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Safety Regulation in Professional Football: Empirical Evidence of Intended and Unintended Consequences

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Safety regulation in professional football: Empirical evidence of intended and unintended consequences

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Abstract

In response to increasing public awareness and negative long-term health effects of concussions, the National Football League implemented the "Crown-of-the-Helmet Rule" (CHR). The CHR imposes penalties on players who initiate contact using the top of the helmet. This paper examines the intended effect of this policy and its potential for unintended consequences. We find evidence supporting the intended effect of the policy- a reduction in weekly concussion reports among defensive players by as much as 32% (34% for all head and neck injuries), but also evidence of an increase in weekly lower extremity injury reports for offensive players by as much as 34%.

Keywords
Safety regulation, Health outcomes, Unintended consequences

1. Introduction

Between 2012 and 2014, the National Football League (NFL) diagnosed 446 separate incidences of concussions among its players (Public Broadcasting System, Concussion Watch). Even after initial recovery, medical research suggests a single concussion can cause persistent headaches, sleep problems, memory disorders, and reduced attention span (Edwards and Bodle, 2014). Multiple concussions can contribute to more severe, longer-term problems such as aggressiveness, depression, suicide, dementia, and Parkinson's disease (Edwards and Bodle, 2014). In a recent legal settlement, the NFL agreed to compensate former players up to $5 million each for serious medical conditions associated with repeated head trauma. Estimates place the settlement's total value at $1 billion (Belson, 2016).

In response to litigation and general concern for worker safety, the NFL implemented the "Crown of the Helmet Rule" (CHR) after the 2012–2013 season. The CHR attempts to reduce the incidence of concussions and head injuries by penalizing a player who intentionally initiates contact with another player using the top of his helmet. We first examine if the CHR alters the incidence of concussion (in addition to head and neck) injuries among affected players. Then, following an established literature on health and safety regulations (Peltzman, 1975, DiNardo and Lemieux, 2001, Conlin et al., 2009, Dickert-Conlin et al., 2011, Carpenter and Stehr, 2011), we examine if the CHR has an unintended consequence. We hypothesize that players substitute towards other forms of game-play because of the CHR, increasing the incidence of lower extremity injuries among offensive players.

We examine the intended and unintended effects of the CHR on player injuries using a difference-in-differences framework. The treatment group includes players who are typically involved in collisions that occur in open space on the field of play (wide receivers and defensive backs, for example). This group is nearly always subject to the CHR, as it applies only in certain on-field circumstances. The comparison group includes players who are typically making contact at shorter distances and not in the open field (offensive and defensive linemen, for example), where the CHR does not apply. We examine how the CHR influences the probability of reporting an injury in any given week using individual micro-level data on all players participating in regular season games during the 2012–2013 (prior to CHR) and 2013–2014 (after CHR) seasons. We extend the analysis to examine how the CHR affects the severity of player injuries by focusing on how many games players miss during the regular season by injury type.

Results from the analysis provide evidence supporting the intended effect of the policy − a reduction in concussion reports among defensive players by as much as 32% (or 34% for all head and neck injuries). However, we also find strong evidence suggesting that the CHR increases lower extremity injury reports for offensive players by as much as 34%. Additionally, the CHR is responsible for increasing the severity of offensive player injuries − resulting in an additional half game missed per lower extremity injury. The marginal increase in missed games for offensive players results in a net productivity loss (net of both the intended and unintended effects) of approximately $27 million in the season after implementation, with a net total cost from the CHR measured in value of statistical life at $285 million for injuries occurring in the 2013/2014 season.

The remainder of the paper proceeds as follows: Section 2 provides background about concussion injuries and the CHR rule. Section 3 describes the difference-in-differences estimation strategy. Section 4 gives details about our data and summarizes injuries in the NFL. Section 5 presents our results. Section 6 discusses several robustness checks, and the final section of the paper offers a discussion of the net benefits of the CHR and concludes.

2. Background and institutional details

In recent years, medical experts have become more aware of the long-term health risks of head-related injuries (Niemeier et al., 2015). As medical research has become clearer, and a demonstrated link between head-injuries and health risks has become more apparent with football, the NFL has increasingly had to answer to the media and current and former players about how the league deals with long-term health concerns (PBS, 2013). In 2013, Ryan Swope announced his retirement from professional football due to concussions before ever playing a single professional game (Strauss, 2013). Concerns over concussions have even affected youth football participation. Pop Warner, the country's largest youth football program, experienced a 9.5% decline in participation between 2010 and 2012 (Fainaru and Fainaru-Wada, 2013). Two main reasons cited for the decline are youth athletes concentrating on a single sport and concerns over head-related injuries, with the latter being the most important. Decreases in Pop Warner enrollment are particularly worrisome for the league because it serves as a stepping-stone into playing professionally, with 60–70% of NFL players having participated in the program.

Due to concerns of general worker safety and long-term league viability, the NFL has taken a major step in regulating game play in an attempt to reduce the incidence of head-related injuries. Following the 2012–2013 season, league owners ratified the "Crown of the Helmet Rule," which went into effect the first week of the 2013–2014 season. Rule 12, Section 2, Article 8 of the NFL Rulebook states the rule and associated penalty:

> *It is a foul if a runner or tackler initiates forcible contact by delivering a blow with the top/crown of his helmet against an opponent when both players are clearly outside the tackle box (an area extending from tackle to tackle and from three yards beyond the line of scrimmage to the offensive team's end line). Incidental contact by the helmet of a runner or tackler against an opponent shall not be a foul.*
>
> *Note: The tackle box no longer exists once the ball leaves the tackle box.*
>
> *Penalty: Loss of 15 yards. If the foul is by the defense, it is also an automatic first down. The player may be disqualified if the action is flagrant.*

Several aspects of the CHR are important for the purposes of determining its effect on injuries. First, it applies to both offensive and defensive players. Defensive players cannot use the crown of the helmet to initiate a tackle and must substitute towards other methods. Offensive players cannot use the crown of the helmet to deliver a blow to a defensive player in an attempt to avoid the tackle. Second, the rule only applies to play outside of the tackle box. Fig. 1 shows the tackle box in relation to representative offensive and defensive player formations.

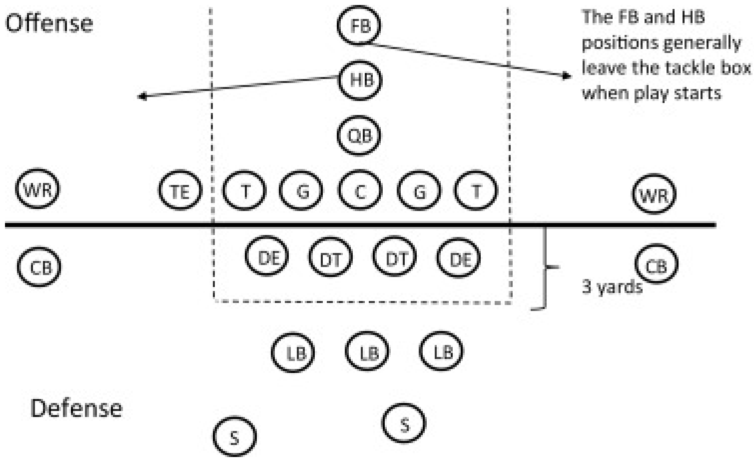


Fig. 1. The Tackle Box.
Notes: This figure demonstrates a typical alignment, but teams employ multiple formations of players throughout a game. In terms of defining a treatment/control group, the only positions that are less likely to be outside of the tackle box are the TE and FB positions.

The group of offensive players directly affected by the CHR includes wide receivers (WR), tight ends (TE), halfbacks (HB), and fullbacks (FB). Players assigned to these four positions constitute our offensive treatment group. As Fig. 1 demonstrates, players in the WR position are typically not inside the tackle box. Wide receivers are in the open field of play and are subject to direct hits from defensive players. The same is true for players in the TE position. However, because coaches use TEs for receiving and blocking purposes, players in this position may not always be in the open field. The HB and FB positions generally begin play inside of the tackle box and leave it with the football during running plays. As with TEs, coaches regularly use FBs for blocking purposes to allow the quicker HB access to the defense's secondary. Therefore, they might not always be in the open field. Before the 2013–2014 season, players in these positions, particularly WR and HB, would be subject to crown of the helmet contact.

The group of defensive players directly affected by the CHR includes cornerbacks (CB), linebackers (LB), and safeties (S). Players assigned to these three positions constitute our defensive treatment group. Fig. 1 shows that these defensive positions typically line-up outside of the tackle box. The LB and S positions can move up the field and line-up inside the tackle box.

The remaining offensive positions (quarterback [QB]; offensive tackle [T]; guard [G]; center [C]) and defensive positions (defensive tackle [DT]; defensive end [DE]) constitute our comparison group we use to estimate the CHRs effect on the probability and severity of injuries. As Fig. 1 shows, these positions are nearly always inside of the tackle box. Therefore, the CHR should not affect these players' behavior.

According to the CHR, players cannot initiate contact by using the crown of the helmet. Referees will impose a minimum 15-yard penalty for any violations (if the defense violates the CHR, the penalty includes an automatic first down for the offense).[1] Therefore, defensive players cannot initiate a tackle, and offensive players cannot protect themselves from a tackle, by using the crown of their helmet. Not only should the CHR reduce the amount of trauma players receive to the head area, but the rule should also specifically reduce the amount of helmet-to-helmet contact experienced during play. These expectations are in line with the spirit of the rule, and the NFL's own expectations (Battista, 2013). The effect of the CHR may be different for the offensive and defensive players because of the way the game is played- defensive players are generally the ones initiating contact, and offensive players are generally avoiding it.

The CHR may have an unintended effect. Specifically, players in the offensive treatment group may experience a larger incidence of lower-extremity injuries in relation to the comparison and defensive treatment groups. Defensive players will change their tackling methods by using fewer helmet-to-helmet hits and attempting instead to tackle the lower body more often. This exposes the offensive players to a higher likelihood of hits to the lower body instead of to the helmet, and, therefore, a higher probability of experiencing lower-body injuries. Offensive player behavior requires more modification when compared to defensive players. The CHR requires players in the offensive treatment group to substitute away from lowering the helmet to running more upright and relying upon spinning, jumping, and other evasive moves to avoid a tackle; increasing the use and variety of tackling evasion methods may also subject offensive players to more injuries.[2] These should occur among the treated group of offensive players if they are present, and not among the treated group of defensive players.

3. Empirical methodology

We implement a difference-in-differences model to estimate the effect of the CHR on player injuries in the NFL. A difference-in-differences estimate is preferable to a simple before-after model because there are many things that change about the safety environment that affect the probability of injury for all players. These factors include innovations in diagnosing and treating head injuries, equipment improvements (such as thickness and material of helmets), field surface changes, and the composition of players in the league. The offensive treatment group includes players assigned to the WR, TE, HB, and FB positions; the defensive treatment group includes the CB, LB, and S positions. All other players are part of the comparison group. We omit kickers, punters, and specialized long snappers from the analysis.[3]

The estimating equation is:

(1)

$$\begin{aligned} Y_{i,j,p,y} = \alpha + \beta_1(D = 1 if Treat)_{i,p} + \beta_2(D = 1 if After)_y \\ + \beta_3(D = 1 if Treat * D \\ = 1 if After)_{i,p,y} + \varphi trend_{j,y} + X'_{i,y}\beta + \varepsilon_{i,j,p,y} \end{aligned}$$

where, Y is an indicator variable equaling one if player i reports an injury during week j, playing position p, during season y. When estimating the intended effects of the policy, we define an injury as any head, neck, or concussion injury. We also estimate Eq. (1) separately after defining Y to equal one when a player reports a concussion only. We estimate the model for the offensive and defensive treatment groups combined and separately, as the policy may differentially change game play among these groups. Specifications estimating separate effects for offensive and defensive players exclude treated players in the other group from estimation.

The coefficient β_3 measures the intended effect of the CHR. The interpretation of this coefficient is the marginal effect on the likelihood of a head, neck, or concussion injury being reported for a treated player in a given week. It is possible for a player to report an injury to the same part of the body for multiple weeks in a row. For example, a player may report a concussion for weeks two through five. However, it is impossible to know if the concussion injury reported during week two is the same as the concussion reported in week five or if the player suffered multiple concussions during weeks two through five. If the policy meets the designed goal, β_3 will be negative. A negative coefficient implies that either the number of reported injuries actually decreased, or the severity of the injuries decreased, or a combination of both.

Trend is a linear time trend that counts the weeks of each season, starting with the first and going to week 17, to account for the fact that there are more injured players as a season progresses. We also estimate (1) substituting a position-specific time trend for $trend_{j,y}$ to account for the possibility that some positions may have differential likelihood of injury as a season progresses. The vector X includes player characteristics, including weight, height, experience (in years), the total number of games played in the regular season, the number of regular season games started, and whether or not the player plays an offensive position. We also include results for a fixed-effects specification, where we include either position-specific or player-level fixed effects. Since the treatment group variable is time invariant, the fixed-effects specification is (where γ_p is substituted for γ_i when we have position fixed-effects instead of player fixed-effects):

(2)

$$Y_{i,j,p,y} = \alpha + \beta_1 (D = 1 if After)_y + \beta_2 (D = 1 if Treat * D = 1 if After)_{i,p,y} + \varphi trend_{j,y} + \gamma_i + \varepsilon_{i,j,p,y}$$

We also estimate (2) substituting a position-specific linear time trend for $trend_{j,y}$.

For the unintended effect, lower-extremity injuries for the offensive treatment group, we re-estimate Eqs. (1) and (2) with Y equal to one if the primary injury reported is on one of the following areas: Achilles, ankle, calf, fibula, foot, groin, hamstring, heel, hip, knee, leg, quadriceps, shin, thigh, or toe.[4] To identify the unintended consequences of the CHR, we adjust our treatment group so that it only includes the offensive positions TE, WR, HB, and FB. The comparison group includes all other players. As before, β_3 from Eq. (1) and β_2 from Eq. (2) measure the effect of the CHR; however, they now show the magnitude of any unintended effects on offensive player lower-extremity injuries. Again, an estimated positive effect implies that either the number of actual injuries increased, the severity of the injuries increased (i.e. the same injury is reported multiple weeks in the season), or both.

Eqs. (1) and (2) estimate the effect of the CHR on the propensity for a player to report an injury in any given week. One shortcoming of these specifications is they do not explicitly examine the possibility that the CHR leads to less severe injuries. Since injury severity correlates highly with missing games, we estimate a similar difference-in-differences specification using the number of weeks a player misses (not including the bye week) due to a specific injury as the outcome. Specifically, we estimate the following regression:

(3)

$$Y_{i,p,y} = \alpha + \beta_1(D = 1ifTreat)_{i,p} + \beta_2(D = 1ifAfter)_y + \beta_3(D = 1ifTreat * D = 1ifAfter)_{i,p,y} + X'_{i,y}\beta + \varepsilon_{i,p,y}$$

where $Y_{i,p,y}$ is a count of the number of games missed by player i, playing position p, during season y due to head, neck, and concussion injuries. All other variables are the same as in Eq. (1). β_3 measures the effect of the CHR on the number of weeks missed due to head-related injuries. We also estimate Eq. (3) by redefining $Y_{i,p,y}$ as the number of games missed due to concussion injuries specifically. We estimate Eq. (3) for the offensive and defensive treatment groups separately. Specifications estimating separate effects for offensive and defensive players exclude treated players from the other group.

We also estimate a model with the count of games missed for the season by players using both player and position fixed effects, in the following regression:

(4)

$$Y_{i,p,y} = \alpha + \beta_1(D = 1ifAfter)_y + \beta_2(D = 1ifTreat * D = 1ifAfter)_{i,p,y} + \gamma_i + \varepsilon_{i,p,y}$$

Where Y_p is substituted for Y_i in Eq. (4) when we have position fixed-effects instead of player fixed-effects.

The CHR may have the unintended effect of increasing the severity of lower-body injuries experienced by players in the offensive treatment group. To this end, we re-estimate Eqs. (3) and (4) after redefining $Y_{i,p,y}$ to equal the number of games missed due to lower-extremity injuries. To identify the unintended effect of the CHR, the treatment group includes only the treated offensive positions, TE, WR, HB, and FB. The comparison group includes all other players.

Standard errors in all specifications are clustered at the position level to reflect the fact that error in explaining injuries are correlated across positions.

It is possible that the coefficients from the estimating equations measuring the CHRs effect on the incidence and severity of injuries will capture the effects from other rule changes that also affect player safety in the league if the other rules affect some groups of players differently than others. According to NFL Football Operations (n.d. a), four other rule changes became effective for the 2013/2014 season: 1) All players are required to wear knee and thigh pads; 2) the long-snapper position was added to the list of defenseless players during field goal attempts and Point After Touchdown plays (PATs); 3) on field goal attempts and PATs, the bunch formation is eliminated; 4) peel back blocks occurring below the waist are deemed illegal when made inside the tackle box. The first additional rule change should not impact our estimates since this applies to all players on the field equally. All kickers, punters, and specialized long-snappers covered by rules 2 and 3 are excluded from our sample, making those rules unimportant for our estimates.[5]

The rule regarding peel back blocks could affect potentially the results, as it differentially effects the propensity for part of our comparison group to sustain a lower body injury. This rule only applies to play inside of the tackle box and was designed to protect defensive players from lower-body injuries during offensive blocks from which they could not protect themselves (Starkey, 2013). The DE and DT positions (as shown in Fig. 1), are the most likely positions affected by this rule. These positions constitute part of our comparison group. When including these positions in the comparison group, this would tend to increase the estimated unintended effect of the CHR for offensive players. We investigate this rule change by excluding the DT and DE positions from the analysis in a robustness check.

4. Data and injury statistics

Our primary source of data on player injuries is pro-football-reference.com. The website aggregates football statistics such as game outcomes, player performance measures, and player injuries on a weekly basis. It is an independent website run by Sports Reference, LLC and claims to be the most complete and organized professional football database on the Internet. We collect weekly injury data for every player during the 2012–2013 and 2013–2014 regular seasons. Each regular season consists of 17 weeks − 16 games played and a bye week. For each player-week, we know if an injury was reported, the type of injury, and if the player missed the game.

We use the player position from pro-football-reference.com to identify players in the treatment groups. We match players' data from pro-football-reference.com to data from NFL.com to obtain player characteristics, which we use as controls in the regressions. These characteristics include weight, height, experience (in years), games played, and games started. We estimate models with and without these characteristics, using position fixed-effects and player fixed-effects as alternatives.

The data includes 66,878 player-week observations over two seasons. During the two seasons, there are 14,734 individual injury-week reports. From those injuries, players missed 7946 games. Table 1 shows a summary of all injury types as reported by pro-football-reference.com. The first column of Table 1shows the number of injury-week reports by type. The most common is a knee injury, with 3633 player-week reports, representing 24.7% of all injuries. Other common injuries include ankle (10.9%), shoulder (8.6%), and hamstring (8.4%). Concussions are much less common, with 463 occurrences, or 3.1% of all reported injuries. It is not possible to describe all of the actions and plays that give rise to different injuries as the possibilities are too numerous. For example, an offensive player's knee injury could be caused by a defender tackling below the waist, by a defender landing on an offensive player after the offensive player was already tackled, by the offensive player landing on his knee after jumping, or by the offensive player twisting in order to avoid a tackle.

Table 1. Injury Summary Statistics.

Injury Type	Injury Weeks Reported	PCT of Injury Weeks	Games Missed	PCT of Games Missed	Missed Games per Reported Injury
Abdomen	57	0.39%	15	0.19%	0.26
Achilles	323	2.19%	271	3.39%	0.84
Ankle	1605	10.89%	788	9.86%	0.49
Arm	58	0.39%	45	0.56%	0.78
Back	568	3.86%	227	2.84%	0.40

Injury Type	Injury Weeks Reported	PCT of Injury Weeks	Games Missed	PCT of Games Missed	Missed Games per Reported Injury
Bicep	77	0.52%	52	0.65%	0.68
Calf	257	1.74%	122	1.53%	0.47
Chest	122	0.83%	55	0.69%	0.45
Collarbone	41	0.28%	36	0.45%	0.88
Concussion	463	3.14%	260	3.25%	0.56
Elbow	198	1.34%	86	1.08%	0.43
Fibula	47	0.32%	46	0.58%	0.98
Finger	92	0.62%	16	0.20%	0.17
Foot	945	6.41%	612	7.66%	0.65
Forearm	31	0.21%	22	0.28%	0.71
Groin	517	3.51%	221	2.77%	0.43
Hamstring	1234	8.38%	706	8.84%	0.57
Hand	192	1.30%	93	1.16%	0.48
Head	161	1.09%	55	0.69%	0.34
Heel	26	0.18%	0	0.00%	0.00
Hip	394	2.67%	154	1.93%	0.39
Illness/Infection	306	2.08%	115	1.44%	0.38
Knee	3633	24.66%	2281	28.55%	0.63
Leg	165	1.12%	131	1.64%	0.79
Neck	268	1.82%	123	1.54%	0.46
Oblique	11	0.07%	6	0.08%	0.55
Pectoral	113	0.77%	105	1.31%	0.93
Quadriceps	196	1.33%	122	1.53%	0.62
Ribs	205	1.39%	68	0.85%	0.33
Shin	42	0.29%	15	0.19%	0.36
Shoulder	1270	8.62%	568	7.11%	0.45
Spine	10	0.07%	10	0.13%	1.00
Thigh	189	1.28%	66	0.83%	0.35
Thumb	107	0.73%	42	0.53%	0.39
Toe	237	1.61%	99	1.24%	0.42
Triceps	97	0.66%	85	1.06%	0.88
Wrist	219	1.49%	98	1.23%	0.45
Other/Undisclosed	258	1.75%	130	1.63%	0.50
Discipline/Personal	53		43	0.54%	0.81
Bye Week	3936		7989		

Injury Type	Injury Weeks Reported	PCT of Injury Weeks	Games Missed	PCT of Games Missed	Missed Games per Reported Injury
No Injury Reported	48,155				

Notes: Injury reports from pro-football-reference.com. Players with multiple injuries are counted in the category of the most severe injury.

Table 1 also shows the number of games missed by injury. Knee injuries lead to the most games missed, 2281 (28.5% of all games missed due to injury). The last column of the table displays the number of games missed per injury reported. While this calculation does not give direct evidence as to which injuries require more recovery time or have the most prolonged effects, it does serve as a measure of severity. Typically, injuries that are more severe in nature require a longer recovery time and potentially have more prolonged effects. Injuries to the spine or fibula, while rare, are among the most devastating − resulting in a player nearly always missing games when these injuries occur. On the other hand, there are no reported games missed for heel injuries. Concussions cause a player to miss games in about half (0.56) of occurrences, while head injuries result in a player missing a game in only one-third of occurrences (0.34).

Table 2 shows the number of injury-week reports by injury category and player position before and after the CHRs ratification. Players in the comparison group reported 44 injury-weeks due to concussion during the 2012–2013 season and 80 weeks during the 2013–2014 season, an 81% increase. Players in the offensive treatment group also exhibit an increase. However, it is much smaller (6%). Players in the defensive treatment group experienced a 23% reduction in the total number of concussion reports between seasons. A similar pattern exists when combining all head, neck, and concussion injuries. Players in the comparison and offensive treatment groups experience an increase in injury-weeks reported, 35% for the comparison group and 17% for the offensive treatment group. The defensive treatment group again shows a reduction, 20%. These statistics provide transient evidence suggesting that the CHR did have the intended effect − players in the defensive treatment group experience a reduction in reported head, neck, and concussion-related injuries. Furthermore, even though the offensive treatment group displays an increase in the incidence of these injuries, it is substantially smaller when compared to the comparison group's increase.

Table 2. Number of Injury-Weeks Reported by Category for Treated and Control Groups.

	Pre-CHR			Post-CHR		
	Concussions	Head, Neck, Concussion	Lower Extremity	Concussions	Head, Neck, Concussion	Lower Extremity
Control Group						
OL (C,G,T)	17	32	713	30	55	895
DL (DE, DT)	14	48	702	22	53	830
QB	13	23	48	28	31	129
Defense Treated Group						
CB	38	87	792	34	52	940
LB	21	68	576	18	58	748
S	16	22	150	6	31	148

	Pre-CHR			Post-CHR		
	Concussions	**Head, Neck, Concussion**	**Lower Extremity**	**Concussions**	**Head, Neck, Concussion**	**Lower Extremity**
Offense Treated Group						
HB	27	41	437	20	57	528
WR	41	68	587	62	92	857
TE	31	43	225	24	30	406
FB	1	1	33	0	0	66

Notes: Injury reports from pro-football-reference.com. Players with multiple injuries are counted in the category of the most severe injury.

The table also shows that lower-body injury reports occur more frequently for all groups when compared to head, neck, and concussion injuries. Each group experiences an increase in the number of lower-body injury reports, 27% for the comparison group, 21% for the defensive treatment group, and 45% for the offensive treatment group. This provides some evidence that the CHR unintentionally increased the number of lower-body injury reports for the offensive treatment group.

Fig. 2, Fig. 3 present the basic results of the paper graphically. Each figure plots the weekly probability of injury report (head, neck, and concussion in Fig. 2, and lower body in Fig. 3) for the comparison and treatment groups. Fig. 2 shows how the incidence of head, neck, and concussion injuries changes with the implementation of the CHR between defensive treated positions and all comparison positions. Fig. 3 shows how the incidence of lower body injury changes with the implementation of the CHR between offensive treated positions and all comparison positions. Fig. 2 shows that there is a relative reduction in head, neck, and concussion probability after the CHR is implemented for the treated group, but that the probability of head, neck, and concussion in any given week is somewhat variable. The relative change is quite clear in Fig. 3, and shows that offensive treated players experienced an increase in the probability of lower body injury reports relative to the comparison group after implementation of the CHR.[6]

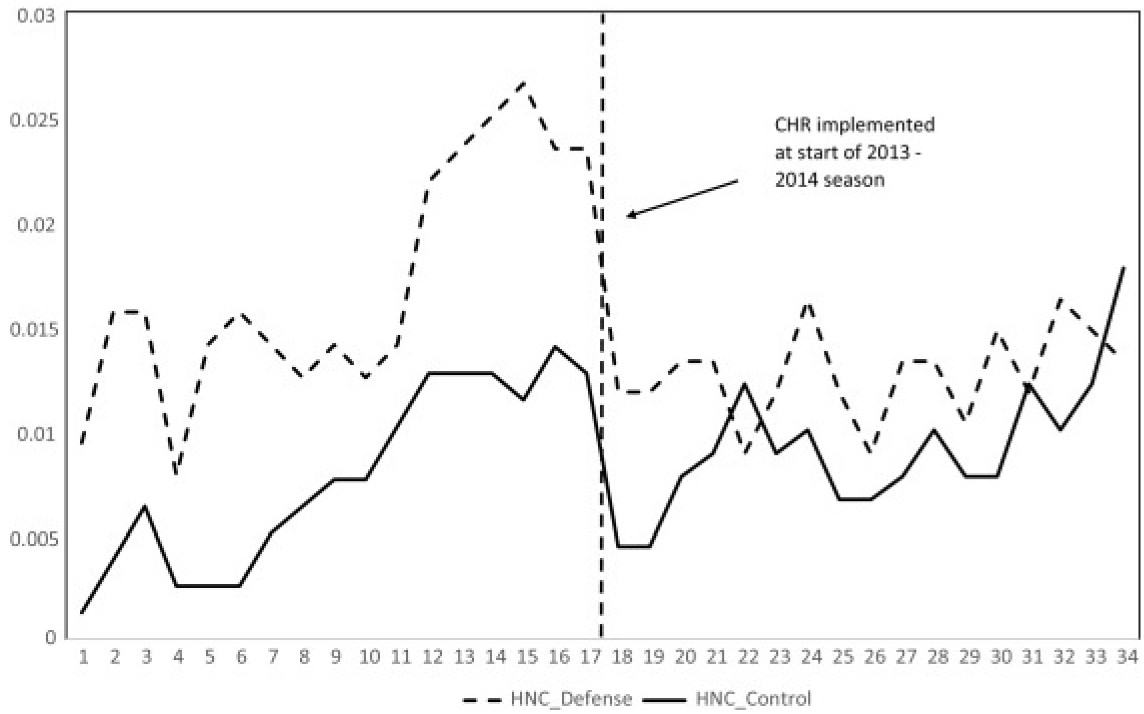


Fig. 2. Probability of Head\Neck\Concussion Injury: Defensive Treated vs. Control Group.

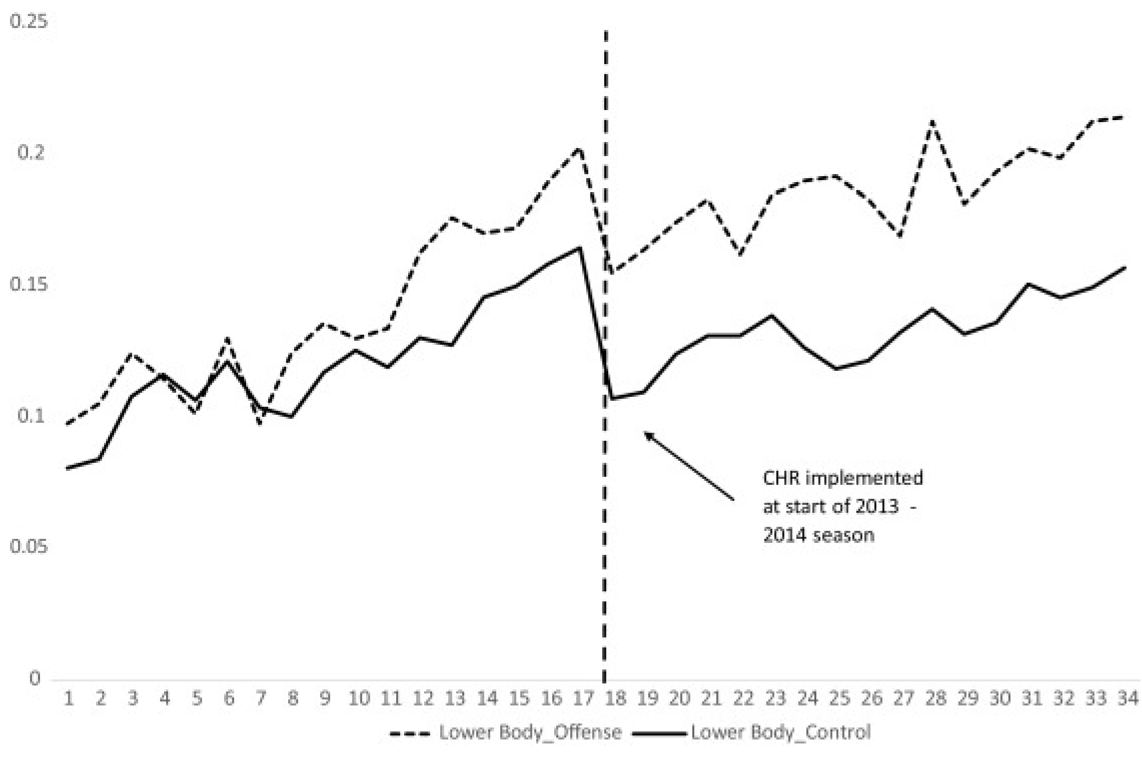


Fig. 3. Probability of Lower Body Injury: Offense Treated vs. Control Group.

5. Results

5.1. Intended effect of CHR: injury probability

Table 3 presents results for the CHRs effect on concussions (columns 1–6) and head, neck, and concussions combined (columns 7–12). The treatment group used in the analysis contains both the offensive and defensive treated positions. The row labeled “Controls” indicates whether the equation uses player characteristics as control variables, position fixed-effects, or player fixed-effects. Finally, the row labeled “Trend” indicates whether the regressions include a general or a group/position-specific linear time trend for weeks for the season.

Table 3. Intended Effect of the CHR on Treated Players.

	Concussions (Baseline Prob = 0.0089)						**Head, Neck, and Concussion Injuries (Baseline Prob = 0.0174)**					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Treat	0.0033*	–	–	0.0016	–	–	0.0073***	–	–	0.0049	–	–
	(0.0016)	–	–	(0.0015)	–	–	(0.0020)	–	–	(0.0030)	–	–
After	0.0019**	0.0018**	0.0030*	0.0020**	0.0018**	0.0030*	0.0015	0.0012	0.0041***	0.0015	0.0012	0.0041***
	(0.0007)	(0.0006)	(0.0016)	(0.0007)	(0.0006)	(0.0016)	(0.0012)	(0.0010)	(0.0005)	(0.0012)	(0.0010)	(0.0005)
*Treat*After*	−0.0028*	−0.0027*	−0.0017	−0.0028*	−0.0027*	−0.0017	−0.0032	−0.0033	−0.0019	−0.0032	−0.0033	−0.0019
	(0.0015)	(0.0015)	(0.0028)	(0.0015)	(0.0015)	(0.0028)	(0.0027)	(0.0024)	(0.0039)	(0.0027)	(0.0024)	(0.0039)
N	66,878	66,878	66,878	66,878	66,878	66,878	66,878	66,878	66,878	66,878	66,878	66,878
Controls	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE
Trend	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin

Notes: Standard errors clustered by player position in parentheses. Treatment group is all treated positions: TE, WR, HB, FB, CB, S, and LB. The baseline probability is for the treated group of players in the season prior to the CHR becoming active.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

Focusing on concussions, the results in column (1) indicate that the CHR reduces the probability a treated player reports a concussion in a given week by 0.0028 percentage points. This estimate is statistically significant at the 10% level. As shown in the top row of the table, the baseline probability of a concussion being reported for players in the treatment group during the 2012/2013 (before CHR) season is 0.0089. Using this as a baseline, the estimate in column (1) suggests that the CHR reduces the weekly probability of a treated player reporting a concussion by 31%. This result suggests that the CHR reduces the number of concussions, the severity of each concussion, or both. Column (2) shows that the estimate changes very little (−0.0027) when using position fixed-effects instead of player control variables. However, when using player fixed-effects in column (3), the estimated coefficient declines by 39% and becomes statistically insignificant. As shown in the table, using position-specific linear trends as opposed to a general linear trend does not change the estimated treatment effect.

When combining all head, neck, and concussion injuries (columns 7–12), the estimated effect of the CHR is negative, ranging from −0.0019 to −0.0033. From a baseline of 0.0174, these results suggest that the CHR reduces the weekly probability of a treated player reporting a head, neck, or concussion injury by between 11 and 19%. However, all of the estimates are statistically insignificant. As before, using position-specific time trends instead of a general linear time trend does not affect the estimated treatment effect. These results provide qualitative (but not statistical) evidence that the CHR reduces the overall probability a treated player reports a head, neck, or concussion injury in a given week. The results in Table 3 include both offensive and defensive treated positions in the treatment group. Ostensibly, the CHRs intent is to reduce concussions for all players. Nevertheless, the rule may differentially affect offensive and defensive players depending on their counterfactual use of the crown of the helmet during game play. The results in Table 4, Table 5 examine the CHRs intended effect on the defensive and offensive treatment groups, respectively.[7]

Table 4. Intended Effect of the CHR on Treated Defensive Players.

	Concussions (Baseline Prob = 0.0112)						**Head, Neck, and Concussion Injuries (Baseline Prob = 0.0173)**					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Treat	0.0007	–	–	0.0013	–	–	0.0081***	–	–	0.0096***	–	–
	(0.0015)	–	–	(0.0013)	–	–	(0.0019)	–	–	(0.0023)	–	–
After	0.0022**	0.0018**	0.003	0.0022**	0.0018**	0.003	0.0019	0.0012	0.0041***	0.0018	0.0012	0.0041***
	(0.0007)	(0.0007)	(0.0016)	(0.0007)	(0.0007)	(0.0016)	(0.0012)	(0.0010)	(0.0005)	(0.0012)	(0.0010)	(0.0005)
*Treat*After*	−0.0035*	−0.0033*	−0.0032	−0.0036*	−0.0033*	−0.0032	−0.0059*	−0.0057**	−0.0049	−0.0059*	−0.0057**	−0.0049
	(0.0014)	(0.0014)	(0.0018)	(0.0014)	(0.0014)	(0.0018)	(0.0024)	(0.0019)	(0.0041)	(0.0024)	(0.0019)	(0.0041)
N	48,212	48,212	48,212	48,212	48,212	48,212	48,212	48,212	48,212	48,212	48,212	48,212
Controls	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE
Trend	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin

Notes: Standard errors clustered by player position in parentheses. Treatment group is all defensive treated positions: CB, S, and LB. Offensive treated positions (TE, WR, HB, FB) omitted from estimates. The baseline probability is for the treated group of players in the season prior to the CHR becoming active.

***p < 0.01.

**p < 0.05.

*p < 0.1.

Table 5. Intended Effect of the CHR on Treated Offensive Players.

	Concussions (Baseline Prob = 0.0112)						**Head, Neck, and Concussion Injuries (Baseline Prob = 0.0175)**					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Treat	0.0054**	–	–	0.0002	–	–	0.0066***	–	–	−0.0008	–	–
	(0.0016)	–	–	(0.0010)	–	–	(0.0016)	–	–	(0.0026)	–	–
After	0.0018**	0.0018**	0.0030	0.0018**	0.0018**	0.0030	0.0014	0.0012	0.0041***	0.0014	0.0012	0.0041***
	(0.0006)	(0.0006)	(0.0016)	(0.0006)	(0.0006)	(0.0016)	(0.0012)	(0.0010)	(0.0005)	(0.0012)	(0.0010)	(0.0005)

	Concussions (Baseline Prob = 0.0112)						Head, Neck, and Concussion Injuries (Baseline Prob = 0.0175)					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
*Treat*After*	−0.0022	−0.0021	−0.0005	−0.0022	−0.0021	−0.0005	−0.0004	−0.0003	0.0018	−0.0004	−0.0003	0.0018
	(0.0025)	(0.0026)	(0.0049)	(0.0025)	(0.0026)	(0.0049)	(0.0031)	(0.0031)	(0.0046)	(0.0031)	(0.0031)	(0.0046)
N	44,812	44,812	44,812	44,812	44,812	44,812	44,812	44,812	44,812	44,812	44,812	44,812
Controls	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE	Standard	Position FE	Player FE
Trend	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin

Notes: Standard errors clustered by player position in parentheses. Treatment group is all offensive treated positions: TE, WR, HB, and FB. Defensive treated positions (S, CB, LB) omitted from estimates. The baseline probability is for the treated group of players in the season prior to the CHR becoming active.

***$p < 0.01$.

**$p < 0.05$.

Focusing on Table 4, defensive treated positions, the results in columns (1), (2), (4), and (5) are negative, range from −0.0033 to −0.0036, and are statistically significant at the 10% level. These results suggest that the CHR reduces the weekly probability of a defensive treated player reporting a concussion by between 29 and 32%. The results do not depend upon the type of trend used. Results using player fixed-effects, while similar in magnitude, are statistically insignificant. The results for the CHRs effect on head, neck, or concussion injuries in columns (7), (8), (10) and (11) suggest that the CHR is responsible for reducing the weekly probability of a defensive treated player reporting one of these injuries by between 32 and 34% from a baseline of 0.0173. Again, estimates using player fixed-effects are statistically insignificant at conventional levels.

In Table 5, we find that the CHR had no effect on reducing the probability of reporting either concussion or head, neck, and concussion injuries for offensive players. These results are, in many cases, an order of magnitude smaller than those for the defensive group and are never statistically significant. Combined, the results in Table 4, Table 5 show that the CHRs intended effect was highly heterogeneous. Defensive players received all of the benefits in the form of reduced probabilities of concussion and head, neck, and concussion injuries, whereas offensive players experienced no change in the probability of reporting these injuries.

5.2. Unintended effect of CHR: injury probability

The CHR changes incentives for the way defensive players tackle by penalizing them for using the helmet to initiate contact with an offensive player. The CHR also penalizes an offensive player for using the crown of his helmet to protect himself from a defensive player. This results in offensive players substituting towards running more upright and trying to maneuver around contact, which exposes them to a higher likelihood of hits to the lower body instead of to the helmet, and, therefore, a higher probability of experiencing lower-body injuries. For these reasons, we hypothesize that the CHR may have the unintended consequence of increasing the probability of lower body injuries for treated offensive players.

Table 6 shows the results of estimating Eqs. (1) and (2) when the dependent variable equals one if the player reports a lower body injury and zero otherwise, and the treatment group is all treated offensive players. All of the estimated treatment effects are positive and statistically significant at least at the ten percent level. Furthermore, the estimates increase in magnitude when including player fixed-effects. The results suggest that the CHR increases the weekly probability of an offensive treated player reporting a lower-body injury by between 0.0343 and 0.0473 percentage points, or between 25 and 34% from a baseline of 0.1390.

Table 6. Unintended Effect of the CHR on Treated Offensive Players.

	Lower Extremity Injuries (Baseline Prob = 0.1390)					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Treat	0.0579	–	–	0.0298	–	–
	(0.0364)	–	–	(0.0268)	–	–
After	0.0009	0.0130**	0.0195**	0.0010	0.0130**	0.0195**
	(0.0046)	(0.0045)	(0.0064)	(0.0046)	(0.0045)	(0.0064)
*Treat*After*	0.0353**	0.0343**	0.0473*	0.0351**	0.0343**	0.0473*
	(0.0137)	(0.0125)	(0.0230)	(0.0136)	(0.0125)	(0.0230)
N	66,878	66,878	66,878	66,878	66,878	66,878
Controls	Standard	Position FE	Player FE	Standard	Position FE	Player FE
Trend	Linear	Linear	Linear	Grp Spf Lin	Grp Spf Lin	Grp Spf Lin

Notes: Standard errors clustered by player position in parentheses. Treatment group is all offensive treated positions: TE, WR, HB, and FB. The baseline probability is for the treated group of players in the season prior to the CHR becoming active.

**$p < 0.05$.

*$p < 0.1$.

5.3. Intended effect of CHR: injury severity

Table 7 shows the results of estimating Eqs. (3) and (4) for the defensive treatment group. These estimates exclude the offensive treated players from the regression, and the dependent variable in these regressions is the number of games missed during the regular season due to either concussions (columns [1]–[3]), or all head, neck, and concussion injuries (columns [4]–[6]). These results generally show that the CHR was responsible for reducing the number of games missed and, therefore, the severity of these injuries for treated defensive players. The magnitude of the results is quite small (increasing average games played by less than 1%), but statistically significant for all specifications besides the player fixed-effects models. Results for the offensive player treatment group, shown in Table 8, show no statistically significant effect of the CHR on concussions or on the grouping of head, neck, and concussion injuries. These results sometimes have the opposite sign, and are even smaller in magnitude than the defensive player estimates.

Table 7. Intended Effect of the CHR on Treated Defensive Players, Games Missed.

	Concussions (Ave. Games Played = 11.87)			Head, Neck, and Concussion Injuries (Ave. Games Played = 11.87)		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Treat	−0.0236	–	–	0.0652	–	–
	(0.0391)	–	–	(0.0622)	–	–
After	0.0363*	0.0333*	0.0468	0.0257	0.0225	0.0572
	(0.0159)	(0.0141)	(0.0498)	(0.0270)	(0.0251)	(0.0431)
*Treat*After*	−0.0670**	−0.0657**	−0.0573	−0.0633*	−0.0676**	−0.0445
	(0.0211)	(0.0228)	(0.0499)	(0.0269)	(0.0263)	(0.0794)
N	2836	2836	2836	2836	2836	2836
Controls	Yes	Position FE	Player FE	Yes	Position FE	Player FE

Notes: Standard errors clustered by player position in parentheses. Treatment group is all defensive treated positions: CB, S, and LB. Offensive treated positions (TE, WR, HB, FB) omitted from estimates. Mean number of games played is for defensive treated players in season prior to CHR implementation.

**p < 0.05.

*p < 0.1.

Table 8. Intended Effect of the CHR on Treated Offensive Players, Games Missed.

	Concussions (Ave. Games Played = 11.33)			Head, Neck, and Concussion Injuries Ave. Games Played = 11.33)		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Treat	0.0607	–	–	0.0371	–	–
	(0.0350)	–	–	(0.0213)	–	–
After	0.0370*	0.0333*	0.0468	0.0267	0.0225	0.0572
	(0.0158)	(0.0139)	(0.0494)	(0.0267)	(0.0248)	(0.0427)
*Treat*After*	−0.0328	−0.0332	0.0197	0.0376	0.0343	0.0911
	(0.0497)	(0.0509)	(0.1470)	(0.0570)	(0.0585)	(0.1370)
N	2636	2636	2636	2636	2636	2636
Controls	Yes	Position FE	Player FE	Yes	Position FE	Player FE

Notes: Standard errors clustered by player position in parentheses. Treatment group is all offensive treated positions: TE, WR, HB, and FB. Defensive treated positions (S, CB, LB) omitted from estimates. Mean number of games played is for offensive treated players in season prior to CHR implementation.

*p < 0.1.

5.4. Unintended effect of CHR: injury severity

Table 9 shows results from Eqs. (3) and (4) when the dependent variable is the number of games missed due to lower body injuries and the treatment group is all treated offensive players. Therefore, Table 9 shows the CHRs unintended effect on the severity of lower extremity injuries among offensive players. Results indicate that the CHR increases the severity of lower body injuries among offensive players. The results are large and significant, except for the player fixed-effects model. The magnitude of the statistically significant coefficients suggests that the CHR is responsible for increasing the number of games missed due to lower extremity injuries of treated offensive players by between 0.4918 and 0.5306 games. At an average of 11.33 games played per year for this group, this represents a 4–5% decrease in the average number of games played.

Table 9. Unintended Effect of the CHR on Treated Offensive Players, Games Missed.

	Lower Extremity Injuries (Ave. Games Played = 11.33)		
	(1)	**(2)**	**(3)**
Treat	0.0647	–	–
	(0.205)	–	–
After	0.0668	0.386***	0.366***
	(0.0606)	(0.0852)	(0.0886)
*Treat*After*	0.5306**	0.4918*	0.6002
	(0.1901)	(0.2223)	(0.4227)
N	3934	3934	3934
Controls	Yes	Position FE	Player FE

Notes: Standard errors clustered by player position in parentheses. Treatment group is all offensive treated positions: TE, WR, HB, and FB. Mean number of games played is for offensive treated players in season prior to CHR implementation.

***p < 0.01.

**p < 0.05.

*p < 0.1.

6. Robustness

In this section, we offer several robustness checks for both the intended and unintended effects of the CHR using injury probability and games missed as outcomes. First, we explore the sensitivity of the intended effects of the CHR on excluding various positions from the treated group. The CHRs intent is to protect players outside of the tackle box. Several positions in our standard treatment group are outside of this area with varying degrees of frequency; therefore, the CHR may have a differential effect even among the treated positions. Next, we explore the sensitivity of the unintended effects to changing the definition of treated positions and the definition of lower-extremity injury. Furthermore, we add an additional year of pre-policy data and estimate a model using changes in annualized weekly injury counts as an outcome. This accounts for the possibility that a longer term injury trend divergence between our treatment and comparison groups is not driving the main results. Finally, we perform a falsification test that examines the effect of the CHR on lower-extremity injuries for players in the defensive treatment group.

6.1. Robustness of intended effects

Table 10 shows the results of re-estimating the intended effects of the CHR after changing the definition of treated players. We re-estimate the model using only the HB position as treated (excluding all other offensive treated positions) and then only the WR position as treated for the offensive groups. We also estimate the model using only the S and CB positions, only the LB and CB positions, and finally only the CB position as treated for the defensive groups. Estimates are from Eq. (2) using a general linear time trend and position fixed-effects. The outcome of interest is all head, neck, and concussion injuries. For the offensive group, we again find no evidence to support the CHR reducing head, neck, and concussion injury reports. Estimates using only the HB position as treated (column [1]) or the WR position (column [2]) are positive. The magnitude is large, and the estimates are statistically significant at the 10% level.

Table 10. Robustness Checks for Intended Effects, Injury Probability and Games Missed.

	Injury Probability					**Games Missed**				
	Offensive Players		**Defensive Players**			**Offensive Players**		**Defensive Players**		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
	Only HB	**Only WR**	**Only S and CB**	**Only LB and CB**	**Only CB**	**Only HB**	**Only WR**	**Only S and CB**	**Only LB and CB**	**Only CB**
After	0.0012	0.0012	0.0012	0.0012	0.0012	0.0225	0.0225	0.0225	0.0225	0.0225
	(0.0011)	(0.0011)	(0.0010)	(0.0010)	(0.0011)	(0.0265)	(0.0265)	(0.0257)	(0.0257)	(0.0265)
*Treat*After*	0.0029*	0.0029*	−0.0063*	−0.0067**	−0.0082***	0.0582	0.1080**	−0.0618	−0.0738**	−0.0723*
	(0.0011)	(0.0011)	(0.0027)	(0.0017)	(0.00116)	(0.0265)	(0.0265)	(0.0291)	(0.0257)	(0.0265)
N	31,433	34,289	39,032	45,985	36,805	1849	2017	2296	2705	2165

Notes: Standard errors clustered by player position in parentheses.
All results reflect position fixed effects specifications and linear time trend within season. Outcome is head, neck, and concussion injury for injury probability columns, and weeks missed due to head, neck, and concussion injury for games missed columns. Offensive player regressions exclude treated defensive players. Defensive player regressions exclude treated offensive players.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

Our primary results for defensive players (columns [1]–[6] of Table 4) are quite robust to the definition of the treated group used. The results in columns (3)–(5) of Table 10 show a negative and statistically significant effect of the CHR on the incidence of head, neck, and concussion injury reports. The magnitude of this effect is generally larger than the primary results. In columns (3) and (4), the magnitude is almost double in size. In fact, for the specification that only includes the CB position as treated, the magnitude of the estimate is almost 2.5 times greater than the estimates presented in Table 4. Players at this position are nearly always outside of the tackle box and, therefore, nearly always covered by the CHR.

Columns (6)–(10) in Table 10 show results for the specifications re-examining games missed due to head, neck, and concussion injuries from Eq. (4) using position fixed-effects. These results generally support our primary findings − there is no distinguishable effect for offensive players in the HB position. For the WR position, the estimate is significant and positive; however, the magnitude is very small. There is a small negative effect on the injury severity for defensive players. The magnitude we estimate for defensive players is somewhat larger than the base result, but still small with at most a 0.0738 games played effect.

6.2. Robustness of unintended effects

Table 11 shows results of re-estimating the unintended effects of the CHR for specifications that change the definition of the offensive treatment group (columns [1]–[4]), the comparison group (column [5]), and the definition of a lower-extremity injury (columns [6]–[7]). All specifications include position fixed-effects and a general linear time trend. Overall, the results in columns (1)–(4) are consistent with our primary results − they show a large increase in the probability of reporting a lower-extremity injury for treated offensive players because of the CHR. When excluding the FB position, our results are nearly identical to the baseline results. For models that exclude the TE position, we still find a large, positive coefficient that is statistically meaningful; however, the magnitude is slightly smaller, equaling 0.0263. This suggests that the probability a lower-extremity injury report occurs for a treated offensive player (HB, FB, or WR) increases by 17.5% (from a baseline of 0.15), whereas the full model suggests a change of between 25 and 34%. The specification using only HB as the treated group has a small magnitude (0.0027) and is insignificant. However, the WR-only specification has large magnitude (0.0358 or 24.5% from a baseline of 0.1456).

Table 11. Robustness Checks for Unintended Effects, Injury Probability.

	Exclude FB	**Exclude TE**	**Only HB**	**Only WR**	**Exclude DL from control**	**Only Knee Injuries**	**Exclude Muscle Injuries**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
After	0.0130**	0.0130**	0.0130**	0.0130**	0.0135*	0.0153***	0.0195***
	(0.0045)	(0.0045)	(0.0046)	(0.0046)	(0.0059)	(0.0047)	(0.0028)
*Treat*After*	0.0320**	0.0263*	0.00272	0.0358***	0.0338**	0.0109	0.0269***
	(0.0127)	(0.0123)	(0.0046)	(0.0046)	(0.0132)	(0.0072)	(0.0057)
N	66,079	62,441	53,499	56,355	55,216	66,878	66,878

Notes: Standard errors clustered by player position in parentheses.
All results reflect position fixed effects specifications and linear time trend within season. Outcome is lower body injury, unless indicated in column.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

In column (5), we remove the defensive line (DL) positions (DE and DT) from the comparison group to account for the peel back block rule change. If this rule change were effective, then players in the DL position would experience a decrease in the probability of experiencing a lower body injury at the same time that the offensive treated positions experience an increase, thereby inflating the estimated CHR unintended effects. The estimate in column (5) shows that this is not the case. The magnitude is similar to the baseline results (columns [1]–[3] of Table 6), and the estimate is statistically significant at the 5% level. When estimating the model without defensive line included in the comparison group, the coefficient estimate is 0.0338 and remains significant at the 5% level.

Columns (6) and (7) show results after changing the definition of lower-extremity injury. Column (6) limits this definition to include only knee injuries, while column (7) excludes any injuries to muscles.[8] It is difficult to say what types of lower-body injuries should increase because of the CHR, as we expect that it changes not only the way defensive players tackle, but also the way offensive players attempt to avoid a tackle. Results from these specifications support our primary findings in terms of sign. The specification using knee injuries shows a smaller, and insignificant, increase in these type of injuries, while the specification excluding muscle injuries is near the low end of our primary estimates, and is significant at the 1% level.

Table 12 is similar to Table 11. However, the results in Table 12 are from specifications using games missed due to lower-extremity injury as the primary outcome along with position fixed-effects. Overall, these results are only weakly supportive of the finding that the CHR increases injury severity for offensive players. For specifications that exclude the FB position from treatment, only include the WR position in the treatment, or exclude the DL positions from the comparison, results are similar to our primary findings in terms of sign, magnitude, and statistical significance. For other robustness checks, we find either smaller magnitudes and/or no statistical significance. We take this as evidence that the CHR increased the probability of reporting a lower-extremity injury among offensive players; however, the severity of these injuries may not be greater than before the rule change.

Table 12. Robustness Checks for Unintended Effects, Games Missed.

	Exclude FB	**Exclude TE**	**Only HB**	**Only WR**	**Exclude DL from control**	**Only Knee Injuries**	**Exclude Muscle Injuries**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
After	0.386***	0.386***	0.386***	0.386***	0.417***	0.292***	0.440***
	(0.0858)	(0.0858)	(0.0873)	(0.0873)	(0.106)	(0.0683)	(0.0841)
*Treat*After*	0.436*	0.465	−0.0820	0.698***	0.460*	0.208	0.400
	(0.226)	(0.282)	(0.0873)	(0.0873)	(0.232)	(0.134)	(0.227)
N	3887	3673	3147	3315	3248	3934	3934

Notes: Standard errors clustered by player position in parentheses.
All results reflect position fixed effects specifications. Outcome is games missed due to lower body injury, unless indicated in column.
***p < 0.01.
*p < 0.1.

6.3. Annualized weekly injury counts

To guard against the possibility that the divergence between comparison and treatment groups attributed to the CHR is not part of a longer-term divergence, or part of a divergence that occurs across weeks of a particular season, we estimate a model using the annual change in reported injuries by type each week as the dependent variable. This specification is:
(5)

$$(Y_{y,p,w} - Y_{y-1,p,w}) = \alpha + \beta_1(D = 1 if After)_y + \beta_2(D = 1 if Treat * D = 1 if After)_{p,y} + \gamma_p + \varepsilon_{y,p,w}$$

Where $Y_{y,p,w}$ is a count of the number of injury reports for position p during week w in year y, and the data is aggregated to the position-week-year level. We estimate (5) separately for concussions alone, all concussion, head, and neck injuries, and lower body injuries. In this specification, the post-policy period is the change in injury reports between corresponding weeks of the 2012 and 2013 seasons (i.e.

the difference between week 1 of the 2013 season and week 1 of the 2012 season). The pre-policy period is the change in injury reports between corresponding weeks of the 2012 and 2011 seasons. Eq. (5) is estimated for the offensive and defensive treatment groups combined and separately. When the dependent variable is the change in the number of lower-body reports, only the offensive treatment group is used. The Y_p denotes position fixed effects.

Table 13 shows the results of estimating (5). The annualized results show a stronger effect of the policy on reducing concussion reports for all players when compared to the primary results. This is especially true for players in the offensive treatment group. The magnitude of the estimate in column (1) suggests the policy reduces the incidence of concussion reports by nearly 2 per week for both treatment groups. These estimates are statistically meaningful at the one-percent level. The results for defensive players are less robust to this alternative specification. They are smaller in magnitude, suggesting a reduction of fewer than 1 concussion per week as a result of the policy. The unintended effect of the policy, an increase in lower body injuries among treated offensive players, shows that the CHR policy is responsible for an increase of 5.4 lower body injury reports per week. The effect is statistically significant at the one-percent level.[9]

Table 13. Annual Changes in Weekly Injury Counts.

	(1) All Players-Concussions	(2) All Players-HNC	(3) Offense-Concussions	(4) Offense-HNC	(5) Defense-Concussions	(6) Defense-HNC	(7) Offense- Lower Body
*Treat*After*	−1.997***	−2.765***	−1.093***	−1.676***	−0.748**	−0.849	5.402***
	(0.340)	(0.513)	(0.328)	(0.492)	(0.355)	(0.533)	(1.508)
N	340	340	340	340	340	340	340

Notes: Standard errors clustered by player position in parentheses.
All results reflect position fixed effects specifications. Outcome is annual change in injuries (by type according to column heading) per week.
***$p < 0.01$.
**$p < 0.05$.

6.4. Falsification test: lower extremity injuries to defensive players

Table 14 shows results of re-estimating Eqs. (1)–(4). The treatment group includes the defensive positions, LB, S, and CB. The comparison group is all other positions. Table 14 shows outcomes for the probability of reporting a lower body injury (columns [1]–[3]), or the number of games missed due to these injuries (columns [4]–[6]). These specifications serve as falsification tests for the results in Tables 6 and 9 because defensive players do have an incentive to change the way they tackle because of the CHR, and they generally do not use their helmet to protect against an oncoming tackler. However, while they can no longer initiate a tackle with the crown of the helmet, they can still tackle by aiming low on the offensive player (resulting in offensive player lower body injuries). Therefore, we do not expect the CHR would result in significant changes to the incidence or severity of lower-extremity injuries for defensive players. The results in Table 14 consistently show that the CHR does not affect the incidence or severity of lower-extremity injuries for defensive treated players. If anything, it may induce a slight reduction in incidence and severity. In total, the results in Table 14 suggest that the negative unintended consequences of the CHR are borne solely by players in the treated offensive positions.

Table 14. Falsification Test: Effect of CHR on Treated Defensive Players Lower Extremity Injury Probability and Games Missed.

	Injury Probability (Dep Var Mean = 0.1364)			Games Missed (Ave. Games Played = 11.87)		
	(1)	(2)	(3)	(4)	(5)	(6)
Treat	0.0119	–	–	0.178	–	–
	(0.0136)	–	–	(0.161)	–	–
After	0.0136	0.0278**	0.0388**	0.257*	0.606***	0.622*
	(0.0093)	(0.0090)	(0.0143)	(0.129)	(0.143)	(0.276)
*Treat*After*	−0.00961	−0.0156	−0.0195	−0.128	−0.250	−0.282
	(0.0121)	(0.0131)	(0.0178)	(0.176)	(0.220)	(0.312)
N	66,878	66,878	66,878	3934	3934	3934
Controls	Yes	Position FE	Player FE	Yes	Position FE	Player FE

Notes: Standard errors clustered by player position in parentheses. Injury probability regressions control for linear time trend in weeks of each season. Treatment group is all defensive treated positions: CB, S, LB.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

7. Discussion/Conclusion

This paper demonstrates that a major rule change in professional football, while effective at reducing concussion and head injuries for some players, has unintended consequences for other players. This finding adds to an existing literature on the unintended consequences of health and safety regulation in general. Related findings demonstrate several side-effects from safety regulation, including reduced bicycling when youth helmet laws are instituted (Carpenter and Stehr, 2011), increased organ donation when motorcycle helmet laws are repealed (Dickert-Conlin et al., 2011), and deer harvesting restrictions leading to fewer hunting accidents by reducing moral hazard (Conlin et al., 2011).
Our results suggest that the crown of the helmet rule reduces the weekly probability of reporting a concussion for defensive players subject to the rule by as much as 32% (or 34% for all head and neck injuries). The results further suggest that the crown of the helmet rule *increases* the weekly probability of reporting a lower-extremity injury for an offensive player subject to the rule by as much as 34%. We also find that the severity of lower-extremity injuries for offensive players increases, resulting in an additional half game missed per season; however, these results are less robust.

Ultimately, a rule like the CHR requires some cost/benefit analysis to know if the benefits of the rule outweigh the costs. A true cost/benefit analysis of the CHR would include many factors outside of player injuries, such as how the rule affects ticket and merchandise sales. Our primary contribution towards that end is to demonstrate that while there are some benefits to safety for some players, costs exist in the form of increasing lower extremity injuries of offensive players. Concussions and many lower extremity injuries may have lasting effects on player health beyond missed games and lost productivity. If we ignore the longer term effects, then it is possible to estimate the productivity cost in terms of lost games. Our results suggest that treated offensive players miss an additional half game per season due to increased severity of lower-body injuries as a result of the CHR. However, treated defensive players experience a very small reduction in games missed (0.05, on average). Given the magnitude of this estimate, we assume no change in games played for treated defensive players. To calculate the net productivity cost in terms of lost games, we multiply the increase in number of games missed by the number of treated offensive players and the average league salary in our data. This leads to a net productivity cost of the CHR equaling $27 million during the 2013/2014 season.

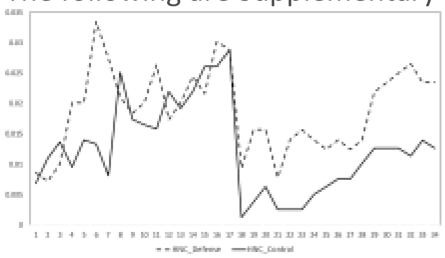
As an alternative to the productivity net benefit measure, we calculate the monetary benefit of reducing concussions and compare it with the monetary cost of increasing lower-extremity injuries using government guidelines on the value of avoiding injuries (Trottenberg, 2013). Following Trottenberg (2013), we set the value of statistical life (VSL) as $9.1 million, and we assume that the value of an offensive and defensive player's life is equal. We further assume that all lower-extremity injuries are classified as "moderate" and all head, neck, and concussion injuries are classified as severe. Using these guidelines, the value of each lower-extremity injury equals $0.43 million (= 0.047*9.1); the value of a head/neck/concussion is $0.96 million (= 0.105*9.1).

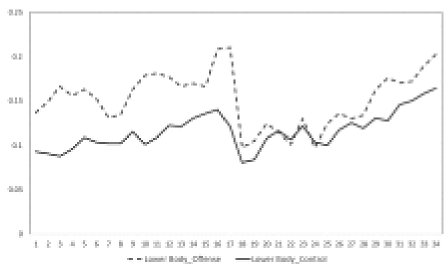
The coefficients from the linear probability models indicate the change in the weekly probability of reporting a particular type of injury. If we assume that this probability remains constant for each week in the season, then multiplying the coefficient by 16 should yield the change in the probability of reporting a particular injury throughout the season. Multiplying this annualized probability by the number of injury-week reports from the treated players in the 2012 season indicates the change in the injury reports due to the CHR. According to Table 2, there were 177 head, neck, and concussion reports in the 2012 season among treated defensive players. Using −0.0059 (column 7 of Table 4) as the change in the weekly probability of a treated defensive player reporting one of these injuries, the CHR reduced the number of head, neck, and concussion injuries among defensive players by 16.7 (=177*-0.0059*16). Multiplying the value of a concussion, head, or neck injury by the predicted decrease in the number of reports yields a benefit of $15.9 million.

Table 2 shows that the number of lower-body reports for treated offensive players equals 1282 during the 2012 season. From column 2 of Table 6, the weekly probability of reporting a lower-body injury increases by 0.0343, or 0.5488 (=0.0343*16) for the season. This suggests an increase in these injury reports of approximately 703.5 (=1282*0.5488). Multiplying the value of a lower-extremity injury by the predicted increase in the number of reports yields a monetary cost of $300.9 million. The monetary benefit subtracted by this cost suggests that the VSL net cost of implementing the CHR is $285 million for injuries occurring in the 2013/2014 season. As discussed before, the coefficients from the linear probability models show either a change in the number of injuries, a change in the severity of the injuries, or a combination of both. This particular calculation assumes that one report equals one injury.

Appendix A. Supplementary data

The following are Supplementary data to this article:





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[1]During the offseason, all NFL officials attend a mandatory training clinic, where attendees take exams and new rules are thoroughly explained (NFL Operations n.d., b.). Additionally, officiating crews are evaluated on a weekly basis during the regular season.

[2]During each game, a staff of approximately 29 medical personnel are present to help diagnose and treat various injuries (NFL, 2015). This staff includes one independent athletic trainer positioned in the press box. This trainer's main responsibility is to watch the field and television monitors to aid in identifying injuries that may be missed during plays. Starting in the 2013 season, an independent neurological consultant was added to the medical staff to assist specifically with concussion-related injuries (NFL, 2013). Also starting in the 2013 season, each team is required to use an electronic tablet to aid in the diagnosis of concussions using a step-by-step checklist of procedures.

[3]Some players can be both a long snapper and another position, such as center. We define a specialized long snapper as someone who plays only that particular position.

[4]We explore the sensitivity of the results by changing the definition of lower extremity injury in the robustness section of the paper.

[5]The analysis was replicated with kickers, punters, and specialized long-snappers included in the sample. The results are extremely similar to results presented here, with only minor differences in magnitude in some specifications.

[6]Both figures also show that injuries exhibit a strong seasonal pattern- they are generally more likely at the end of a season and less likely at the beginning, a pattern that is also true of previous seasons.

[7]The results in Fig. 2, Fig. 3 and Table 2 suggest an overall increase in injuries between the 2012/2013 and 2013/2014 seasons. This is supported in Table 3, Table 4, Table 5, Table 6, Table 7, Table 8, Table 9, Table 10, Table 11, Table 12, Table 13 by a positive and, in many cases, significant estimate of the *After* dummy variable. This could be due to an actual increase in injuries due to game play, medical care, general player health, field conditions, an increase in reporting, or other factors.

[8]These specifications exclude injuries to the calf, groin, hamstring, and quadriceps from our definition of lower-extremity injury.

[9]We also estimated (5) after adding data from the 2014/2015 season as a treated year. These results show a small, but significant effect of the CHR policy on reducing head, neck, and concussion injury reports for offensive players; however, the unintended effect for offensive players on lower body injuries is insignificant. This suggests that players may be adjusting game play in response to rule changes over time as the NFL continues to implement new policies regarding player safety. It may also suggest that the policy is less emphasized after the first year of implementation as new rules are introduced.