Trends in concussion reporting and depression across debut years in professional American-style football play

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Abstract

Head injuries accrued during professional football have been associated with long term health issues. Efforts over the last 80 years to limit concussions have included rule changes, improved helmet technologies, and increased general awareness of the negative health consequences of head injury, including depression. However, few studies have evaluated whether these exposures and outcomes change over time. This work addresses this knowledge gap by evaluating the extent to which concussion symptoms and depression symptoms (measured by the PHQ-2) change by a player's debut year. Using multivariable models, it was found that concussion scores and depressive symptoms both change over the time period of 1960-2020 in a similar way. Furthermore, since head exposure has been found to depend on position, I investigated whether changes over time were different by position. Stratification by position showed no changes in the patterns of reporting compared to one another nor patterns seen in the entire cohort, although linemen and speed positions did report higher concussion and depression scores overall, as expected. I also examined whether eras defined by rule-based changes were associated with these patterns through non-linear models for three pre-defined, rules-based eras – 1960-1976, 1977-2010, and 2011-2020. Despite the inclusion of rules-based eras, the driving forces behind these changes in reporting remained unclear. Future work is needed to establish influencers of concussion and depression reporting change if we hope to improve player safety and post-career quality of life.

Dedication

I would like to dedicate this thesis to Brandon, my family, and my mentors at the Football Players Health Study. To Marc Weisskopf and Rachel Grashow, for their hours of mentorship and guidance on this paper and in inspiring my growth as a researcher at FPHS. To Brandon for cooking all the meals, for the sanity checks, and for pulling me out of the chair to go for a walk. To my siblings for those moments that took my mind off of this paper whether for a few minutes or a few hours. To my mom for always wanting to learn about the things I am passionate about, simply because I am passionate about them. And especially to my father, whom I credit for my love of football. For never suggesting it wasn't for me to learn because I am a girl, but instead excitedly taking me to games, teaching me, answering questions, and showing me what it means to be a true and loyal fan of the game.

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Chapter I.

Introduction

The physical nature of American-style football is an exciting and entertaining facet of the sport, but it also puts players at risk for head injury and the repercussions that follow. In 2005, Dr. Bennet Omalu presented results from an autopsy he conducted on a former NFL player where he reported evidence of diffuse amyloid plaques and neurofibrillary tangles consistent with chronic traumatic encephalopathy neuropathological change (CTE-NC), a disease thought to be associated with repetitive head trauma, but can only be diagnosed post-mortem (Omalu et al., 2005). After a number of former players had been diagnosed with CTE-NC after their deaths by suicide the New York Times had released an article titled "Football Player Who Killed Himself Had Brain Disease" (Tierney, 2012) detailing CTE-NC, its discovery, and the fears of its negative health impacts. With popular journalism sources sharing the CTE-NC story and the release of a movie detailing Dr. Omalu's discovery, the conversation about CTE-NC, concussion, and head injury in football grew (Shpigel, 2022).

While this study focuses not on CTE-NC, but rather concussion history in athletes, it is important to acknowledge how the CTE-NC conversation has inspired growing media and research attention on head injury in athletes. These concerns have forced the NFL to adjust their priorities and game rules which has been demonstrated through the work of the NFL Players Association in negotiating Collective Bargaining Agreements and by those facing the NFL in Concussion Settlements (Turner & Wooden v National Football League & National Football League Properties, LLC, 2015). With

concern for player safety growing, it is important to identify which features of the sport are putting players at risk for adverse effects and whether efforts to mitigate them are working, specifically in living players before post-mortem CTE-NC diagnoses are possible. Evidence has suggested that poor health effects may follow a history of concussion in former American-style football players, including cognitive impairment (Izzy et al., 2021), cardiovascular effects (Grashow et al., 2023), and mood disorders (Vos et al., 2018).

A concussion is a traumatic brain injury due to a blow to the head, commonly experienced by football players (Gouttebarge & Kerkhoffs, 2021). Symptoms of concussion include headaches, dizziness, mood and sleep disturbances, cognitive impairment and sometimes loss of consciousness (Didehbani et al., 2013). The risk of sustaining a concussion increases when players are exposed to multiple head injuries without taking the time to heal, which may be common in professional American-style football when there is incentive to play through injury or a diagnosis is missed (Didehbani et al., 2013). In fact, it has been found that those athletes who have experienced one concussion are twice as likely to sustain future concussions compared to their non-concussed peers (Gouttebarge & Kerkhoffs, 2021). In addition, multiple concussions are associated with greater risk of long-term cognitive impairment and mood disorders (Kerr et al., 2012; Montenegro et al., 2017) and have been reported at greater rates in football players than in the general population (Hart et al., 2013). The adverse effects of multiple concussions are an obvious cause for concern for this population. Due to different roles and exposures by the different positions played in football, it is worth

asking if different positions, exposed to different numbers and types of hits, are at higher risk for concussions and later negative health effects than others.

In fact, some playing positions do seem to experience "bigger" head impacts while others are frequently impacted by smaller head hits. It has been found that faster, speed positions such as running backs, tight ends, and cornerbacks are at greater risk for concussions than others (Dai et al., 2018; Nathanson et al., 2016). It is suggested that these players may experience head hits less frequently but those they do sustain tend to lead to more games missed and more typical concussion symptoms (Dai et al., 2018). Others have noted that frequent smaller hits, like those often experienced by offensive and defensive linemen, may have negative impacts on cognitive health even though they are not, by definition, considered concussive hits (Martini et al., 2013). Literature from military populations has suggested that different mechanisms of injury, (e.g., blast versus impact) may result in different neurological, musculoskeletal, and immunological symptoms (Belding et al., 2020). Thus, it is reasonable to consider whether different types of playing positions with different head injury profiles will result in different consequences later, including depression. Developing an understanding of who is most at risk for later-life challenges, like depression, will be necessary to improve mental health and quality of life for these players.

Mental Health, Depression, and Concussion

Depression in football players has been reported, although the extent to which players are at an increased risk for mental health disorders, as compared to the general population, is poorly understood. One study that examined publicly available data on the cases of suicide in former NFL players between 1920 and 2015 found that 26 men had

committed suicide during that time (Webner & Iverson, 2016). Depression is a risk factor of suicide (Dong et al., 2019) and Webner and Iverson agree that the disproportionate number of players who had committed suicide after 2009 calls for an understanding of the causes of depression and suicide in this group to help reduce the suffering players experience after their careers. Interestingly, two separate neuroimaging studies have suggested depression prevalence in former NFL players as high as 23.5% (Hart et al., 2013; Strain et al., 2013), although the size of their cohorts were small. However, others have suggested that previous works have not considered the role of comorbid health factors, such as chronic pain, and lifestyle changes post-play, such as a loss of income in depression diagnoses (Iverson, 2020).

Nevertheless, there is evidence of some relationship between depression and concussion in football players. A nine-year follow-up study assessed the relationship between diagnosis of depression and self-reported concussions in 1,316 professional football players (Kerr et al., 2012). It was found that depression diagnoses increased linearly with number of self-reported concussions and those who reported no concussions were at a lesser risk of having a depressive episode, later in life, than those who reported concussion events (Kerr et al., 2012). Similarly, Roberts and colleagues (2019) examined the impact of number of seasons in the NFL, playing position, and experience of concussion on self-reported depression symptoms using the PHQ-4. While position-related differences in depression were observed, their significant finding demonstrated that each 5 seasons of play was associated with a 9% increase in risk of depression in former professional American-style football players (Roberts et al., 2019). Moreover, a systematic review compiled the literature related to cognitive and physical function,

mood, and sports-related functioning in professional football players who had experienced some kind of head injury, including concussion (Vos et al., 2018). Their findings suggested a relationship between concussion and depression which was strongest in players over 45 years old, although they noted most populations in the literature were older than the average player. An effort to understand the impacts of concussion seems to have revealed a strong association between the number of concussions experienced in a football career and depression later in life.

Depression is just one of many consequences of concussion and may be associated with other health issues associated with head injury. Other health conditions affected by a career in football are important in understanding the holistic health in former players. In a study of 9,205 hospitalized adult concussion patients and non-concussed hospitalized controls, researchers found that concussed patients were at a significantly higher risk of cardiovascular challenges, depression, psychosis, and epilepsy (Izzy et al., 2021). Likewise, a survey study was conducted on over 4,000 former professional football players to ask about health history and football exposures (Zafonte et al., 2019). Concussion Symptom Score, used to quantify concussion symptom history, was collected, and found to be associated with later-life hypertension suggesting that repetitive head injury may have implications for later-life cardiovascular health (Grashow et al., 2023). Notably, cardiovascular risks, including hypertension, are associated with cognitive and mood decline in other cohorts (Knopman et al., 2001). A review of case-control and cohort studies was conducted to measure the effect of concussion on risk of future health in athletes (Iverson et al., 2023). This team noted that studies that have suggested risk of neurological and mood disorders after concussion need to be validated

with stronger statistical methods and a focus on controlling for confounding health outcomes (Iverson et al., 2023). Thus, while assessing data to draw conclusions about head injury and its impact on a former player later in life, the role confounding health effects may play should be considered.

Measuring Concussion: Commonly Used Measures, Challenges, and the Football Players Health Study Concussion Symptom Score

The difficulty in measuring concussion history has led to the development of a number of tools aiming to diagnose and collect concussion history, and to measure frequency, severity, and enduring symptoms of head injury. Commonly used scales in sports include the Post-Concussion Symptom Scale (PCSS), Standard Assessment of Concussion (SAC), Standard Concussion Assessment Tool (SCAT3) (Dessy et al., 2017), the Ohio State University TBI Identification Method (OSU TBI-ID) (Corrigan & Bogner, 2007), and the Concussion Symptom Inventory (CSI) (Randolph et al., 2009). Most of these tools are often used closer to the time the head injury occurs, especially the SCAT3, SAC, and PCSS, which are recommended to be used on the sideline, immediately after a potential concussion incident for diagnosis (Dessy et al., 2017). The CSI is also used as an acute measure of injury and is often used to assess injury at the time of the incident, and track symptom progress over days or weeks (Randolph et al., 2009). These scales are used to evaluate symptoms for diagnosis, recovery monitoring, and return-to-play purposes (Chen et al., 2007; Dessy et al., 2017). The OSU TBI-ID is considered to be the current gold standard for retrospective, concussion history data collection (Corrigan & Bogner, 2007). The OSU TBI-ID is an interview tool asking questions about loss of consciousness episodes or lost memory after a hit to the head or neck. This instrument

documents each head injury separately (Corrigan & Bogner, 2007). The development of such tools allows for clinicians and researchers to assess concussion and concussion history, but measuring head injury and its consequences has presented some challenges.

The main challenges seen in measuring retrospective concussion history include the nonspecific nature of its later-life consequences, recall bias, and respondent interpretation. As highlighted earlier, later life conditions thought to be associated with concussion history include depression (Roberts et al., 2019) and cognitive impairment (Kerr et al., 2012). However, others have noted the association between concussion history and accumulation of poor health outcomes including mood and cognitive function (Iverson et al., 2023; Roberts et al., 2021) and cardiovascular issues like hypertension (Grashow et al., 2023). These challenges make it difficult to untangle associations and find a relationship between head injuries and later-life health outcomes that cannot be attributed to for other reasons. Recall bias is another major limitation to concussion history reporting. In general, self-reported histories may not be reliable because answers may depend on the person's current health status (Grashow et al., 2019b). Concussion reporting can be especially unreliable because memory problems can result from concussion (Brett et al., 2022) such that those with more concussions will remember it less accurately (Grashow et al., 2019b). Further, current societal factors, such as the NFL Concussion Settlements, may present incentives to over or under report and what some might consider a concussion may not be true for others (Corrigan & Bogner, 2007). This brings forth another challenge, noted by Corrigan and Bogner (2007). They acknowledge that previously used retrospective questions of concussion history included phrases such as "head injury," "TBI," "concussion," and others that can be interpreted differently by

survey respondents. Thus, tools like the Football Players Health Study's Concussion Symptom Score were developed to assess head impacts years after injury through an array of symptoms and limit bias based on respondent interpretation.

The Football Players Health Study's Concussion Symptom Score (CSS) measures concussion history symptom severity by querying 10 football-related concussion symptoms during playing years. It asks: "While playing or practicing football, did you experience a blow to the head, neck, or upper body followed by: headaches, nausea, dizziness, loss of consciousness, memory problems, disorientation, confusion, seizure, visual problems, and feeling unsteady on your feet?" Participants then select how often each symptom occurred: never, once, 2-5, 6-10, or 11+ times. This scale was developed in an effort to capture the multitude of possible concussion symptoms and to eliminate terminology that may be open for interpretation. While the CSS is still at risk of recall bias, (as most, if not all, retrospective concussion measures are) it presents a new way to collect history of football related head injury and capture the range of head injury sequelae that can occur. Notably, the Football Players Health Study has demonstrated associations between concussion symptom score and later life mental health issues such as depression (Kerr et al., 2012; Roberts et al., 2019), cardiovascular dysfunction (Grashow et al., 2023; Izzy et al., 2022), and hormonal insufficiencies (Grashow et al., 2019a; Izzy et al., 2022). Using this tool and the FPHS dataset, this work will determine if concussion symptoms and depression reporting have changed throughout the NFL's history. However, it is important to acknowledge the list of reasons why such changes may occur including changing societal norms around depression and concussion reporting, changing rules in the NFL, and updated helmet technology.

A New Openness to Report: Depression, Concussion, and the Importance of Education

Depression reporting in the general population has changed over time as it has become a more accepted and encouraged discussion. A meta-analysis conducted to evaluate global trends in the prevalence and incidence of depression found a clear increasing trend in depression prevalence (Moreno-Agostino et al., 2021). While the authors hypothesize why this trend exists, their data cannot conclude whether rates of depression have truly risen, or if societal factors, such as education, may increase reporting. In fact, other studies have suggested that awareness and understanding of depression may be responsible for rising rates, not necessarily that more of the general population is now depressed (Baumeister et al., 2015; Herrman et al., 2019). Interestingly, Baumeister and colleagues found that, while lifetime depressive symptoms in Germany rose from 13.2-27.8% in their population-based cohort, the increase was strongest in men and in people ages 35 to 64 years old (2015). They cite that the perceived stigmatization of mental illness in Germany has changed since 1990 leading to reduced fear of rejection and possibly more allowance to report symptoms. Similarly, people with depression in other populations have reported fear of being thought of as weak, lazy, or inferior if they were to admit to feeling depressed (Barney et al., 2009). Focus group participants claimed that they were driven not to report depressive symptoms because of such fears (Barney et al., 2009). These works demonstrate that as stigma surrounding depression is broken down through education and awareness, the willingness to report symptoms increases. This may be especially true in a population of men in a physical, demanding, and deemed "manly" sport that have been conditioned to "tough out" hardships.

Thus, the role of masculinity, both in the general population and likely in football populations, in changing rates of depression reporting must be examined. In a prospective study following young adult men over six months, researchers observed the role of masculine norms like "toughness" on depression and mental health service utilization (Sileo & Kershaw, 2020). They found that greater endorsement of masculine norms, especially toughness, was associated with less mental health service utilization and this effect was greatest for those who met the criteria for depression at baseline. Moreover, compared to women, men report depression diagnoses at lower rates but are more likely to commit suicide and tend to avoid seeking professional help compared to women (Cochran & Robinowitz, 2000). It is important to recognize unique challenges men face in reporting mental health struggles and may lead to underreporting depression, especially in football, which some consider to be the most masculine and violent team sport in United States culture (Rader, 2004). However, some suggest that societal awareness and reaction to sport concussion and CTE-NC and media endorsement of athletes' health stories over masculinity may be breaking down masculine norms (Anderson & Kian, 2012). This change in football culture may play a role in opening space for male athletes to feel comfortable to report mental health struggles, thus leading to changing depression reporting.

Similar to depression and mental health, awareness and education of concussion in sports may play a role in reporting over time. In one study of NCAA athletes, those who had been provided education materials endorsed that concussion training modules "greatly improved" their knowledge, attitudes, self-efficacy, and intentions to report concussion during their sport season (Schmidt et al., 2020). They suggest that education

targeted sports culture in a way that significantly improved concussion reporting. Another group studying collegiate men's hockey players found that preseason concussion knowledge was not significantly associated with reporting during the season, but rather intention to report symptoms was associated with actual reporting (Kroshus et al., 2015). Thus, it follows that education that impacts sports culture is a powerful tool that changes attitudes and concussion reporting behaviors in athletes. The media may play a role in these changing cultures as it has been suggested that their focus on concussion and CTE-NC stories have broken down masculine norms that may have been keeping football players from reporting symptoms, previously (Anderson & Kian, 2012). Even internationally, it has been demonstrated that sports media influences perceptions and attitudes towards concussion and concussion management in sports like football and rugby (Ku et al., 2020). Between awareness, education, and media attention, conversations around concussion are changing attitudes and possibly symptom reporting in athletes. In assessing concussion reporting in athletes who played during different eras, the changes in societal factors should be considered as a possible contributing factor to patterns of change. Interestingly, as these societal views have changed, so have rules in the NFL.

NFL Rule Changes that May Affect Concussion Rates

With the compiled research and attention highlighting the troubling effects of head injury and concussion in American-style football, the NFL has had to take steps to improve the safety of the sport. Since 1960, the year that helmets with hard plastic shells were largely enforced (Harrison, 2014), the NFL has continued to update rules, through their Collective Bargaining Agreements (CBAs) with the NFL Players Association

(NFLPA), in an effort to promote safety in the league (NFLPA, 2023). There have been eight Collective Bargaining Agreements established since 1960 and each has made changes to such issues as disciplinary consequences for certain breaches in rules, drafting practices, team personnel requirements and weekly practice hours during offseason, preseason, regular season, and postseason, among others (NFLPA, 2023).

Notable changes to the rules of the game that may impact the rate of concussion in the NFL have been incorporated in each CBA. The signing of CBA three in 1977 was the first update that limited off-season training camp and enforced no contact practices (e.g., blocking, tackling, pass rushing, etc.; Deubert et al., 2016). 2011 marked the start of more widespread change with head injury in focus. During this year, the seventh CBA was signed (National Football League Management Council & National Football League Players Association, 2011) and a wealth of rule changes, seemly related to head safety, were made. First, offseason practice programs were reduced from 14 to 9 weeks and two-a-day practices were eliminated. Training camp hours were limited to a maximum of 4.5 hours of on-field practice per day with a maximum of 3 hours in full pads (e.g., contact work allowed). Additionally, the number of contact work practices were reduced to 14 per regular season which aligned with one contact work practice per week excluding bye-week and multi-game weeks (i.e., if a team was scheduled to play on Sunday and Thursday of the same week). During preseason, players were guaranteed one day off every seven days and four days off per month during regular and postseason play. Notably, this CBA allowed players "…to obtain disability benefits for psychological disorders caused by NFL activities," NFL teams were required to have a neurological consultant, and a mandated Concussion Protocol was developed, standardizing

concussion diagnosis and management practices in the NFL (National Football League Head, Neck & Spine Committee, 2022). This protocol sets forth a regulated definition of concussion, clear signs and symptoms, assessment types, game day procedures, diagnosis and management plans, and defined roles for key personnel in the management of the injury (NFL, 2022).

Beyond the Collective Bargaining Agreements, the NFL has also made changes to hitting techniques in the game with the hopes of keeping players safe from constant exposure to head hits. In 2018, the NFL adopted the "Use of Helmet" rule which included fouls for "lowering the head and initiating contact with the helmet to any part of the opponent's body" (NFL, 2023b). These rules were later modified to prevent players from using any part of their helmet to make forcible contact to another's head or neck area (NFL, 2023b). Kickoff modifications were also carried out in 2018 as data reported by the NFL suggested that kickoffs represented 12% of concussions in players but only 6% of plays in a game (NFL, 2023a). They instated a ban on specific plays, such as the two-man wedge formation, that may have increased risk of concussion in players (NCAA, 2023). Other notable rule changes preventing head injury include fouls and fines for illegal hits on a player in a defenseless posture, roughing the passer and kicker, chop blocks, and "initiating contact with the crown of the helmet" (NFL, 2023b). These updates largely came after 2011 when the extension of the CBA was signed and the NFLPA negotiated for more direct action concerning concussions in NFL players (NFL Management Council & NFLPA, 2020). Such rules and regulations are frequently reviewed and updated as new CBAs and extensions continue to be negotiated.

Changing Helmet Technology in the NFL

Updated helmet technology may have also impacted head injury reporting in the NFL. In 1960, the NFL largely moved away from leather helmets and required players to wear those with hard plastic shells (Harrison, 2014). In 1969, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was founded to develop standards with which to measure how effective football helmets are at protecting players from head impacts (Levy et al., 2004). They initiated research efforts focusing on head protection and the first of these standards were implemented for football helmets in 1973. Since then, NOCSAE continues to be the certification necessary to assert a helmet as safe for football play and their development has been a critical catalyst to major changes in helmets.

For example, helmet weight, size, and design has evolved as concussion and head injury concerns have circulated (Bailey et al., 2021). From 1970 to 2022 helmets gradually increased in weight from 0.65 kg to 2.27 kg and the padding inside, designed to absorb some of the impact, increased in thickness from 1.3 cm to approximately 5 cm of foam (Viano & Halstead, 2012). Studies have tested the effectiveness of different helmets to withstand lab-simulated helmet-to-helmet impacts and found that helmets developed in the 2010s had significantly lower head responses than those used from 1970-1990 (Viano & Halstead, 2012). Specifically, it is thought that the increased padding thickness around primary areas of impact plays a major role in absorbing the energy from helmet-to-helmet hits (Viano et al., 2006). The NFL even credits new helmet technology, including some position-specific helmets, with a reduction in reported concussions by 25% in each of the 2018-2021 seasons (NFL, 2022). Updates to helmet technology appear to have improved safety performance, especially in lab settings. However, few studies have measured

concussion rates and severity in game and practice situations. It is likely that changing helmet technology has an impact on concussion symptom reporting and hopefully improves the symptoms and consequences that come later, such as depression.

Conclusions

Concussion in American-style football players has been a concern for players, researchers, clinicians, and others because of the clear negative health impacts that follow. Depression, in particular, has been noted as a common outcome of concussion exposure (Kerr et al., 2012), although the consequences of concussion are challenging to untangle with many interrelated confounders at play (Grashow et al., 2023; Roberts et al., 2021). Still, depression is a major focus of research at present, especially with the societal focus on CTE-NC. Exploring how concussion symptom severity changes over time may reveal driving factors that contribute to reporting. Moreover, investigating the extent to which depression reporting mirrors concussion symptom reporting patterns offers the opportunity to better understand the relationship between concussion and later-life depression. Further examination of time trends defined by rule changes and helmet technology may shed light on approaches to improving the lives of football players, even after their careers.

Study Aims and Hypotheses

The aims of this study and hypotheses are presented below to outline the structure of this paper.

Aim 1

Using the Concussion Symptom Score (CSS) I investigate the self-reported history of concussion symptom accumulation in former professional football players. I will measure non-linear patterns of concussion symptom reporting based on professional football debut year to assess changes over time. I hypothesize that concussion reporting will not be the same across all debut years because the variables outlined above will all play a role in changing reporting. Additionally, as depression is a known outcome of concussion exposure (Kerr et al., 2012), I will also investigate whether depression symptom reporting changes across debut years. If concussion symptom burden is associated with later-life depression in former professional football players, then patterns of depression reporting by debut year should be similar to those seen in concussion symptom reporting over time. I hypothesize that players--regardless of when they played professionally--who have the highest concussion symptom score would report the most depression symptoms after their playing career.

Aim 2

Field positions in football have different profiles of exposure to head injury. The association of different types of hits or head injuries may lead to distinct symptoms as has been explored in military (Belding et al., 2020) and football populations (Dai et al., 2018). To this effect, I will explore if differences in concussion symptom and depression

symptom reporting exist by football position categories. Specifically, I will split the cohort into "speed" (running backs, linebackers, defensive backs, tight ends, and wide receivers), "linemen" (offensive and defensive), and "skill" (quarterbacks, kickers, and special teams only) positions. If position category reflects different concussion experiences and symptoms, then each category of football position will report different concussion symptoms and depression scores that will persist over time. Specifically, I hypothesize that patterns of concussion and depression reporting will differ by position across the entire cohort over time, and that skill players, who typically take the fewest head hits on the field, will report the lowest concussion symptom and depression scores across all debut years.

Aim 3

Based on the idea that rule changes may have impacted reporting, I will then break up the cohort into three eras of debut year based on historical rule changes. If rule changes in the NFL are associated with the number and severity of concussion symptoms, then former players who played more recently will report fewer and less severe concussions during their playing years. Specifically, if this is true, former players who played professionally after 2010 will report the lowest concussion symptom scores because rules implemented in 2011, including the implementation of a mandated Concussion Protocol, fewer hours of padded practice, and updated legal hitting techniques, will have protected players from head injury more so than players in earlier decades. Depression symptom reporting will also be examined by defined eras to provide insight into whether the timing of rule changes is reflected in later life depression symptom reporting. If rule changes keep players safer and improve health later in life,

those who played after the implementation of recent NFL rule changes will report fewer depression symptoms than those who played before them.

Chapter II.

Methods

This research examines survey data from 4,184 former American-style football players who played professional American-style football (ASF) after 1960, when helmets with a hard plastic shell were largely adopted (Harrison, 2014). The existing dataset is provided by the Football Players Health Study at Harvard University. To be eligible to join the Football Players Health Study, participants must be living men who played professional ASF in 1960 or later, be retired from football play, and not currently be incarcerated.

Measures

Self-reported survey data was used to conduct this research. The Football Players Health Study (FPHS) was launched in 2015 and is the largest study of living former players to date. The First Health and Wellness Questionnaire (Q1) was completed either through paper scantron form and returned via mail or online via Research Electronic Data Capture (REDCap™) and asks questions about demographics, football exposures, health history, and lifestyle factors. The study protocol was approved by the IRB and all subjects provided informed consent before participating.

Demographics

Demographic variables included age, race, and body-mass index (BMI) at survey completion. Age was calculated using date of birth and date of questionnaire completion. Race was categorized as Black, white, other, or missing based on participants' self-report. BMI was calculated using self-reported height and weight, then categorized into < 25.0, 25.0-30.0, > 30.0 or missing.

Football Exposures

Relevant football exposures included the debut (first) calendar year of professional ASF play, number of seasons in professional ASF, and main position played in professional ASF. Main position was collected by asking "During your professional football career what position did you most often play?" and the following options were presented: offensive line, defensive line, linebacker, defensive back, running back, wide receiver, tight end, quarterback, kicker/punter, and special teams. Based on their selection, participants' main position was further categorized into "linemen" (offensive line and defensive line), "speed" (defensive back, running back, tight end, linebackers, and wide receiver), or "skill" (quarterback, kicker/punter, and special teams only) positions.

Concussion History

Concussion history was measured using the Concussion Symptom Score (CSS) which is a tool developed by the Football Players Health Study. Ten football-related concussion symptoms during playing years were queried with the following: "While playing or practicing football, did you experience a blow to the head, neck, or upper body

followed by: headaches, nausea, dizziness, loss of consciousness, memory problems, disorientation, confusion, seizure, visual problems, and feeling unsteady on your feet?" Participants selected from one of the following for each of the 10 symptoms: no, once, 2-5, 6-10, or 11+ times. These were then coded as 0, 1, 3.5, 8, and 13, respectively. The coded symptom scores across all 10 symptoms were then added together to obtain the total CSS for each former player.

Depression History

For these analyses, depression will be categorized only using the PHQ-2 to measure current depressive symptoms at the time of survey completion. Participants who reported a score ≥ 3 on the two depression-related questions of the PHQ-2 are considered to have had depression.

Statistical Analysis

Univariate analyses were conducted to calculate descriptive statistics on demographics, football exposures, and health outcomes for the entire cohort and for each decade of play. This also identified areas of missing data, which were removed for the purpose of these analyses because they were assumed to be missing at random. All analyses were conducted using R Statistical Software and statistical significance was set at $p \leq 0.05$ (R Core Team, 2021).

To address the first aim of the study and see if any differences in concussion symptom score and depression exist over different times of professional ASF play, two non-linear multivariable linear regression models were run, one predicting concussion symptom score by debut year and another predicting depression reporting by debut year.

Both were adjusted for using a spline term for age (which will be called "age spline"), race, current BMI, and a spline term for the number of professional ASF seasons (which will be called "number of professional ASF seasons spline"). Age was modeled with a spline term so as not to assume linearity in the relationship between age and concussion symptom score. A spline term was also used for number of professional ASF seasons to account for potential survivor bias issues such that those who played the most professional seasons may have been able to do so because they were not frequently exposed to concussions and other injuries (Grashow et al., 2019b). Then, to address aim two and assess whether there are differences in concussion symptom score and depression symptom reporting by position, position category was added to the non-linear multivariable regression models.

Finally, to address aim three and visualize whether rule changes in professional ASF have changed concussion symptom score and depression symptom reporting, participants' era of play was first identified (before 1977, between 1977 and 2010, and after 2010) based on their self-reported first year of professional ASF play, and I calculated descriptive statistics by each of era of play. Then, non-linear multivariable regression analyses were conducted such that concussion symptom score reporting by debut year, included as a spline term, was modelled in 1) the 1960-1976 era, 2) the 1977-2010 era, and 3) the 2011-2020 era. These same models were run for depression symptom reporting by debut season as well. To further understand if different positions report concussion and depression symptoms differently within these rules-based eras, these non-linear models were run again, stratified by position category.

Chapter III.

Results

This chapter details the results found in the analyses outlined above.

Full Cohort Demographics

In the 4,183 former professional football players, the average age was 51.8 (14.4) years, 39% (1,619) identified as Black, and 41.1% (1,711) reported a BMI between 25.0 and 30.0 (healthy weight) at the time of their survey completion (Table 1). In this dataset, no player indicated a professional ASF debut year past 2020.

Full Cohort Football Exposures

The average time these former players spent in the NFL was 6.6 (3.8) years and they completed their survey an average of 23.6 (14.3) years after leaving the NFL (Table 1). Across each decade and the entire cohort, the most commonly endorsed main positions played were offensive lineman, defensive lineman, and linebacker. In total, 34% of the cohort reported their main position as lineman, offensive or defensive, and 15.3% reported being a linebacker. Defensive back (14.4%), wide receiver (10.5%), and running back (9.3%) were also commonly reported while special teams only (0.8%), quarterback (4.6%), tight end (7.8%), and kicker (3.2%) were less common (Table 1). Of the entire cohort, 57.4% (2,389) former players were categorized as playing speed

positions, 34% (1,416) reported playing linemen, and 8.6% (357) were categorized as skill players (Table 1).

Full Cohort Concussion Symptom Scores and Depression

On average, former NFL players reported a Concussion Symptom Score (CSS) of 31 (27.2). In the 4,162 total former players, the average depression score was 1.4 (1.7) which falls below the clinical cutoff of 3 or more on the PHQ-2 (Table 1). Specifically, players who started their NFL careers in the 90s had the highest scores with an average of 1.6 (1.7) on the PHQ-2 (Table 1).

Table 1. Demographic Characteristics and Football Exposures of all Completers by Decade.

	1960 (*N*=580)	**1970 (*N*=823)**	**1980 (*N*=943)**	**1990 (*N*=733)**	**2000 (*N*=792)**	**2010 (*N*=203)**	**Total (*N*=4075)**	***p*-value**
Age								< 0.001
Mean (*SD*)	72.2 (3.4)	62.7 (3.2)	53.4 (3.6)	43.2 (3.8)	34.3 (3.2)	28.6 (2.0)	51.2 (13.9)	
Range	52.0-87.0	48.0-73.0	33.0-64.0	28.0-54.0	25.0- 44.0	24.0-36.0	24.0-87.0	
Race								< 0.001
White	449(77.4%)	523(63.5%)	513(54.4%)	304(41.5%)	381(48.1%)	114(56.2%)	2285(56.1%)	
Black	105(18.1%)	266(32.3%)	402(42.6%)	404(55.1%)	364(45.9%)	73 (36.0%)	1614(39.6%)	
Other	12 (2.1%)	21 (2.6%)	24 (2.5%)	19 (2.6%)	34 (4.3%)	15 (7.4%)	125 (3.1%)	
Missing	14 (2.4%)	13 (1.6%)	4 (0.4%)	6 (0.8%)	13 (1.6%)	1 (0.5%)	51 (1.3%)	
Current BMI								< 0.001
<25.0	49 (8.4%)	50 (6.1%)	35 (3.7%)	26 (3.5%)	33 (4.2%)	15 (7.4%)	208 (5.1%)	
25.0-30.0	260 44.8%)	347(42.2%)	362(38.4%)	254(34.7%)	352(44.4%)	90 (44.3%)	1666(40.9%)	
>30.0	265 45.7%)	422(51.3%)	542(57.5%)	446(60.8%)	406(51.2%)	95 (46.8%)	2176(53.4%)	
Missing	6 (1.0%)	4 (0.5%)	4 (0.4%)	7 (1.0%)	1 (0.1%)	3 (1.5%)	25 (0.6%)	
Number of NFL Seasons								< 0.001
Mean (*SD*)	7.5 (3.7)	7.1 (3.8)	6.7 (4.0)	7.3 (4.1)	5.4 (3.0)	3.5 (2.8)	6.6 (3.8)	
Range	1.0 - 21.0	1.0 - 26.0	1.0 - 23.0	1.0 - 25.0	1.0 - 23.0	1.0 - 20.0	1.0 - 26.0	
Missing	12	16	19	15	13	0	75	
Years since NFL play								< 0.001
Mean (*SD*)	43.4 (4.7)	34.3 (5.0)	25.2 (5.5)	14.0 (5.3)	7.0 (3.5)	3.5 (1.5)	23.0 (13.9)	
Range	18.0 -55.0	10.0 - 48.0	2.0 - 39.0	2.0 - 28.0	0.0 - 19.0	0.0 - 8.0	0.0 - 55.0	
Missing	0	1	0	1	0	1	3	
Main Position								0.003
Defensive back	82 (14.1%)	123(14.9%)	147(15.6%)	99 (13.5%)	113(14.3%)	22 (10.8%)	587 (14.4%)	
Defensive line	76(13.1%)	99 (12.0%)	117(12.4%)	95 (13.0%)	96 (12.1%)	28 (13.8%)	511 (12.5%)	
Kicker	11 (1.9%)	31 (3.8%)	40 (4.2%)	22 (3.0%)	21(2.6%)	4 (2.0%)	129 (3.2%)	
Linebacker	82 (14.1%)	139(16.9%)	146(15.5%)	113(15.4%)	118(14.9%)	26 (12.8%)	624 (15.3%)	

Offensive line	120(20.7%)	167(20.3%)	184(19.5%)	168(22.9%)	192(24.2%)	45 (22.2%)	876 (21.5%)	
Quarterback	33 (5.7%)	48 (5.8%)	45 (4.8%)	31 (4.2%)	20 (2.5%)	10 (4.9%)	187 (4.6%)	
Running back	66 (11.4%)	78 (9.5%)	98 (10.4%)	69 (9.4%)	56 (7.1%)	14 (6.9%)	381 (9.3%)	
Tight end	47 (8.1%)	44 (5.3%)	65 (6.9%)	54 (7.4%)	85 (10.7%)	24 (11.8%)	319 (7.8%)	
Wide receiver	60 (10.3%)	89 (10.8%)	98 (10.4%)	73 (10.0%)	82 (10.3%)	26 (12.8%)	428 (10.5%)	
Special teams only	3 (0.5%)	5 (0.6%)	3 (0.3%)	9 (1.2%)	9 (1.1%)	4 (2.0%)	33 (0.8%)	
Position Category								0.214
Skill positions	47 (8.1%)	84 (10.2%)	88(9.3%)	62 (8.5%)	50 (6.3%)	18 (8.9%)	349 (8.6%)	
Linemen positions	196(33.8%)	266(32.3%)	301(31.9%)	263(35.9%)	288(36.3%)	73 (36.0%)	1387(34.0%)	
Speed positions	337(58.1%)	473(57.5%)	554(58.7%)	408(55.7%)	454(57.3%)	112(55.2%)	2339(57.4%)	
Concussion Symptom Score								< 0.001
Mean (*SD*)	23.1 (22.7)	29.2 (26.8)	34.6 (28.1)	33.5 (27.9)	33.2 (28.1)	25.2 (23.8)	31.0(27.2)	
Range	0.0 - 130.0	0.0 - 130.0	0.0 - 130.0	0.0 - 130.0	0.0 - 130.0	0.0 - 105.0	0.0 – 130.0	
Missing	29	23	13	12	7	1	85	
Depression Score								< 0.001
Mean (*SD*)	1.0 (1.5)	1.2 (1.6)	1.5 (1.7)	1.6 (1.7)	1.6 (1.8)	1.3 (1.5)	1.4 (1.7)	
Range	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	
Missing	1	2	2	1	0	1	7	

Non-linear Multivariable Analyses

Concussion symptom score and depression reporting trends across debut year

Models predicting concussion symptom score by debut year revealed a non-linear relationship where there is an increase in symptom reporting in the earlier years, significantly highest reporting sustained from approximately the late 1970s to 2000s (p = 0.007; Table 2), and then a decrease in reporting in the later years (Figure 1). These patterns were seen when adjusted for age spline, race, BMI at time of survey completion, and number of professional ASF seasons spline.

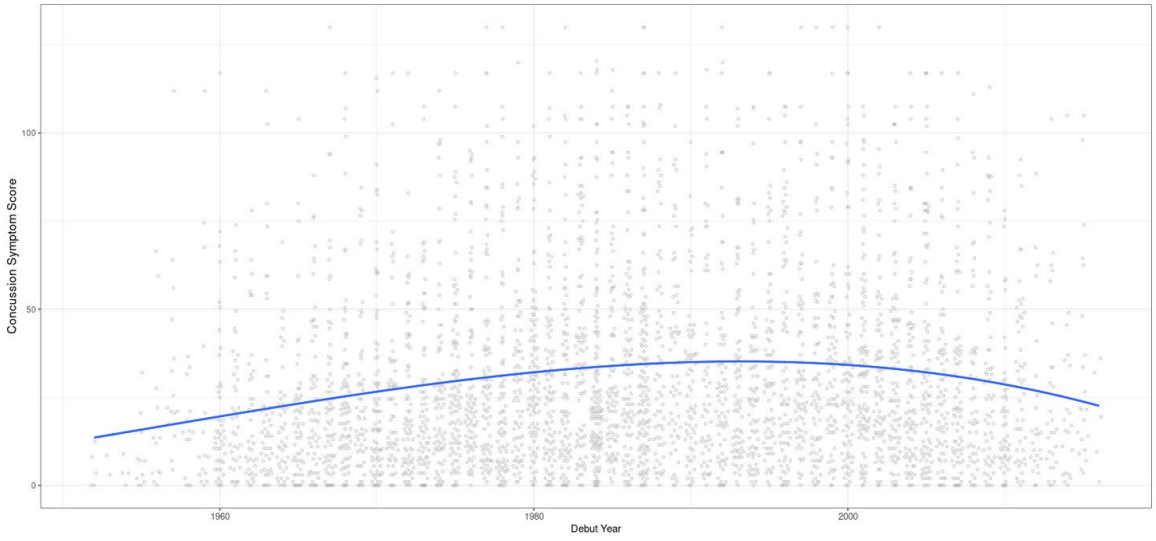

Figure 1. Concussion Symptom Score (CSS) Reporting by Professional American-style Football (ASF) Debut Year from 1960-2020.

This model is adjusted by age spline, race, current BMI, and number of professional ASF seasons spline.

A similar, but less pronounced, pattern was seen in non-linear models predicting depression symptom reporting by debut year, even when adjusted for age spline, race, current BMI, and number of professional ASF seasons spline. Similar to concussion symptom reporting, depression symptoms gradually increased from 1960 until they reached their peak approximately the late 1970s. Depression symptoms maintained at their highest level until approximately the 2000s at which point reporting gradually decreased (Figure 2). However, none of these changes in reporting were significant (Table 2).

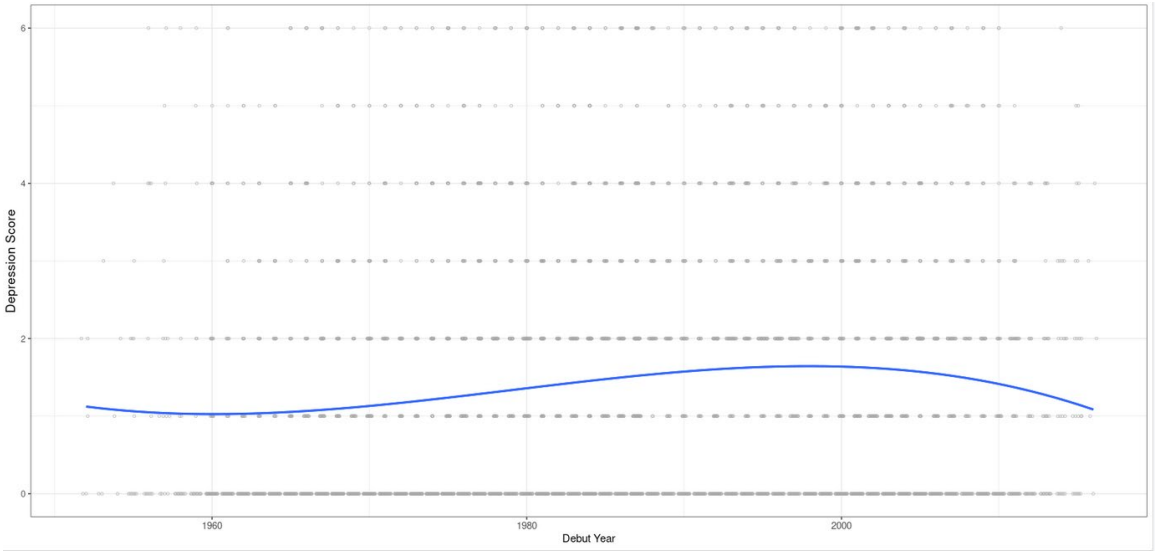

Figure 2. Depression Symptom Reporting by Professional ASF Debut Year from 1960-2020.

This model is adjusted by age spline, race, current BMI, and number of professional ASF seasons spline.

Table 2. CSS and Depression Symptom Reporting by Professional ASF Debut Year from 1960-2020.

	Estimate	95% CI		*p*
		LL	*UL*	
Concussion Symptom Score				
bs(Debut Year)1	9.121	-38.566	56.808	0.708
bs(Debut Year)2*	43.4	11.785	75.015	0.007
bs(Debut Year)3	-20.829	-52.857	11.2	0.202
Depression Symptoms				
bs(Debut Year)1	0.226	-2.678	3.13	0.879
bs(Debut Year)2	1.137	-0.797	3.072	0.249
bs(Debut Year)3	1.074	-0.894	3.043	0.285

*This model is adjusted for age spline, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Concussion Symptom Score and Depression Symptom Reporting Over Debut Year by Position Category

Non-linear models of concussion symptom score reporting by professional ASF debut year did not change by position. The same pattern seen in Figure 1 was sustained across speed, skill, and linemen positions (Figure 3). However, while not unexpected, skill positions report the lowest concussion symptom scores across debut years compared to linemen *($p < 0.001$)* and speed positions *($p < 0.001$)* who report almost the same (Figure 3 and Table 3).

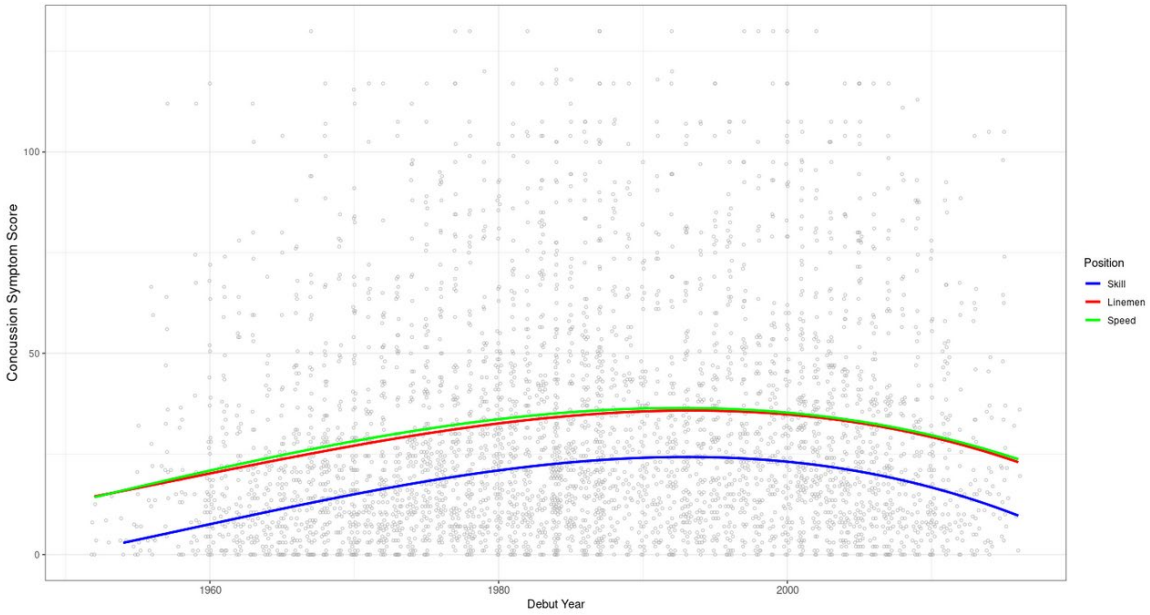

Figure 3. CSS Reporting by Professional ASF Debut Year from 1960-2020 Stratified by Position Category.

This model is adjusted by age spline, race, current BMI, and number of professional ASF seasons spline.

Depression symptom reporting by debut years maintained a similar shape found in Figure 2 within each position category (Figure 4). Again, speed and linemen reported more depression symptoms than skill positions (Figure 4). Speed positions reported significantly higher depression scores *(p* = 0.024*)* while linemen reported more depression symptoms than skill positions at a rate approaching significance *(p* = 0.058*)*. (Table 3).

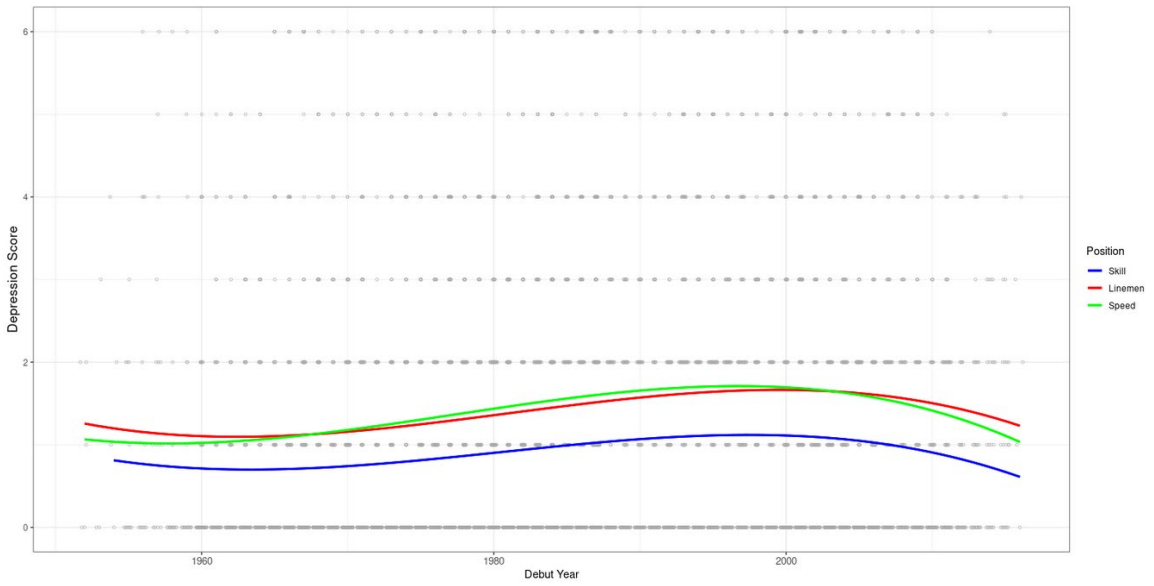

Figure 4. Depression Symptom Reporting by Professional ASF Debut Year from 1960-2020 Stratified by Position Category.

This model is adjusted by age spline, race, current BMI, and number of professional ASF seasons spline.

Table 3. CSS and Depression Symptom Reporting by Professional ASF Debut Year from 1960-2020 Stratified by Position Category.

	Estimate	95% CI		*p*
		LL	*UL*	
Concussion Symptom Score				
bs(Debut Year)1	14.932	-32.364	62.227	0.536
bs(Debut Year)2*	51.135	19.747	82.523	0.001
bs(Debut Year)3	18.835	-13.227	50.897	0.25
Speed Positions*	14.003	10.749	17.256	< 0.001
Linemen Positions*	11.073	7.741	14.406	< 0.001
Depression Symptoms				
bs(Debut Year)1	0.304	-2.601	3.208	0.838
bs(Debut Year)2	1.265	-0.672	3.202	0.20
bs(Debut Year)3	1.198	-0.774	3.17	0.234
Speed Positions*	0.23	0.031	0.428	0.024
Linemen Positions	0.197	-0.007	0.401	0.058

*This model is adjusted for age spline, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Exploring Changing Trends in Concussion Symptom Score and Depression Symptom Reporting within Rules-Based Eras

In exploring changes in concussion symptom and depression symptom reporting trends by rule-change eras, three datasets, one for each era, were created. The results are presented below.

Era Demographics

Of the entire cohort of 4,162 former ASF players, there were 1,239 (29.8%) who played between 1960 and 1976, 2,771 (66.6%) who played from 1977-2010, and 152 (3.7%) who played in 2011 and beyond (Table 4). Players of color were most represented in the 1977-2010 era with 46.6% of the cohort identifying as Black, and those who

identified as “other” represented 6.6% of the 2011-2019 cohort (Table 4). In addition, the 1960-1977 cohort reported the most former players with a BMI less than 30.0, including 8.2% (102) under 25.0 and 43.9% (544) between 25.0 and 30.0 (Table 4). The 1977-2010 group, though, reported the most players with a BMI over 30.0 at 55.8% (1,547) (Table 4).

Era Football Exposures

Across the three eras, the most commonly endorsed main positions included linebackers, offensive line, and defensive line (Table 4). Of the entire cohort, 57.4% (2,389) former players were categorized as playing speed positions, 34% (1,416) reported playing linemen, and 8.6% (357) were categorized as skill players (Table 4). The average number of seasons played decreased by era with an average time spent playing professional ASF of 7.3 (3.8) years in the 1960-1976 era, 6.5 (3.8) years in the 1977-2010 era, and only 3.3 (2.5) years in the 2011-2020 era (Table 4). Average time since their professional career also decreased with each era with the 1960-1976 group reporting an average of 40.4 (6.5) years since play, 17.1 (9.9) years in the 1977-2010 group, and 3.4 (1.4) years since play in the 2011-2020 group (Table 4).

Era Concussion Symptom Scores and Depression

Those who played in the 1977-2010 era reported the highest average CSS with a score of 33.4 (28.1) (Table 4). The 1977-2010 era players also reported the highest depression scores with an average of 1.5 (1.7) (Table 4). These were slightly higher averages than what was reported across the entire cohort who had an average concussion symptom score of 40.7 (27.2) and a PHQ-2 score of 1.4 (1.7) (Table 4).

Table 4. Demographic Characteristics and Football Exposures of all Completers by Rules-Based Eras.

	1960-1976 (*N*=1239)	**1977-2010 (*N*=2770)**	**2011-2020 (*N*=152)**	**Total (*N*=4162)**	***p*-value**
Age					< 0.001
Mean (*SD*)	69.0 (5.8)	45.3 (9.6)	28.4 (2.0)	51.8 (14.4)	
Range	49.0 - 89.0	25.000 - 76.0	24.0 - 36.0	24.0 - 89.0	
Race					< 0.001
White	913 (73.7%)	1364 (49.2%)	86 (56.6%)	2364 (56.8%)	
Black	274 (22.1%)	1290 (46.6%)	55 (36.2%)	1619 (38.9%)	
Other	24 (1.9%)	92 (3.3%)	10 (6.6%)	126 (3.0%)	
Missing	28 (2.3%)	24 (0.9%)	1 (0.7%)	53 (1.3%)	
Current BMI					< 0.001
<25.0	102 (8.2%)	110 (4.0%)	10 (6.6%)	222 (5.3%)	
25.0-30.0	544 (43.9%)	1099 (39.7%)	67 (44.1%)	1711 (41.1%)	
>30.0	582 (47.0%)	1547 (55.8%)	73 (48.0%)	2202 (52.9%)	
Missing	11 (0.9%)	14 (0.5%)	2 (1.3%)	27 (0.6%)	
Number of NFL seasons					< 0.001
Mean (*SD*)	7.3 (3.8)	6.5 (3.8)	3.3 (2.5)	6.6 (3.8)	
Range	1.0 - 26.0	1.0 - 25.0	1.0 - 16.0	1.0 - 26.0	
Missing	26	52	0	78	
Years since NFL play					< 0.001
Mean (*SD*)	40.4 (6.5)	17.1 (9.9)	3.4 (1.4)	23.5 (14.3)	
Range	18.0 - 56.0	0.0 - 40.0	1.0 - 8.0	0.0 - 56.0	
Missing	0	2	1	3	
Main position					0.004
Defensive back	175 (14.1%)	409 (14.8%)	14 (9.2%)	599 (14.4%)	
Defensive line	162 (13.1%)	340 (12.3%)	22 (14.5%)	524 (12.6%)	

Kicker	30 (2.4%)	97 (3.5%)	2 (1.3%)	129 (3.1%)	
Linebacker	196 (15.8%)	420 (15.2%)	18 (11.8%)	634 (15.2%)	
Offensive line	257 (20.7%)	600 (21.7%)	35 (23.0%)	892 (21.4%)	
Quarterback	71 (5.7%)	117 (4.2%)	7 (4.6%)	195 (4.7%)	
Running back	130 (10.5%)	252 (9.1%)	10 (6.6%)	392 (9.4%)	
Tight end	76 (6.1%)	224 (8.1%)	23 (15.1%)	323 (7.8%)	
Wide receiver	136 (11.0%)	287 (10.4%)	18 (11.8%)	441 (10.6%)	
Special teams only	6 (0.5%)	24 (0.9%)	3 (2.0%)	33 (0.8%)	
Position Category					0.929
Skill position	107 (8.6%)	238 (8.6%)	12 (7.9%)	357 (8.6%)	
Linemen	419 (33.8%)	940 (33.9%)	57 (37.5%)	1416 (34.0%)	
Speed position	713 (57.5%)	1592 (57.5%)	83 (54.6%)	2389 (57.4%)	
Concussion Symptom Score					< 0.001
Mean (*SD*)	25.0 (24.2)	33.4 (28.1)	26.8 (24.9)	30.7 (27.2)	
Range	0.0 - 130.0	0.0 - 130.0	0.0 - 105.0	0.0 - 130.0	
Missing	50	38	1	89	
Depression Score					< 0.001
Mean (*SD*)	1.1 (1.6)	1.5 (1.7)	1.4 (1.4)	1.4 (1.7)	
Range	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	0.0 - 6.0	
Missing	3	3	1	7	

Non-linear Multivariable Models by Era

Concussion symptom score reporting trends by debut year in three rules-based eras

Multivariable, non-linear regression models which assessed concussion symptom reporting by debut year within each of the three identified rules-based eras, 1960-1976, 1977-2010, and 2011-2020, showed similar patterns as was demonstrated in Figure 1 such that there was an increase in reporting from 1960-1976 (Figure 5), almost a flat line from 1977-2010 (Figure 6), then a decrease after 2011 (Figure 7). However, none of the models demonstrated any significant difference in concussion symptom reporting by debut year within each of these eras (Table 5). Additionally, although the general trend in reporting was down from 2011-2020, the shape of the line showed a slight increase in reporting between 2013 and 2015 (Figure 7).

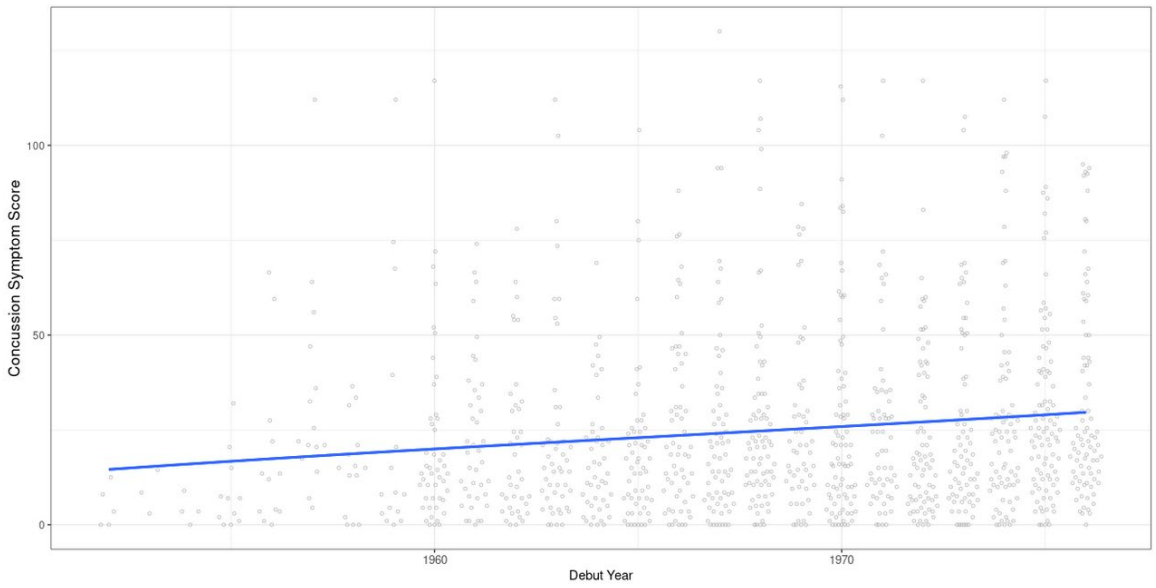

Figure 5. CSS Reporting by Professional ASF Debut Year from 1960-1976.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

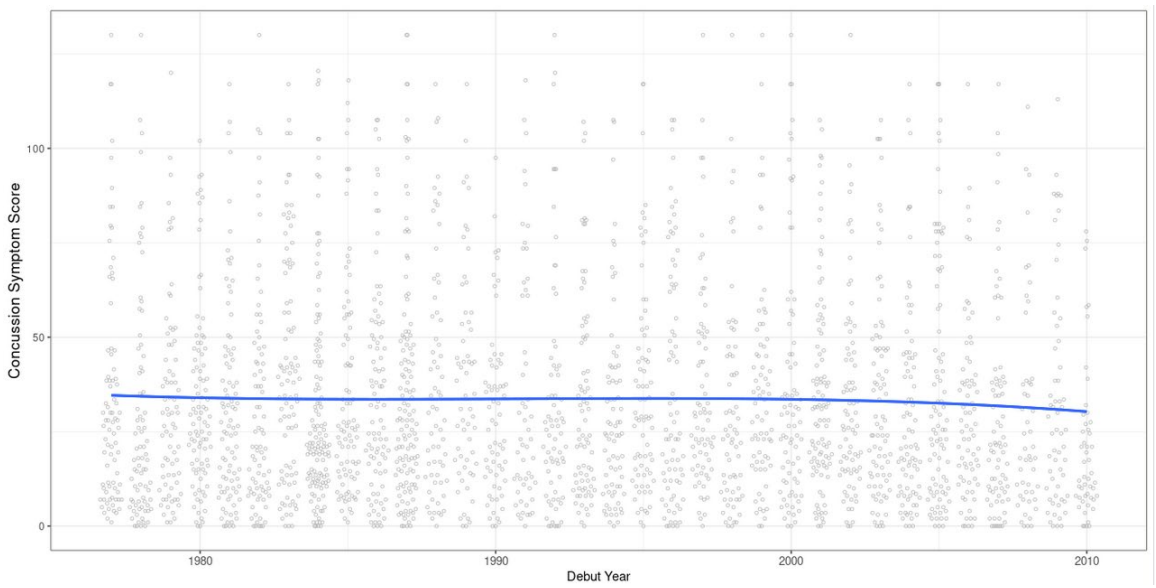

Figure 6. CSS Reporting by Professional ASF Debut Year from 1967-2010.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

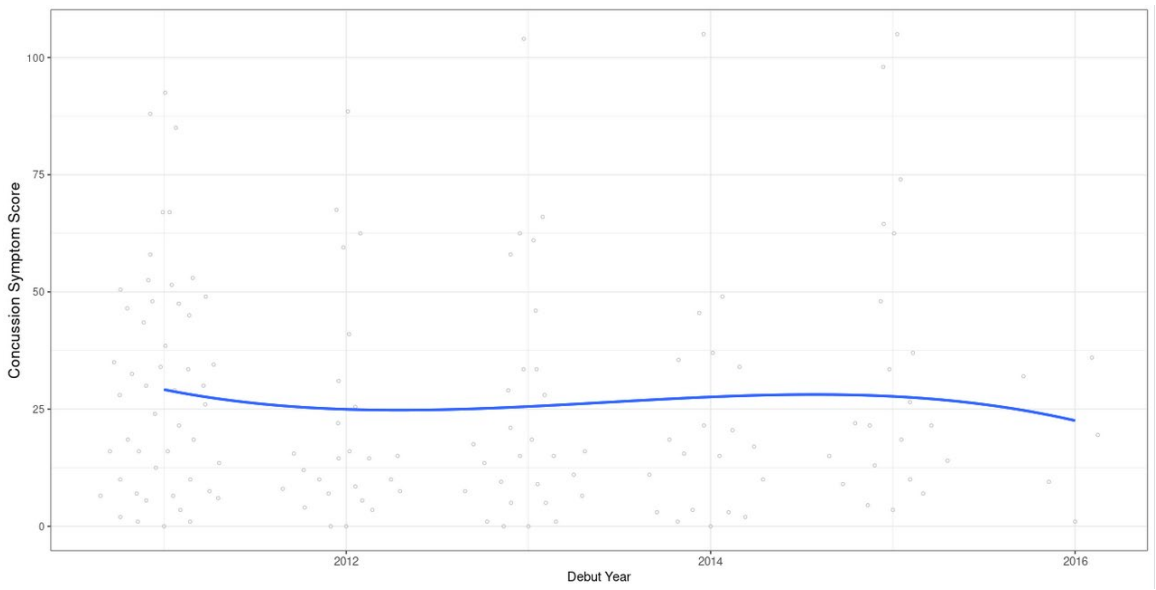

Figure 7. CSS Reporting by Professional ASF Debut Year from 2011-2020.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

Table 5. CSS Reporting by Debut Year in Rules-Based Eras.

	Estimate	95% CI		*p*
		LL	*UL*	
Concussion Symptom Score in 1960-1976 Debut Year	0.424	-0.348	1.196	0.282
Concussion Symptom Score in 1977-2010 Debut Year	0.126	-0.327	0.58	0.585
Concussion Symptom Score in 2011-2020 Debut Year	-2.257	-5.422	0.909	0.162

*This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Depression symptom reporting trends by debut year in three rules-based eras

Similar non-linear models were run to examine how depression reporting changes by debut year in the three identified rules-based eras. Trends of reporting in each era mostly reflected what had been seen across the entire 1960-2020 timeframe in Figure 2 with a gradual increase in depression symptom reporting from 1960-1976 (Figure 8), a sustained height in reporting from 1977-2010, and a small decrease in reporting after 2010 (Figure 9). However, in the 2011-2020 era a slight increase in reporting can be seen starting around 2013 (Figure 10) which was not seen in the entire cohort (Figure 2). Just as with concussion symptom score reporting, there was no demonstrated significant difference in depression symptom reporting by debut year within each of these eras (Table 6).

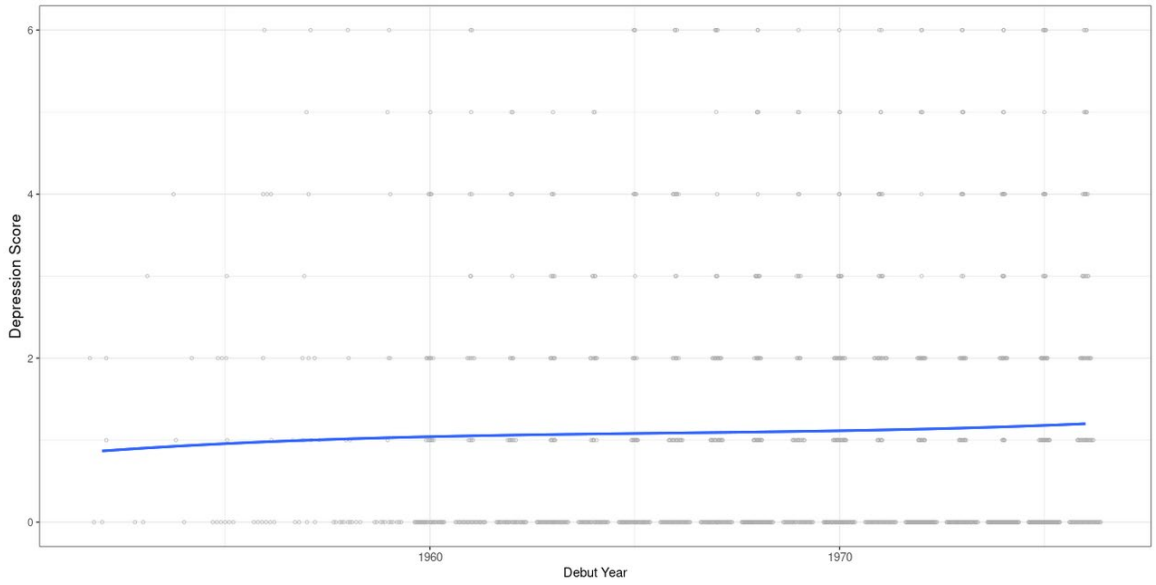

Figure 8. Depression Symptom Reporting by Professional ASF Debut Year from 1960-1976.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

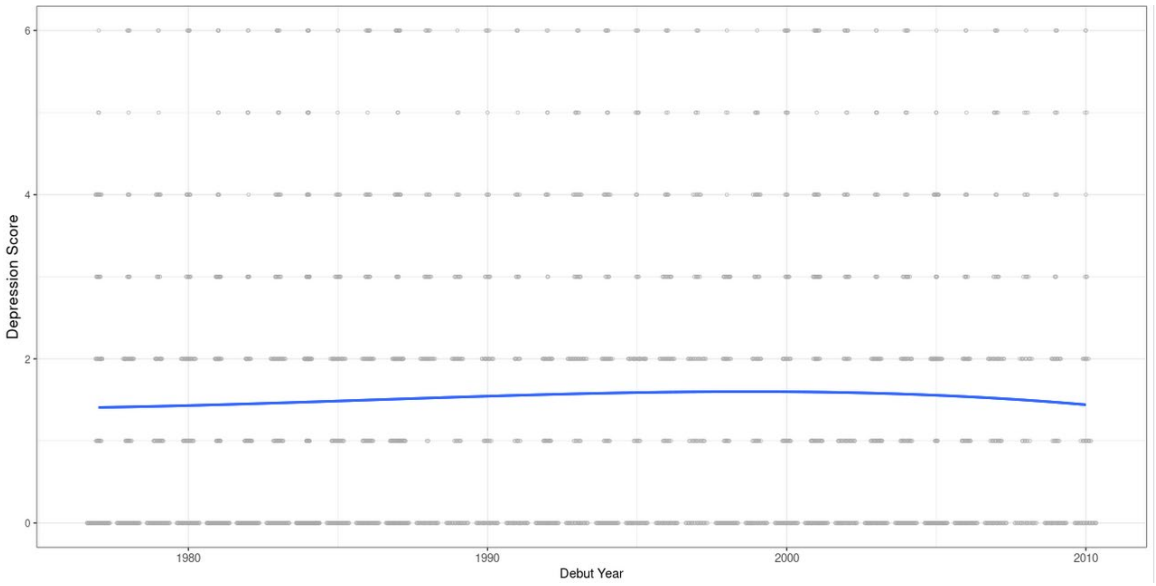

Figure 9. Depression Symptom Reporting by Professional ASF Debut Year from 1977-2010.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

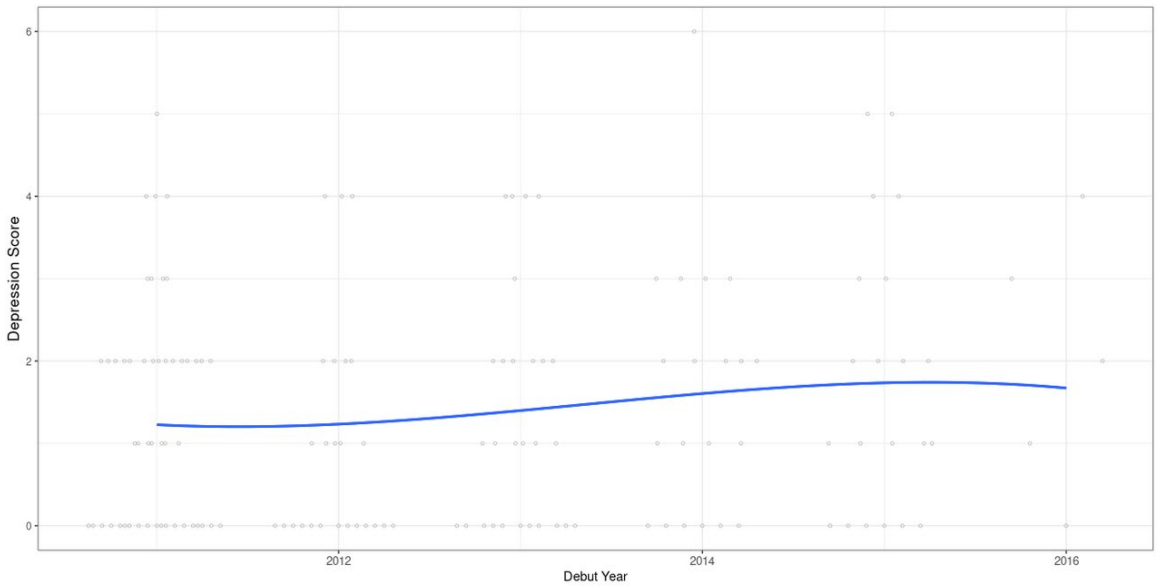

Figure 10. Depression Symptom Reporting by Professional ASF Debut Year from 2011-2020.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

Table 6. Depression Symptom Reporting by Debut Year in Rules-Based Eras.

	Estimate	95% CI		*p*
		LL	*UL*	
Depression Symptoms in 1960-1976 Debut Year	0.008	-0.042	0.059	0.743
Depression Symptoms in 1977-2010 Debut Year	0.017	-0.01	0.044	0.227
Depression Symptoms in 2011-2020 Debut Year	0.089	-0.093	0.271	0.339

*This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Concussion symptom score and depression symptom reporting in three rules-based eras by position category

Non-linear models stratified by position category within the 1960-1976 and 1977-2010 eras showed similar patterns to what was seen in Figures 5 and 6. All position categories followed the pattern of increased concussion symptom reporting from 1960-1976 (Figure 11) followed by heightened reporting from 1977-2010 when a gradual decrease in reporting appears (Figure 12). In each of these eras, linemen *(*$p = 0.06$ and $p < 0.001$*)* and speed positions *(*$p < 0.001$ and $p = 0.001$*)* (Table 7) reported similar concussion symptom scores as each other and higher scores than skill positions. This similarity in reporting trends was also found in non-linear models predicted depression reporting in the 1960-1976 and 1977-2010 eras, stratified by position category (Figures 13 and 14). Linemen and skill positions reported the most depression symptoms compared to skill positions in these eras and all positions followed the shape of the trends seen in Figures 8 and 9 (Figures 13 and 14). However, only in the 1960-1976 era did speed *(*$p = 0.05$*)* and linemen *(*$p = 0.05$*)* positions report significantly more depression symptoms than skill players (Table 8).

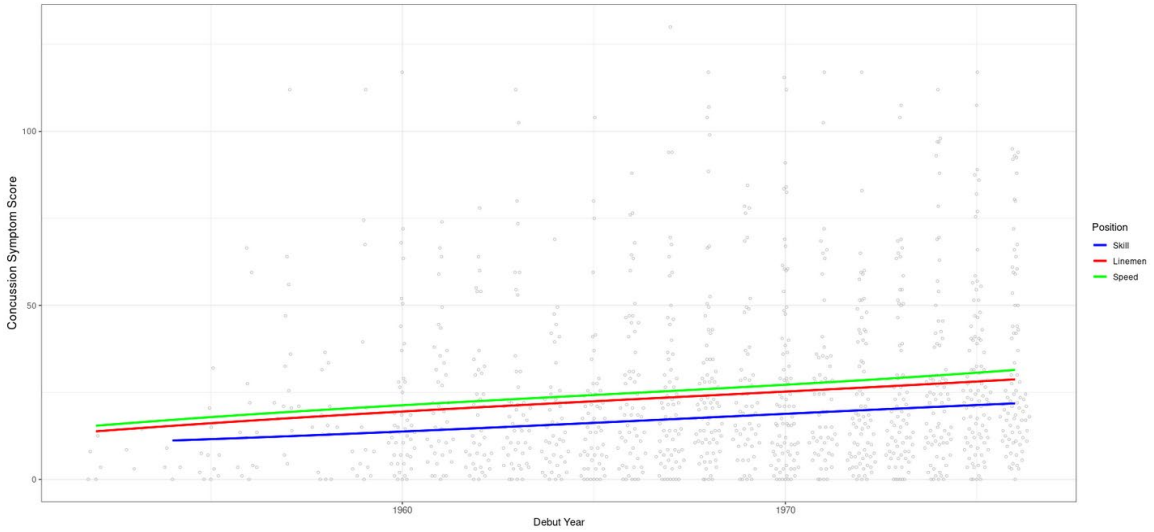

Figure 11. CSS Reporting by Professional ASF Debut Year from 1960-1976 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

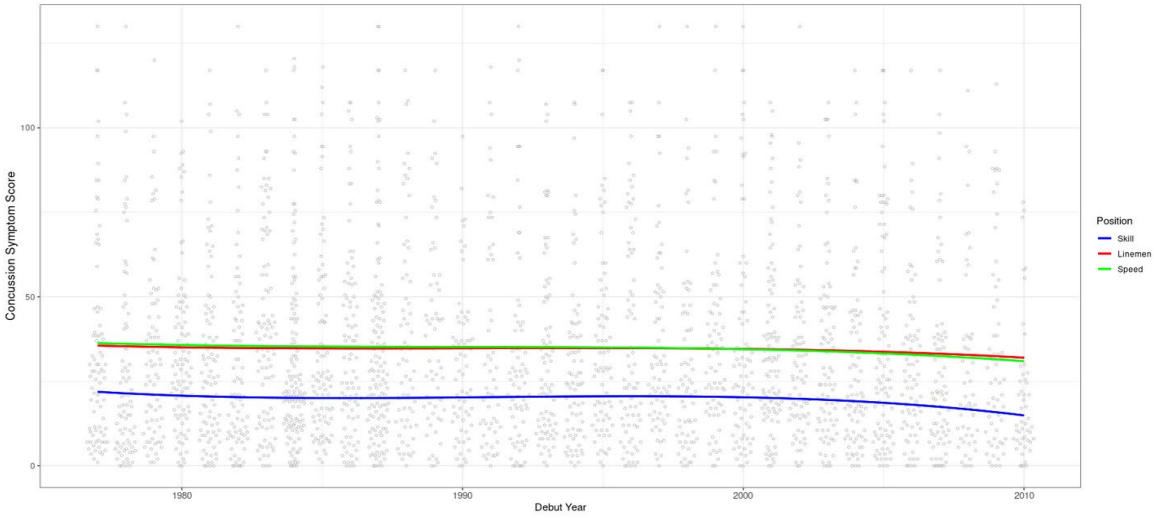

Figure 12. CSS Reporting by Professional ASF Debut Year from 1977-2010 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

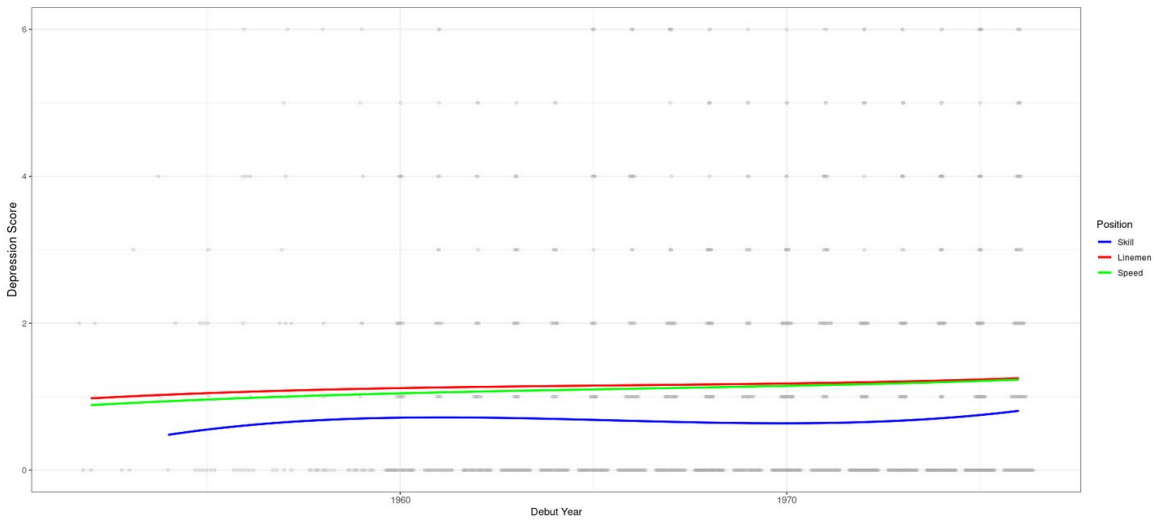

Figure 13. Depression Symptom Reporting by Professional ASF Debut Year from 1960-1976 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

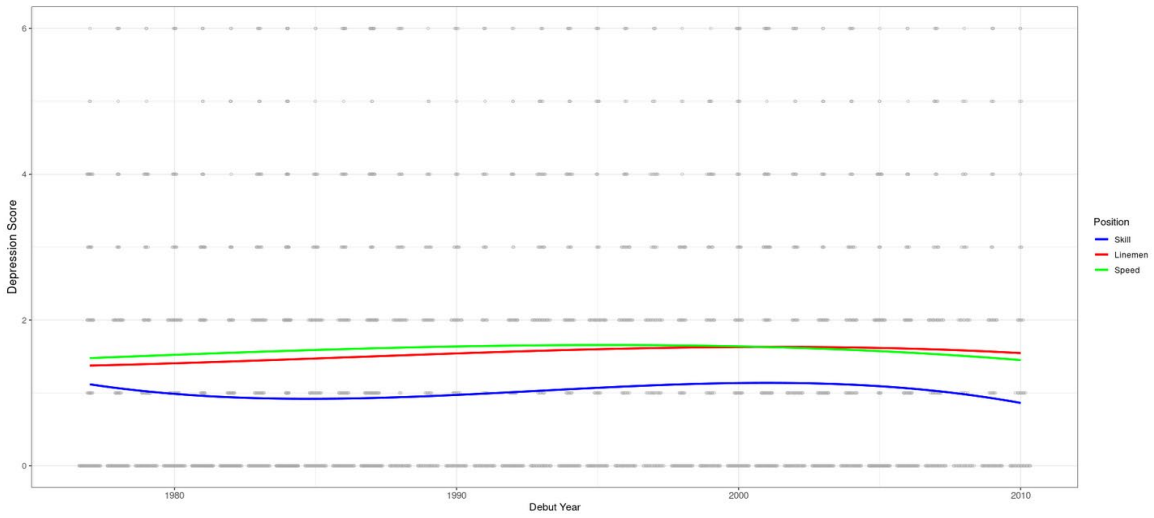

Figure 14. Depression Symptom Reporting by Professional ASF Debut Year from 1977-2010 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

In the 2011-2020 era, neither concussion symptom score reporting nor depression reporting were uniform across all positions (Figure 15 and 16). For linemen, concussions symptom score reporting maintained a mostly flat line (Figure 15) while their depression reporting increased throughout the era (Figure 16). Speed positions also reported increasing depression symptoms until approximately 2015 where scores dropped below those of both linemen and skill positions (Figure 16). Concussion symptom score reporting in speed positions showed two U-curves where reporting was lowest between 2011 and 2013, was then highest out of all position categories from 2014 to 2015 and then decreased to similar concussion symptom reporting as skill positions (Figure 15). In both concussion symptom score and depression score, skill positions demonstrated a U-curve in their reporting trends (Figures 15 and 16). They maintained their position as the

lowest concussion symptom score reporters throughout this era (Figure 15), but surpassed speed positions in depression reporting around 2016 at which point their symptom reporting reached similar scores to that of linemen (Figure 16).

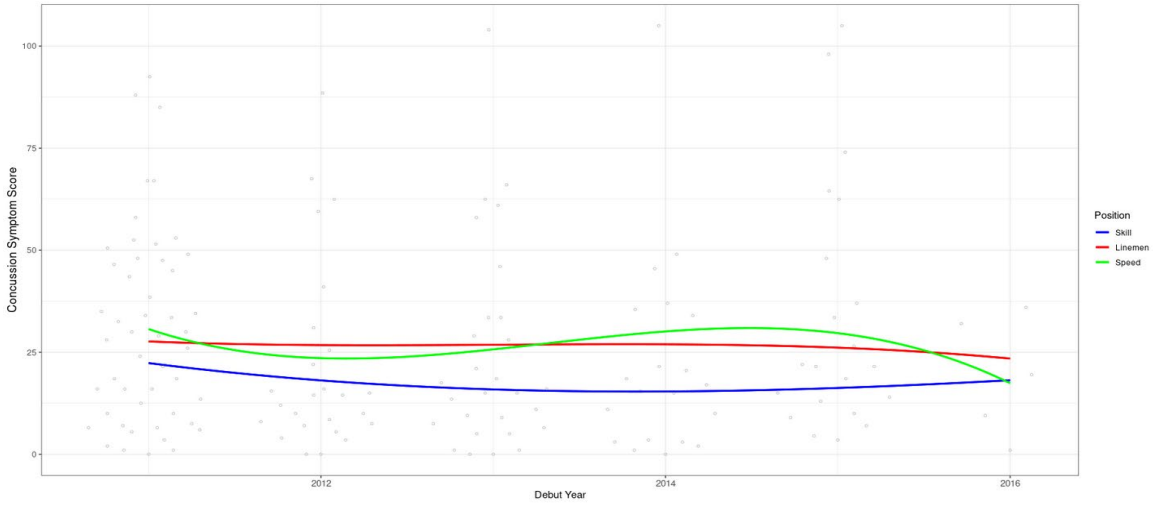

Figure 15. CSS Reporting by Professional ASF Debut Year from 2011-2020 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of NFL seasons spline.

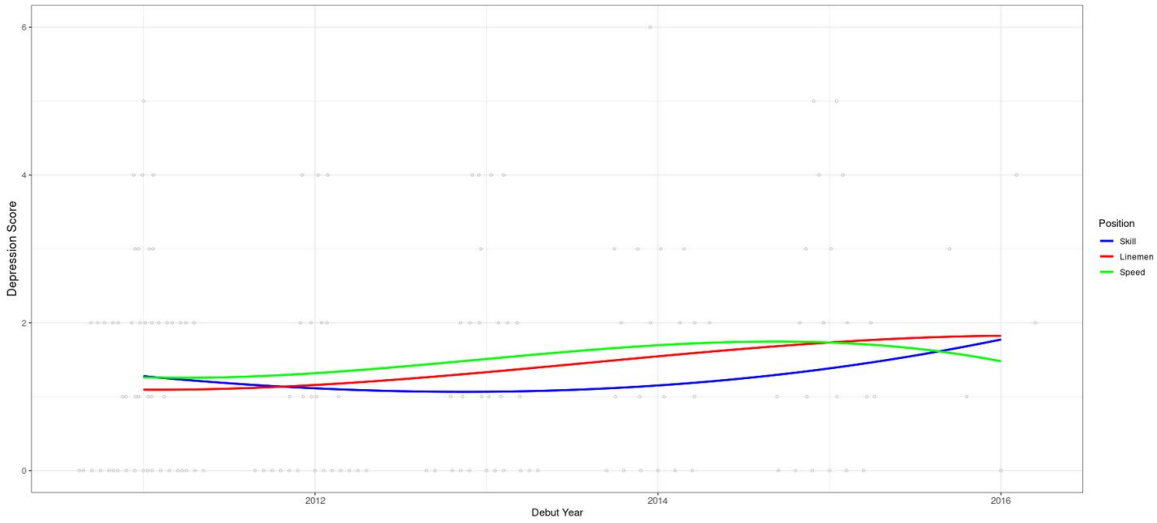

Figure 16. Depression Symptom Reporting by Professional ASF Debut Year from 2011-2020 Stratified by Position Category.

This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline.

Table 7. CSS Reporting by Debut Year in Rules-Based Eras Stratified by Position Category.

	Estimate	95% CI		*p*
		LL	*UL*	
Concussion Symptom Score in 1960-1976				
Debut Year	0.528	-0.242	1.299	0.179
Speed Positions*	8.865	3.567	14.164	0.001
Linemen Positions	5.217	-0.241	10.675	0.061
Concussion Symptom Score in 1977-2010				
Debut Year	0.177	-0.301	0.655	0.469
Speed Positions*	16.525	12.338	20.711	<0.001
Linemen Positions*	13.203	8.928	17.478	<0.001
Concussion Symptom Score in 2011-2020				
Debut Year	-2.473	-5.653	0.707	0.128
Speed Positions	11.577	-4.924	28.077	0.169
Linemen Positions	13.38	-4.142	30.901	0.134

*This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Table 8. Depression Symptom Reporting by Debut Year in Rules-Based Eras Stratified by Position Category.

	Estimate	95% CI		*p*
		LL	*UL*	
Depression Symptoms in 1960-1976				
Debut Year	0.012	-0.039	0.062	0.652
Speed Positions*	0.349	0.007	0.691	0.045
Linemen Positions*	0.357	0.005	0.709	0.047
Depression Symptoms in 1977-2010				
Debut Year	0.023	-0.006	0.052	0.125
Speed Positions	0.183	-0.069	0.435	0.155
Linemen Positions	0.103	-0.155	0.361	0.434
Depression Symptoms in 2011-2020				
Debut Year	0.085	-0.099	0.27	0.364
Speed Positions	-0.057	-1.018	0.903	0.907
Linemen Positions	0.074	-0.944	1.091	0.887

*This model is adjusted for age, race, current BMI, and number of professional ASF seasons spline. *Statistically significant.*

Chapter IV.

Discussion

The aims of this work were 1) to demonstrate whether there was a change in retrospective concussion symptom score and depression symptom reporting by professional ASF debut year, 2) whether trends in reporting change by position category, and 3) if changing reporting by debut year can be attributed to pre-determined rules-based eras. The data presented above demonstrate that retrospective concussion symptom score and depression symptom reporting do change relative to the time that former ASF players were in the league, regardless of position. However, it is not clear that rule changes are a major driving force of these trends, although it likely plays a role. Identifying factors that contribute to concussion symptom reporting remains important in understanding what puts football players at risk for concussion exposure and the mental health consequences that follow.

Research Findings

A non-linear relationship between concussion symptom score and debut year and depression symptom reporting and debut year were found. A clear gradual increase in concussion symptom reporting was found in those who played from 1960 to the late 1970s or 1980 at which point reporting appears to be sustained at its peak until tapering off around the early 2000s and reporting decreases. As depression has been found to be associated with concussions (Plessow et al., 2020; Roberts et al., 2021; Vos et al., 2018) and the Concussion Symptom Score (Roberts et al., 2021) it is not unexpected that

depression reporting trends change in a similar way to concussion symptom reporting by debut year.

Secondly, it was found that position category did not change how concussion symptom score, nor depression symptoms, were reported by debut year in former professional ASF players. Previous works have suggested that certain positions are at increased risk of more concussions, more severe concussions, and potentially later-life depression. Linemen, in particular, have been highlighted as at risk for frequent head hits due to the nature of their position (Martini et al., 2013) while others note that the faster, speed positions may not get hit as often but sustain larger concussions leading to more severe symptoms (Nathanson et al., 2016). These data agree that linemen and speed positions report more concussion symptoms and depression symptoms than their skill position peers, with linemen and speed positions reporting similarly across the 1960-2020 timeline. Interestingly, though, trends in concussion symptom score and depression symptom reporting in all three position categories, linemen, speed, and skill, mirrored one another, suggesting that changes in reporting trends over time are not position dependent.

Next, it was found that changes in concussion symptom score and depression reporting cannot be fully explained by ASF rule changes. The non-linear model of concussion symptom score reporting across the 1960–2020 timeframe demonstrated increased reporting from 1960 to the early 2000s, at which point reporting begins to decrease. Upon visual inspection, non-linear models of concussion symptom score reporting in each of the pre-determined, rules-based eras, 1960-1976, 1977-2010, and 2011-2020, showed similar patterns. In 1977, the third CBA was signed that enforced no

contact practices while 2011 marked the beginning of a mandated Concussion Protocol, fewer padded practices allowed in a season, and the banning of multiple hitting techniques in game play (NFL Management Council & NFLPA, 2011). The decreased concussion symptom score reporting after 2011 follows the variety of rule changes that occurred after 2011, but the increased reporting in the late 1970s into the 2000s is unexpected if we assume that fewer contact practices would lead to fewer potential head injury exposures.

The 1960-1976 and 1977-2010 eras demonstrate a similar pattern seen in depression reporting across the 1960-2020 timeframe, and they also follow similar trends to concussion symptom reporting during these eras, with increased reporting until the 2000s. However, in the 2011-2020 era, depression reporting increases again after 2012, rather than gradually decreasing the same way concussion symptom score reporting had. As depression and concussion symptoms have been demonstrated to be closely associated (Roberts et al., 2019; Vos et al., 2018) it would be expected to see depression reporting follow that similar trend downward. However, this may make a case for the impact of societal conversation around depression and head injury changing.

There are likely a few factors that may explain these reporting trends including rule changes, updated helmet technology, and societal conversation around head injury. It has been suggested that educating athletes in concussions and how to identify them has increased intention to report which eventually leads to higher rates of concussion reporting (Kroshus, et al., 2015). On top of education practices, media attention surrounding concussions and their negative outcomes has been credited with breaking down masculine norms, common in football, that may have deterred players from

reporting in earlier years (Anderson & Kian, 2012). Increased societal attention may partially explain increased depression symptom reporting by educating about and normalizing symptoms, especially as many of these educational and media efforts have occurred after the 2000s (Schmidt et al., 2020; Shpigel, 2022), when reporting appears to increase.

Some unexpected trends in concussion symptom score and depression symptom reporting by position category also appeared in the 2011-2020 era. Namely, around 2014, speed positions began to report fewer concussion and depression symptoms, especially compared to linemen, and skill players, such as quarterbacks, kickers, and special teams players. This is particularly interesting as previous works have suggested that quarterbacks and kickers report fewer concussion symptoms than other positions (Dai et al., 2018), thus it may be assumed that they would report less depression. It is possible that increased societal awareness and acceptance of depression and concussion symptoms is also influencing the increased reporting. With changes around masculine norms and mental health acceptance in recent years (Anderson & Kian, 2012; Baumeister et al., 2015), it is plausible that concussion and depression symptom reporting in football players may be increasing because players feel they have more space to be open about their experiences now than they did in earlier decades. These trends also suggest that rule changes may impact certain positions differently. Perhaps adopting rules such as the "Use of Helmet" rule (NFL, 2023b) have protected speed players from being hit helmet-to-helmet, decreasing their head injury exposure, and leading to less depression reporting down the road. However, these data cannot make any conclusions about the weight of rule changes, societal influences, or others in how concussion and depression symptom

reporting changes by debut year. Another influence of reporting trends may be the work in updating and improving helmet technology for professional ASF players throughout history.

The high rates of concussion symptom reporting from the late 1970s to around 2000 was unexpected when one considers that those players in 1977 and beyond had rules which limited contact practice hours and helmet designs were supposedly improved from the 1960s to early 1970s (NFL, 2022; NFL Management Council & NFLPA, 1993). If such improvements limited head injury exposure, symptom reporting should decrease. Some of these changes may be explained by the introduction of the NOCSAE standards for helmet technology in 1973 (Levy, et al., 2004). Intuition would suggest that new safety standards and increased efforts to develop more effective helmets would lead to a decrease in concussion exposure and therefore concussion and depression symptom reporting. However, determining what helmet features are most effective in keeping players safe means figuring out which features do not. It is possible that, with more testing occurring after 1973, players were not wearing the safest helmets on the market. It was found that helmets developed after 2010 were responsible for significantly lower head responses than those used from 1970-1990 (Viano & Halstead, 2012), which follows the general trend downward in both concussion symptom score and depression symptom reporting at that time. Additionally, recent helmet technology has focused on creating position specific helmets (NFL, 2022). This may partially explain the decreased concussion symptom and depression reporting in speed players but is curious in contrast with the increased reporting in skill and linemen positions, where most of the work on position-specific helmets have been directed (NFL, 2022).

Such findings exemplify the challenge in teasing out the drivers of change in concussion and depression reporting. The overlap of societal influences, changes in ASF rules, and updated helmet technology are to be considered when determining what factors are responsible for reporting changes over time. This work cannot definitively determine that rule changes have not kept players safe because awareness and willingness to report depression has increased and helmet technology has only become more effective over time. It is important to give credit to all potential influences when considering player health and safety in this way.

Research Limitations

Due to the self-reported nature of the data collected in the FPHS First Health and Wellness Questionnaire, a major limitation of this work is exposure misclassification, and recall bias, especially in participants' reports of health history, concussion symptom score, and number of diagnosed concussions. In general, self-reported data are difficult to verify. Furthermore, concussion symptom reporting also depends on participants' memory of events that occurred years ago (Grashow et al., 2022). As concussions and their symptoms cannot be verified, concussion data may not be accurate. Additionally, the complex relationship between depression and concussion has yet to be untangled (Brett et al., 2019; Iverson et al., 2023). This work did not consider comorbid health outcomes that can both impact mood and be affected by concussion history, so was not able to provide a definitive connection between depression and concussion history independent of other influences.

Another limitation of this work is the potential misclassification of players into specific rules-based eras based on their professional ASF debut year. Using debut year as criteria for era categorization ignores the likely possibility of certain players beginning their careers in one era while most of their career was spent playing in the next one. Similarly, special teams only players may not be best categorized as skill players with quarterbacks and kickers. Special teams players have a unique job in football where some play a position more closely aligned to linemen while others play a position more closely aligned to speed players. However, those who only play on special teams tend to play the fewest snaps, just 6%, in a game (NFL, 2023a). None of the three position categories accurately captures the true role of a special teams player, but with such little on-field exposure, categorizing them with quarterbacks and kickers, who are thought to be less exposed to head injury (Dai et al., 2018; Roberts et al., 2019), fit for this work.

This work is also limited in that it cannot draw conclusions about what changes, societal, rules, or helmet technology, are affecting how concussion and depression reporting changed over time. It is likely that a combination of these factors, and others, impacts perception, awareness, and willingness to report. As these factors have been happening continuously and synchronously throughout football's history, even splitting the data by eras of rule changes does not eliminate the impact of societal influences or changing helmet technologies.

Future Research

Longitudinal research would aid in determining associations between debut year, concussion exposure, depression symptoms, and rule-based changes. That is, studies with

repeated measurements could verify concussion reporting by following players during their careers and collecting data on concussions as they happen. Additionally, recreating this work while re-categorizing players into eras where they spent most of their career or only analyzing those who played in a single era would strengthen any associations found between concussion symptom score and depression symptom reporting by debut year in specific eras. Also, identifying inflection points of changing concussion and depression symptom reporting through statistical analyses would help to verify if changes in reporting align with years where new rules were implemented. Another extension of this work could be a psychological-historical approach to understand whether social influences, especially conversations around head injury in the NFL and masculinity and mental health, have impacted the rate of concussion and depression reporting in this cohort. It is feasible that concussion symptom reporting, and self-reported depression have increased overtime due to the normalization of these health issues and may overshadow the potentially positive effects of rule changes and their efforts to protect player health.

Conclusions

Throughout the football's history, changes have been implemented (e.g., rule changes, helmet technology) in an effort to limit head injury exposure and its consequences in American-style football players. To date, studies that evaluate the efficacy of these updates are lacking. Additionally, societal perceptions of concussion and depression change will impact reporting. These data show a changing pattern in concussion and depression symptom reporting overtime but cannot determine whether rule changes or other factors are contributing to that change. In fact, this work represents

one of the first steps in understanding changing patterns of concussion symptom reporting. It also sets up further research to identify the elements that influence such reporting to determine if and how we can continue to improve safety measures for football players and, hopefully, their mental health after the game.

Appendix I.

Concussion Symptom Score

While playing or practicing football, did you experience a blow to the head, neck, or upper body followed by:

	No	Once	2-5 times	6-10 times	11 or more
Headaches					
Nausea					
Dizziness					
Loss of consciousness					
Memory problems					
Disorientation					
Confusion					
Seizure					
Visual problems					
Weakness on one side of the body					
Feeling unsteady on your feet					

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