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Utility of providing a concussion definition in the assessment of concussion history in former NFL players

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Abstract

Objective: Former National Football League (NFL) players working knowledge of concussion has not yet been evaluated, despite this population being a major clinical research target due to the association between repetitive head impacts (RHI) and long-term clinical impairments. This study examined former NFL players' understanding of the current concussion definition, and the association between number of concussions with clinical function.

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Methods: 95 former NFL players (mean age=55.29; mean NFL year=8.10) self-reported number of concussions before being provided with a concussion definition and after being read a modern definition of concussion. Subjects reported number of concussions with loss of consciousness (LOC). Principal Component Analysis of a battery of tests generated behaviour/mood, psychomotor speed/executive function, and verbal and visual memory factor scores.

Results: Post-definition number of concussions (median=50) was five times the pre-definition (median=10; $p<0.001$). Greater pre- ($p=0.019$) and post-definition concussions ($p=0.036$) correlated with worse behaviour/mood scores, after controlling for years of football played, with specific effects for depressive symptoms and impulsivity. LOC did not account for variance beyond number of concussions.

Conclusions: Practitioners and clinical researchers should provide a definition of concussion in the assessment of concussion history in former football players to facilitate accuracy and standardization.

Keywords

American football; Concussion knowledge; depression; impulsivity; mild traumatic brain injury

Introduction

U.S. professional football players often experience numerous concussions throughout their athletic career[1–4], and recurrent concussions may place this population at risk for later-life clinical impairment. A history of recurrent concussions has been linked with structural and functional brain changes, cognitive impairment, depression, and impulsivity in former National Football League (NFL) players[5–10]. Exposure to repetitive head impacts (RHI; i.e., repetitive symptomatic concussions and asymptomatic subconcussive injuries) is also associated with chronic traumatic encephalopathy (CTE), a neurodegenerative disease that has been diagnosed neuropathologically in former professional American football players[11–13]. Of note, not all neuropathologically diagnosed cases of CTE have had a reported concussion history[14], and the independent contribution of recurrent concussions in the development of later-life neurological and neuropsychiatric impairment remains poorly understood.

Estimating history of recurrent sports-related concussions has become a priority to the practicing clinician and clinical researcher. It is critical, however, that accurate estimates are obtained to optimize clinical care (e.g., determine return to play, provide recommendations for retirement, improve differential diagnosis), and to improve reliability and validity of research study findings. Unfortunately, concussion exposure history is frequently assessed through retrospective self-report, which is often inaccurate. Kerr et al.[3] asked former NFL players to estimate their total number of concussions in 2001 and again in 2010 (using the same questionnaire in a subset of subjects from the initial evaluation) and found only moderate reliability. Kerr et al.[15] recently found low agreement between athlete-recalled and clinically-documented concussion histories in 130 former collegiate athletes. Of the sample, 73% did not know they had a concussion, representing one of the most common reasons for the low agreement.

In addition to recall bias and other limitations associated with retrospective self-report, another possible reason for the inaccuracies and inconsistencies associated with reported concussion exposure history in current and former athletes is its dependence on the individuals' working knowledge of what defines a concussion. The definition of concussion has significantly evolved throughout the years. In the 1940s, the Medical Research Council, Brain Injuries Committee defined concussion to involve unconsciousness or impaired consciousness, often followed by retrograde amnesia [16]. In 1943, Denny-Brown proposed the definition of concussion to be a "type of traumatic paralysis which undergoes spontaneous resolution..." [17]. In the 1960s, the Ad Hoc Committee to Study Head Injury Nomenclature developed a graded system that emphasized loss of consciousness (LOC) less than or greater than five minutes as the prominent indicator of concussion. This was revised by Cantu[18, 19] and Kelly et al.[20] to include symptoms, such as post-traumatic amnesia (PTA) and confusion. In 2009, the Third International Conference on Concussion in Sports stressed the *brief* presentation of any of the following post-head impact symptoms as an indicator of a concussion: headaches, visual disturbances, nausea, dizziness, sleep disturbances, and memory problems[21]. In 2012, the Fourth International Conference on Concussion in Sports made only minor revisions to the definition. This is now the modern medical framework for defining concussion[22–24] and has been used by health legislative (e.g., Center for Disease Control and Prevention (CDC) Heads Up) and sports groups (e.g., National Collegiate Athletic Association, NFL) to facilitate knowledge translation of concussion.

Many current and former athletes still are not aware of the current definition of concussion. Robbins et al.[25] asked over 400 current and former contact- and non-contact sport athletes to estimate their total number of concussions initially without providing any guidance, and then again after providing a modern definition of a concussion. The results showed that the number of post-definition concussions reported doubled the baseline estimate, suggesting the sample lacked understanding of the current medical definition of concussion. This effect was observed in contact and non-contact sport athletes, and at each competitive level (high school, college, and professional). Lack of awareness to the definition of concussion has been observed in other populations, including parents of youth football players [26]. Providing the current definition of concussion to athletes may have important clinical implications, as the number of estimated concussions after being provided with a definition has been shown to correlate with aspects of reported executive function in college and professional American football players[27].

Former NFL players working knowledge of the current definition of concussion is unclear. Older adults, in general, may be more accustomed to more severe symptom sequelae (e.g., LOC, PTA) as the defining features of concussion. Former NFL players are also less likely to be the target of current educational campaigns on concussion, which are usually directed to active players [28–30]. This is concerning given this population is a major clinical research target due to their high exposure history to RHI and related risk for later-life neurological impairment and neurodegenerative disease, including CTE[11, 12].

The purpose of this study was to examine whether former NFL players base their estimates of concussion history on the currently accepted definition of concussion by assessing change

in concussion estimates before and after a definition of concussion is provided. We also investigated the association between pre- and post-definition reported number of total concussions with measures of cognition, mood, and behaviour. The relationship between number of concussions with LOC and these measures of clinical functioning was additionally examined. We hypothesize that the former NFL players estimates of lifetime concussion exposure history will significantly increase after being provided with a modern definition of concussion. Greater pre- and post-definition estimates of concussion history will be associated with worse clinical impairment, and history of LOC will not have any additive clinical utility in predicting clinical function.

Materials and methods

Subjects

The sample included 95 former NFL players that were part of a larger funded study, entitled, “Diagnosing and Evaluating Traumatic Encephalopathy using Clinical Tests” (DETECT). The purpose of DETECT was to develop potential neuroimaging and fluid biomarkers to diagnose CTE during life. Recruitment and data collection for DETECT began in November 2011 and concluded in October 2015. Former NFL players were recruited through the NFL Players Association and/or NFL Alumni Association, in addition to Boston University Alzheimer’s Disease and CTE Center (BU ADCTEC) social media postings, and through word of mouth. All subjects must have been between ages 40–69 years, had a minimum of two years of active playing time in the NFL, and had 12 or more total years of participation in organized tackle football; 12 years was chosen to ensure significant exposure to RHI and risk for CTE[11]. Inclusion criteria also included self-reported complaints of cognitive, behavioural, and mood symptoms for at least six months prior to study entry, as determined by brief questions during telephone screening. Exclusion criteria included English as a second language, MRI and/or lumbar puncture contraindications, and history of any other central nervous system diagnosis. Test effort was also assessed through a combination of methods, including embedded and non-embedded performance validity measures, and evaluation of neuropsychological test scores by two neuropsychologists for any peculiar score profiles. The final sample of 95 was derived following exclusion of one subject due to failure on multiple performance validity tests (embedded and non-embedded measures), neuropsychological scores were at floor, in addition to other external evidence that supported intentional poor effort.

All subjects underwent a single two- to three-day comprehensive evaluation that involved a neurological and motor exam, neuropsychological testing, a structured psychiatric interview, extensive self-report measures of mood and behaviour, neuroimaging, blood and cerebrospinal fluid collection, and genetic testing. Only neuropsychological and neuropsychiatric (i.e., mood, behaviour) data relevant to the current study were examined. All protocols were approved by the local Institutional Review Board. Subjects provided their written informed consent prior to participation and were given a copy of all signed consent forms.

Measures

Concussion history—Subjects were first asked to report the total number of concussions they experienced throughout their lifetime without being provided with a definition of concussion or any other guidance, i.e., they were simply asked how many total concussions they experienced throughout their life. This was the subjects' "pre-definition" response and was based on their own working knowledge of what constitutes a concussion. After subjects provided this initial estimate, a trained research assistant read a definition of concussion that is based on the Centers for Disease Control and Prevention (CDC)[22] statement on sports-related concussion and the consensus statement in sport from the Third International Conference on Concussion in Sport held in Zurich[21]. A more recent consensus statement has been published since the start of DETECT, but the definition of concussion remained similar [23, 24]. The concussion definition read verbatim to each subject included:

"Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. But, in reality, a concussion has occurred anytime you have had a blow to the head that caused you to have symptoms for any amount of time. These include: blurred or double vision, seeing stars, sensitivity to light or noise, headache, dizziness or balance problems, nausea, vomiting, trouble sleeping, fatigue, confusion, difficulty remembering, difficulty concentrating, or loss of consciousness. Whenever anyone gets a ding or their bell rung, that too is a concussion."

After this definition was read, the research assistant then prompted the subject to provide their "post-definition" total number of concussions experienced. Subjects were also asked to report the total number of concussions they experienced that resulted in LOC of any duration.

Cumulative Head Impact Index (CHII)—The CHII is a metric that was developed to retrospectively estimate cumulative exposure to RHI from football[31]. The CHII is based on self-reported athletic exposure (e.g., level of play, seasons played, positions played), and frequency of head impacts received each season using previously published helmet accelerometer studies. The CHII was developed in former amateur football players because there are no helmet accelerometer studies in professional football players. The CHII was thus calculated for each subject in this sample using college level helmet accelerometer statistics for their NFL seasons. The CHII was included in this study in order to provide a metric to relate the post-definition number of concussions to.

Measures of neuropsychological and behaviour/mood Function—All subjects completed a neuropsychological test battery that assessed attention, executive function, psychomotor speed, visual and verbal episodic memory, language, motor, and visuospatial functions. Raw scores were converted to standardized scores that account for age, gender, and/or educational attainment. Participants also completed standardized self-report and semi-structured interviews to assess behaviour and mood symptoms, including depression, suicidality, hopelessness, apathy, aggression, impulsivity, and hostility. A complete list of neuropsychological tests and measures of behaviour and mood have been reported elsewhere [32]. As described previously [32], Principal Component Analysis (PCA) generated four

factors from the neuropsychological and behaviour/mood measures and included: Behavioural/mood, Psychomotor Speed/Executive Function, Verbal Memory, and Visual Memory. PCA was performed to minimize the number of analyses and reduce type I error risk. Sample size was reduced to 85 on factor scores due to missing data on the individual tests that comprise the factor scores.

Statistical analysis

Pre- and post-definition number of concussions, and history of LOC were all highly skewed and kurtotic. Due to the presence of zero as a response for the pre-definition number of concussions and history of LOC, a log ($x+1$) transformation was applied to these variables, and also to the post-definition estimate of concussions to maintain consistency in transformation across variables. Paired-samples t-test examined change in the log-transformed pre- to post-definition number of concussions for the entire sample, as well as by position group. Even with the log transformation, there was one pre-definition estimate that was >3 SD from the sample mean and analyses for the entire sample were repeated after removal of this potential outlier. Bivariate correlations examined the relationship between the log transformed pre- and post-definition number of concussions and the CHII.

Multiple linear regression models were then performed to examine the association between the log-transformed concussion history variables and behaviour/mood and neuropsychological factor scores. All models controlled for years of football played to account for differences in exposure duration. A separate regression model was performed for each concussion variable (i.e., pre- and post-definition concussion, and history of LOC) and each clinical factor score. For those clinical factor scores that demonstrated a significant relationship with LOC, another regression analysis was conducted to determine the clinical utility of a history of LOC beyond total number of concussions. The above regression framework was followed, but a third regression block was added that included history of LOC (block 1 had years of football play, and block 2 included pre- and post-definition number of concussions).

Results

Pre- to post-definition change in number of concussions

Table 1 presents the demographic, athletic, and clinical characteristics of the sample. Subjects reported an average of 154.18 (SD = 595.76; range = 0 to 5000) pre-definition lifetime concussions, and an average of 621.56 (SD = 1939.99; range = 2 to 16360) post-definition concussions. The median pre- and post-definition number of concussions was 10 and 50, respectively. In addition, subjects also reported an average of 4.63 (SD = 16.45; range = 0 to 150) concussions that resulted in LOC. Paired-samples t-test revealed a significant increase in log-transformed pre- to post-definition concussions ($t(94) = -9.70$, $p < 0.001$) that remained significant after removal of the one potential outlier ($p < 0.001$). 87 of 95 subjects' estimates increased following the definition, and the remaining eight subjects estimates were stable. Bivariate correlations showed a negative relationship between age and number of pre-definition lifetime concussions ($r = -0.20$, $p = 0.053$).

Change in pre- to post-definition number of concussions was significant for each position group (see Table 2). Of note, there were no significant differences between linemen (offensive and defensive) and the remaining position groups for pre- ($p = 0.50$) or post-definition concussion ($p = 0.07$), or history of LOC ($p = 0.57$). Bivariate correlations showed total years of football played was not associated with any of the concussion variables ($p > 0.10$ for all), but there was marginal significance for more years played in the NFL and greater number of post-definition concussions ($r = 0.20$, $p = 0.056$). Greater post-definition number of concussions was associated with a higher CHII ($r = 0.28$, $p = 0.006$), however, the pre-definition number of concussions was not associated with the CHII ($r = 0.11$, $p = 0.280$).

Concussion history and neuropsychological test performance

Linear regression analyses controlling for years of football played showed that pre- ($\beta = 0.26$, $p = 0.019$) and post-definition number of concussions ($\beta = 0.23$, $p = 0.036$), as well as number of concussions with LOC ($\beta = 0.29$, $p = 0.008$) correlated with the Behaviour/Mood factor score. In each case, greater number of reported concussions and concussions with LOC correlated with worse current behaviour/mood function. Follow-up partial correlations controlling for years of football played showed specific effects between the pre-definition number of concussions with the Hamilton Depression Rating Scale (HDRS) ($r = 0.20$, $p = 0.042$), Behaviour Rating Inventory of Executive Function—Adult Version (BRIEF) Behavioural Regulation Index (BRI) ($r = 0.27$, $p = 0.010$), the Barratt Impulsivity Scale (BIS-11) ($r = 0.24$, $p = 0.019$), and the Apathy Evaluation Scale (AES) ($r = 0.25$, $p = 0.016$). Post-definition number of concussions correlated with the Beck Hopelessness Scale (BHS) ($r = 0.24$, $p = 0.021$), BIS-11 ($r = 0.27$, $p = 0.009$), and the BRIEF BRI ($r = 0.23$, $p = 0.025$). (Of note, sample size slightly varied across correlations due to missing data on individual tests). When history of LOC was entered by itself in block 3 of the regression model (block 2 included pre- and post-definition concussion estimate), it did not account for any additional variance beyond the pre- and post-definition number of concussions in predicting the behaviour/mood factor score ($R^2 = 0.035$, $p = 0.075$). None of the concussion variables exhibited associations with the Psychomotor Speed/Executive Function, or Visual and Verbal Memory factor composites ($p > 0.10$ for all).

Discussion

The definition of concussion has evolved throughout the years and the currently accepted medical definitions emphasize the possibility of a *brief* presentation of a variety of symptoms following a direct or indirect blow to the head [21, 23, 24]. We found that former NFL players reported number of lifetime concussions significantly increased by approximately five-fold after a current definition of concussion was provided. Pre- and post-definition number of concussions were also associated with self-reported behavioural and mood impairment, particularly symptoms of depression and impulsivity. Number of concussions with LOC correlated with behaviour/mood symptoms, but did not account for any additional variance beyond total number of concussions. Recent work also found LOC did not predict cognitive outcomes in former NFL players [9], and these findings are consistent with previous work that has questioned the additive utility of LOC in grading

concussion severity due to its lack of sensitivity to acute post-concussion symptom sequelae [33, 34].

Lack of awareness to the current definition of concussion is one possible explanation for the increased number of concussions from pre- to post-definition. Former NFL players may be more accustomed to the remote definitions of concussion from the era of their athletic play that emphasize more severe symptoms as defining features, such as LOC or PTA. This claim is somewhat supported by the negative relationship between age and number of pre-definition lifetime concussions. Although a number of educational campaigns by large-scale sport (e.g., NCAA, NFL) and non-profit or government organizations (e.g., Concussion Legacy Foundation, Centers for Disease Control) have been launched to facilitate a shift in perspective towards the modern definition of concussion, these efforts are still relatively new and not yet assimilated into current and former contact sport athletes working knowledge[25]. Moreover, knowledge translation efforts for concussion are often targeted to *active* athletes in order to promote proper concussion management[28–30]. There are several other potential explanations for our findings in addition to lack of awareness. The nature of the study (investigation of neurological outcomes associated with RHI exposure) and simply asking for a repeated estimate of concussion after the definition was provided could have resulted in demand characteristics that contributed to the increased concussion history. However, the eight subjects that remained stable argues against this possibility. Recall bias of remote information could have also been a contributor to our findings. In particular, the current sample included symptomatic former NFL players from the NIH-funded DETECT study, which was designed to recruit subjects at high risk for CTE in order to develop *in vivo* biomarkers to detect and diagnose CTE during life. Consequently, it is possible that memory impairment may have precluded accurate recall of concussion history, including confabulation of injury events. Alternatively, this sample of former NFL players may be more likely to recall a greater number of concussions because of their symptomatic status. It would be important for future work to directly examine former NFL player's perceived definition of concussion to more accurately understand the underlying cause for increased reported concussion history after a definition is provided.

Our findings have potential clinical research implications. First, former NFL players tend to have inconsistent reports of their total number of lifetime concussions[3], raising concerns for accuracy. Former American football players are currently a major target of large-scale clinical research investigations that seek to improve understanding of the long-term sequelae of RHI and recurrent concussions. The validity and reliability of these studies are dependent on self-reported estimates of concussion exposure history. The growing awareness to the long-term consequences of RHI has also led to increased clinical evaluations of former American football players, where practitioners rely on reported concussion history in their case conceptualization and diagnosis. At the present time, self-report is the only available method to quantify total number of lifetime concussions in former athletes. Although medical records would seemingly be a source to ascertain concussion history, a majority of concussions are not reported and medical charts accordingly do not accurately represent an individual's concussion history. Systematically providing a definition to all patients or subjects, as well as explaining the concepts underlying concussion injury, may be a brief method to possibly improve accuracy and reduce inter-individual differences in knowledge

of concussion definition. Until more refined methods for gathering accurate retrospective concussion exposure history are established, developing a uniform definition of concussion to be implemented across studies is essential for improving reliability and validity. Research studies should incorporate a definition of concussion when asking about concussion history and report this definition in publications to facilitate validity of study findings.

Both pre- and post-definition number of concussions correlated with worse behaviour/mood function. Although providing a definition may improve accuracy and standardization, reported estimates of concussion history without providing a definition may still bear important clinical utility in former NFL players. It is likely that the risk level for later-life clinical impairment at the individual level remains constant for the pre- and post-definition estimates. Those with the greatest exposure to RHI (e.g., linemen) may be at higher risk for later-life clinical impairment, and likely to report the most number of concussions (regardless of the definition) relative to other subjects with lower RHI exposure.

Our study provides further evidence for the association between recurrent concussion history and long-term clinical impairment in former NFL players, and found specific effects for depressive symptoms and impulsivity. Extant research has correlated greater reported concussion history with cognitive impairment in former NFL players[7, 9]. In contrast, Wright et al.[9] found that concussion frequency and dose were not independently related to cognitive outcomes in former NFL players. (Of note, when these concussion variables were combined into an index with demographic variables and premorbid intellect, the index predicted cognitive outcomes). However, there have been robust findings (including class 2 evidence) between total lifetime number of concussions and risk for later-life behaviour/mood symptoms in former NFL players, especially depression[5, 7, 35], but also impulsivity[10]. Relative to cognitive impairment, behaviour/mood dysfunction in former NFL players could be more sensitive (or there could be a lower threshold) to chronic axonal damage associated with concussion[8, 36]. White matter alterations of the frontal lobes, in particular, play a key role in the manifestation of depression and impulsivity[37–40]. Frontal lobe white matter dysintegrity has been shown to be strongly associated with depressive symptoms in past work among former professional American football players with a history of concussions[8, 10]. Even more compelling, Goswami et al.[10] found that diffusion imaging of the uncinate fasciculus (the pathway connecting the anterior temporal lobe and orbitofrontal cortex) differentiated former professional American football players with a history of multiple concussions from healthy controls. In this same study, the former football players had thinner anterior temporal lobes, and there were inverse correlations between orbitofrontal cortex thickness and uncinate fasciculus axial diffusivity with aggression and error rates on a go/no-go task (suggestive of impulsivity). Despite the robust evidence supporting the link between recurrent concussion and later-life behavioural/mood problems, due to the cross-sectional nature of this study, it is plausible that greater behavioural/mood symptoms may have also led to increased reporting of concussions. As an example, depression is associated with a negative process biasing, potentially leading to exaggeration of concussion history.

This study is limited in several ways. Some of the former NFL players reported rather extreme values for total number of concussions following the definition and this is likely a

product of the broad definition provided to the subjects. Some former NFL players may have speculated on all of the practices and games they played where they hit their head on each play and calculated an extreme number of concussions. This may have been particularly influenced by aspects of the definition read to them, in which it includes the terms “bell rung” or “ding.” The definition did not provide a temporal component regarding symptom duration, resulting in differences in interpretation of what these terms mean, with some former players possibly interpreting this to be every time they hit their head. Overall, the accuracy of the post-definition number of reported concussions is unclear, and there was no objective component of this study to validate the responses of the subjects. While retrospective video analysis of NFL games is one plausible method to validate self-reported concussion, it would only capture the major head trauma events, and does not address lifetime concussion history or concussions that occurred in practice. The current findings are only generalizable to former NFL players, although lack of awareness to concussion definition has been documented in other more diverse samples of contact and non-contact sport athletes[25]. The cross-sectional design of this study limits casual inferences, and the directionality between relationships reported in this study, notably for concussion history and clinical function, remains unclear. Longitudinal research is needed to examine consistency of concussion recall history over time and its association with changes in clinical status. As previously mentioned, the exact reason for the increase in reported concussions after a definition is provided is not known and likely multifaceted and should be the target of future work. Differences in personality and mental health conditions (e.g., somatization) could have contributed to the extremely high reporting of concussions in some former NFL players. Other possibilities include differences in education level [26], lack of access to healthcare resources, socioeconomic status, to name a few.

One a final note, in the examination of recurrent concussion history in former NFL players, it is critical to consider subconcussive trauma history—possibly a more sensitive predictor of later-life clinical impairment (including cognition) and neurological conditions, like CTE[11, 13, 14]. Former NFL players can experience thousands of subconcussive head impacts throughout their athletic career[41, 42]. A recently developed metric of RHI and subconcussive impacts (i.e., CHII) was shown to have greater predictive validity of later-life clinical outcomes, including cognitive impairment, depression, apathy, and behavioural dysregulation, relative to reported concussion history in a sample of former high school and college football players[31]. Interestingly, the post-definition, but not pre-definition, number of concussions correlated with the CHII, suggesting the the post-definition number of concussions may be capturing many of these more minor head impacts. Future work by our group will examine the utility of the CHII in former NFL players, and the differential role of concussions and subconcussive trauma in the different clinical phenotypes observed in this population[35].

Conclusions

Former NFL players inaccuracies in their self-report of concussion exposure history could potentially compromise the reliability and validity of clinical research evaluations. Providing a definition and explaining the underlying concepts of concussion in the assessment of concussion exposure history may help to improve accuracy and standardization. The current

study also provides evidence for an association between a history of recurrent concussions and later-life neuropsychiatric dysfunction, particularly depressive symptoms and impulsivity, in former NFL players.

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Table 1.

Sample Characteristics of 95 Former NFL Players

	Mean (SD)	n(%)
Age, years	55.29 (7.88)	--
Education, years	16.41 (0.97)	--
^a African American (N = 94)	--	41 (43.6)
^a AFE to football, years (N = 94)	11.93 (2.56)	--
Duration of football play, years	18.22 (3.50)	--
Duration of play in the NFL, years	8.10 (2.80)	--
Total no. of pre-definition of concussions	154.18 (595.76)	--
Total no. of post-definition of concussions	621.56 (1939.99)	--
Total no. of concussions with LOC	4.63 (16.45)	--
Primary Position Group		
Offensive line		28 (29.5)
Running back		8 (8.4)
Tight end		5 (5.3)
Offensive skill		1 (1.1)
Defensive line		15 (15.8)
Linebacker		20 (21.1)
Defensive Back		18 (18.9)
Body mass index, kg/m ²	33.42 (5.09)	--
Played other contact sports	--	24 (25.3)
^a Hypertension (N = 92)	--	47 (51.1)
^a High cholesterol (N = 89)	--	47 (52.8)
^a Diabetes (N = 91)	--	8 (8.8)
^a Heart disease, (N = 90)	--	8 (8.9)
Use of excessive alcohol	--	49 (51.6)
Use of illicit drugs	--	60 (63.2)
^a Use of performance enhancing drugs (N = 87)	--	13 (14.9)

Abbreviations: AFE= age of first exposure, NFL= National Football League; LOC = loss of consciousness

^a sample size reduced due to missing data

Table 2.

Pre- and Post-Definition Number of Concussions Reported by Position

	N	Concussions with LOC	Pre-Definition	Post-Definition	* <i>P</i> -value
Offensive line	28	4.52 (10.64)	119.91 (377.49)	1050.07 (3193.05)	<0.001
Running back	8	5.00 (8.16)	41.06 (94.59)	595.38 (1539.66)	0.032
Tight end	5	0.60 (0.89)	223.90 (487.53)	474.40 (960.77)	0.037
Offensive skill	1	1.00	3.00	11.00	--
Defensive line	15	2.57 (3.90)	71.23 (218.46)	258.33 (338.72)	<0.001
Linebacker	20	9.78 (33.09)	330.93 (1121.02)	576.90 (1195.43)	0.001
Defensive back	18	1.97 (2.17)	119.53 (421.85)	393.72 (1107.93)	0.011

Note. Values are mean (SD) of original responses, but log transformations were used in statistical analyses.

* Paired-samples t-test examined change in pre- to post-definition concussion frequency for each position. Analyses that compared linemen (offensive and defensive) to rest of group showed no between group differences; Abbreviations: LOC = Loss of consciousness