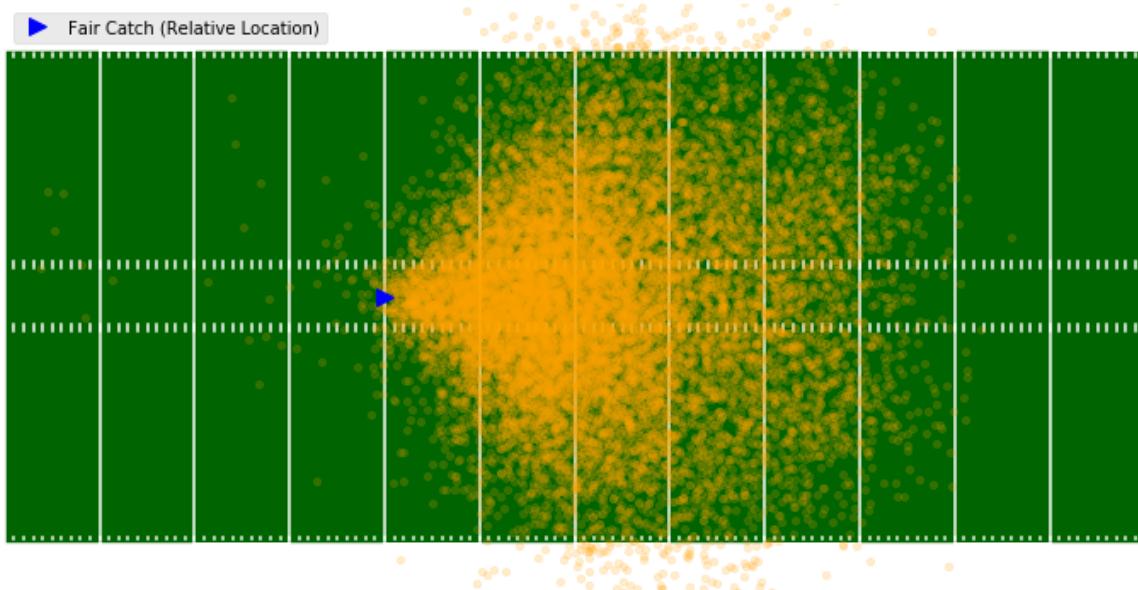
Median closest player to punter returner on a fair catch is 3.19 yars

Punting Team Non-Gunners Relation to Received Punt

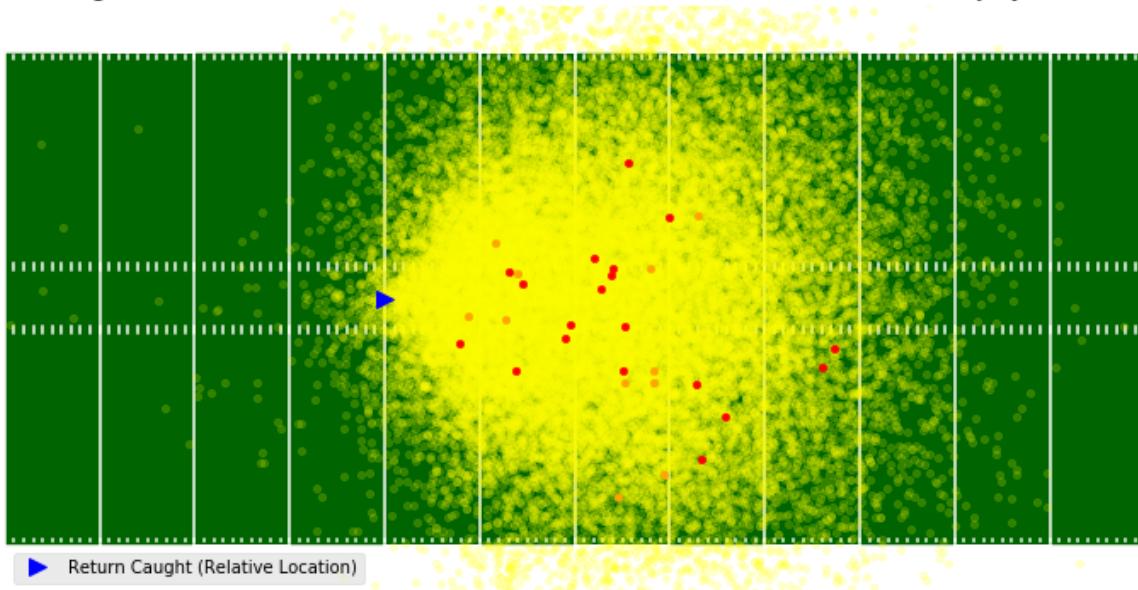
In this plot we remove the gunners to focus on non-gunners relative location to the punt returner at the moment of catch or fair catch. The distinction between between fair catches and returned punts for non-gunner players is fairly similar. This leads us to conclude that the gunners are the main factor in a punt returners decision to fair catch the ball.

Code

Punting Team - Non-Gunners Relative to Fair Catch Punt Returner at Catch

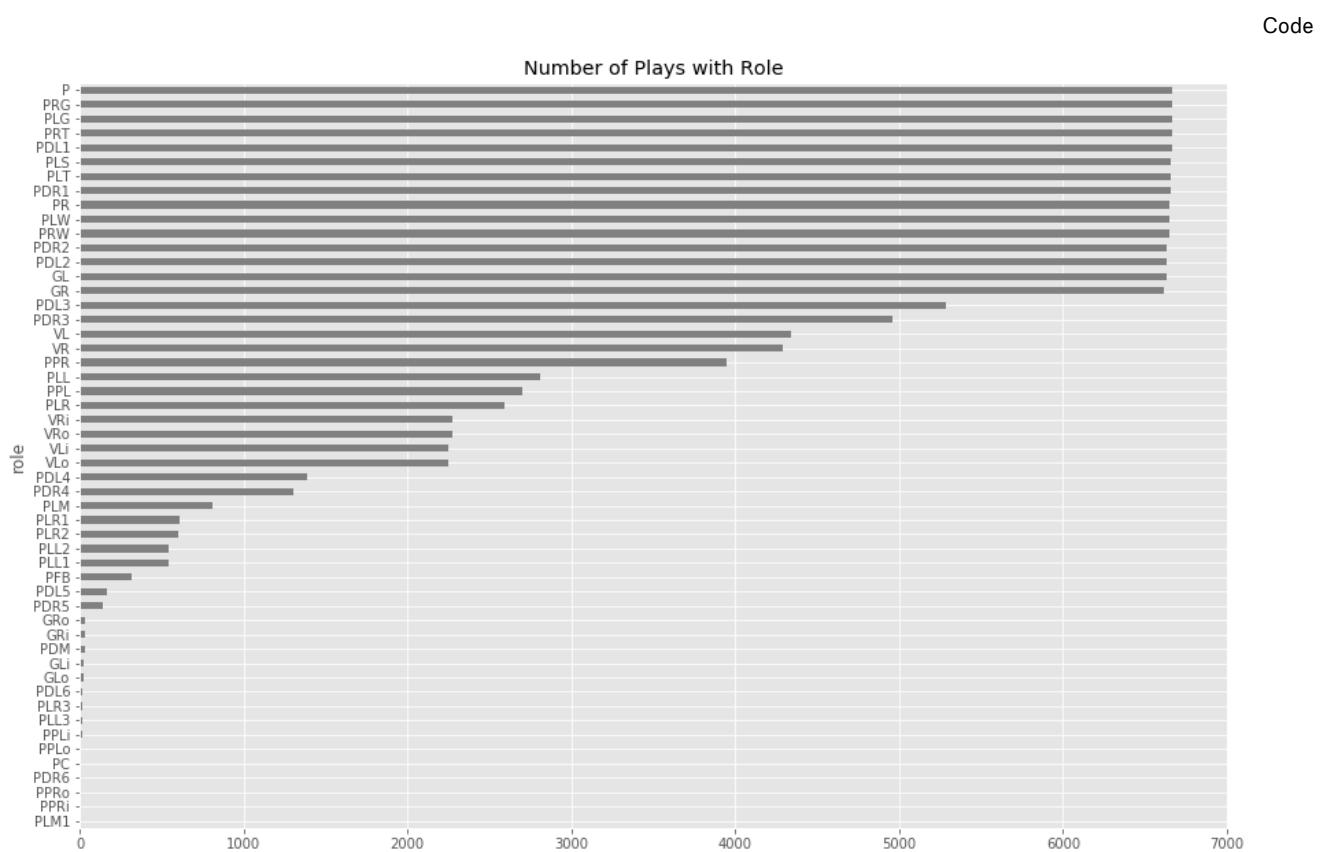
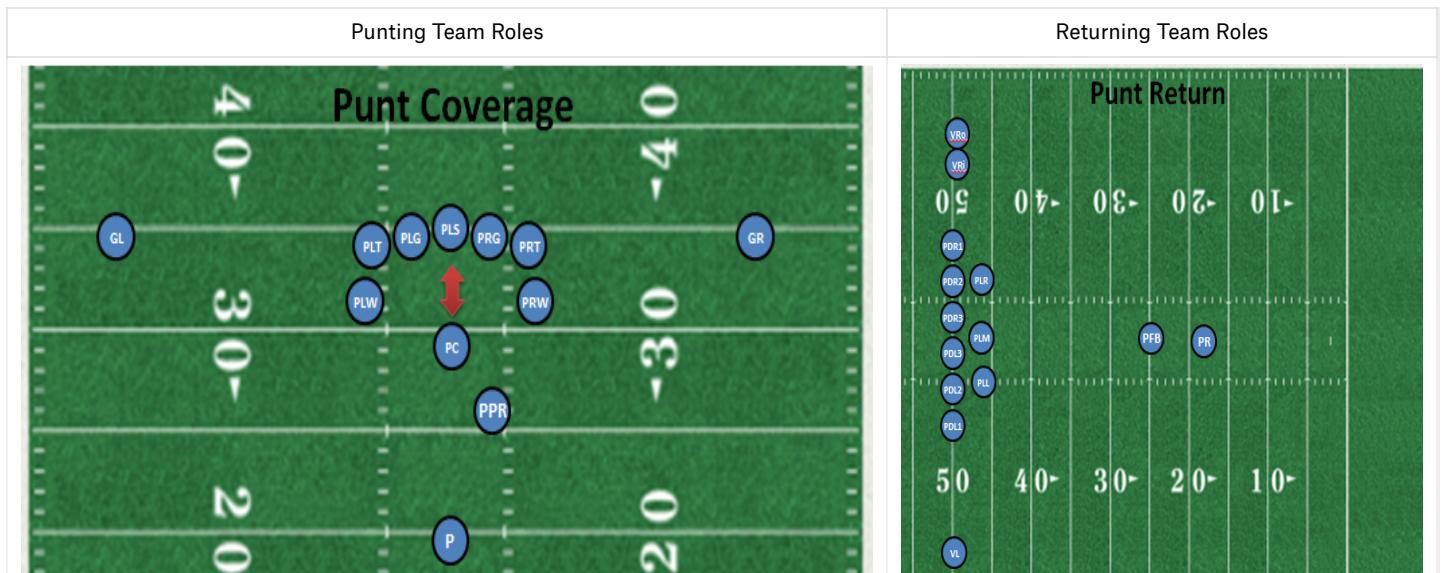


Punting Team - Non-Gunners Relative to Punt Returner at Moment of Catch (Injury Colored)



Punting Formation / Detailed Role Analysis

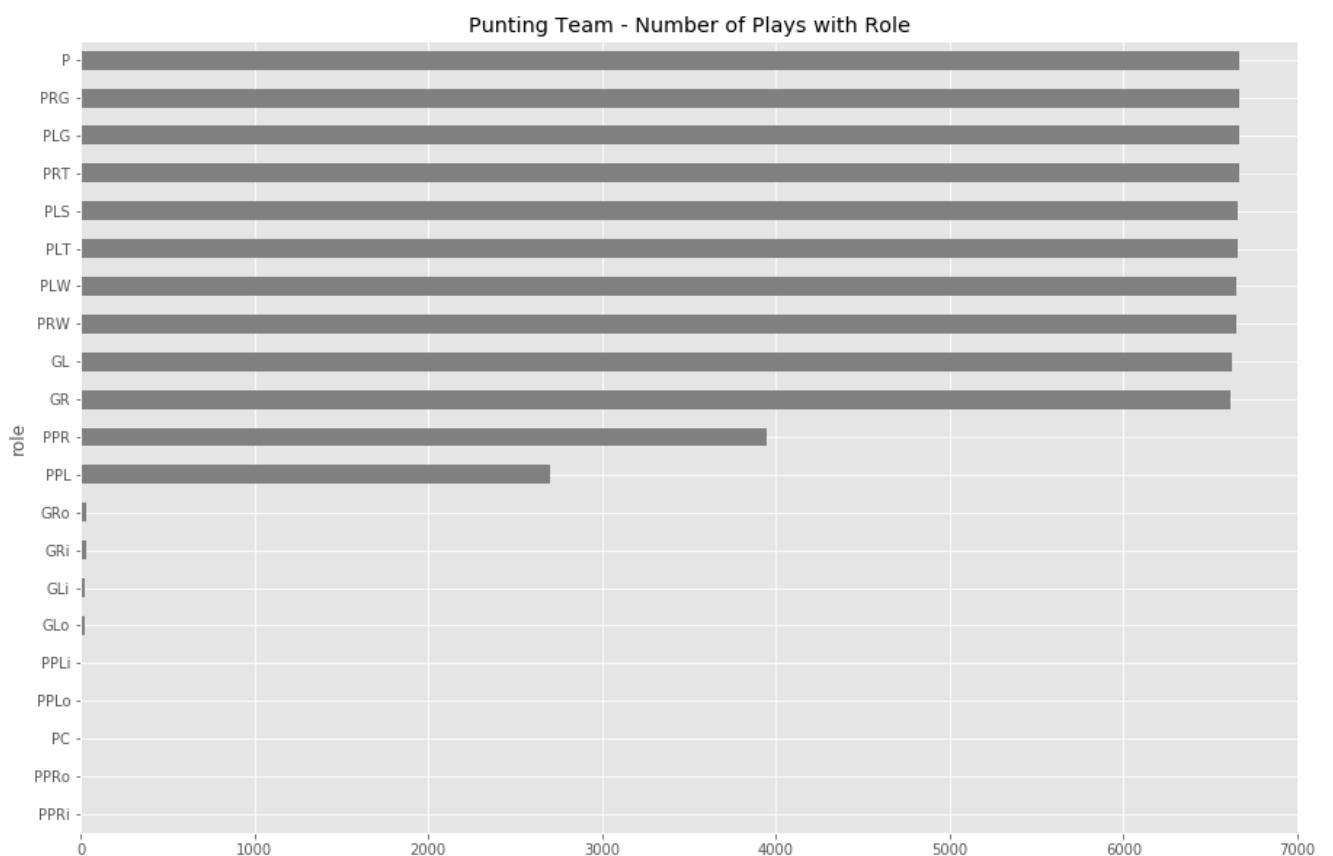
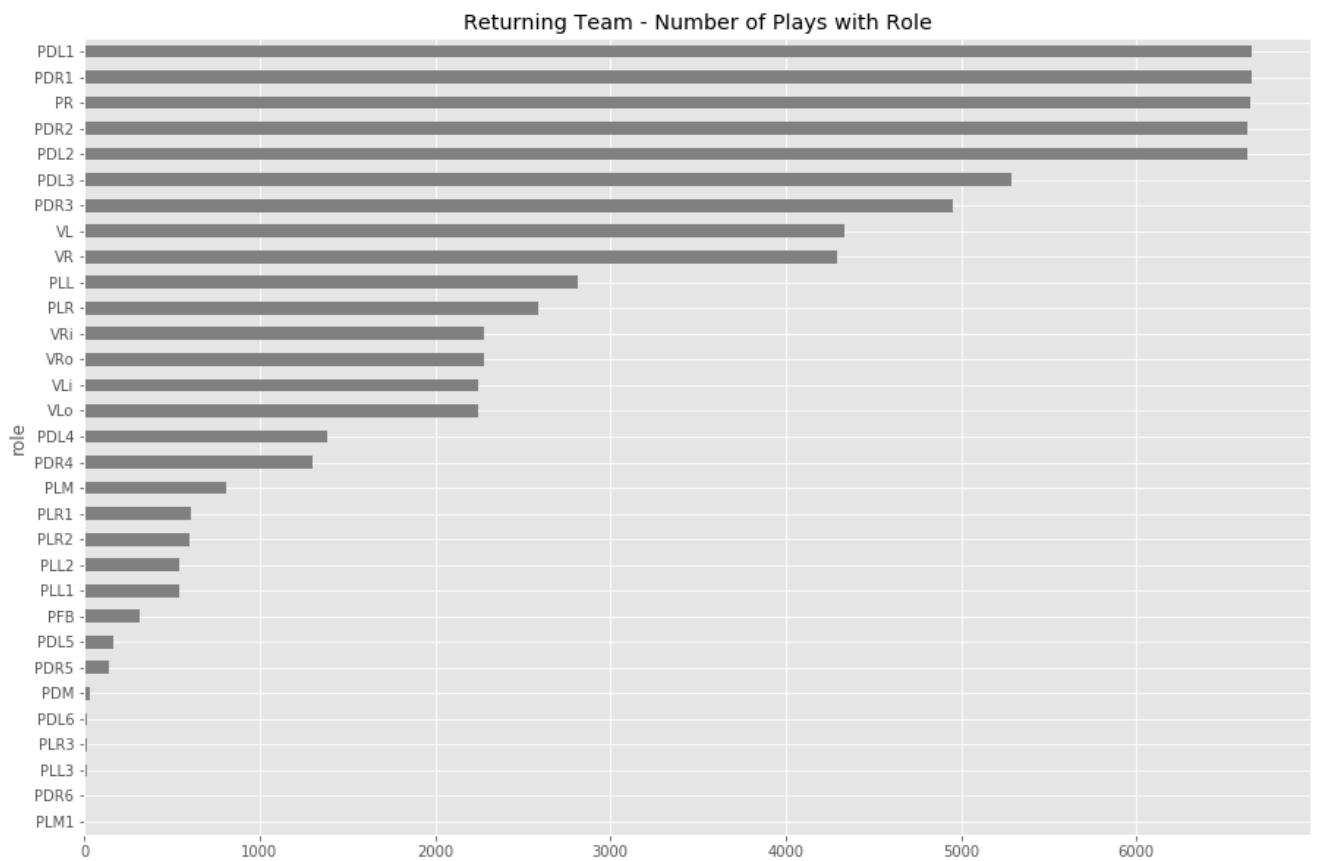
Next we will look at individual player roles and their frequency in punting plays. We can see some positions (Punter, PRG, PLG, PRT, etc) appear in nearly every punting play. Other positions are commonly swapped out for each other. The positions that vary appear to mainly be on the returning side of the ball. For instance, the returning team can either setup for a return by double teaming the punting team's gunners with multiple jammers (VRi, VRo, VLi, VLo) - or they could decide to single cover the gunner and have more players around where the ball is snapped. Additionally we see many times where the returning team plays in a hybrid formation with two jammers on one side and single coverage on the other.



Insights from Player Roles

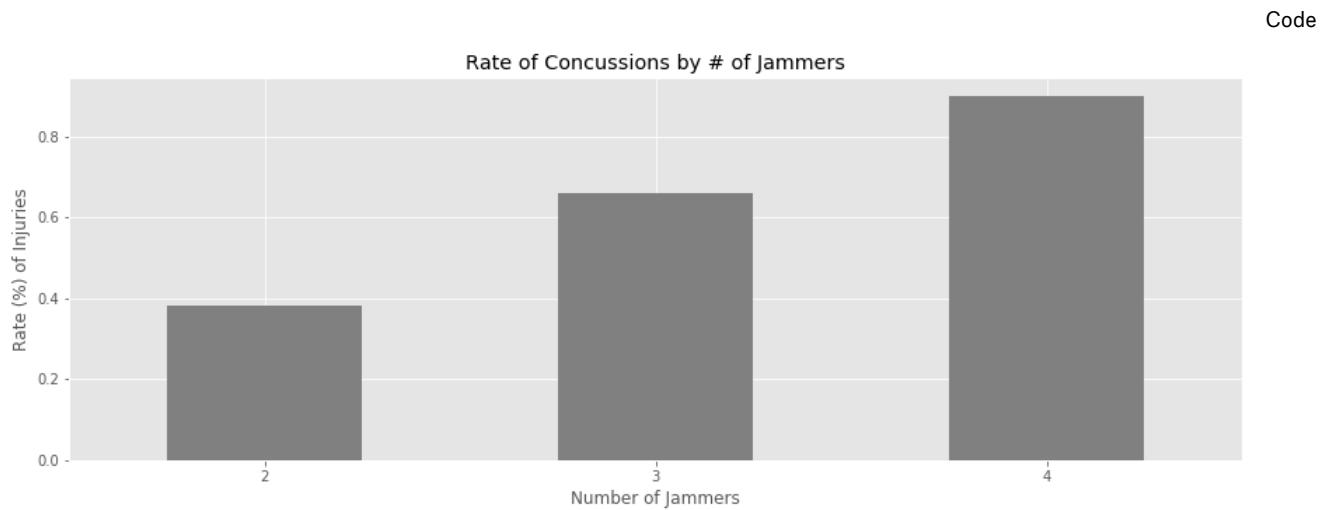
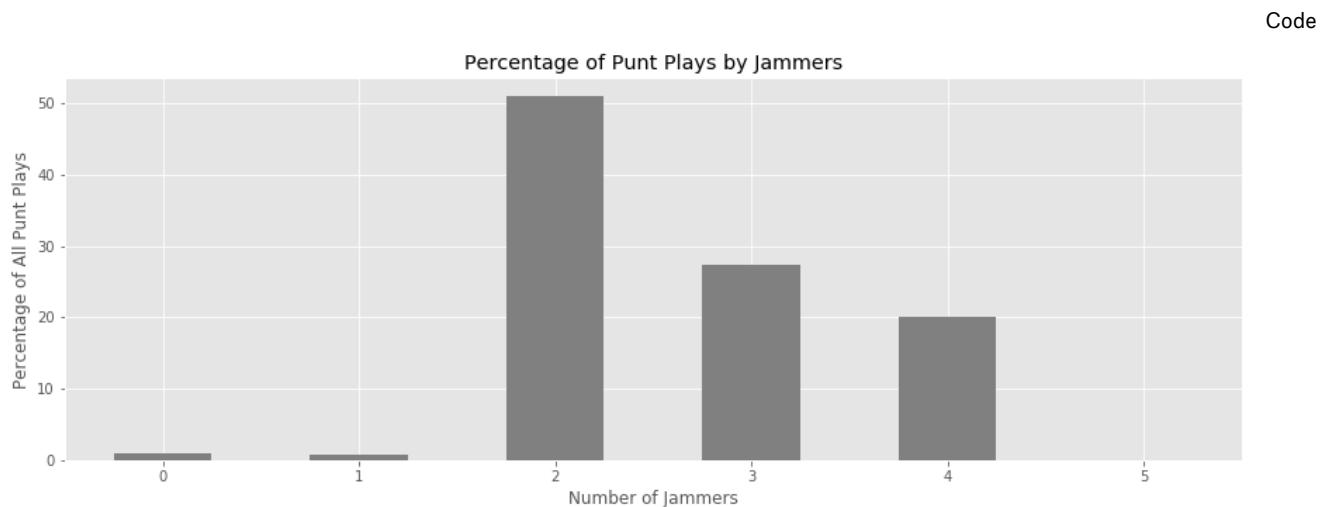
- The punting team tends to have the same roles on punting plays. The returning team however can decide depending on the position to setup for a return or try for a block.
- Jammers have a huge influence on the play. A defensive team can double team both, one or none of the punting team's gunners. This appears to have large consequences on the result of the play.

Code



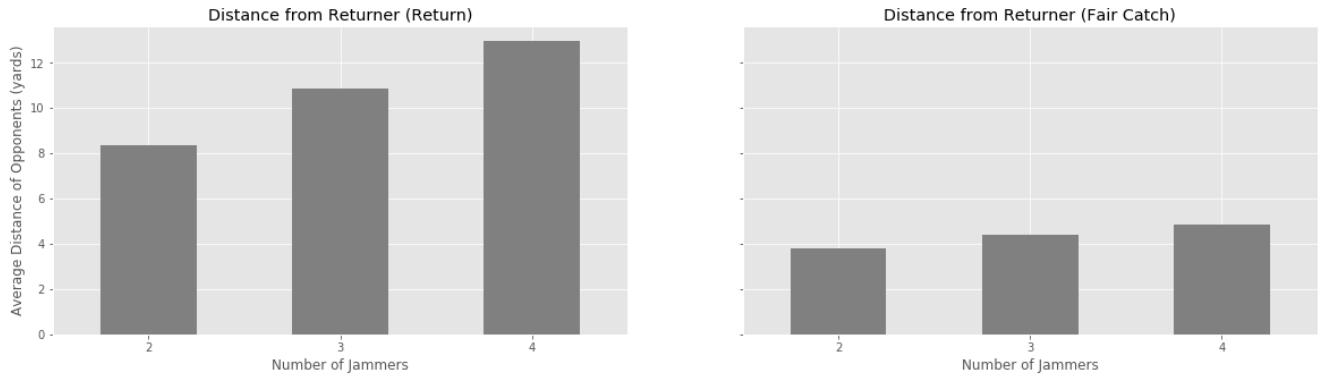
Number of Jammers on Play (Double teaming gunners)

Over half of the punts don't double team gunners- and yet the rate of concussions increases as the number of gunners increases from 2 to 4. We believe there are two reasons for this (1) as shown in the previous section, fair catches are commonly made when gunners are relatively close to the punt returner (~3 yards). When a team chooses to double team gunners it is more likely that the punt returner will choose to return. (2) Gunners, when double teamed, create an imbalance on the field between punting and returning players positions. This opens up the center of the field for punting team's linemen to gain higher velocity, and as a result make them more likely for high velocity impact.



Average Values of Distance to Returner depending on single, double, or hybrid coverage

In the process of analyzing players position to punt returners we noticed that there is a correlation between the number of jammers on the returning team with the distance of the punt. As we see in the plots below, the number of jammers appears to correlate with the punting team being further from the returner when he catches the ball.



Section IV - Visualizing Players Path Relative to Punt

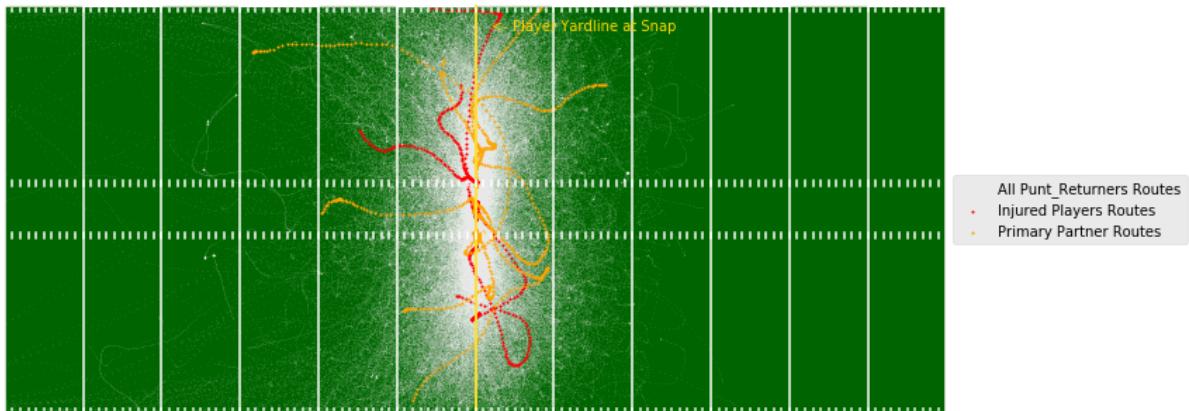
We wanted to look and see if the paths taken by players who were involved in a concussion were somehow unique. To visualize this we plot all the paths by player type in relation to their starting position of the play. These plots are very helpful in gaining high level insights to the paths of players involved in concussions compared to the average path.

Code

First we will look at the punt returners path. From this plot we see a lot of the paths appear to be sideline to sideline movements. In a few instances the punts are returned for gains of 10+ yards, but even in these we see a lot of horizontal movement. We also see from the white dots, that longer returns tend to have the punt returner going up a sideline, rarely do the punt returns go up the middle for large gains. Overall we can see the movement of punt returners are relatively condensed to +/- 10 yards from their starting location at the time of snap.

Code

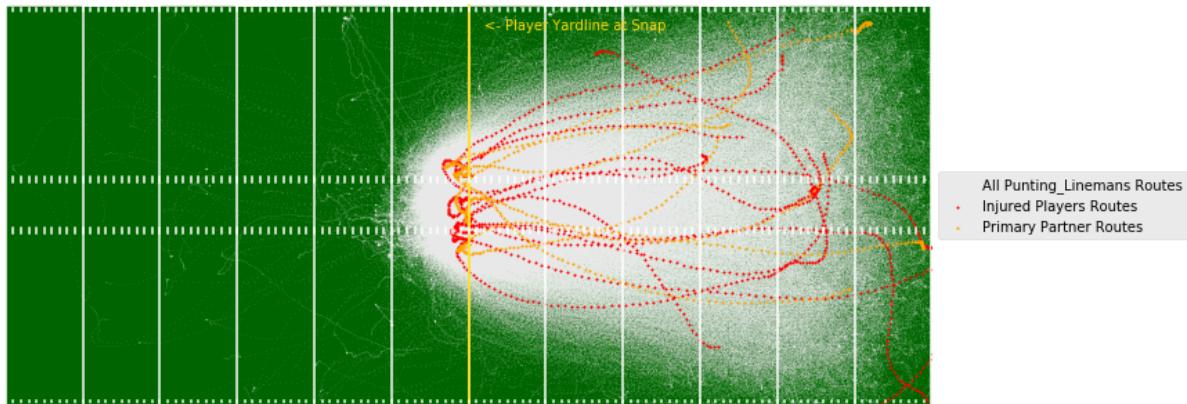
Punt Returner Routes on Punt Plays



We know that punting linemen are commonly involved in the concussion plays so we will plot their paths relative to snap position next. One thing that is immediately clear is that punting linemen, when involved in concussion plays look to travel a long distance. This supports the theory that punting linemen, when unblocked, reach higher velocity and are more likely to be injured or cause injury. We also notice that the injured punting linemen rarely travel inside the hash marks after the first 20 yards- because at this point they are in pursuit of the punt returner who has moved to one of the sidelines (identified in the last plot).

Code

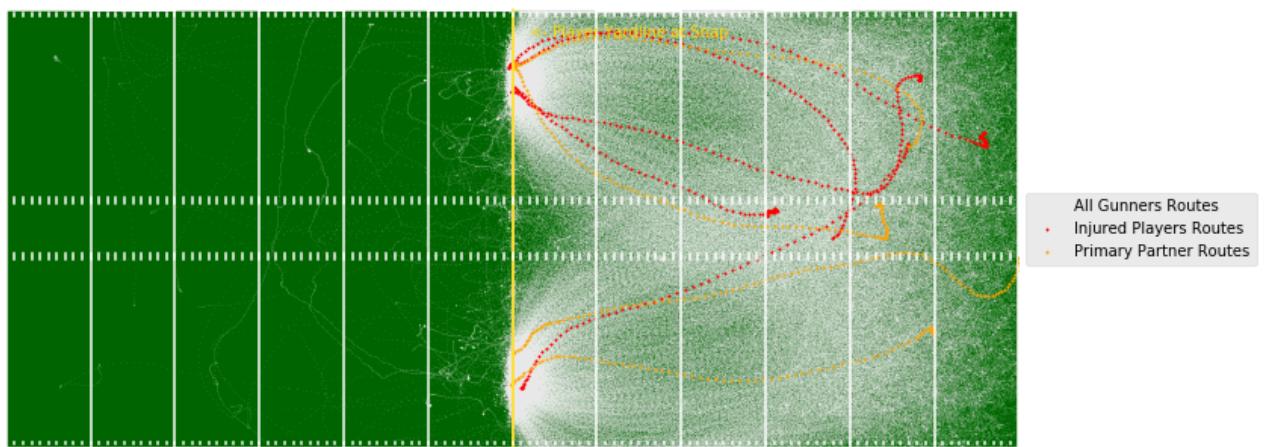
Punting Lineman Routes on Punt Plays



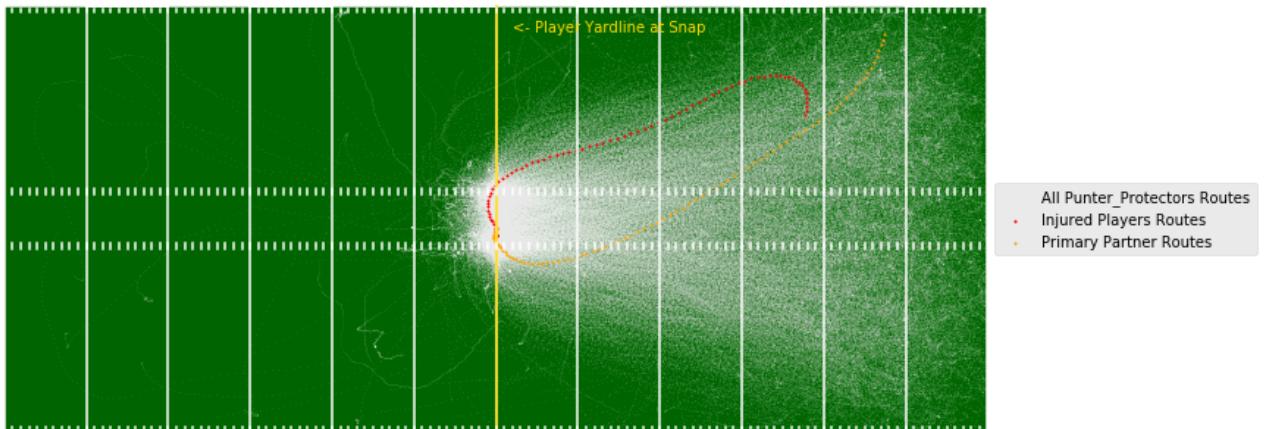
We will not discuss the remainder of the positions in detail, but provide the plots as we believe they each show us something interesting about how that player responds on a punting play.

Code

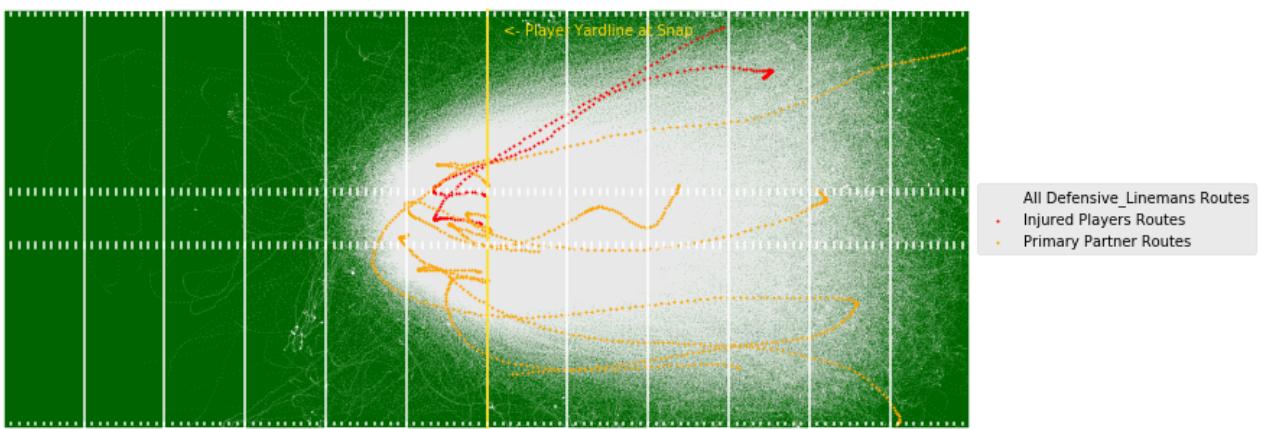
Gunner Routes on Punt Plays



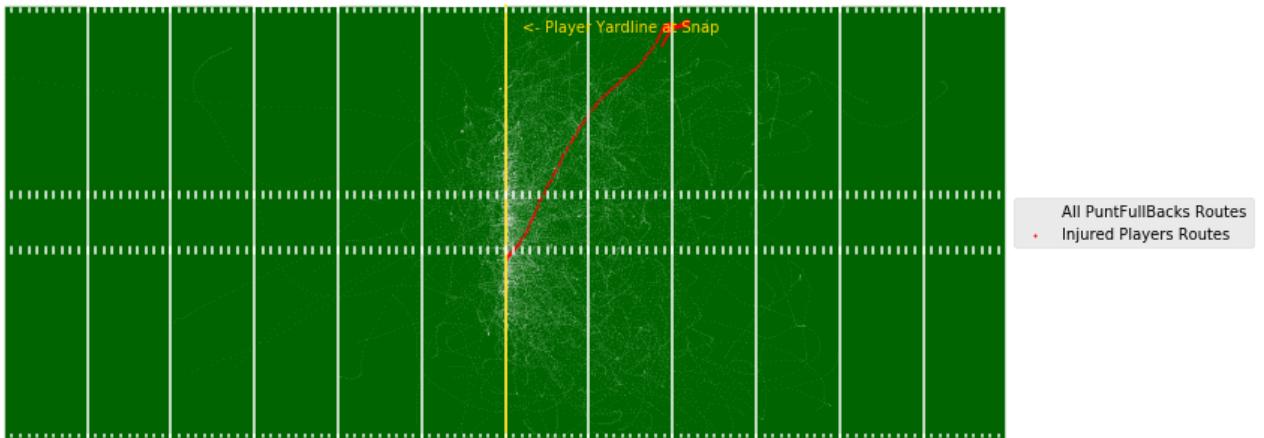
Punter Protector Routes on Punt Plays



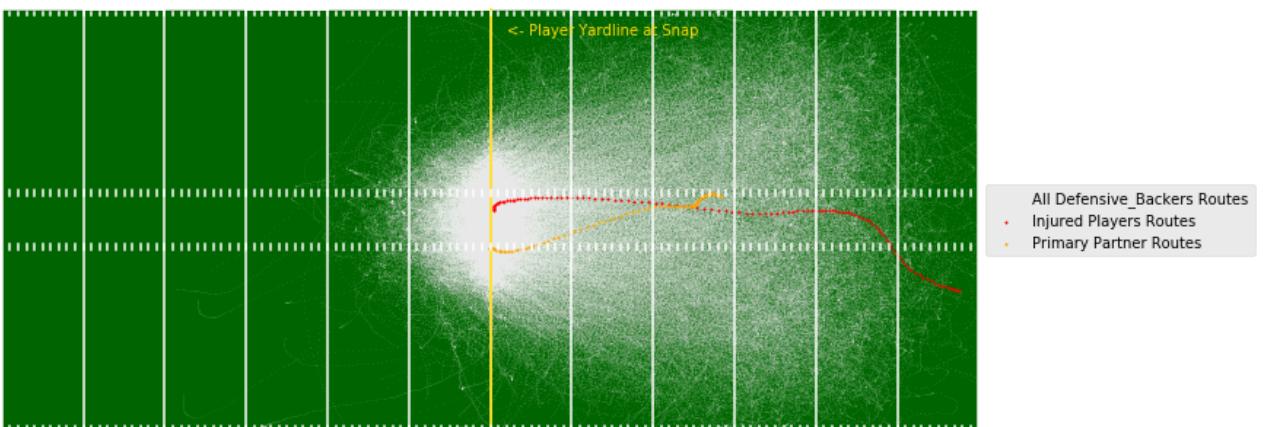
Defensive Lineman Routes on Punt Plays



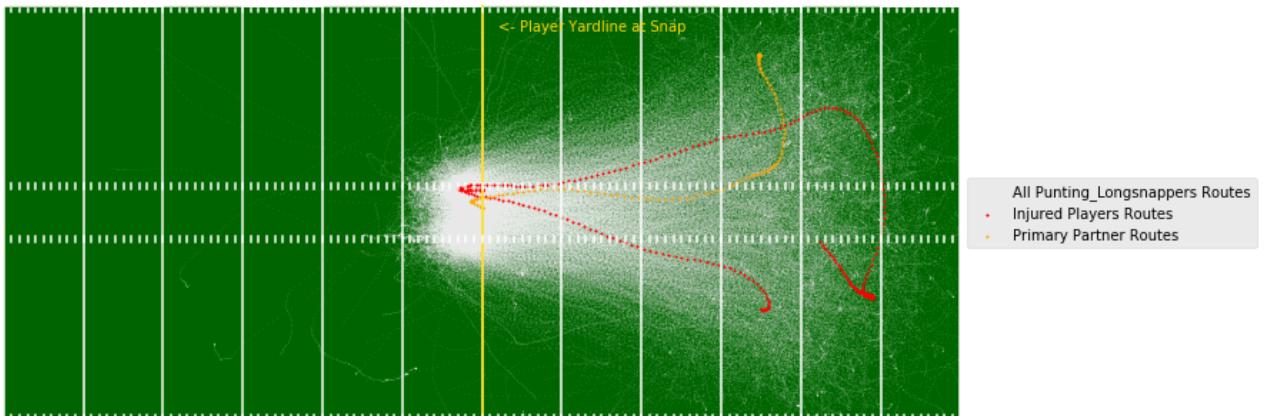
PuntFullBack Routes on Punt Plays



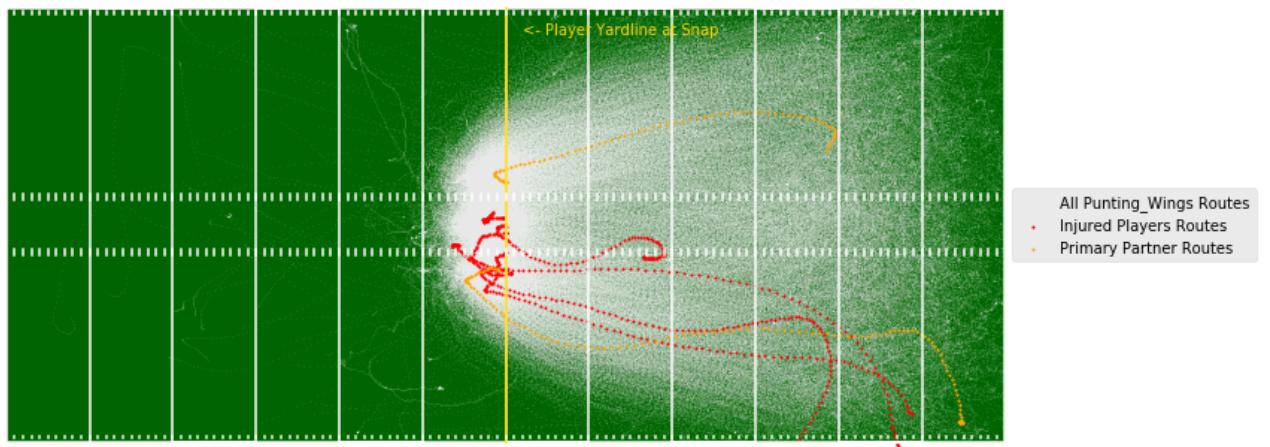
Defensive Backer Routes on Punt Plays



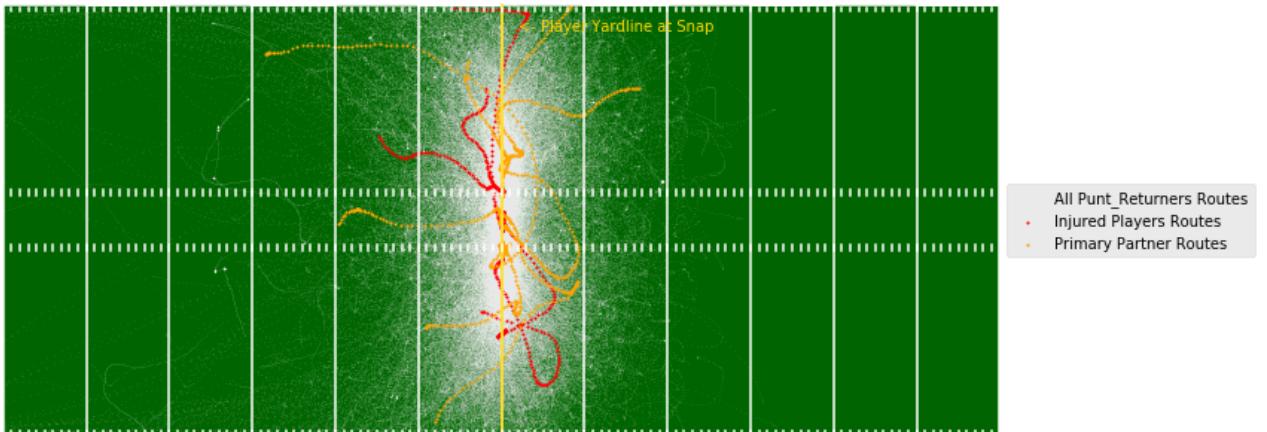
Punting Longsnapper Routes on Punt Plays



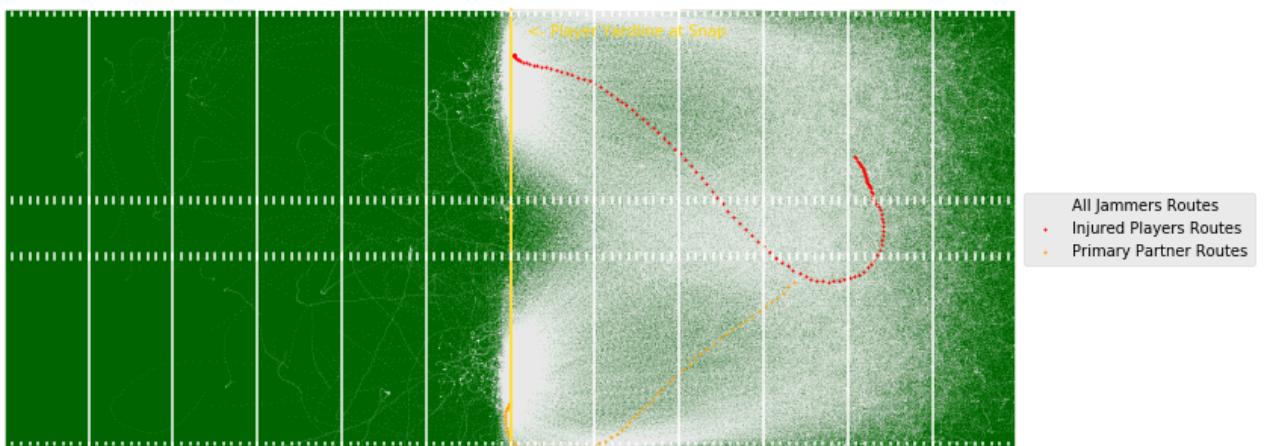
Punting Wing Routes on Punt Plays



Punt Returner Routes on Punt Plays



Jammer Routes on Punt Plays



Section V - Modeling Risk of Punt Plays based on Physics

In this section we will explain a metric we developed to help determine player risk. This research is still can be improved but we believe it shows great promise for evaluating risk with the goal of minimizing unnecessary injuries, not only for punt plays, but for all plays where NGS data is available. As we've stated before, football is a violent and risky game - we cannot and should not attempt to remove all risk from the sport. We do however feel that by focusing on **uncessarily high risk** plays (ie. ones with little excitement or impact on the game yet have high risk) - we can reduce the likelihood of concussions.

Because we have such a small number of plays which resulted in concussions (37) this heuristic provides us a to determine every single player's risk for any given play. Using NextGen Stats data with player's location, direction every tenth of a second during every punt play we did the following:

1. Calculated the momentum of every player in both the x and y direction during the play. Momentum is velocity multiplied by mass (kg * m/s). We assumed every player has the mass of 245.86 pounds (the average size of an NFL player). This calculation could be improved if we had actual player weights or average player weight per position.
2. Calculated the distance of every player in relation to each other. For every play we have 22 players. There are 22 * 21 combinations of each player in relation to each other. We calculated the distance for each player pair during the play.
3. Calculated the opposing momentum that each player has in relation to each other. Because we assume players are moving on a linear plane, we can use geometry to calculate each pair of players opposing momentum in the x and y direction. If two players are moving at high velocity but in the same direction this opposing momentum value would be small. Conversely if the two players are moving in high velocity towards each other the opposing momentum would be large.
4. Calculate the heuristic of Injury_Risk as the opposing momentum divided by the distance of the players from each other. While two players may have high opposing momentum, this only creates a risk if they are also in close proximity to each other.
5. We then take the **maximum risk of every pair of players** during a play. Allowing to see if during a play any two players were at a high right for collision.
6. Finally we normalized this risk value by dividing by the (mean + 1 standard deviation of all players on all plays. This last step allows our metric to be easier to interpret.

Our calculation can be seen as:

$$\begin{aligned} & \text{Injury_Risk} \\ &= \max \left(\frac{\sqrt{(momentum_{player1x} - momentum_{player2x})^2 + (momentum_{player1y} - momentum_{player2y})^2}}{distance_{p1vsp2}} \right) \\ Normalized_Injury_Risk &= \frac{Injury_Risk}{average_risk_allplays + stddev_risk_allplays} \end{aligned}$$

In summary, our risk metric is calculated based of two players *opposing momentum* and *distance from each other* and allows us to measure the potential injury for any two pairs of players.

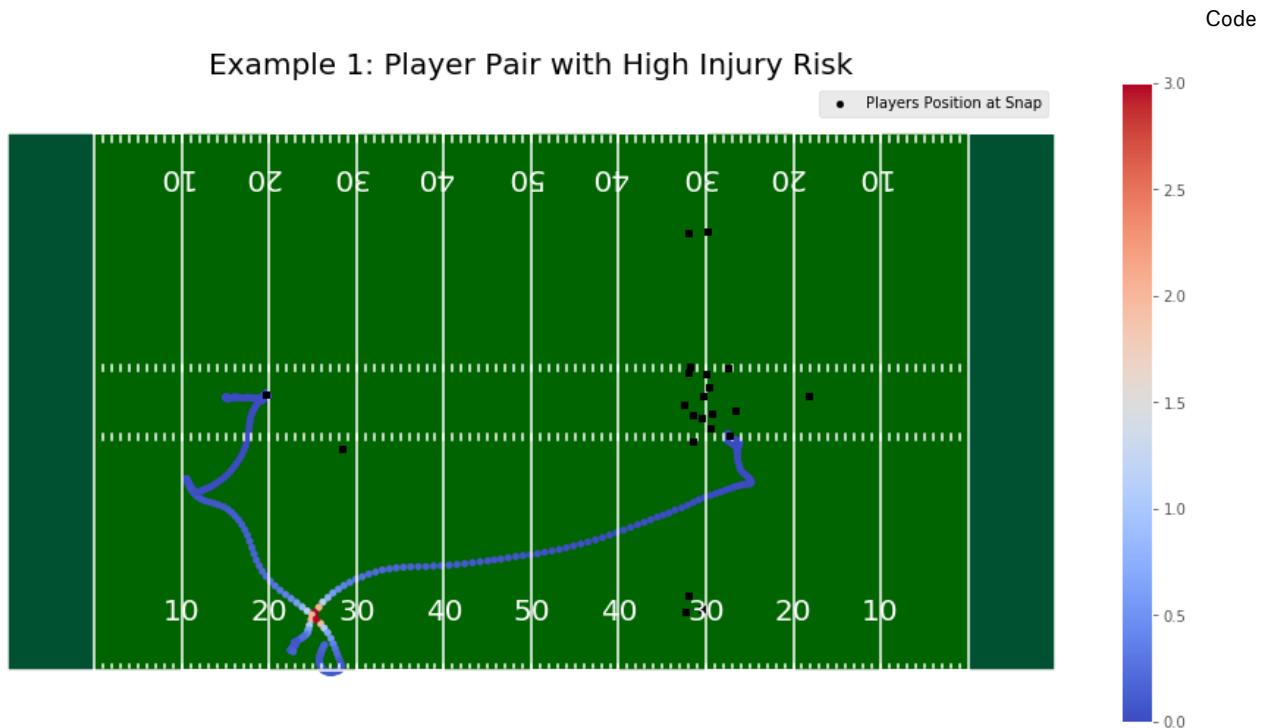
Example of Injury Risk

Below we've plotted the `Injury_Risk` heuristic for two players during a play. You can see the risk is increased as they approach each other. You can also see that due to the high momentum of both players, angle of the momentum in relationship to each other, and distance from each other all combine to create this metric.

Code
Code
Code
Code

Example 1: High Injury Risk Player Pair

In the first example we see who players who approach eachother with high momentum and opposing directions and a close distance. The result is a high injury risk prior to moment of impact. This example did end in a concussion for one of the players.

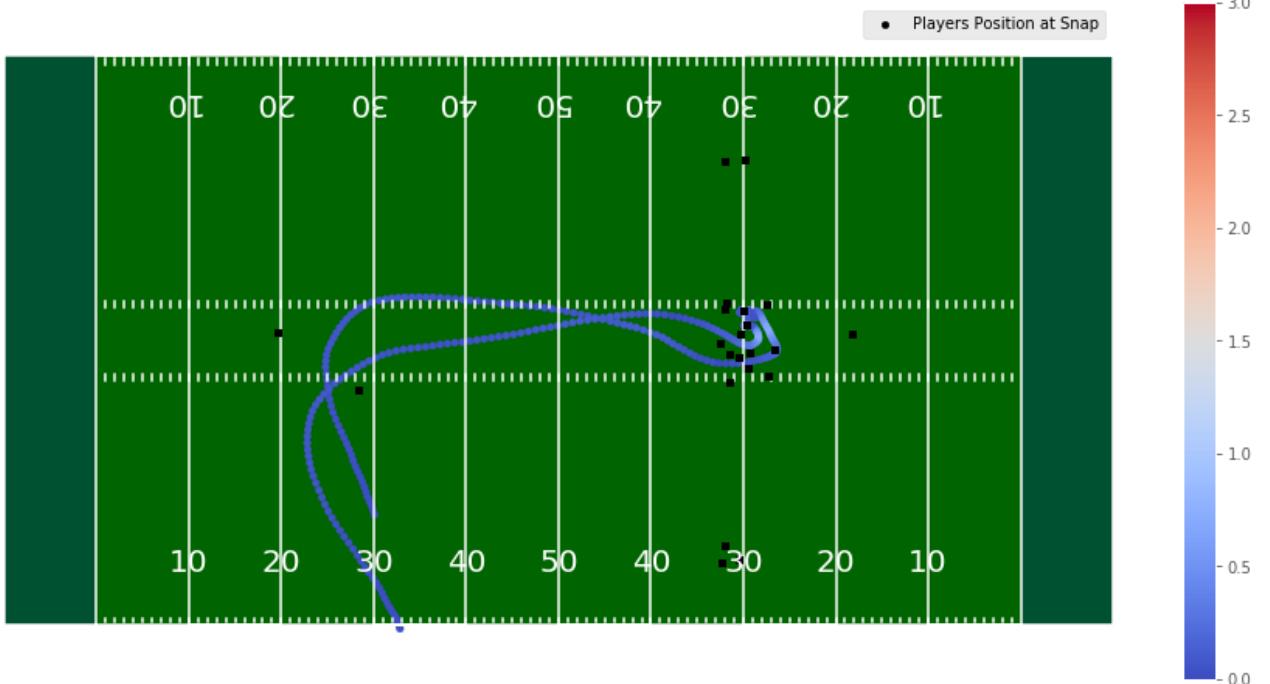


Example 2: Low Injury Risk Player Pair

Below is a plot of two players who's pair has relatively low risk. Despite the fact that both players are in close proximity at the end of the play, they are both moving in relatively the same direction, which results in a low opposing momentum.

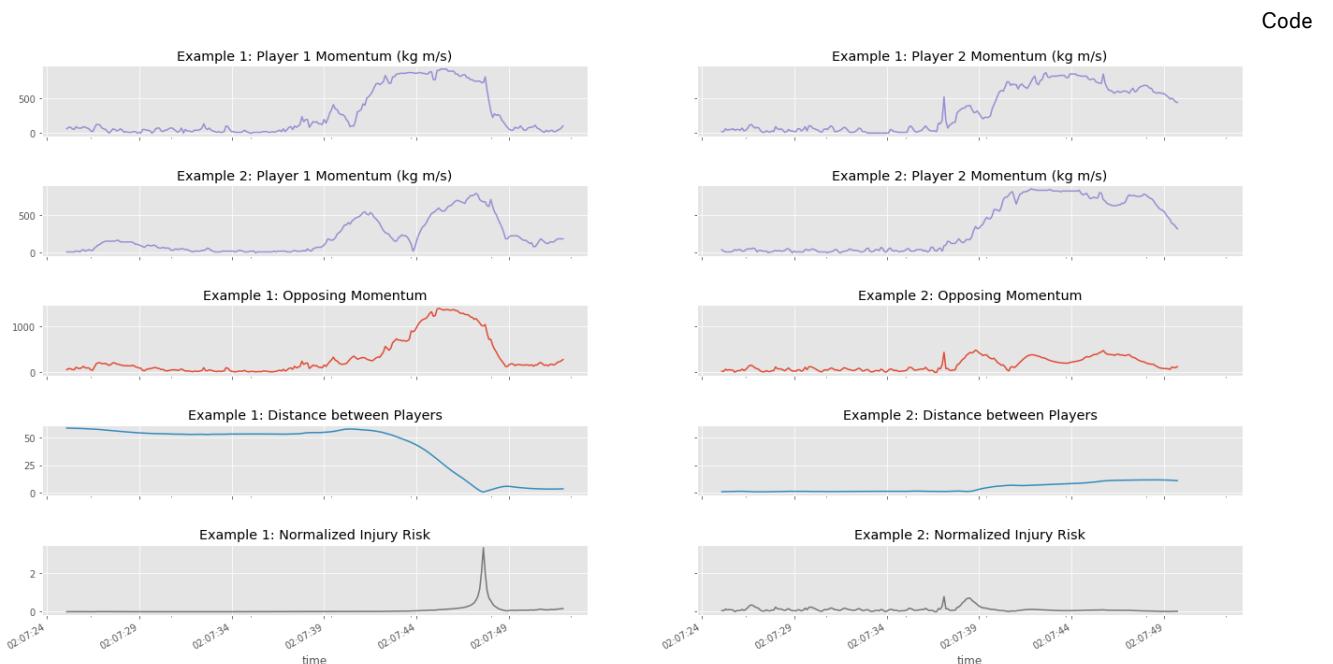
Code

Example 2: Player Pair with Low Injury Risk



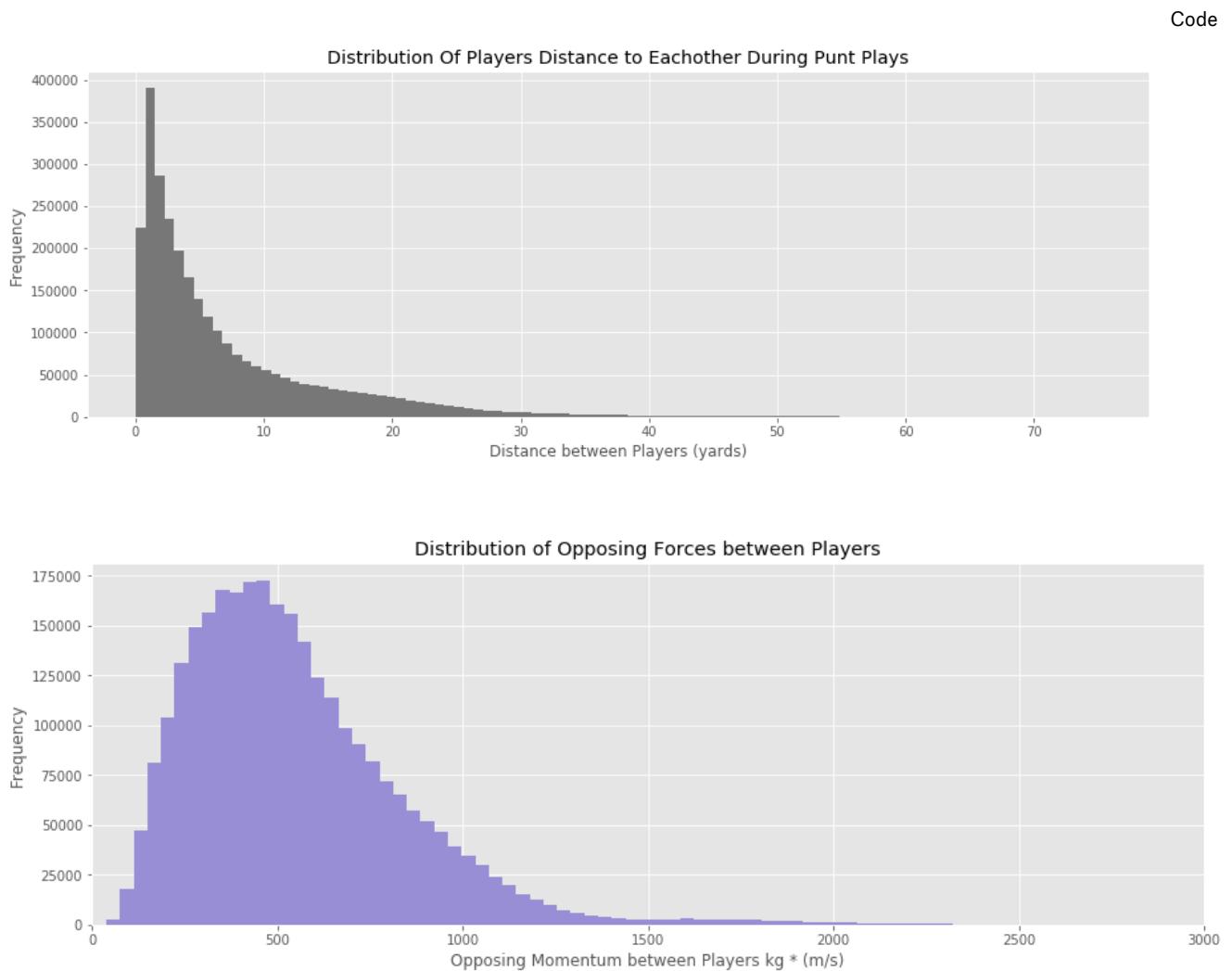
Breaking down the components of our two examples

While both examples have player pairs who are moving at high velocity. The relative distance, and opposing momentum of players in the second example are much less. This is because their momentum is moving in the same direction. However in example 1 the players start to move in opposition to each other- resulting in a high injury risk level. We can see below the components that make up the final risk calculation. We pulled the maximum risk per player pair on every given play.



Evaluating the components of this metric

With the 2016 and 2017 NGS data we were able to calculate this metric for over **2.8 Million different plays and player combinations**. We can see below the distribution of players distance to each other, as well as the distribution of opposing forces for each player. These two components are what is used to compute `injury_risk`.



Code

Interpreting the Normalized Risk Factor

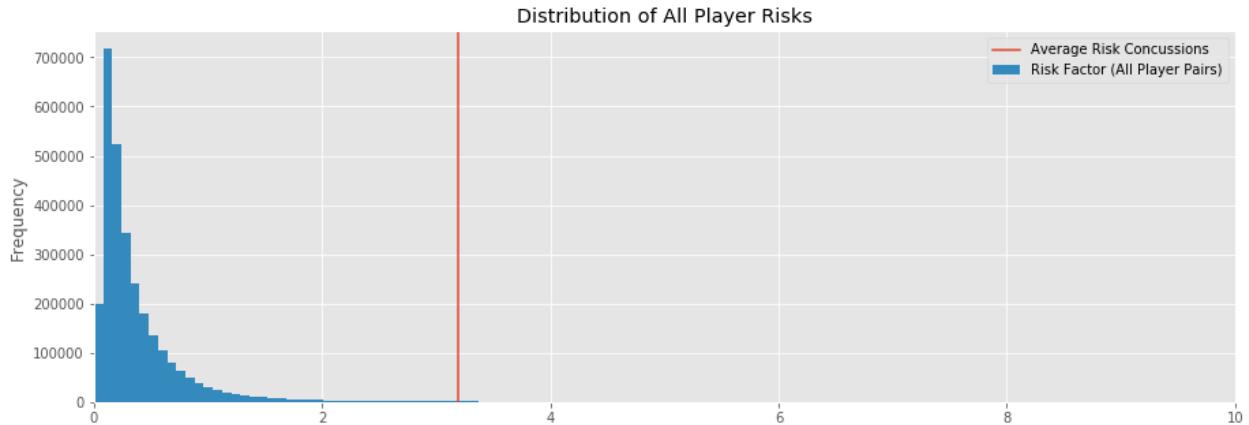
$$RiskFactorNormalized = \frac{RiskFactor}{RiskFactorMean + RiskFactorStdDev}$$

Our Normalized Risk Factor can now be thought of in terms of:

- **Very High Risk** Normalized Risk factor > 1
- **High Risk** Normalized Risk factor between 0.75 and 1
- **Medium Risk** Normalized Risk factor between 0.5 and 0.75
- **Low Risk** Normalized Risk factor less than 0.5

What is the calculated injury risk on concussion plays?

Until this point our calculation of risk was merely hypothetical. We will test our hypothesis by looking at the injury risk for player pairs where a injury occured.



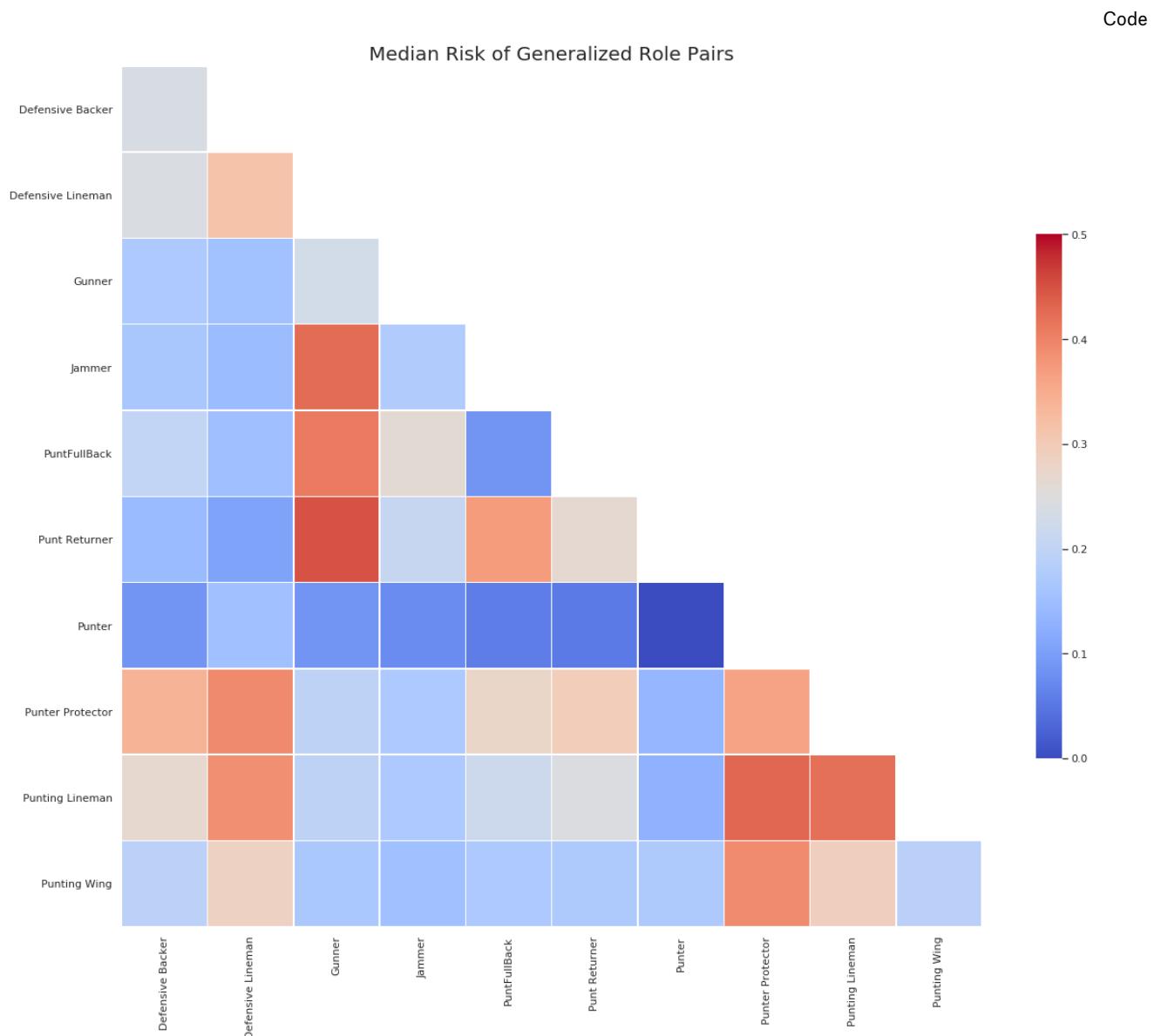
Looking at the risk of all injury plays. We can see that out of 33 concussion plays involving two players - 27 of them occurred are **Very High Risk** (above 1). The rest are at least above 0.5. This supports our idea that concussions will occur when the injury risk is high.

Out[67]:

	season_year	gamekey	playid	generalized_role	generalized_role_partner	risk_factor_normalized
0	2016	266	2902	Punt_Returner	Gunner	20.279792
1	2016	234	3278	Punting_Lineman	Punt_Returner	6.641888
2	2016	54	1045	Punting_Lineman	Gunner	5.845673
3	2016	189	3509	Punt_Returner	Punting_Lineman	5.315850
4	2016	274	3609	Punter	Jammer	4.982041
5	2016	280	2918	Punting_Wing	Defensive_Lineman	4.913482
6	2016	21	2587	Gunner	Defensive_Backer	4.541684
7	2016	144	2342	Jammer	Punting_Lineman	4.339474
8	2016	280	3746	Gunner	Punt_Returner	3.784812
9	2017	567	1407	Defensive_Backer	Gunner	3.528138
10	2016	289	2341	Gunner	Defensive_Lineman	3.365907
11	2016	5	3129	Punting_Wing	Punt_Returner	3.278280
12	2016	149	3663	PuntFullBack	Punting_Lineman	3.137692
13	2016	281	1526	Punting_Lineman	Punting_Wing	3.086369
14	2016	29	538	Gunner	Punt_Returner	3.050464
15	2017	397	1526	Punting_Lineman	Punt_Returner	2.677711
16	2016	296	2667	Gunner	Gunner	2.673068
17	2016	45	1212	Punting_Lineman	Punt_Returner	2.334179
18	2017	399	3312	Punt_Returner	Punting_Lineman	2.226337
19	2017	553	1683	Defensive_Lineman	Punting_Longsnapper	1.771539
20	2017	618	2792	Punting_Lineman	Defensive_Lineman	1.669002
21	2017	364	2764	Punting_Lineman	Defensive_Lineman	1.506926
22	2017	384	183	Punter_Protector	Punting_Lineman	1.486104
23	2017	357	3630	Punting_Lineman	Punt_Returner	1.203448
24	2017	448	2792	Defensive_Lineman	Punting_Lineman	1.186066
25	2017	601	602	Punting_Longsnapper	Punt_Returner	1.140125
26	2017	473	2072	Punting_Lineman	Punting_Lineman	1.114167
27	2016	60	905	Punting_Wing	Defensive_Lineman	0.947424
28	2017	607	978	Punting_Wing	Defensive_Lineman	0.820698
29	2017	585	2208	Punt_Returner	Punter_Protector	0.791918
30	2017	364	2489	Punting_Lineman	Defensive_Lineman	0.680360
31	2016	231	1976	Punting_Lineman	Punting_Wing	0.596972
32	2017	392	1088	Punting_Longsnapper	Defensive_Lineman	0.578938

Role Pairings that have High Risk

Now that we've developed this risk metric, we can look at general trends to see which players tend to have high risk in relationship to each other. As expected Gunners and Punt Returners have very high risk. Jammer/Gunners and PuntingLinemen/PuntProtector also show high risk. Punters have the lowest risk during punt plays.



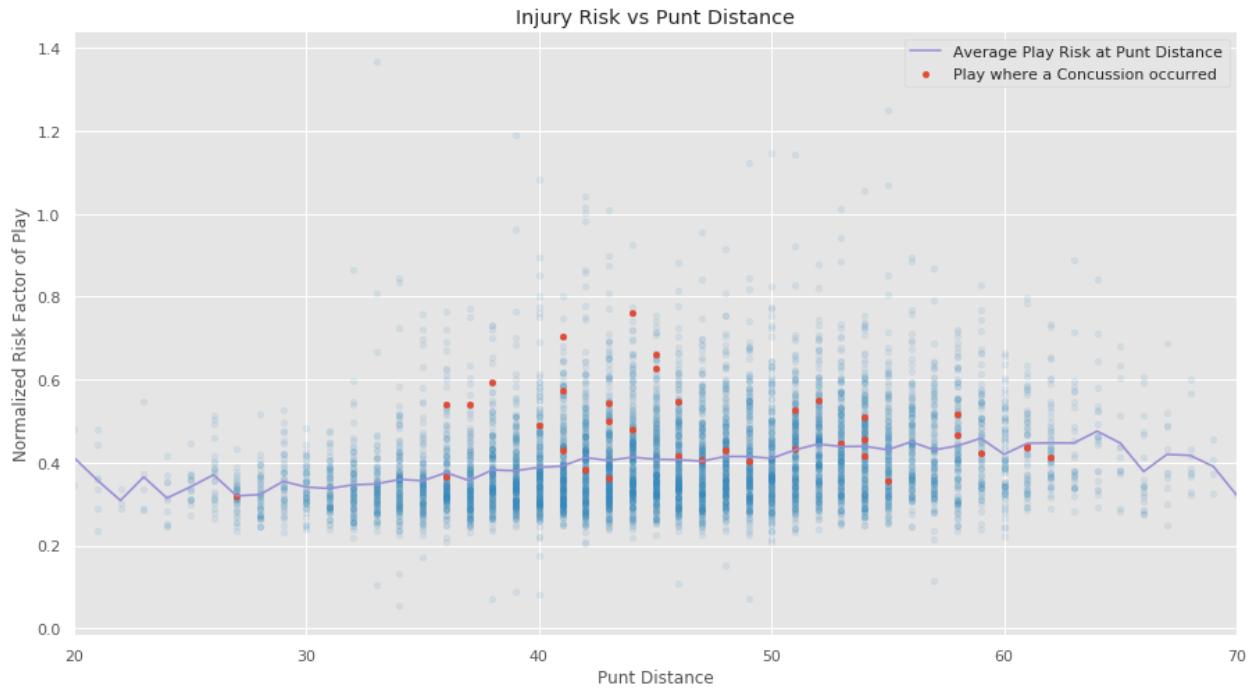
Aggregating Injury Risk Metric at the Play Level

Next we will aggregate this risk to the play level, to help us identify if a play shows a higher propensity for risk. In the plot below you can see the risk of all plays by the distance of the punt. The red dots indicate plays where a concussion occurred. Visually you can see these plays are on the high side of the risk factor for punt plays.

$$Play_Risk_Factor = \frac{\sum(Play_Risk_{player1v2})}{Count_of_Player_Pairings}$$

Where: Total player pairing is $22 \times 21 = 462$ player pairing on the field.

Code



Risk by Play Result

Now that we've aggregated our injury risk metric at the play level we can look at different play results, and see if the risk factor is higher or lower for those types of plays. It's clear to see that Out of Bounds and Fair Catch plays have lower mean and variance of risk, while plays with Fumbles and those that are returned for No Gain have higher.

Code

Code

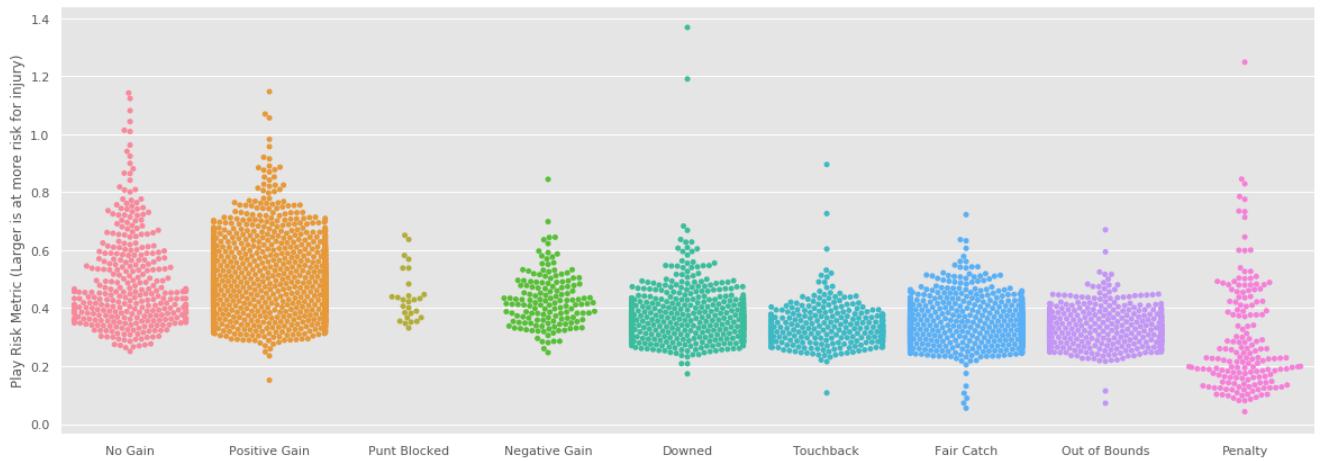
Code Output

Code

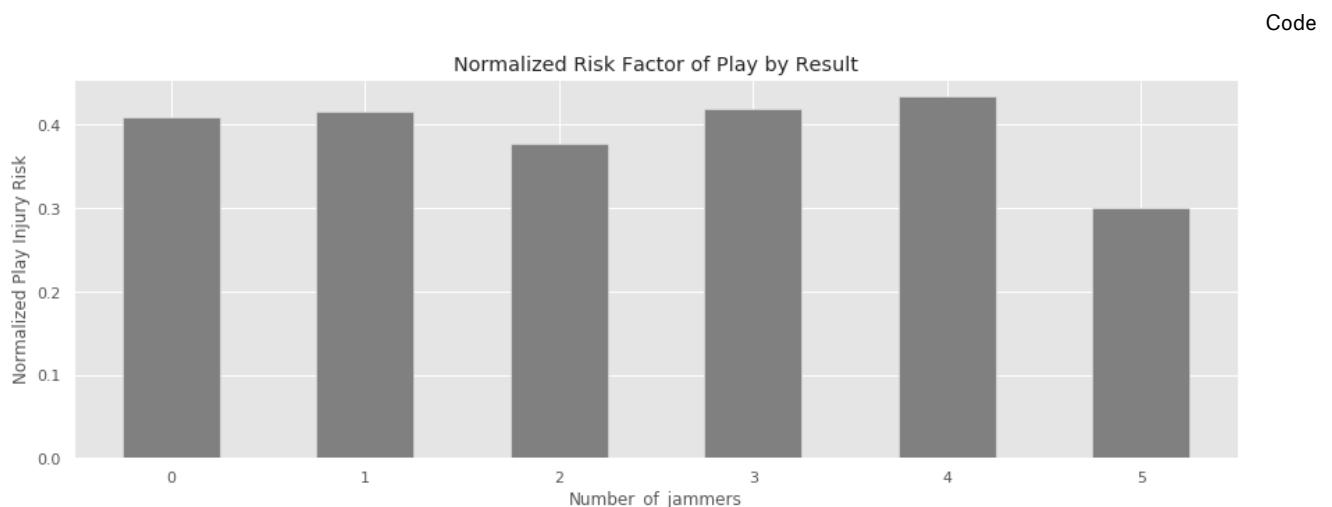
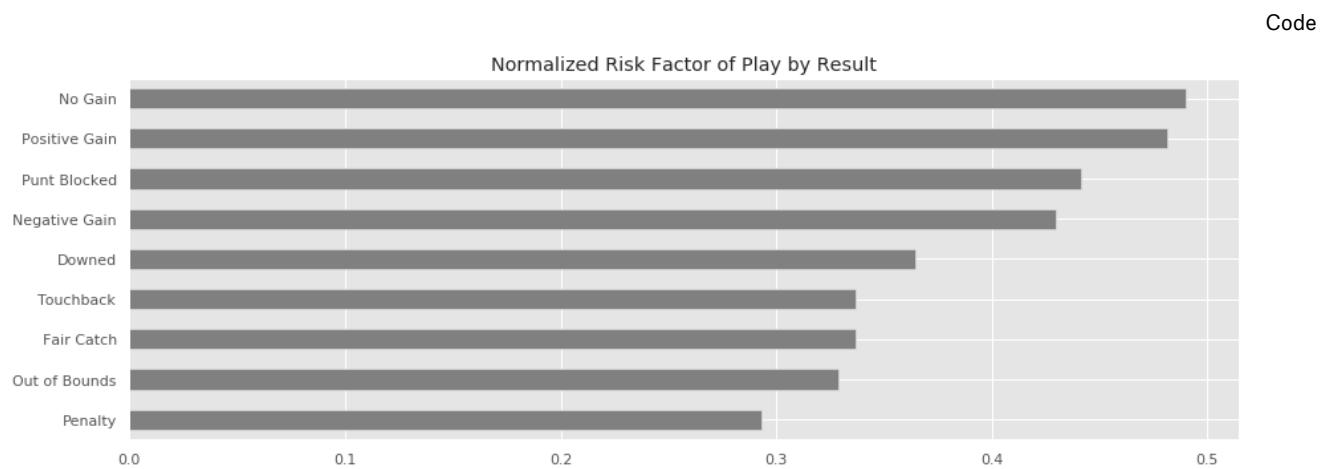
This plot shows us the risk of plays grouped by their outcome. They are ordered by the mean risk of the play. We can see that returns for `No Gain` have higher variance in the risk factor, but also the highest average risk. These are the types of plays we would like to avoid and encourage to be fair catches. As you would expect plays resulting in a `Fair Catch` have far less injury risk.

Code

Risk of Plays by Outcome (Each dot represents a play)



The following plot shows only the average risk



Predicting a Play's Injury Risk Based on Formation

We now have a metric we can use to try and predict based on the formations and roles of players for each team. Because we want a model that is easy to interpret we choose a simple linear model as opposed to a complex black-box machine learning model.

We fit a linear regression lasso model using 5 fold cross validation. We then can interpret the coefficients to see which player position impacts the injury risk of the play.

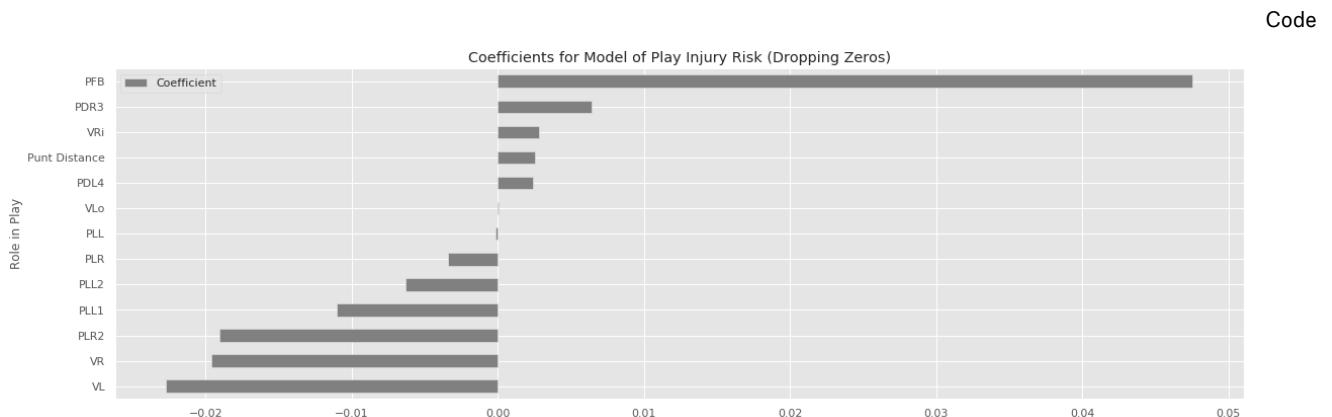
We include punt distance as a variable for our model so that we can account for different distances impact on the injury risk of the play.

Out[76]:

```
Lasso(alpha=0.0004012807031942776, copy_X=True, fit_intercept=True,  
max_iter=1000, normalize=False, positive=False, precompute=False,  
random_state=None, selection='cyclic', tol=0.0001, warm_start=False)
```

Code

The model coefficients show us that injury risk is increased when a PFB position is in place on the punt return team. If we look at our analysis from before the PFB position is rarely VL and VR (the jammer positions) have the strongest correlation with less injury risk. VL and VR are roles used only when in single coverage.



Section VI - Proposed Rules

Rule Change Proposal 1 - Incentivize the Fair Catch

On a completed Fair Catch, the ball is awarded to the returning team 5 yards in advance of the fair catch location.

Rule Change Proposal 2 - Improve Defenseless Player Rules to Include Certain Punt Coverage Players

Add the verbiage to defenseless players - A player returning upfield in pursuit of a punt returner Currently, the defenseless player rule specifically applies during punt plays to:

1. A kicker/punter during the kick or during the return (Also see Article 6(h) for additional restrictions against a kicker/punter)
2. A kickoff or punt returner attempting to field a kick in the air
3. A player who receives a “blindsight” block when the path of the offensive blocker is toward or parallel to his own end line.

We believe the NFL should explicitly add verbiage to include punt coverage players in pursuit of the punt returner once the punt returner have passed them upfield. While this may already be accounted for in the blindsight block rule- it should be explicitly states this as a point of emphasis for officials to focus on.

Rule Change Proposal 3 - No double teaming of Gunners

Returning Team Can only have one player engaged with the punting team's gunners per gunner within 5 yards of the line of scrimmage (2 maximum)

This rule may be the least practical to implement. We understand that returning teams consider several different formation depending on the game situation, location on the field, and opposing gunners. Regardless of these issues, the data is clear that hybrid or double teaming of gunners is correlated strongly with a players having high injury risk.

Section VII - Solution Efficacy and Impact on Game Integrity

In this section we will clearly demonstrate how our previous analysis supports these rule changes as an effective way to reduce concussions on punt plays. We also discuss how the changes may impact the integrity. We also explore possible new risks added by this new rule.

Rule Change 1 - On a completed Fair Catch, the ball is awarded to the returning team 5 yards in advance of the fair catch location.

Findings in support of this rule change.

1. Approximately 35% of all returned punts are for less than 5 yards (ignoring plays with penalties).
2. Our Injury Risk Factor calculates the risk of injury for pairs of players during a play based on player momentum, direction and distance apart. This metric shows that plays that are **Returned No Gain** average the highest risk for injury. Additionally we see that fair catches are amongst the plays that put players at the lowest risk for injury.
3. When reviewing visually the paths taken by punt returners. Most movements made by punt returners are 5 yards of the catch location. Most of these movements are from sideline to sideline and not upfield.
4. On fair catches, the median distance of the closest opponent to the punt return, at the moment of the receiving the punt is roughly 3.19 yards. On punt returns the median distance is 10 yards. It's hard to define what this distance would be with the new rule change, but we can assume that fair catches will be made with higher frequency and with opponents farther away. Both of which would reduce the time that players are put at risk.
5. If we assume, conservatively that plays returned for negative yards or no gain will be eliminated by this change, then 434 plays from two seasons would have resulted in a fair catch. These are plays that we consider **unnecessarily risky** because they are associated with high risk of injury but produce no exciting, game-changing moments.

Impact on Game Integrity

1. This rule's simplicity allows it to easily be implemented by the NFL. Officials would have the added role.
2. Game dynamics will change as a result of this rule, but we believe the evolution of the punt play is necessary to increase player safety. Areas where we believe this rule change will have an impact are:
 - Punt returners must now consider and anticipate punting team's distance from them and decide whether they feel they have the ability to gain at least 5 yards.
 - Coaches will need to calculate the benefits of punt returns and how to coach their players in when to decide and attempt a return.
 - Depending on the situation, the new rule may increase the punting team to instead go for it on 4th down.
 - Punting teams may attempt "rugby" style punts in order to make fair catches harder to receive. Punters may also attempt more kicks out of bounds.
3. Potentially new risks to players:
 - Punt returners will now need to consider where coverage players are. This added uncertainty may lead to more muffed punts, which could negate this benefit.
 - Punts landing near the endzone that would previously be left alone by the returning team (in hopes of a touchback) may now be fair caught. This could add some additional risk as opposed to a touchback.

Rule Change 2 - Add verbiage to defenseless players to include punting team players in pursuit of punt returner during the return.

Findings in support of this rule change.

1. In reviewing the video footage and NGS path data of plays involving a concussion, we see that approximately 9 of these involve players that were running upfield in pursuit of the punt returner and then changed direction to follow the returner.
2. Only one play in the 37 provided resulted in a penalty of Unnecessary Roughness.
3. Player velocity and direction data shows that many of the plays involving concussions also have players hit soon after changing direction.
4. We believe that by emphasizing the defenseless player verbiage to include players in pursuit of a punt returner officials would be more confident in calling roughness for these plays.

Impact on Game Integrity

1. This rule is actionable by the NFL, however, like all judgement calls is subject to interpretation by the officials calling the game. Our hope would be that officials, taking this as a point of emphasis would call these penalties more often therefore reducing their likelihood to occur in the future.
2. Potentially new risks to Players:
 - Punt coverage players may be more likely to put themselves at risk, believing they will not be blocked by the returning team. It is important to players to be aware of possible impact and have their "head on a swivel". There is the potential that coverage players may gain a false sense of safety by this rule change. Still, we believe if these penalties are called correctly this will not be an issue.

Rule Change 3 - Returning Team Can only have one player engaged with the punting team's gunners per gunner within 5 yards of the line of scrimmage (2 maximum)

Findings in support of this rule change.

1. We see that Punting Linemen are the most common role in punt plays that are involved in concussions (19 of 37 plays involved as injured or primary partner)
2. The data also show that the rate of concussions increases when the number of jammers increases.
3. Double coverage of gunners results in an imbalance on the field of offensive and defensive players in relationship to each other - allowing for punting linemen to gain more velocity and opening up the possibility for concussions. This is supported by the fact that our Injury Risk Factor is highest in plays where there are 4 jammers.
4. By visualizing the routes of punting linemen we see that these players are commonly Punting Linemen 30 or more yards up field from their starting position. Showing they are commonly unblocked defenders reaching high velocity.
5. When modeling the injury risk of plays we find that having single coverage roles (VR and VL) is correlated with a decrease in injury risk.

Impact on Game Integrity

1. We believe this rule change would be the hardest for the NFL to implement. There are many factors to consider by both teams when deciding to line up for a punting play. When we interviewed Frank Beamer he was not in favor of this rule change - saying it gave too much advantage to the punting team. Regardless, the data points to this as a key factor and we would be remiss to not propose something surrounding the double teaming of gunners.
2. This rule change has the potential to be gamed by teams on fake punts. If they would like to take advantage of the one-on-one coverage. Additionally teams may show a punting formation on field goal attempts, restricting the defensive strategy on these types of plays.
3. Potential new risks to players:
 - By forcing the single coverage on gunners, defensive teams may choose to have more players lined up further back behind the line of scrimmage.
 - Gunners would have more of a chance to reach returners than they would have if single teamed, increasing the potential for high velocity hits by gunners on punt returners.
 - We don't believe that these are a huge concern considering most punting plays in the provided dataset were already single coverage. Of those plays the concussion rate was less than that of four jammers.