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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
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Abstract

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American football has always been regarded as a high-impact, physical sport. Recently, more and more ex-NFL players have come forward with complaints about their health, blaming their deteriorating neurodegenerative state on the hard hits inherent to the game. This paper seeks to understand how NFL rule changes and the number of years played in the NFL affect a player's age of death. The paper computes the different causes of death by player position and race with the ultimate goal of better informing young athletes and incoming NFL players of the delayed health costs that can be expected from a football career.

Using data from Pro Football Reference, this paper finds that an additional year in the NFL increases the probability of dying from neurodegenerative causes by 5% relative to all other causes of death. The data further claims that positions with shorter career lengths, such as the running back, are less susceptible to early mortality and that positions, like the linebacker, which generate and experience the most impact per tackle, have a higher probability of dying from neurodegenerative causes. This paper also demonstrates the success that NFL rule changes and safety protocols have had in increasing players' lifetimes.

Given the results, the NFL should continue to devise new rules limiting the impact per tackle. The NFL should also look into alternative ways to improve player safety, such as upgraded helmet models and padding. The data also advises the NFL to reduce the number of games played per season; the change from a 14 to 16 game season in 1990 significantly increased the average NFL players' mortality rate.

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The Long-Term Health Implications of an NFL Career

Gabriel James Moynihan

American football has always been regarded as a high-impact, physical sport. Recently, more and more ex-NFL players have come forward with complaints about their health, blaming their deteriorating neurodegenerative state on the hard hits inherent to the game. This paper seeks to understand how NFL rule changes and the number of years played in the NFL affect a player's age of death. The paper computes the different causes of death by player position and race with the ultimate goal of better informing young athletes and incoming NFL players of the delayed health costs that can be expected from a football career.

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I. Introduction

As American football gained traction throughout the 1900s, President Theodore Roosevelt coined the sport as a "death harvest," referencing football's injurious and barbarous nature (Maroon et. al, 2014). Since the advent of football in 1869, numerous rules and regulations have come to define and police the sport as we know it today. Specifically, the establishment of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) and helmet requirements in 1969 reduced in-game concussions and traumatic brain injury diagnoses by 74% (Levy, et. al, 2004). In 1975, tackling rules changed to deter helmet-to-helmet contact (Levy, et. al, 2004). Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) was developed in the early 1990s, leading to significant concussion-preventative research efforts and the switch from suspension-type to padded-type helmet liner in 1997 (Maroon et. al, 2014; Levy, et. al, 2004). This switch to pads lowered concussion incidence rates from 19% to 2% at low severity impact and from 65% to 11% at high severity impact (Levy, et. al, 2004). Ultimately, these improvements in equipment, technology and rules have been consistent throughout the history of football with marked changes occurring roughly each decade (NFL History by Decade, 2016).

An increasing wave of research pertains to the relationship between an NFL careers and chronic traumatic encephalopathy (CTE); CTE is a progressive neurodegenerative disease attributed to repetitive traumatic brain injuries. Contemporary research finds that there are no signs of CTE in the brains of people who had never played contact sports growing up, but that CTE is very common among those who played for as few as one year of high school football. As such, Kevin Bieniek, postdoctoral research fellow in the Mayo Clinic's Department of Neuroscience, claims that CTE disease may be widespread among the general population

(Fainaru, 2016). The Boston University Center for the Study of Traumatic Encephalopathy has similarly found that CTE can result from trauma confined to just a high school football career (Toporek, 2012). Most children fantasize about becoming an NFL player without knowing the *true* cost, or long-term impact the sport can have on their quality of life.

In 2015, a biographical football film on CTE injury, called *Concussion,* came out with Will Smith as the lead actor. The reason for the intensified research scrutiny and Hollywood attention is partially due to recent, high-profile deaths of former NFL athletes. Beloved San Diego Chargers Hall of Fame linebacker Junior Seau committed suicide at age 43 as did Atlanta Falcons safety Ray Easterling (Koning et. al, 2014). Former Oakland Raiders quarterback Ken Stabler also suffered and recently died from CTE disease, as confirmed by Dr. Ann McKee in February 2016 (ESPN, 2016). As of March 2016, Jeff Miller, the NFL's senior VP for health and safety, publicly acknowledged a connection between football and CTE for the first time (Fainaru, 2016).

This recent attention has brought the morality of the NFL into question. Does the delayed physical and mental toll of an NFL career outweigh the fame and wealth of being a professional athlete? Are these delayed health effects understood by and communicated to players who sign NFL contracts? How should we protect youth, collegiate and professional athletes around the nation from CTE? This paper attempts to quantify the risks associated with playing in the NFL in mortality terms as well as quantify how successful rule changes have been in protecting players' health. In better understanding the health risks by position and over a career, young players and upcoming professional football players can better assess alternatives and payoffs.

This paper uses mortality data from 1945-2015. This dataset, collected from Pro Football Reference and cross-referenced with Oldest Living Pro Football Database, incorporates all NFL players that have died within years 1945-2015. For example, if an athlete played sometime within 1945-2015 and still has not died yet, he would *not* be incorporated in that dataset. The last year played by an individual in this deceased dataset was 2013, indicating that no player who has played in the 2014 or 2015 season has died yet (Pro Football Reference, 2016).

Intuitively, one would expect a negative relationship between years played in the NFL and average age of death. As a professional NFL athlete, repeated concussions should increase the propensity for early mortality ceteris paribus. However, an arm of the Center for Disease Control (CDC), the National Institute for Occupational Safety and Health (NIOSH), convincingly finds that NFL players have longer expected lives than the general United States population (Baron et. al 2012; Lehman et. al, 2012). Such findings suffer from omitted variable bias. NFL players are not the average United States male. NFL athletes are said to have won the "genetic lottery" (Mythrandirs Blog, 2009). They exercise rigorously, have higher salaries, are constantly monitored by world-class personal trainers, smoke less, have higher BMIs, different average IQs, unique athletic ability and many other genetic dissimilarities. This bias has been studied as the "employee effect" or "healthy worker effect (HWE)". HWE states that the average employee is healthier than the average adult as employees meet certain health requirements (Shah, 2009; McMichael, 1976). In the instance of professional football, the HWE is extreme. This paper eliminates the HWE and such omitted variable biases by comparing different cohorts of NFL players to one another and not to the general United States population.

Only one other study, conducted by a Ph.D. student in the Massachusetts Institute of Technology (MIT) Economics Department, Tyler Williams, compares NFL cohorts with one another to eliminate HWE and the "genetic lottery" effect. However, Williams' study chooses to focus on players that were *born* in 1937-1975 – a much smaller sample than the one used in this study (Williams, 2012). Not only did major health and safety improvements, like the establishment of NOCSAE, take place in 1969, but Williams' 1937-1975 time period focuses on a players' birthdate rather than the time period in which they played. For example, most of the players on the latter end of this cutoff will have careers spanning the next largest shift in league safety, the 1997 change from suspension-type to padded-type helmet liner (NFL History by Decade, 2016). These changes had drastic and immediate benefits on player safety and concussion prevention, as previously quantified (Levy, et. al, 2004). Williams' study does not account for or mention these changes, whereas my regressions will incorporate health and safety improvement variables and controls (Williams, 2012). Playing in the NFL after these constructive protocols would be negatively correlated to mortality, biasing estimate upwards.

Aside from considering rule changes and safety protocols, my paper also differentiates itself by determining how the impact versus quantity of tackles influences the cause of death outcome. Are positions, such as linemen, which experience a large volume of hits at low impact more susceptible to a certain cause of death? On the other hand, the linebacker position builds up speed prior to tackling an opposing player who is usually running full-tilt in the opposite direction. Naturally, these tackles have much greater impact. As such, does the linebacker position have a greater susceptibility to developing neurodegenerative disease than other positions?

II. Related Literature

This section focuses mainly on medical journal studies that compare NFL players to the general United States population. These studies distinguish NFL players by position and different long-term disease/risk exposures that each position faces; then, this section covers a study that compares NFL athletes with short careers versus NFL athletes with long careers to correct for variable differences between the general United States population and professional athletes, such as lower smoking habits, genetic advantages, high aerobic levels and greater salaries and quality healthcare access.

In January 1994, the National Institute for Occupational Safety and Health (NIOSH) conducted a comprehensive mortality study (n=6,848) on the cause of death of NFL athletes per the request of the National Football League Players Associations (NFLPA) (Taft, 1994). The study determined that NFL players who participated in five or more seasons had a 46% lower rate of death compared to the general United States population with controlled age and race differences. NFL players with less than five seasons of play had a 56% lower rate of death in comparison. By position, this study established that linemen had a 52% higher cardiovascular mortality rate than the general United States population (Taft, 1994).

Everett J. Lehman of the CDC extends these results. Using data from 3,439 NFL players with at least five pension-credited or vested seasons from 1959-1988, Lehman et. al (2012) finds that NFL players have roughly three times higher neurodegenerative mortality risk compared to the general United States population. His study substantiates that speed positions (non-linemen and non-kicker/punter) are at higher risk than non-speed positions (linemen) for neurodegenerative diseases, such as Alzheimer Disease (AD) and Amyotrophic Lateral Sclerosis, (ALS) more commonly known as Lou Gehrig's Disease (Lehman et. al, 2012). In further agreement with the NIOSH mortality survey, Lehman et. al finds that overall NFL player mortality rates are 47% less than the general United States population and that NFL player cancer mortality rates are 42% less than the general United States population (Lehman et. al, 2012). Overall, cardiovascular disease (CVD) is 32% less in NFL players compared to the general United States population (Baron et. al, 2012). By race, CVD mortality rates were significantly higher in non-Caucasian players. Lehman et. al calculated this hazard ratio as 1.69, suggesting that non-Caucasian players die from CVD 1.69 times more than Caucasian players (Lehman et. al, 2012).

Cross-referencing Lehman's study, *Neurodegenerative Causes of Death among Retired National Football League Players*, with Dr. Lori B. Croft's study on NFL linemen's left ventricular and left atrial sizes, it is clear that linemen, or non-speed positions, are exposed to different long-term diseases compared to speed positions, like wide receivers and running backs. Croft et. al pooled data from echocardiography tests on 487 retired NFL players, calculating Body Mass Index (BMI)[1], left ventricular and atrial mass, systolic blood pressure, and intraventricular septal and posterior wall thickness. Conclusively, left ventricular mass was largest in retired linemen while player BMI, position and systolic blood pressure were significant predictors of this left ventricular mass. Croft et. al concludes that cardiac adaptations (like increased left ventricular mass and left atrial area size) of NFL linemen contribute to their roughly 3.7 times higher cardiovascular mortality rate (Croft et. al, 2008; Selden et. al 2009). Ultimately, linemen have a higher probability for cardiovascular mortality while non-linemen

[1] BMI is calculated as *[weight in lbs / (height in inches^2)] x 703*. This measure is taken from the National Institute of Health (NIH) as well as similar studies that use BMI as an independent variable (Williams, 2014).

have higher chance of neurodegenerative mortality (Baron and Rinsky, 1994; Lehman et. al, 2012; Croft et. al, 2008).

These empirical findings are not surprising. Nura Sadeghpour of the CDC reasons that linemen make immediate contact after the football is snapped and are therefore exposed to more repetitive, but softer contact; they don't build up speed on each play. Running backs, on the other hand, make contact at full speed and would likely suffer concussive hits more often (Sadeghpour, 2012). According to Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), NFL concussions occur at contact speed of 20.8 +/- 4.2 mph (Pellman et. al 2006; Maroon et. al, 2014). Linemen do not engage in contact at nearly these speeds, whereas wide receivers do.

Furthermore, through a cross-sectional data screen on 510 ex-NFL players from 2004-2006, Dr. Marc A. Miller finds that metabolic syndrome (MS) is more likely in linemen at 59.8% compared to non-linemen (30.1%) and adult males in the United States (24.0%) (Miller et. al, 2007). The International Diabetes Federation criteria used to assess MS includes a BMI>30kg/m^2, reduced high-density lipoprotein and raising fasting glucose. The high levels of MS, and of its three defining components, in linemen compared to non-linemen underscores the increased risk for CVD that linemen experience (Miller et. al, 2007). Like others, this study, *Prevalence of Metabolic Syndrome in Retired National Football League Players*, relies on the 1994 NIOSH mortality study by finding other explanations for the higher cardiovascular mortality experienced by NFL linemen, aside from higher BMIs. The NIOSH study did not account for variables such as dyslipidemia, insulin resistance and hypertension, which are CVD indicators and individual components of MS (Miller et. al, 2007). In proving the disparate prevalence of MS (and dyslipidemia, insulin resistance and hypertension) in linemen, Miller identifies other risk factors that contribute to cardiovascular mortality in linemen, aside from greater BMIs (Miller et. al, 2007).

Dr. Andrew M. Tucker corroborates these results nearly identically, comparing 504 retired NFL players with data from the Coronary Artery Risk Development in Young Adults (CARDIA) survey; the CARDIA study observed 1,959 United States young adults from 1985-1986. Like Miller's MS study, Tucker et. al finds lower impaired fasting glucose and smoking levels and higher dyslipidemia and hypertension rates among the NFL cohort (Tucker et. al, 2009). These evolutions of NFL linemen help to explain the higher CVD mortality rates.

Professor Kevin Guskiewicz of University of North Carolina's Department of Exercise and Sports Science uses a unique data collection method to measure the long-term health implications of an NFL career. Guskiewicz sent out a general health questionnaire to 2,552 ex-NFL players and followed up with a second, memory-related questionnaire sent to 758 members of the initial cohort (Guskiewicz et. al, 2005). The questionnaire results established a relationship between repeated, NFL-related concussions and mild cognitive impairment (MCI). Specifically, NFL retirees with three or more self-reported concussions had a five times more likely chance of being diagnosed with MCI and a three times more chance of reporting significant memory issues (Guskiewicz et. al, 2005).

Professor Zachary Kerr of University of North Carolina's Department of Epidemiology conducts a similar survey to his colleague, Professor Guskiewicz. Kerr sent out a 2001 general health survey (GHS) to retired NFL athletes and a follow-up GHS nine years later that tested for depression-related symptoms (Kerr et. al, 2012). Out of the 1,044 sample, 106 individuals reported clinical depression diagnosis during the nine year gap. Kerr et. al found that professional football players, who self-reported three or more concussions during their playing days, were three times more likely to self-report depressive episodes during post-career life (Kerr et. al, 2012).

Thus far, the considered literature has established lower overall mortality rates in NFL players than the general United States population, higher cardiovascular mortality rates in linemen and higher neurodegenerative mortality rates in speed positions compared to the general NFL population. However, there are several omitted variables that specific studies identify. Tucker shows that NFL players smoke less than the general United States population, according to the CARDIA survey (Tucker et. al, 2009). Such habits potentially indicate why the Lehman et. al study found that NFL player cancer mortality rates are 42% less than the general United States population (Lehman et. al, 2012). In *A Physiological Review of American Football,* Professors Danny Pincivero and Tudor Bompa recognize additional differences between NFL players and the general United States population that skew these results. NFL players' extreme fitness regimes and workout routines likely contribute to their lower than expected mortality rate (Pincivero and Bompa, 1997). Professor Mikael Fogelholm, of the University of Helsinki, Finland, further highlights the impact of these omitted variables. In his systematic review, *Physical Activity, Fitness and Fatness*, Fogelholm accentuates that individuals with high BMI and high aerobic exercise levels (NFL athletes) are at a lower risk for cardiovascular mortality compared to individuals with normal to low BMI levels and normal to low aerobic activity (the general United States population) (Fogelholm, 2009).

Tyler Williams of the Massachusetts Institute of Technology (MIT) solved for these aforementioned omitted variable biases in his thesis, *Long-Term Mortality Effects of an NFL Career (2014).* Williams employs mortality data from 1937-1975 to compare an NFL cohort with three or more years of NFL experience with an NFL cohort with three or less years of NFL experience. In juxtaposing NFL players with long (3+ years) versus short (3- years) careers, Williams attempts to correct for the differences in income levels (access to quality healthcare), smoking habits, genetic advantages and physical fitness levels between NFL athletes and the general United States population (Williams, 2014). His study, however, introduces other biases such as career-shortening injuries, skill level differences, player motivation and attitude discrepancies and team success (Williams, 2014). His results suggest that players who play longer than three years in the NFL have a 40% higher mortality than players who player less than three years. For positions with high injury risk, such as wide receiver, tight end, and defensive end, the hazard ratio is nearly 2 times, indicating that players in high risk positions have twice as high a mortality rate compared to players with less exposure to heavy hits (Williams, 2014).

NFL players only vaguely understand the empirical consequences that their football careers have on their health. In *Football Career is Taking its Toll on NFL's Players,* 66% of the 440 ex-NFL athletes claimed that their careers would shorten their lifespans, citing excessive weight gain from steroid use, traumatic physical injury and severe mental stress (Wojciechowski and Dufresne, 1988). From 1960-1988, 78 pension-credited (4+ seasons) NFL players died at an average age of 38.2 (Wojciechowski and Dufresne, 1988; Pro Football Reference). 55% of the athletes surveyed admitted that they would play in the NFL again, even if it meant sacrificing ten to twenty years of their life (Wojciechowski and Dufresne, 1988).

III. Data

This paper uses individual player data from NFL Pro Football Reference. This site is a highly detailed statistical source that covers all professional sports, not just the NFL. My sample includes 5,524 players, dating back to 1945. I cross-referenced this data with the Oldest Living Pro-Football Online Encyclopedia to ensure its accuracy on key variables (games played, years played, age of death). I gathered additional information, such height and weight, from NFL.com's player profiles (NFL Players, 2016). These height and weight (BMI) measures are consistently taken early on in a players' career.

I also collected salary-level data from Rodney Fort's Sports Economics website.[2] This salary data includes salary figures for every player until 1985. Prior to 1985, the data is neither accurate nor complete. Thus, one of my data samples includes 82 players (those who played in 1985 and onward); for these players, we have the average base salary variable to control for, whereas the larger sample of 5,524 does not have the salary variable.

Next, I collected race and cause of death data manually for 960 of the 5,524 players. I looked up obituaries, death records and university news articles for cause of death data and searched for individuals' race through family lineages, team photos, football playing cards, biographies and player background summaries. I numerically inputted these categorical variables into the dataset. Due to time constraints and data availability, I started collecting from the most recently deceased players and worked my way backward as best I could. Not only was the process too time-consuming to attain the information on 5,524 players given the hard submission deadline, but the race and cause of death data gets more difficult to find the farther

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[2] Rodney Fort's Sports Economics database is available at https://sites.google.com/site/rodswebpages/codes

back one goes in time. Circa 1965, it becomes impossible to find these variables for the average player.

Of the 960 players I searched for manually, I could only find cause of death information for about 503, or half, of the players. The cause of death information for the other half was likely omitted from online sources because their families did not wish to disclose their son's cause of death.

IV. Empirical Methodology

For reference, the summary statistics of this study are presented in Tables 1, 2, and 3. These statistics breakout the number of observations per regression as well as the average distribution of each categorical and binary variable. Table 2, for instance, shows that 4.06% of all observations were linebackers and that 74.93% of all observations were Caucasian.

$$\text{Health} = \beta_1(\textit{years played}) + \beta_2(\textit{games played}) + \beta_3(\textit{position}) + \beta_4(\textit{race}) + \beta_5(\textit{BMI}) + \beta_6(\textit{16 game season}) + \beta_7(\textit{post-merger}) + \beta_8(\textit{NOCSAE standards}) + \beta_9(\textit{helmet pads switch}) + \beta_{10}(\textit{touchbacks}) + \beta_{11}(\textit{average base salary})$$

As seen in the equation above, health is the outcome variable, measuring *age of death* and *cause of death*. In the ensuing results and analysis section, several regressions are run off of this model with these outcome variables.

In all of the figures and tables (shown at the end of the paper), the baseline position variable is the linebacker (LB) position. The running back (RB) position encompasses any type of running back, such as a full back, halfback, wingback, etc. The quarterback position includes only quarterbacks. The wide receiver (WR) position is any type of receiver, including tight ends. The defensive back position includes cornerbacks and safeties. The lineman (offensive or defensive) position includes guards, tackles, centers, and ends. The placekicker position includes any special teams kickers or punters.

The baseline race variable is Caucasian. The second race is African-American. The third race is American Indian/Alaska Native. The fourth race is Asian. The fifth race is Native Hawaiian/Pacific Islander. The sixth race is Hispanic Latino.

There are several controls in these regressions based on the time period in which players performed. 16 game season controls for if a player played in a 16 game season as opposed to 14 game seasons. This extension of the regular season took place in 1990. Post-merger controls for if a player played after the NFL and AFL merged in 1970 (NFL History by Decade, 2016). NOCSAE standards controls for if a player played after NFL helmets were certified to NOCSAE (National Operating Committee on Standards for Athletic Equipment) standards in 1980. Helmet pad switch controls for if a player played after the NFL switched from suspension-lined to padded helmet interiors. This change occurred in 1997. Touchbacks controls for if a player played after the 2011 rule change that moved the restraining line from 30 to 35 yards, generating a significant increase in touchbacks (or fewer kick return attempts) and less hard hits on kick returners (NFL History by Decade, 2016).

In the cause of death and multinomial logit regressions, the dependent variable is an indicator for each cause of death outcome, either cardiovascular, cancer, neurodegenerative, internal, accident, drugs, suicide, or external. Cardiovascular signifies cardiovascular death, such as a stroke, heart attack, acute asthma attack or pulmonary disease. Cancer signifies any type of cancer-related death, including myeloma, myelofibrosis, lymphoma or peritoneal mesothelioma. Neurodegenerative signifies a neurodegenerative cause of death such as ALS, Parkinson's, Chronic Traumatic Encephalopathy (CTE), dementia, Alzheimer's, amyotrophic lateral sclerosis, or a brain aneurysm. Internal signifies some other type of internal disease that lead to the player's death. Examples include a staph infection, pneumonia, liver disease, kidney failure, gastrointestinal bleeding, diabetes, HIV, pancreatitis and bone marrow malignancy. Accident signifies a transportation-related death, such as a car or motorcycle crash or boating incident. Drugs signifies a death caused by a drug or alcohol overdose. Suicide signifies a suicide. External signifies an outside factor that lead to the player's death. Examples include surgical complications, carbon monoxide poisoning, gun wounds, a traumatic fall, drowning, weight lifting accidents, house fires and horse riding incidents. These cause of death criteria are based on the CDC's Wide-ranging Online Data for Epidemiologic Research (WONDER) system classifications (CDC WONDER, 2016).

The first linear regression considers *age of death* without the *average base salary* variable on the right-hand side of the equation. By excluding the salary measure, the regression uses 960 observations.

The second linear regression again considers *age of death*, but includes the *average base salary* variable. As such, it looks at 82 observations. The salary data was very limiting to this study.

The third linear regression considers *age of death* again, but without the salary measure and without the race variable. This increases the number of observations to 5,524. There is such a large increase in observations because race data was not compiled for 4,564 (5,524-960) players due to time constraints.

The latter half of the linear results section is run with the *cause of death* outcome. Each of the regressions looks at a specific cause of death – either cardiovascular, cancer, degenerative, other internal, transport accident, drugs and alcohol, suicide, or other external. Each linear regression examines 503 observations. This size of observations is again due to time constraint issues as well as the lack of cause of death information available online. Furthermore, each of these cause of death regressions excludes the *average base salary* variable because, with it included, the sample size is too small to estimate.

Additional analyses use a multinomial logit function, examining the relative risks ratios and predictive probabilities of each cause of death outcome and the average marginal effects associated with each linear and binary variable. For example, if one plays an additional season in the NFL, by how much does the probability of dying from neurodegenerative disease increase or decrease? If one's BMI increases by one unit, by how much is that player more or less likely to develop and die from cardiovascular disease relative to other causes of death?

i. Limitations

- Serious injury may shorten players' careers. Career-ending injuries likely increase mortality rates, biasing the estimates of years played on mortality rates downwards.
- The longer a player stays in the league, the more susceptible they are to risk. They are given significantly more attention by the training staff and even protected through the coaches' actions. Coaches in all professional sports will rest their aging players whenever they are given the chance. Resting players would be negatively associated with mortality rates, biasing estimates upwards.

- The NFL has become a more competitive landscape over time. It is much harder to stay relevant in the league for the same length of time. Compared to teams in the 1970s, the body mass of offensive and defensive linemen has increased substantially as well as the speed of the average NFL player (Kraemer et. al, 2005; Allen et. al, 2015). Players are also trained harder and coached in all aspects of life to improve performance (Evolution of the NFL Player, 2016). With bigger and faster players, injuries are likely to occur more often. This increased propensity for injury is positively correlated with mortality rates, biasing estimates downwards.
- In the WSJ article *The Shrinking Shelf Life of NFL Players,* Rob Arthur finds that players' careers are substantially shorter than they have been in the past, especially at the quarterback position (Arthur, 2016). By retiring earlier, NFL players lessen their exposure to traumatic brain injury. Thus, early retirement is negatively correlated with mortality rates, biasing estimates upwards.
- Many veterans speak about the "learning curve" of the NFL. The longer one plays in the league, the more adaptive and effective the player becomes in his role. The player experientially acclimates to avoid injury-prone activities and impulses. This "learning curve" phenomenon would be negatively correlated to mortality rates, biasing estimates upwards.
- Upon entering into the NFL, individuals gain a myriad of employment opportunities such as coaching, scouting, community service and, most notably, broadcasting and TV sports coverage. For instance, Tiki Barber, a standout running back for the New York Giants for ten seasons, retired during the prime of his career to join NBC's *The Today Show* and

Sunday Night Football coverage (O'Connor, 2012). These safer alternatives are likely to decrease player mortality rates, biasing estimates upwards.

- NFL players have improved access to healthcare during their careers because their health is directly correlated to their performance. Thus, NFL teams provide the best possible care for the players during their playing years. This provision of elite healthcare would be negatively correlated with mortality rates, biasing estimates upwards.
- Although there are several time-specific control variables used in this paper, it is impossible to entirely control for the changing and dynamic nature of the NFL, especially in terms of player position. Certain positions have grown and taken on different roles. A modern tight end has different expectations and functions than a tight end of the 1980s. Some contemporary positions didn't even exist in the past. As such, categorizing players by position creates inherent imprecision.
- One last potential limitation of this study is the accuracy of the BMI measures. The height and weight figures reported by the NFL when a player enters the league (and used in this study) are subject to change; players have been known to significantly fluctuate weights throughout a career. These changing body mass figures highlight a potential source of inaccuracy in the BMI data.[3]

[3] It should also be noted that BMI is not always an accurate indicator of an athlete's health. A higher BMI does not always signify worse relative health.

V. Results & Discussion

i. Linear Age of Death Regressions

Table 4 displays the main linear regression on death age of NFL players. There are several statistically significant results in this table. Compared to linebackers (the baseline position), running backs live roughly 3.39 years longer. Wide receivers and tight ends live roughly 4.71 years less. Defensive backs live roughly 2.57 years less. Linemen live roughly 4.60 years longer. Compared to Caucasians (the baseline race), African-American NFL players live roughly 2.64 years less. This result is consistent with the finding that the average U.S. African-American dies five years earlier than the average U.S. Caucasian, according to researcher Tim Green of the University of Texas at Austin (Green, 2011). Such a similar result substantiates the accuracy of the data.

In Table 4, all of the controls are statistically significant at the 1% level. All the time controls, except touchbacks¸ have a p-value of 0.00. For every point increase in BMI, the data suggests that you will die roughly one year earlier. Intuitively, the larger and more overweight an individual becomes, the more likely they are going to die earlier from a disease or complication.

If a player played after the 16 game season rule took effect in 1990, they died, on average, 9.09 years earlier. This finding supports the hypothesis that tacking on two regular season games to the average season has a negative effect on one's life expectancy. Not only do the extra games take a toll on one's health, but each additional game added on to the end of the season makes a player more susceptible to injury and probably has a greater impact on one's long-term health. Players are fresh during their first game of the season and much more worn-out and vulnerable by the 14th game of the season.

The NFL is currently considering extending the regular season to 18 games, claiming that it's worth $3 billion to $4 billion per year in extra revenue – or another $46 million to $62 million per year in cap space per team" (Florio, 2015). According to this paper's data on the 16 game season variable, this league change should certainly not pass. This modern, 18 game season debate critiques the NFL's morality. Extending the season to 18 games would boost league profits, but at the cost of the players' health. This extension might have an even greater effect on player health than the extension from a 14 game season to a 16 game season. The 17th and 18th game of the season would be the most strenuous and injury-ridden as players are the most fatigued and spent by that point in the season.

If a player played after the NFL and AFL merged in 1970, they died on average 14.06 years earlier. If a player played after NFL helmets were certified to NOCSAE standards, they died on average 8.66 years earlier. If a player played after the NFL improved helmet safety, switching from suspension-lined to padded helmets, they died on average 6.74 years earlier. If a player played after the NFL established the touchback rule in 2011, they died on average 7.19 years earlier. Although these rule changes all suggest that players died earlier after their implementation, the respective magnitudes of their coefficients is important to examine. Figure 1 orders the size of the coefficients according to when these changes took place.

As depicted in Figure 1, players died roughly 14 years earlier if they played during the post-merger period. This justifies the hypothesis that, as American football became more popular in the 1970s and as players grew in size and strength, they were subjected to harder hits and a higher likelihood of long-term injury (Kraemer et. al, 2005). However, as you continue across Figure 1, you begin to see the coefficients on these controls trend downward. Such a trend suggests that improvements in league safety are catching up and having a positive effect on life expectancy. It would be important to analyze this bar chart in the future to see whether this trend continues or if this phenomena is coincidence. The time span of this dataset would need to be longer to demonstrate a convincing relationship between safety improvements and player health. Some players who played after these rule changes may not have died yet, especially from neurodegenerative disease (Alzheimer's disease is associated with older age).

Moreover, 16 game season has a larger coefficient (9.09) than the other rule changes, which is exactly what one would expect. All of the other controls lead to increased safety within the league (i.e. NOCSAE certification, padded helmets and more touchbacks); one would expect these pro-safety changes to increase one's lifespan. 16 game season is the only anti-safety variable; one would expect to see an earlier death age with more games being played per season. Some may refute this finding on the claim that two less pre-season games are played now that the season length has been extended to 16 games. However, these pre-season games are not comparable to regular season games. Pre-season games are much less intense and coaches and players are much more cautious about player exposure and exertion.

Table 5 displays the linear regression on death age of NFL players, adding in the average base salary variable. Post-merger and NOCSAE standards were omitted due to collinearity. This regression only includes 82 observations because of limited salary data.

Table 5 indicates that running backs live 4.18 years longer than the baseline case – linebackers. This is roughly the same size result as Table 4 where the running back coefficient is 3.39. This finding that running backs live longer than linebackers supports the argument that NFL career length is related to early mortality as running backs typically have the shortest career out of any position (Ninomiya, 2015). It makes sense that the dataset shows them living longer than linebackers. Moreover, linebackers are exposed to harder hits as well as a high quantity of hits per game; it is the linebacker's duty to generate tackles while running backs are forced to avoid heavy hits and contact. Running backs also have a restricted amount of space to build up speed before they hit the line of scrimmage, whereas linebackers have unlimited space to roam and no restrictions on gaining momentum before impact.

This mortality data signifies that there should be a rule restricting the space a linebacker has to build up speed before each play. They should be confined like a running back. Potentially, it should be enforced that each linebacker substitutes out for a certain amount of plays per game. These regulations would limit force per hit as well as the amount of hits that individual linebackers experience per game.

Reinforcing Table 5 and these proposed rules, Table 4 shows that linemen live roughly 4.60 years longer than linebackers. Linemen even live, on average, one year longer than running backs, despite their massive size. This result supports the belief that positions which gain more momentum before impact are more severely affected by long-term health issues and die earlier. Linemen do experience a high volume of physical contact per game, but the least amount of momentum per hit. Linemen have about one foot of space to build up steam before impact on again given play. This demonstrates that the force per hit may have a greater detrimental effect on your long-term health compared to the quantity of hits.

Table 5 illustrates that African-Americans die 2.34 years earlier than Caucasians, a similar result to Table 4 where the African-American coefficient is 2.64. Native Hawaiian/Pacific Islanders die on average 5.03 years earlier than Caucasians as well. This result corroborates the dataset as it is empirically true that Caucasians outlive Hawaiians and Pacific Islanders by an average of 6.2 years (Blair, 2013).

All of the other control variables are significant and their coefficients align with those in Table 4. However, a one unit increase in BMI suggests that one will live 0.37 years longer – the opposite direction as Table 4 which predicted that an increase in BMI would lead to an earlier age of death. The only difference between Table 4 and Table 5 is the inclusion of the salary measure. Thus, one can deduce that salary has a positive effect on life expectancy. Such a result is in line with CDC statistics and makes logical sense (Woolf, 2015).

Table 6 employs the largest number of observations because it excludes the race variable. Table 6 further substantiates the results of Table 4 and 5. Again, running backs live roughly 2.63 years longer than linebackers. We find that quarterbacks live roughly 2.54 years longer than linebackers as well; unlike Tables 4 and 5, this result is significant at the 5% level. This outcome helps to affirm the theory that quarterbacks live longer than linebackers because they are protected on each play and exposed to less hits. In addition, as we will see in Table 7, quarterbacks are also less susceptible to certain types of injuries and die later from specific causes of death, like neurodegenerative disease. Also, quarterbacks tend to make significantly more money per year compared with any other position. This fact alone would make them live longer because of the increased healthcare quality and overall lifestyle associated with higher levels of income.

The BMI coefficient in Table 6 aligns with that of Table 4, solidifying that a one unit increase in BMI takes off approximately one year of life.

From Table 6, the control variables point in the same directions and with similar magnitudes to Figure 1, supporting the trend that these rule changes and protocols have been creating a safer sport since the 1970 merger. Post-merger has the largest negative coefficient (-13.92), reaffirming the hypothesis that American football became much more dangerous after the merger – when the sport became more popular and players' size and strength began to increase substantially. Without the race variable and with a much more robust set of observations, Table 6 reinforces the findings of the principal linear regression.

ii. Linear Cause of Death Regressions

In Tables 7 and 8, there are 503 observations compared to the 960 observations of Table 4. This discrepancy is due to the fact that cause of death information is limited on a player-to-player basis. It was substantially easier to find the race of an individual player compared to cause of death. This is because most families do not wish to disclose their son's cause of death in an obituary or online, especially if the cause was abnormal.

Table 7 regresses the same variables as in Table 4, but on a different outcome – cause of death. Compared to Caucasians, Hispanics/Latinos have a 71% higher probability of dying from cardiovascular disease relative to all other causes of death. However, tabulating the race variable, there are only three Hispanics/Latinos in the dataset. Two of these Hispanics/Latinos die of cardiovascular disease while the third Hispanic/Latino has a missing cause of death variable.

Table 7 also highlights that receivers, compared to linebackers, have a 19% higher probability of dying from cancer relative to all other causes of death.

The third column, neurodegenerative cause of death, is of principal interest given the current controversy surrounding the relationship between American football and CTE-linked deaths. Table 7 shows that one additional year played leads to a *4.83% increase* in the probability of dying from the neurodegenerative cause of death. This is a very important result and can also be found in Table 13 – the average marginal effects of an additional year played.

Table 7 also shows that, compared to linebackers, quarterbacks are 19% less likely to die from neurodegenerative disease relative to all other cause of death outcomes. This information builds off of the data gathered in Table 6, which states that quarterbacks outlive linebackers by 2.54 years on average. Thus, Tables 6 and 7 establish that quarterbacks not only live longer than linebackers overall, but they also are less likely to develop and die from neurodegenerative causes. Linebackers generate more hits per game and also tackle players who are running at full speed towards them. The impact of their tackles is much greater in comparison to the impact a quarterback experiences when tackled. Quarterbacks are only sacked, on average, two times per game and typically fall down on their own accord before taking a hit by a defensive player (NFL Football Stats, 2015). Nonetheless, in addition to the rules restricting a linebacker's space and their amount of plays per game, a rule that shields the quarterback from sacks is warranted. Perhaps, a "wrap-up" rule, which signifies that the quarterback is "down" when he is wrapped up by an opposing player, should be implemented. This type of rule change, like the other two put forth in this paper, seems to take away from the traditional nature of the NFL and would likely be opposed by the majority of football fans. However, these kinds of changes need to be installed given the detrimental health issues correlated with years of hard, NFL contact.

As mentioned earlier in the discussion of Table 6, quarterbacks earn a higher income than any other position, including linebackers. Unlike some of the other causes of death, neurodegenerative diseases are not preventable or curable with higher levels of wealth. This means that, holding income constant across all positions, theoretically quarterbacks should die earlier from neurodegenerative disease. Thus, the aforementioned *19% probability* could even be an understatement. With more income, quarterbacks have access to better healthcare which can help with preventing cardiovascular and internal diseases. Neurodegenerative diseases stemming specifically from football are a more newly studied phenomena and would not be *as* preventable or curable from higher incomes. Accidents and other external causes of death would more likely be avoided by higher income levels compared to these neurodegenerative causes of death.

In Table 8, touchbacks has an approximately 0.27 coefficient for both accident and suicide causes of death and is significant at the 1% level. This 0.27 signifies that after the touchbacks rule was implemented, players were 27% more likely to die from suicides and car accidents relative to all other causes of death. The touchbacks rule was instituted in 2011 so very few players have played and died after its implementation. Confirming this with the summary statistics of Table 3, we find that only 1% of all players in the data have played after the touchbacks rule. It makes sense that the players who played after the touchbacks rule, either died from an accident or a suicide as these two cause of death outcomes can result in younger individuals. Players would be much less likely to die from neurodegenerative causes of death which are associated with old age and very infrequently seen in 30 year old men.

Table 8 also demonstrates, at a marginally significant level, that defensive backs, compared to linebackers, have an 8.32% lower probability of dying from external causes relative to all other cause of death outcomes.

iii. Multinomial Logit Function

Tables 9 and 10 illustrate the multinomial logit cause of death regressions with cardiovascular cause of death as the base outcome. A multinomial logit function is employed here to determine the probabilities of the different, categorically distributed cause of death outcomes. Table 9 represents the first four causes of death (cardiovascular, cancer, neurodegenerative, internal) and Table 10 represents the latter four causes of death (accident, drugs, suicide, external). These figures are then transformed into relative risk ratios in Tables 11 and 12, which give the proportionate change in risk from choosing one alternative over another when the independent variable increases by one unit. As such, Tables 11 and 12 are difficult to interpret for categorical variables, like position and race. For example, if a Caucasian player's race were to increase by one unit, that would mean the player suddenly became African-American. One potential significant result to report is in the fourth column of Table 12. It shows that, by playing in the post-merger period compared to the pre-merger period, the relative odds of dying from an external accident than cardiovascular disease (base case) are 3.57 times what they were before the change. Simply put, this result means that the relative odds have increased. As player's health and fitness increased and as the sport became more popular post-merger, players died less frequently from cardiovascular problems and more from external factors. The following predictive probabilities and average marginal effects derived from this multinomial model are more informative and valuable.

As seen in Table 13, which summarizes the probabilities of each cause of death outcome in the dataset, the proportion of players that died from the first outcome, cardiovascular disease, is roughly 28%. The probability of the second outcome, dying from cancer, is roughly 25%. The probability of the third outcome, dying from neurodegenerative causes, is roughly 20%. The probability of the fourth outcome, dying from internal causes, is roughly 17%. The probability of the fifth outcome, dying from driving accidents, is roughly 3%. The probability of the sixth outcome, dying from drugs and alcohol, is roughly 1%. The probability of the seventh outcome, committing suicide, is roughly 1%. The probability of the eighth outcome, dying from external causes, is roughly 5%. All of these probabilities are also listed in Table 2, which breaks out cause of death data in percentages.

From Table 13, the probability of dying from neurodegenerative disease, 20%, does not match the CDC FactSet estimate percentages (Health, U.S., 2014). As of 2013, the percentage of males dying from Alzheimer's disease and related neurodegenerative conditions was only 2%. This 18% difference between CDC estimates and this dataset's cause of death percentages supports the hypothesis that football is correlated to one's long-term brain health. All other causes of death are in line with the same CDC estimates. The CDC reported 22% of the causes of death in 2013 as diseases of the heart, which is similar to the 28% demonstrated by this paper's data. The CDC also reported 2% of the causes of death in 2013 as suicides, which is similar to the 1% demonstrated by this paper's data (Health, U.S., 2014).

The final two tables, Tables 14 and 15, demonstrate the average marginal effects of binary (i.e. 16 game season) and linear (i.e. Years played) variables. Tables 14 and 15 do not include position and race variables because they take on categorical values. As previous mentioned, a one unit increase in position or race would signify that a player changed position or became a different race. In terms of analysis, these marginal effects are more useful and direct than Table 13's probabilities, which simply provided a summary of the probabilities of each cause of death outcome. The signs of coefficients in Tables 14 and 15 state whether the variable increased (+) or decreased (-) the probability of dying from a specific cause of death relative to all other causes of death. There is no base case cause of death with average marginal effects.

Examining the results presented in Table 14, one finds several informative results. The first column shows that a one unit increase in BMI results in a 2% increase in dying from a cardiovascular cause of death compared to other causes of death. This finding seems correct because the heavier the individual, the more likely they are to suffer from a heart attack or stroke.

Of most interest, in the third column (neurodegenerative), an additional year played in the NFL leads to a *4.84% increase* in the probability of dying from a neurodegenerative disease relative to all other causes of death. This result confirms the main hypothesis of this paper – that football careers are related to the development of long-term brain damage. Magnifying this result, if a player played more than one year, the increase in their probability of dying from a neurodegenerative cause would be greater than 4.84%. According to the NFLPA (National Football League Players Association), the average career length is 3.3 years (Statista, 2016). As such, this increase in the likelihood of dying from neurodegenerative disease may be exponential. The longer one extends their playing career, the more susceptible one is to CTE of an increasing severity. This 4.84% probability increase is also shown and discussed in the previous analysis of Table 7.

Again looking at the third column of Table 13, an additional game played in the NFL leads to 0.2% decrease in the probability of dying from a neurodegenerative disease relative to all other cause of death outcomes. This coefficient of games played is extremely small. It should be the case that only *one more* game played in the NFL has a very small impact on one's cause of death outcome. When one starts adding on additional *years* to a player's career, then the cause of death outcome should be affected, which is what Table 14 finds.

Turning to the fourth column in Table 15, one finds that an additional year played in the NFL leads to a 2.2% increase in dying from an external cause of death compared to all other causes of death. This result is only marginally significant at the 10% level. This coefficient's direction seems intuitive. Players that play longer in the NFL and thus expose themselves to greater brain damage are more likely to die from lapses in judgment and not taking proper precaution, such as a traumatic fall or drowning.

VI. Conclusion

This study expands upon existing literature concerned with contact in the NFL. This study helps to quantify how a career in the NFL can detrimentally affect a player's brain and overall health by position and race. The paper discusses the NFL's growing consciousness towards CTE-linked health issues and the NFL's success, thus far, at implementing rule changes to prevent them. Overall, the data and results substantiate several significant trends briefly highlighted below:

- First, league rule changes have been effective in that they extend NFL players' lifetimes
- Second, the change from a 14 to 16 game season lowered the age at which the average NFL player died, suggesting that the NFL should return to a shorter season.
- Third, running backs die later than linebackers which testifies to the hypothesis that the shorter the career, the longer you live; running backs have shortest careers, are exposed to less heavy hits compared to linebackers and build up less speed prior to hitting the line of scrimmage.

- Fourth, linemen die later, on average, than any other position, supporting the hypothesis that positions which build up more momentum prior to tackles suffer more from long-term health complications. Although linemen may experience the most contact on a play-to-play basis, the force per hit they experience is very small; they have less than one foot of space to build momentum.
- Fifth, quarterbacks outlive linebackers *and* specifically die later from neurodegenerative diseases, supporting the fact that harder hits and blows to the head in the NFL are associated with neurodegenerative problems later on.
- Sixth, the average marginal effect of playing an additional season in the NFL increases one's likelihood of dying from neurodegenerative disease by roughly 5% compared to all other causes of death. This finding supports the overarching hypothesis of this paper.

Ultimately, these conclusions demonstrate that a relationship between football and brain damage exists and should be addressed. The league should continue to develop new rules, specifically those which can find a way to limit the force per hit experienced by positions such as the linebacker. For instance, the NFL should institute a rule restricting the amount of space a linebacker has to build up speed prior to each play. Linebackers should also be substituted out for a mandatory amount of plays per game as they most commonly experience and generate concussive impact. The NFL should further implement a "wrap-up" rule for sacking a quarterback. This "wrap-up" rule would effectively eliminate traumatic hits to the quarterback's head.

Overall, this dataset and the associated health effects only scrutinize NFL player samples. As mentioned previously in a study conducted by the BU Center for the Study of Traumatic Encephalopathy, CTE can develop from merely playing high school football and participating at collegiate levels (Fainaru, 2016; Toporek, 2012). This fact alone urges the institution of new safety rulings at all levels and expanded research efforts altogether.

In a recent, high-profile Wall Street Journal article, *Rethinking the Next-Generation Helmet,* Matt Futterman summarizes some of the cutting-edge helmet technologies in the research and development (R&D) pipeline (Futterman, 2015). These contemporary helmet models include coil sports safe technology, isolation dampers, multi-layer designs and collar and blood flow clamps (Futterman, 2015). This paper's data and conclusions support spending on these types of R&D efforts that look to improve football helmets across all playing levels. Not only does this thesis advocate such helmet improvements, like the 1997 switch to helmet pads from suspension-liner, but it also encourages the NFL to continue devising new regulations (i.e. the touchback rule) to prevent the quantity and especially the impact of tackles.

As the average marginal effects in Table 14 show, each additional year played in the NFL increases one's susceptibility to brain damage. This outcome regarding neurodegenerative disease urges CTE research to expand to other sports, such as soccer, boxing and hockey. ESPN analysts and Boston University neuropathologist, Dr. Ann McKee, recommend spreading out research funding to every type of activity involving recurring impact to the head (Fainaru, 2016).

Finally, on a moral note, researchers cannot rely on the NFL and other professional sports administrations to accurately report and diagnose concussions (Schwarz, 2016). The New York Times recently acquired concussion data from 1996-2001 that was purposefully omitted to make concussions "appear less frequent than they actually were" (Schwarz, 2016). These omitted concussion diagnoses constituted over 10% of the total amount reported (Schwarz, 2016). This news questions the morality of the NFL; did the league understand the neurological consequences of its sport and deliberately sweep data under the rug? The negative publicity of this data would surely have cut into the profits of NFL operations. Perhaps there is an even larger issue here aside from CTE – the NFL's integrity.

VII. References

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Figure 1: Coefficients on Control Variables

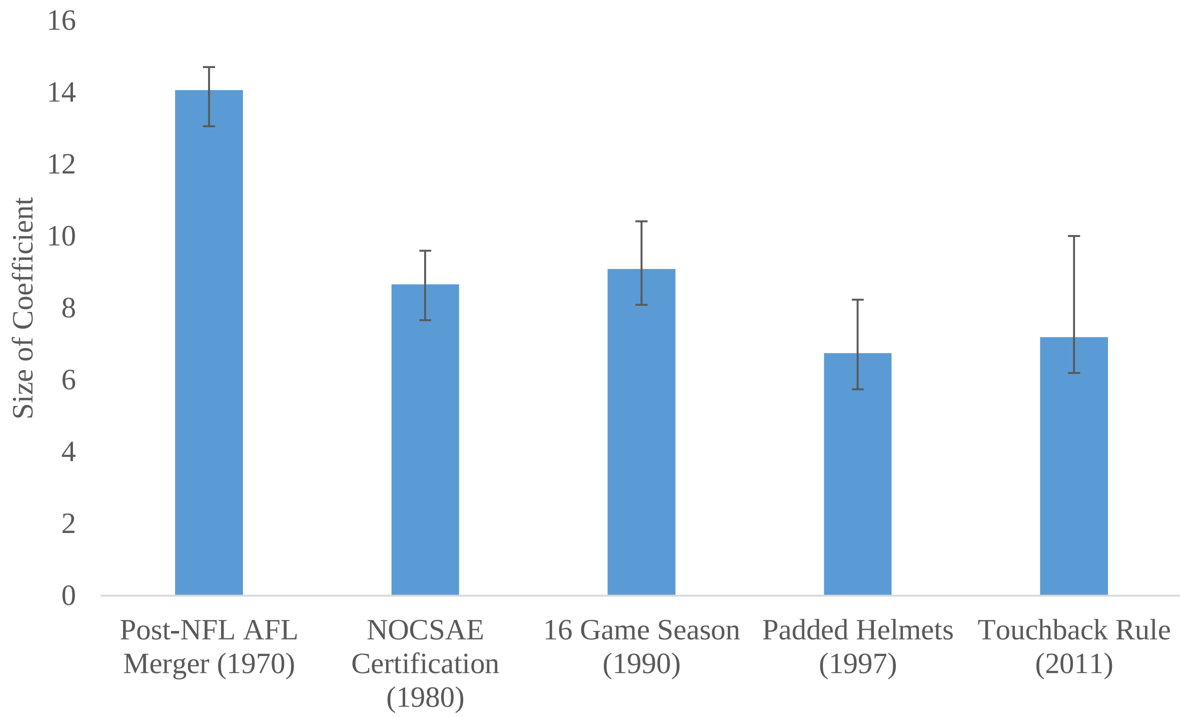

Table 1
Number of Observations per Regression

	# of Observations (n)
Linear Age of Death Regression excluding Salary	960
Linear Age of Death Regression including Salary	82
Linear Age of Death Regression excluding Salary and Race	5,524
Linear Cause of Death Regressions	503
Multinomial Logit Regression	503

Table 2
Data Summary of Categorical Variables

Position	% of Total
Linebacker	4.06
Running Back	30.64
Quarterback	2.9
Wide Receiver	2.07
Defensive Back	5.05
Lineman	54.66
Kicker	0.62
Race	% of Total
Caucasian	74.93
African-American	24.01
American Indian/Native American	0.1
Asian	0.1
Native Hawaiian/Pacific Islander	0.58
Hispanic	0.29
Cause of Death	% of Total
Cardiovascular	28.43
Cancer	23.4
Neurodegenerative	19.92
Internal	15.67
Accident	4.64
Drugs	1.35
Suicide	0.97
External	5.61

Table 3
Data Summary of Binary Variables

	Pre-	Post-
Post-merger (1970)	Pre-	Post-
% of Total	88.47	11.53
NOCSAE Certification (1980)	Pre-	Post-
% of Total	94.19	5.81
16 Game Season (1990)	Pre-	Post-
% of Total	97.5	2.5
Helmet Pads (1997)	Pre-	Post-
% of Total	98.72	1.28
Touchbacks (2011)	Pre-	Post-
% of Total	99.9	0.1

Table 4

Linear Age of Death Regression Excluding Salary

	(1)
VARIABLES	death_age
Years played	0.4198
	(0.3030)
Games played	-0.0030
	(0.0231)
Running back	3.3915***
	(0.8469)
Quarterback	0.3228
	(1.1236)
Receiver	-4.7114***
	(1.1297)
Defensive back	-2.5738***
	(0.9664)
Lineman	4.6048***
	(0.7549)
Placekicker	-4.1240**
	(1.6491)
African-American	-2.6411***
	(0.5739)
American Indian/Alaska Native	-0.9708
	(6.4959)
Asian	4.8566
	(6.3143)
Native Hawaiian/Pac. Islander	-1.6681
	(2.6311)
Hispanic Latino	-2.6912
	(3.7054)
BMI	-1.0639***
	(0.0980)
16 game season	-9.0988***
	(1.3196)
Post-merger	-14.0699***
	(0.6431)
NOCSAE standards	-8.6634***
	(0.9362)
Helmet pads switch	-6.7476***
	(1.4876)
Touchback rule	-7.1935**
	(2.8108)
Constant	108.2041***
	(2.8524)
Observations	960
R-squared	0.8340

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5

Linear Age of Death Regression Including Salary

VARIABLES	(1) death_age
Years played	1.0579*
	(0.6156)
Games played	0.0063
	(0.0414)
Running back	4.1886**
	(1.8700)
Quarterback	5.3128
	(3.2745)
Receiver	3.4520*
	(2.0094)
Defensive back	3.3087*
	(1.8407)
Lineman	0.5514
	(1.7078)
Placekicker	3.3111
	(2.7279)
African-American	-2.3493**
	(1.0803)
American Indian/Alaska Native	0.5804
	(5.5535)
Asian	-5.0304**
	(2.4667)
BMI	0.3732**
	(0.1755)
Hispanic Latino	-7.1592***
	(1.7404)
Helmet pads switch	-8.4138***
	(1.1290)
Touchback rule	-5.5275**
	(2.2488)
Average base salary	-0.0000**
	(0.0000)
Constant	36.2057***
	(5.4152)
Observations	82
R-squared	0.8322

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6

Linear Age of Death Regression Excluding Salary and Race

	(1)
VARIABLES	death_age
Years played	0.2180
	(0.2396)
Games played	0.0111
	(0.0192)
Running back	2.6385***
	(0.9111)
Quarterback	2.5433*
	(1.2985)
Receiver	-1.5314
	(1.4749)
Defensive back	-1.3561
	(1.1384)
Lineman	4.1418***
	(0.8747)
Placekicker	0.7113
	(2.2425)
BMI	-0.7462***
	(0.0759)
16 game season	-5.6511***
	(1.7416)
Post-merger	-13.9278***
	(0.7982)
NOCSAE standards	-9.7598***
	(1.1708)
Helmet pad switch	-4.3212**
	(2.0906)
Touchback rule	-5.7013
	(5.3134)
Constant	88.9693***
	(2.2814)
Observations	5,524
R-squared	0.2982

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7

Linear Cause of Death Regressions: 1-4

VARIABLES	(1) Cardio	(2) Cancer	(3) Degen	(4) Internal
Years played	-0.0103	-0.0413	0.0483**	-0.0220
	(0.0272)	(0.0257)	(0.0243)	(0.0225)
Games played	0.0007	0.0028	-0.0029	0.0017
	(0.0020)	(0.0019)	(0.0018)	(0.0017)
Running back	0.0435	0.1232*	-0.0866	0.0111
	(0.0784)	(0.0742)	(0.0702)	(0.0648)
Quarterback	0.0458	0.1720*	-0.1924**	0.0388
	(0.1010)	(0.0956)	(0.0904)	(0.0835)
Receiver	-0.1050	0.1966**	-0.0548	0.0547
	(0.1004)	(0.0950)	(0.0899)	(0.0831)
Defensive back	0.0771	0.1108	-0.1054	0.0417
	(0.0872)	(0.0825)	(0.0780)	(0.0721)
Lineman	0.0313	0.0753	-0.0913	-0.0324
	(0.0693)	(0.0656)	(0.0620)	(0.0573)
Placekicker	0.0400	0.1796	-0.0321	-0.0467
	(0.1494)	(0.1413)	(0.1337)	(0.1235)
African-American	0.0849	-0.0169	-0.0426	-0.0604
	(0.0545)	(0.0516)	(0.0488)	(0.0451)
American Indian/Alaska Native	-0.2289	0.0046	0.6868*	-0.1319
	(0.4632)	(0.4383)	(0.4145)	(0.3831)
Native Hawaiian/Pac. Islander	-0.3478*	0.0250	0.2522	0.0038
	(0.2056)	(0.1946)	(0.1840)	(0.1701)
Hispanic Latino	0.7107**	-0.2634	-0.3205	-0.1833
	(0.3255)	(0.3080)	(0.2912)	(0.2692)
BMI	0.0211**	-0.0053	-0.0071	0.0134*
	(0.0092)	(0.0088)	(0.0083)	(0.0077)
16 game season	-0.0747	-0.0591	0.0699	-0.0735
	(0.0971)	(0.0919)	(0.0869)	(0.0803)
Post-merger	-0.0869	0.0851	-0.0195	-0.0758
	(0.0563)	(0.0533)	(0.0504)	(0.0466)
NOCSAE standards	0.0945	-0.0905	-0.0452	0.0683
	(0.0760)	(0.0719)	(0.0680)	(0.0629)
Helmet pad switch	-0.0125	-0.0327	-0.1121	-0.0514
	(0.1077)	(0.1019)	(0.0964)	(0.0891)
Touchback rule	-0.3144	-0.1018	0.0610	-0.0668
	(0.2007)	(0.1899)	(0.1796)	(0.1660)
Constant	-0.3348	0.3443	0.4422*	-0.1604
	(0.2689)	(0.2545)	(0.2406)	(0.2224)
Observations	503	503	503	503
R-squared	0.0631	0.0495	0.0558	0.0250

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8

Linear Cause of Death Regressions: 5-8

VARIABLES	(5) Accident	(6) Drugs	(7) Suicide	(8) External
Years played	-0.0011	0.0085	-0.0058	0.0237*
	(0.0120)	(0.0066)	(0.0056)	(0.0135)
Games played	-0.0003	-0.0007	0.0005	-0.0018*
	(0.0009)	(0.0005)	(0.0004)	(0.0010)
Running back	-0.0423	-0.0131	0.0059	-0.0417
	(0.0346)	(0.0191)	(0.0162)	(0.0391)
Quarterback	-0.0353	0.0020	0.0332	-0.0640
	(0.0446)	(0.0246)	(0.0209)	(0.0503)
Receiver	-0.0171	-0.0189	0.0258	-0.0813
	(0.0444)	(0.0245)	(0.0208)	(0.0500)
Defensive back	-0.0317	-0.0161	0.0068	-0.0832*
	(0.0385)	(0.0212)	(0.0181)	(0.0434)
Lineman	-0.0260	0.0072	0.0165	0.0194
	(0.0306)	(0.0169)	(0.0144)	(0.0345)
Placekicker	-0.0066	-0.0176	-0.0330	-0.0834
	(0.0660)	(0.0364)	(0.0310)	(0.0744)
African-American	0.0083	-0.0096	0.0061	0.0303
	(0.0241)	(0.0133)	(0.0113)	(0.0272)
American Indian/Alaska Native	-0.1496	-0.0509	-0.0611	-0.0690
	(0.2047)	(0.1128)	(0.0960)	(0.2308)
Native Hawaiian/Pac. Islander	0.1211	-0.0296	-0.0122	-0.0126
	(0.0908)	(0.0501)	(0.0426)	(0.1024)
Hispanic Latino	0.0175	0.0083	0.0242	0.0065
	(0.1438)	(0.0792)	(0.0674)	(0.1622)
BMI	-0.0034	-0.0021	-0.0033*	-0.0133***
	(0.0041)	(0.0023)	(0.0019)	(0.0046)
16 game season	0.0558	0.0600**	0.0058	0.0158
	(0.0429)	(0.0237)	(0.0201)	(0.0484)
Post-merger	0.0346	0.0118	0.0083	0.0424
	(0.0249)	(0.0137)	(0.0117)	(0.0281)
NOCSAE standards	-0.0025	-0.0007	-0.0102	-0.0137
	(0.0336)	(0.0185)	(0.0158)	(0.0379)
Helmet pad switch	0.1249***	-0.0092	0.0573**	0.0356
	(0.0476)	(0.0262)	(0.0223)	(0.0537)
Touchback rule	0.2615***	-0.0433	0.2875***	-0.0837
	(0.0887)	(0.0489)	(0.0416)	(0.1000)
Constant	0.1553	0.0614	0.0771	0.4148***
	(0.1188)	(0.0655)	(0.0557)	(0.1340)
Observations	503	503	503	503
R-squared	0.1473	0.0411	0.1682	0.0347

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 9
Multinomial Linear Regression: Cause of Death 1-4

VARIABLES	(2) Cancer	(3) Degen	(4) Internal
Years played	-0.1618	0.2509	-0.1215
	(0.1848)	(0.1831)	(0.2051)
Games played	0.0112	-0.0150	0.0097
	(0.0138)	(0.0138)	(0.0153)
Running back	0.5368	-0.6094	-0.0108
	(0.5596)	(0.5055)	(0.5590)
Quarterback	0.6942	-1.1894*	0.1305
	(0.6931)	(0.7099)	(0.7293)
Receiver	1.5737**	0.3278	1.0013
	(0.7623)	(0.7470)	(0.7962)
Defensive back	0.3347	-0.8485	0.0411
	(0.6141)	(0.5780)	(0.6306)
Lineman	0.3750	-0.5654	-0.3043
	(0.5155)	(0.4362)	(0.4950)
Placekicker	0.8340	-0.2279	-0.3829
	(1.0291)	(1.0271)	(1.3346)
African-American	-0.3677	-0.5369	-0.7076*
	(0.3455)	(0.3756)	(0.3991)
American Indian/Alaska Native[4]	1.1297	16.3962	0.0551
	(6,509.0565)	(4,376.6197)	(7,307.1199)
Native Hawaiian/Pac. Islander[4]	15.4172	16.2656	15.2914
	(1,542.4388)	(1,542.4387)	(1,542.4388)
Hispanic Latino[4]	-16.7315	-17.0918	-16.7192
	(2,989.2043)	(3,282.0282)	(3,711.3248)
BMI	-0.1013	-0.1268*	0.0236
	(0.0635)	(0.0668)	(0.0683)
16 game season	-0.0835	0.6949	-0.2653
	(0.6651)	(0.6720)	(0.7129)
Post-merger	0.6627*	0.2830	-0.1729
	(0.3603)	(0.3801)	(0.4269)
NOCSAE standards	-0.6916	-0.6507	0.1186
	(0.4683)	(0.5420)	(0.5409)
Helmet pad switch	-0.2231	-0.5135	-0.3828
	(0.8292)	(0.8075)	(0.8699)
Constant	2.4238	3.5187*	-0.8360
	(1.8597)	(1.9353)	(2.0010)
Observations	503	503	503

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[4] Standard errors are very large due to small number of observations within these race categories. The Asian category, for instance, was omitted from regressions because there was only one reported observation in the dataset.

Table 10

Multinomial Linear Regression: Cause of Death 5-8

VARIABLES	(5) Accident	(6) Drugs	(7) Suicide	(8) External
Years played	-0.3699	0.2600	-1.7105	0.4439
	(0.3825)	(0.4847)	(1.1294)	(0.2822)
Games played	0.0119	-0.0199	0.1299	-0.0337
	(0.0266)	(0.0342)	(0.0820)	(0.0214)
Running back	-1.2156	-14.3474	-13.8874	-0.8544
	(0.9597)	(1,316.5394)	(899.9058)	(0.8279)
Quarterback	-0.5063	-0.1360	2.6521	-1.3698
	(1.3385)	(1.9668)	(2.2943)	(1.1164)
Receiver	0.2205	-14.3170	0.8356	-1.1457
	(1.1925)	(1,869.1722)	(2.2357)	(1.3334)
Defensive back	-0.7098	-14.9820	-0.6885	-2.0541**
	(0.9363)	(1,510.5374)	(1.7437)	(1.0354)
Lineman	-0.7013	0.7559	0.2557	0.2847
	(0.7779)	(1.3570)	(1.9021)	(0.6946)
Placekicker	0.2589	-15.0193	-18.0387	-15.3628
	(1.5372)	(3,209.9920)	(2,043.7964)	(1,980.3810)
African-American	-0.1762	-0.8260	-0.7286	0.2912
	(0.6531)	(1.1025)	(1.7409)	(0.5807)
American Indian/Alaska Native	0.6426	-2.0626	-3.7998	-0.2059
	(11,757.8772)	(21,810.0319)	(23,811.3844)	(11,158.2341)
Native Hawaiian/Pac. Islander	16.2234	-0.0514	0.7561	1.2273
	(1,542.4390)	(5,632.9411)	(4,625.8796)	(3,705.5543)
Hispanic Latino	-14.4068	-0.7249	15.2327	-14.9265
	(6,071.8778)	(12,657.2340)	(14,786.4676)	(5,481.3488)
BMI	-0.1337	-0.2870	-0.4400	-0.3422***
	(0.1057)	(0.1879)	(0.3082)	(0.1068)
16 game season	1.3944	16.1208	-0.6787	0.5027
	(1.0268)	(1,502.2542)	(2,117.7526)	(1.0258)
Post-merger	1.6530*	1.6995	14.8289	1.2727**
	(0.9188)	(1.5911)	(688.8211)	(0.6297)
NOCSAE standards	-0.4257	-13.9712	-14.4929	-0.6489
	(1.0177)	(1,502.2543)	(1,405.5865)	(0.8016)
Helmet pad switch	1.2432	0.4733	19.0934	0.6736
	(0.8500)	(1.2444)	(1,584.0476)	(1.0643)
Constant	2.0478	3.6711	-5.1619	7.5457**
	(3.0112)	(5.0689)	(688.8698)	(2.9780)
Observations	503	503	503	503

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 11

Relative Risk Ratios per Cause of Death Outcomes 1-4

VARIABLES	(2) Cancer	(3) Degen	(4) Internal
Years played	0.8506	1.2852	0.8856
	(0.1572)	(0.2354)	(0.1816)
Games played	1.0112	0.9851	1.0097
	(0.0139)	(0.0135)	(0.0154)
Running back	1.7105	0.5437	0.9893
	(0.9572)	(0.2749)	(0.5530)
Quarterback	2.0022	0.3044*	1.1394
	(1.3877)	(0.2161)	(0.8310)
Receiver	4.8242**	1.3879	2.7219
	(3.6774)	(1.0367)	(2.1673)
Defensive back	1.3976	0.4281	1.0420
	(0.8582)	(0.2474)	(0.6571)
Lineman	1.4549	0.5682	0.7376
	(0.7501)	(0.2478)	(0.3652)
Placekicker	2.3026	0.7962	0.6819
	(2.3695)	(0.8178)	(0.9101)
African-American	0.6924	0.5846	0.4928*
	(0.2392)	(0.2195)	(0.1967)
American Indian/Alaska Native	3.0947	1.3206e+07	1.0567
	(20,143.6503)	(5.7800e+10)	(7,721.2123)
Native Hawaiian/Pac. Islander	4961644.3812	1.1589e+07	4374745.6886
	(7.6530e+09)	(1.7875e+10)	(6.7478e+09)
Hispanic Latino	0.0000	0.0000	0.0000
	(0.0002)	(0.0001)	(0.0002)
BMI	0.9037	0.8809*	1.0239
	(0.0574)	(0.0588)	(0.0700)
16 game season	0.9199	2.0035	0.7670
	(0.6118)	(1.3464)	(0.5468)
Post-merger	1.9401*	1.3271	0.8412
	(0.6990)	(0.5044)	(0.3591)
NOCSAE standards	0.5008	0.5217	1.1259
	(0.2345)	(0.2827)	(0.6090)
Helmet pad switch	0.8000	0.5984	0.6819
	(0.6634)	(0.4832)	(0.5932)
Constant	11.2882	33.7402*	0.4334
	(20.9932)	(65.2983)	(0.8673)
Observations	503	503	503

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12

Relative Risk Ratios per Cause of Death Outcomes 5-8

VARIABLES	(5) Accident	(6) Drugs	(7) Suicide	(8) External
Years played	0.6908	1.2970	0.1808	1.5587
	(0.2643)	(0.6286)	(0.2042)	(0.4399)
Games played	1.0120	0.9803	1.1387	0.9669
	(0.0269)	(0.0335)	(0.0933)	(0.0207)
Running back	0.2965	0.0000	0.0000	0.4255
	(0.2846)	(0.0008)	(0.0008)	(0.3523)
Quarterback	0.6027	0.8729	14.1835	0.2542
	(0.8067)	(1.7168)	(32.5410)	(0.2837)
Receiver	1.2467	0.0000	2.3063	0.3180
	(1.4866)	(0.0011)	(5.1562)	(0.4240)
Defensive back	0.4917	0.0000	0.5023	0.1282**
	(0.4604)	(0.0005)	(0.8759)	(0.1327)
Lineman	0.4959	2.1294	1.2914	1.3294
	(0.3858)	(2.8897)	(2.4563)	(0.9234)
Placekicker	1.2955	0.0000	0.0000	0.0000
	(1.9913)	(0.0010)	(0.0000)	(0.0004)
African-American	0.8384	0.4378	0.4826	1.3380
	(0.5476)	(0.4827)	(0.8402)	(0.7770)
American Indian/Alaska Native	1.9015	0.1271	0.0224	0.8139
	(22,357.6307)	(2,772.6756)	(532.7652)	(9,081.5830)
Native Hawaiian/Pac. Islander	1.1111e+07	0.9499	2.1300	3.4122
	(1.7138e+10)	(5,350.4642)	(9,852.9770)	(12,643.9289)
Hispanic Latino	0.0000	0.4844	4125479.1084	0.0000
	(0.0034)	(6,130.5430)	(6.1001e+10)	(0.0018)
BMI	0.8749	0.7505	0.6440	0.7102***
	(0.0924)	(0.1410)	(0.1985)	(0.0758)
16 game season	4.0327	1.0027e+07	0.5073	1.6532
	(4.1408)	(1.5063e+10)	(1,074.3168)	(1.6958)
Post-merger	5.2228*	5.4714	2754852.8523	3.5705**
	(4.7988)	(8.7058)	(1.8976e+09)	(2.2484)
NOCSAE standards	0.6533	0.0000	0.0000	0.5226
	(0.6649)	(0.0013)	(0.0007)	(0.4190)
Helmet pad switch	3.4667	1.6053	1.9595e+08	1.9613
	(2.9466)	(1.9976)	(3.1039e+11)	(2.0874)
Constant	7.7512	39.2954	0.0057	1,892.6152**
	(23.3405)	(199.1832)	(3.9477)	(5,636.1727)
Observations	503	503	503	503

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 13

Summary of Predictive Probabilities on Cause of Death Outcomes

Variable	Obs	Mean	Std. Dev.	Min	Max
cardio	960	0.2849	0.0978	4.79E-08	1.0000
cancer	960	0.2456	0.0861	3.39E-08	0.4939
degen	960	0.2051	0.0838	4.22E-08	1.0000
internal	960	0.1669	0.0534	2.92E-08	0.3254
accident	960	0.0319	0.0651	1.46E-09	0.5622
drugs	960	0.0085	0.0220	7.96E-16	0.3018
suicide	960	0.0056	0.0351	4.03E-21	0.5899
external	960	0.0515	0.0435	8.12E-15	0.3908

Table 14

Marginal Effects on Cause of Death Outcomes 1-4

	cardio	cancer	degen	internal
Years played	0.0033	-0.0353	0.0484**	-0.0182
Games played	-0.0002	0.0024	-0.0029*	0.0014
BMI	0.0199**	-0.0062	-0.0097	0.0147*
16 game season	-0.0931	-0.0802	0.0717	-0.0845
Post-merger	-0.1189	0.0570	-0.0241	-0.0855
NOCSAE standards	0.1581	-0.0374	-0.0179	0.0970
Helmet pad switch	-0.0037	-0.0415	-0.0886	-0.0480

*** p<0.01, ** p<0.05, * p<0.1

Table 15

Marginal Effects on Cause of Death Outcomes 5-8

	accident	drugs	suicide	external
Years played	-0.0113	0.0032	-0.0125	0.0224*
Games played	0.0003	-0.0002	0.0010	-0.0017
BMI	-0.0013	-0.0021	-0.0026	-0.0128***
16 game season	0.0284	0.1729	-0.0128	-0.0026
Post-merger	0.0192	0.0097	0.1069	0.0358
NOCSAE standards	0.0405	-0.1450	-0.1035	0.0082
Helmet pad switch	0.0115	-0.0002	0.1428	0.0277

*** p<0.01, ** p<0.05, * p<0.1