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# Career duration and later-life health conditions among former professional American-style football players

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► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/oemed-2024-109571).

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Received 10 April 2024
Accepted 26 September 2024



**To cite:** Grashow R, Tan CO, Thomas JD, *et al*. *Occup Environ Med* Epub ahead of print: [please include Day Month Year]. doi:10.1136/oemed-2024-109571

## ABSTRACT

**Objectives** Career duration is often used as a metric of neurotrauma exposure in studies of elite athletes. However, as a proxy metric, career length may not accurately represent causal factors, and associations with health outcomes may be susceptible to selection effects. To date, relationships between professional American-style football (ASF) career length and postcareer health remain incompletely characterised.

**Methods** We conducted a survey-based cross-sectional cohort study of former professional ASF players. Flexible regression methods measured associations between self-reported career duration and four self-reported health conditions: pain, arthritis, mood and cognitive symptoms. We also measured associations between career duration and four self-reported ASF exposures: prior concussion signs and symptoms (CSS), performance enhancing drugs, intracareer surgeries and average snaps per game. Models were adjusted for age and race.

**Results** Among 4189 former players (52±14 years of age, 39% black, 34% lineman position), the average career length was 6.7±3.9 professional seasons (range=1–20+). We observed inverted U-shaped relationships between career duration and outcomes (all $p<0.001$), indicating that adverse health effects were more common among men with intermediate career durations than those with shorter or longer careers. Similar findings were observed for play-related exposures (eg, CSS and snaps).

**Conclusions** Relationships between ASF career duration and subsequent health status are non-linear. Attenuation of the associations among longer career players may reflect selection effects and suggest career length may serve as a poor proxy for true causal factors. Findings highlight the need for cautious use of career duration as a proxy exposure metric in studies of former athletes.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Career duration is often used as a proxy metric of neurotrauma exposure in health studies of elite and professional athletes, likely due to ease of recall and verification using public records. However, important considerations related to its use in this setting have not been investigated.

### WHAT THIS STUDY ADDS

⇒ In this study of former professional American-style football (ASF) players, former players with both the shortest and longest careers had comparatively lower risk of adverse health outcomes when compared with players with midrange career lengths. In addition, former professional ASF players with the longest careers reported fewer adverse play-related exposures (eg, concussion history and average number of snaps per game).

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Relationships between ASF career duration and subsequent health status may be non-linear. Specifically, attenuation of associations among longer career players could be related to selection effects resulting in reduced susceptibility of longer career players to certain exposures or to career length serving as a poor proxy for true causal factors.

## INTRODUCTION

There is increasing interest in the possible long-term health impacts of participation in elite-level contact and collision sports.[1–3] Professional American-style football (ASF) participation has been associated with later-in-life cardiovascular disease,[4 5] neurocognitive dysfunction[6–8] and mental health problems.[7–9] An important aspect of prior work has been the search for potential exposures associated with ASF participation and mid-life and late-life health outcomes.

Total professional career duration, a metric that is subject to minimal recall bias and is verifiable using publicly available records, has been used by researchers as a predictor of health outcomes across numerous contact and collision sports including ASF,[10–13] soccer,[14 15] hockey[10 16] and rugby.[10] The use of professional career duration in previous studies as a predictor of subsequent health outcomes has been predicated on the assumption that longer athletic career length equates to more

exposures during playing years that could increase the risk of adverse health outcomes. Support for this concept emerged from studies that reported significant associations between years of professional ASF play and the development of both amyotrophic lateral sclerosis and chronic traumatic encephalopathy neuropathological change.[12 16 17] These data led to the development of ASF risk exposure tools that rely heavily on career length that have been proposed for scientific and clinical use.[13 18]

In contrast, other recent studies examining former ASF athletes in larger cohorts have found that years of play seemed to be protective or have non-significant relationships with outcomes.[5 6 16 19–22] Healthy worker selection bias (HWSB) may be one potential contributor to these findings, whereby retention in employment is differentially associated with health outcomes.[23] Often described in occupational health studies, HWSB remains largely unexplored in sports medicine. We therefore endeavoured to delineate relationships between total years of professional ASF and several later-in-life health outcomes among a large former player cohort. We also investigated associations between total years of professional ASF and alternative ASF exposure metrics to determine whether career duration reflected other exposures across the continuum of career length.

## METHODS

### Study sample

The Football Players Health Study (FPHS) at Harvard University[24] recruited former professional ASF players from those who signed a contract with a professional ASF league (eg, the National Football League or the American Football League) in or after 1960 when hard plastic helmets had largely been adopted.[25] Residential and electronic mail was used to invite 16 138 eligible players to complete a health questionnaire. Among 12 350 participants for whom we had evidence of engagement with our study material (opened the invitation email, clicked on an embedded link or opened another communication sent on behalf of the study), 4189 (33.9%) enrolled. Those who opted to enrol resembled those who did not participate in career duration, age, position and body mass index (BMI).[24]

### Measures

Age was determined using date of birth. Race was categorised as black, white, American Indian/Alaska Native/Asian/Native Hawaiian/Pacific Islander/other, or missing, as previously described.[4 26] BMI was calculated using self-reported height and weight and categorised into <25.0, 25.0–30.0 and >30.0. Years of professional ASF play were queried with 'How many seasons did you actively practice or play professional football?', and treated both continuously and categorically as <4, 4–8, 9–12 and 13–20+. Position was divided into linemen (defensive line, linebacker and offensive line) and non-linemen (defensive back, kicker/punter, quarterback, running back, tight end, wide receiver and special teams only).

Health conditions included (1) arthritis, (2) chronic pain, (3) mental health problems (anxiety and/or depression) and (4) subjective neurocognitive symptoms. Survey phrasing was based on National Health and Nutrition Examination Survey (NHANES)[27] surveys of similar conditions. Condition prevalence estimates were determined based on their responses to 'Has a medical provider ever recommended or prescribed medication for any of the following conditions?' for 'chronic pain', 'depression' and 'anxiety'. Arthritis was assessed with the question 'Has a health care provider ever told you that you have arthritis?'. Participants also were administered the Patient Health Questionnaire-4, which includes questions pertaining to depression symptoms and questions relating to anxiety symptoms. Participants were coded as having a mental health problem if they scored ≥3 on the two items assessing anxiety or ≥3 on the two items assessing depression[28] or reported being recommended or prescribed medication for that condition. Neurocognitive symptoms were assessed using the Quality of Life in Neurological Disorders (Neuro-QoL) Applied Cognition-General Concerns.[29] Briefly, the frequency of eight symptoms over the previous week was summed and assigned a T-score using a standardised US population as reference (mean=50; range=20–60).[29]

Additional ASF-related measures included cumulative professional career-related concussion signs and symptoms (CSS) history, performance enhancing drug use, number of intracareer orthopaedic surgeries and average snaps (individual play periods within a game) per game. Concussion history during ASF participation was quantified by querying the occurrence and severity of 10 common CSS over years of active ASF participation including headaches, nausea, dizziness, confusion, loss of consciousness, memory problems, seizure, visual problems, disorientation and feeling unsteady on one's feet. Estimates of symptom occurrence were summed to create a CSS score.[5 7 19 30] Participants who responded affirmatively to the question, 'During your active playing years, did you take medication or other drugs to help performance?' were considered to have taken performance enhancing drugs. Participants were asked, 'During your active playing years, did you have neck surgery, back surgery, knee surgery, ankle surgery, anterior cruciate ligament reconstruction, shoulder surgery and/or hand surgery'. The total number of intracareer surgeries represents the sum of all surgeries during years of ASF play. A follow-up survey completed by 1980 FPHS participants asked 'Over your whole professional football career, on average how many snaps did you participate in per game?' Players selected 'none', 1–10, 11–29, 30–49, 50–69 or 70+ snaps and these responses were then converted into 0, 5, 20, 39, 59 and 70, respectively, for analyses.

### Statistical analysis

Descriptive characteristics were compared between total season categories using Kruskal-Wallis rank sum tests and $\chi^2$ tests. Logistic regression was used to estimate associations between career duration categories and outcomes separately, after adjusting for age, race, and position (BMI was included in table 1 to describe the study population in total and by career duration category but not included in regression models). To further characterise non-linear associations between career duration and health outcomes or ASF career characteristics, we used penalised B-splines for the continuous career duration variable. Differences from linear fit were determined using likelihood ratio tests. We then used an iterative procedure to fit a piecewise linear regression model to the data, which identifies the career duration values or 'breakpoints' at which the slope of the exposure–outcome relationship shows the most significant change. We then estimated the intercept and linear slopes before and after estimated breakpoints.[31] The Neuro-QOL, CSS score and average number of snaps were treated as continuous variables and analysed using ordinary least squares (linear) regression in models adjusted for age, race and position. For the number of intracareer surgeries, we used Poisson regression models adjusted for the same covariates. For binary variables (chronic pain, arthritis, mental health problems and performance enhancing drugs), separate logistic regression models were used to predict the odds for each outcome or exposure after covariate adjustment. To investigate effect

**Table 1** Cohort characteristics

| | | Number of professional seasons | | | |
|---|---|---|---|---|---|
| | Total (N=4189) | <4 (N=1433) | 4–8 (N=1790) | 9–12 (N=617) | 13+ (N=349) |
| Age | | | | | |
| Mean (SD) | 51.78 (14.4) | 48.1 (14.5) | 52.9 (14.5) | 55.2 (13.2) | 55.2 (12.8) |
| Race | | | | | |
| Black | 1634 (39.0%) | 551 (38.5%) | 738 (41.2%) | 243 (39.4%) | 102 (29.2%) |
| White | 2376 (56.7%) | 825 (57.6%) | 966 (54.0%) | 354 (57.4%) | 231 (66.2%) |
| Missing | 53 (1.3%) | 16 (1.1%) | 26 (1.5%) | 7 (1.1%) | 4 (1.1%) |
| Other | 126 (3.0%) | 41 (2.9%) | 60 (3.4%) | 13 (2.1%) | 12 (3.4%) |
| Body mass index | | | | | |
| Mean (SD) | 31.3 (5.0) | 31.5 (5.2) | 31.1 (5.0) | 31.3 (4.9) | 31.0 (4.9) |
| N-Miss | 30 | 9 | 12 | 5 | 4 |
| Lineman status | | | | | |
| No | 2769 (66.1%) | 954 (66.6%) | 1224 (68.4%) | 376 (60.9%) | 215 (61.6%) |
| Yes | 1420 (33.9%) | 479 (33.4%) | 566 (31.6%) | 241 (39.1%) | 134 (38.4%) |
| Years since professional play | | | | | |
| Mean (SD) | 23.6 (14.3) | 23.2 (14.7) | 24.6 (14.6) | 23.4 (13.3) | 20.6 (12.5) |
| N-Miss | 5 | 3 | 2 | 0 | 0 |
| Number of professional seasons | | | | | |
| Mean (SD) | 6.7 (3.9) | 2.8 (1.1) | 6.8 (1.4) | 10.8 (0.8) | 14.9 (2.3) |

modification by position, we stratified analyses by linemen and non-linemen. Analyses were conducted using R Language for Statistical Computing[32] and statistical significance was set at 0.05.

## RESULTS

Former ASF players (n=4189, mean±SD=52±14 years of age) who played on average 23.6±14.3 years prior to enrolling reported an average BMI of 31.3±5.0 kg/m$^2$ (table 1). Approximately one in three players (n=1629 (39.0%)) identified as black, and a similar percentage played a lineman position (n=1413 (33.9%)). Players reported 6.7±3.9 years of prior professional ASF play, a CSS score of 31±27 and 1.4±1.2 intracareer surgeries. 656 former players (16.0%) reported using performance enhancing drugs during their professional careers. The prevalence of postcareer chronic pain, arthritis and either depression or anxiety was 28%, 38% and 30%, respectively. Participants received an average T-score of 40.5±9.8 on the Neuro-QOL, indicating that their perceived cognitive abilities were one SD worse than the general population. The adjusted odds of postcareer chronic health outcomes varied by quartile of years of play, but not in a monotonic fashion (figure 1). Compared with those with 0–3 years of play, the odds of chronic pain significantly increased among those with 4–8 years of play (OR 1.21; 95% CI 1.02, 1.42, p=0.02) and then more among those with 9–12 years of play (OR 1.32; 95% CI 1.07, 1.64, p=0.01). However, among those who played the longest (13+ years), the OR was not different from the reference category of 0–3 years of play (OR 0.96; 95% CI 0.73, 1.26, p=0.76). Compared with those with 0–3 years of play, the odds of arthritis increased among those with 4–8 years of play and further increased among those with 9–12 years of play and then levelled off—those with 13+ years of play had roughly the same odds of arthritis as those with 9–12 years of play. The association of years of play categories with mental health problems was similar but less pronounced, and only those with 4–8 years of play had significantly elevated odds (OR 1.19; 95% CI 1.01, 1.39, p=0.03). Finally, subjective cognitive symptoms (Neuro-QOL T-score) was similarly significantly lower for those in the 4–8 and 9–12 career duration categories, while the reduction was less pronounced and not statistically significant compared with the reference group among those with the longest careers.

Spline models showed statistically significant non-linear relations between years of play and all of our outcomes (p values for all likelihood ratio tests ≤0.001; table 2). The association between career duration and log odds of reporting chronic pain (figure 2A), arthritis (figure 2B) or a mental health problem (figure 2C) was roughly an inverted U-shape. Specifically, players with the longest and shortest duration of career were less likely to report each of those outcomes than those in the mid-range of career duration. The observed association for subjective cognitive symptoms was similar but inverted since higher scores reflect fewer cognitive symptoms: former players having the shortest and longest careers reported better subjective cognitive health than their mid-range career counterparts. The curvature pattern was similar across models stratified by linemen status, suggesting no effect modification of these findings by position-related factors.

Piecewise linear analyses identified inflection points at 7, 10, 5 and 7 seasons for chronic pain, arthritis, mental health problems and declining cognitive function, respectively, at which in all cases the slope flipped sign (table 2). The uncertainty associated with the spline model fits became greater at the longest playing years due to fewer data points (online supplemental figure 1), but in all cases, uncertainty was low where the inversion of the slope occurred.

To determine whether the association between years of play and experience of common football exposures followed a similar pattern to the one observed above for the health outcomes, we replicated the spline analyses using four common football exposures: CSS score, performance enhancing drugs, number of intracareer surgeries and average number of snaps per game (figure 3). For all of the football exposures, the relation with years of play was significantly non-linear (likelihood ratio tests; p<0.001; table 2), and we observed similar inverted-U patterns to what was seen with the health outcomes. Stratified analyses

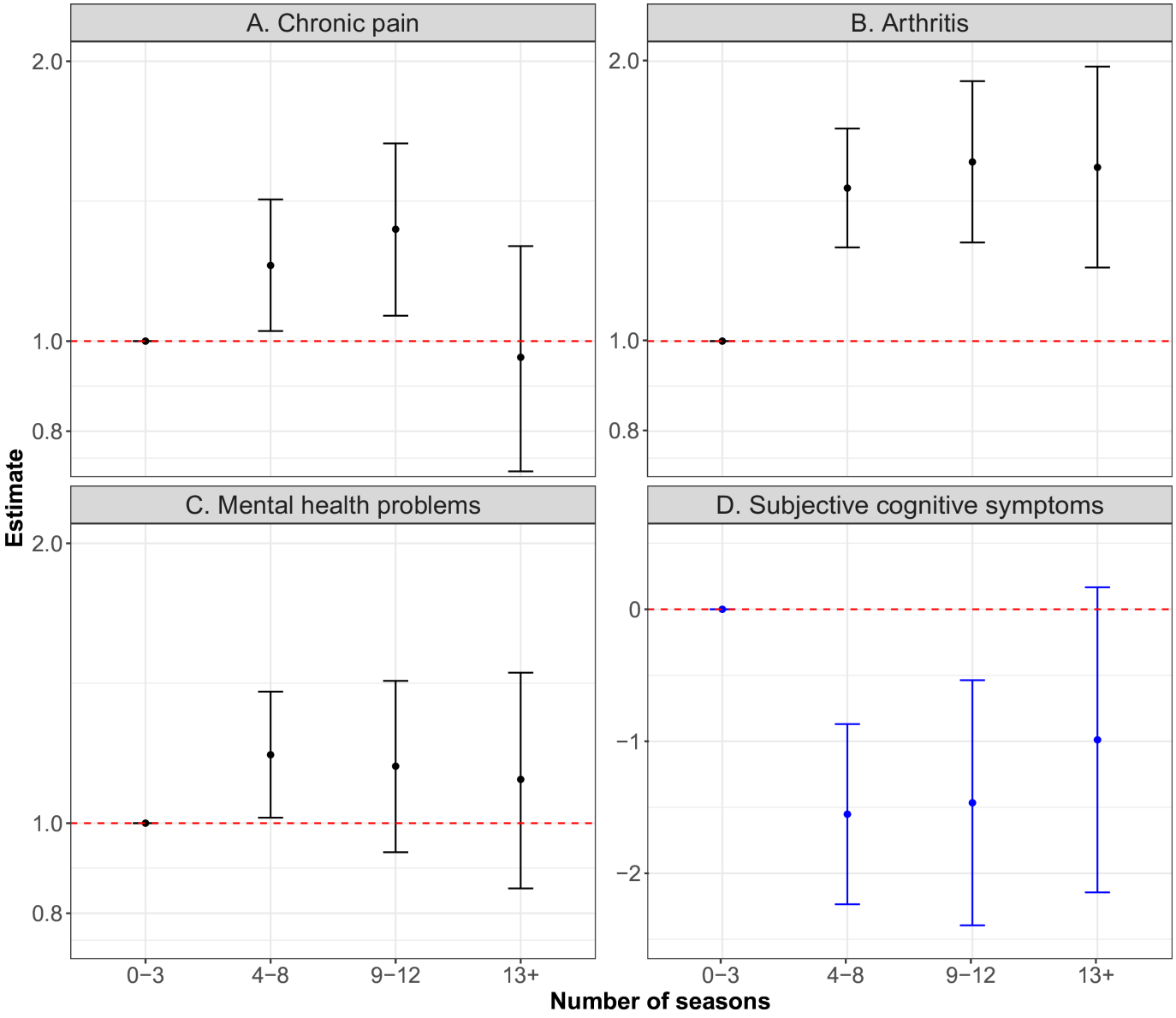


**Figure 1** ORs (black) or β estimates (blue) with 95% CIs for four health outcomes by number of professional seasons. (A) chronic pain, (B) arthritis, (C) mental health problems (anxiety or depression) and (D) subjective cognitive symptoms (Neuro-QOL). All models adjusted for age, race and linemen status. Red line denotes null value of 1.0 for ORs and 0.0 for β estimates.

by field position status showed inverted U-shaped associations for both lineman and non-lineman. Also, as with the health outcomes, piecewise linear analyses identified one break point for all the football exposures, identified as 7, 7, 12 and 9 seasons for CSS score, mean number of snaps per game, use of performance enhancing drugs and number of intracareer surgeries, respectively (table 2), and the linear slope reversed at that point. Similar to the health outcome variables, uncertainty estimates became greater at the longest playing years due to relatively few players with these values (online supplemental figure 2), but uncertainty was low where the inversion occurred.

## Discussion

In the largest epidemiological study of approximately 4200 former ASF players with a range of career durations, we found that years of play did not have a linear relationship with a number of common health outcomes including chronic pain, arthritis, mental health problems and subjectively experienced cognitive problems (reported more frequently in our cohort than in the general population).[29] In all cases, the association with career duration initially indicated a worse outcome with increasing years of play, but the trend reversed with longer career durations. We found similar non-linear patterns for career duration and four football exposures. The reversals of relations with years of play and the outcomes or exposures varied between 6 and 12 years of play. Taken together, these data challenge the assumption that career duration can serve as a simple proxy for neurotrauma and other ASF exposures.

Inverted-U relationships are commonly seen in occupational epidemiology[33 34] but have not been extensively considered in the context of professional sports. The non-linear associations seen here in an ASF cohort could result from several mechanisms. First, the use of career duration as a proxy for ASF exposures that are expected to have direct causal health effects assumes a monotonous association between duration of play and those other culprit exposures. However, these assumptions do

**Table 2** Piecewise regression analyses and likelihood ratio tests comparing linear and b-spline models

| | | | Piecewise regression | | |
|---|---|---|---|---|---|
| Variable | N | LRT p value | First slope (95% CI) | Career duration breakpoint (seasons) | Second slope (95% CI) |
| Outcomes | | | | | |
| Chronic pain | 4182 | <0.001 | 0.02 (0.02, 0.02) | 6.9 | −0.03 (−0.03,−0.03) |
| Arthritis | 4182 | <0.001 | 0.03 (0.03, 0.03) | 9.5 | −0.03 (−0.04,−0.03) |
| Mental health problems | 4174 | <0.001 | 0.02 (0.01, 0.02) | 4.5 | −0.02 (−0.02,−0.02) |
| Subjective cognitive symptoms | 4172 | 0.001 | −0.43 (−0.7, −0.17) | 7.0 | 0.58 (0.27, 0.88) |
| Exposures | | | | | |
| Concussion signs and symptoms score | 4101 | <0.001 | 1.82 (1.24, 2.39) | 7.0 | −2.18 (−2.95,−1.41) |
| Mean snaps per game | 1980* | <0.001 | 1.59 (1.34, 1.84) | 7.4 | −1.82 (−2.15,−1.49) |
| # active career surgeries | 4189 | <0.001 | 0.08 (0.06, 0.1) | 8.6 | −0.09 (−0.11,−0.07) |
| Performance enhancing drug use | 4189 | <0.001 | 0.01 (0.01, 0.01) | 11.5 | −0.01 (−0.02,−0.01) |

Piecewise regression was used to identify the first slope (95% CI), breakpoint in number of professional seasons and second slope (95% CI) for outcomes and exposures.
*A subset of 1980 study participants returned to complete a follow-up survey that included the snap question.
CI, confidence interval; LRT, likelihood ratio test.

not hold in our analyses. For example, players with the greatest career duration reported on average fewer CSS. If career duration itself does not directly affect health outcomes, a U-shaped association could be observed with career duration because the prevalence of those other causal factors is lower among those who played the longest. Second, as years of football play increase, the group of players who remain active may specifically be those who experience fewer critical exposures or are inherently less susceptible to certain exposures since previous exposures may have caused some players with greater susceptibility to quit playing. This phenomenon, known in the epidemiology literature as health worker survivor bias (HWSB), may occur if those who remain in the sport and have longer careers are biologically, behaviourally and/or psychologically distinct from those who left professional play earlier. To date, the impact of survivor bias on the study of elite athletes is not well understood. Third, it is also possible that extended duration careers confer a causal protective effect through mechanisms involving increased physical activity, lengthier exposure to team-based medical care and higher income. Taken together, these different mechanisms could each lead to the observed finding of attenuated effect estimates among those with the longest duration of professional play when using years of play as the exposure.

The results of the current study have important statistical and epidemiological implications. First, if one's primary interest is solely in depicting the association between duration of play and certain health outcomes, use of statistical approaches that enable to capture non-linear associations is warranted. These include, for example, regression splines and stratification of the exposure to specific career duration windows. Researchers who employ modelling techniques to uncover relationships between football-related exposures and health outcomes may enhance the accuracy of their findings by ensuring that analytical approaches are constructed to avoid calculation of biased parameter estimates and CIs.

Second, if duration of play is used as a proxy for other neurotrauma exposures of interest, preliminary examinations of the association between duration of play and such exposures are needed. As we observed, duration of play is often a suboptimal proxy for such play-related exposures, and thus its use may be better avoided in some situations, despite the ease of ascertainment. Third, researchers should be aware of the HWSB, which can lead to attenuated associations with the outcome at the right tail of the career duration distribution. Researchers should consider stratifying their data to obtain different effect estimates for each duration strata, or restricting inference to player populations of specific career duration length, and recognise that the relation between years of play and causal exposures for a given outcome may be weaker in those with longer career durations or those with longer career durations are a group less susceptible to the exposures. Several causal inference methods could also be used to address HWSB in certain situations, although many depend on the collection of longitudinal sports exposure data rather than relying on postcareer cumulative or average exposure metrics.[35–37] Over the longer term, studies that investigate the genetic, lifestyle, team-specific and other factors that may affect career length are warranted. Identifying such factors would be of relevance to players, coaches, sports physicians and others and would also inform future studies aiming to delineate causal pathways affecting players' health.

Our findings are also relevant for medical providers of elite performance populations, former athletes and scientists engaged in the study of sports. It might seem intuitive to assume that players with longer career durations are at greater risk for adverse health outcomes, and these assumptions may induce concerns in former professional ASF players with the longest playing careers. Clinicians caring for former elite ASF players should note that those with the longest career durations, at least in the present study, are not necessarily more likely to have worse clinical outcomes compared with those with shorter careers, even though the data presented here cannot identify causal factors associated with longer careers. Importantly, there is considerable interest in the role of health-promoting behaviours and the identification of treatable clinical conditions for improving outcomes and quality of life for former professional athletes,[38 39] and clinicians are encouraged to focus on these factors when working with former athletes.

We acknowledge several limitations of this study. First, all outcomes and play-related exposures were self-reported, and therefore lack clinical confirmation. However, health status pertaining to arthritis and other conditions was phrased similarly to other larger national studies of self-reported health conditions like the NHANES.[4 27] Moreover, findings were consistent when the number of intracareer surgeries was considered, which likely serve as salient events that are less subject to recall bias. Further, for a differential misclassification bias to have caused the observed findings, the health outcomes and play-related exposures would have had to be under-reported specifically

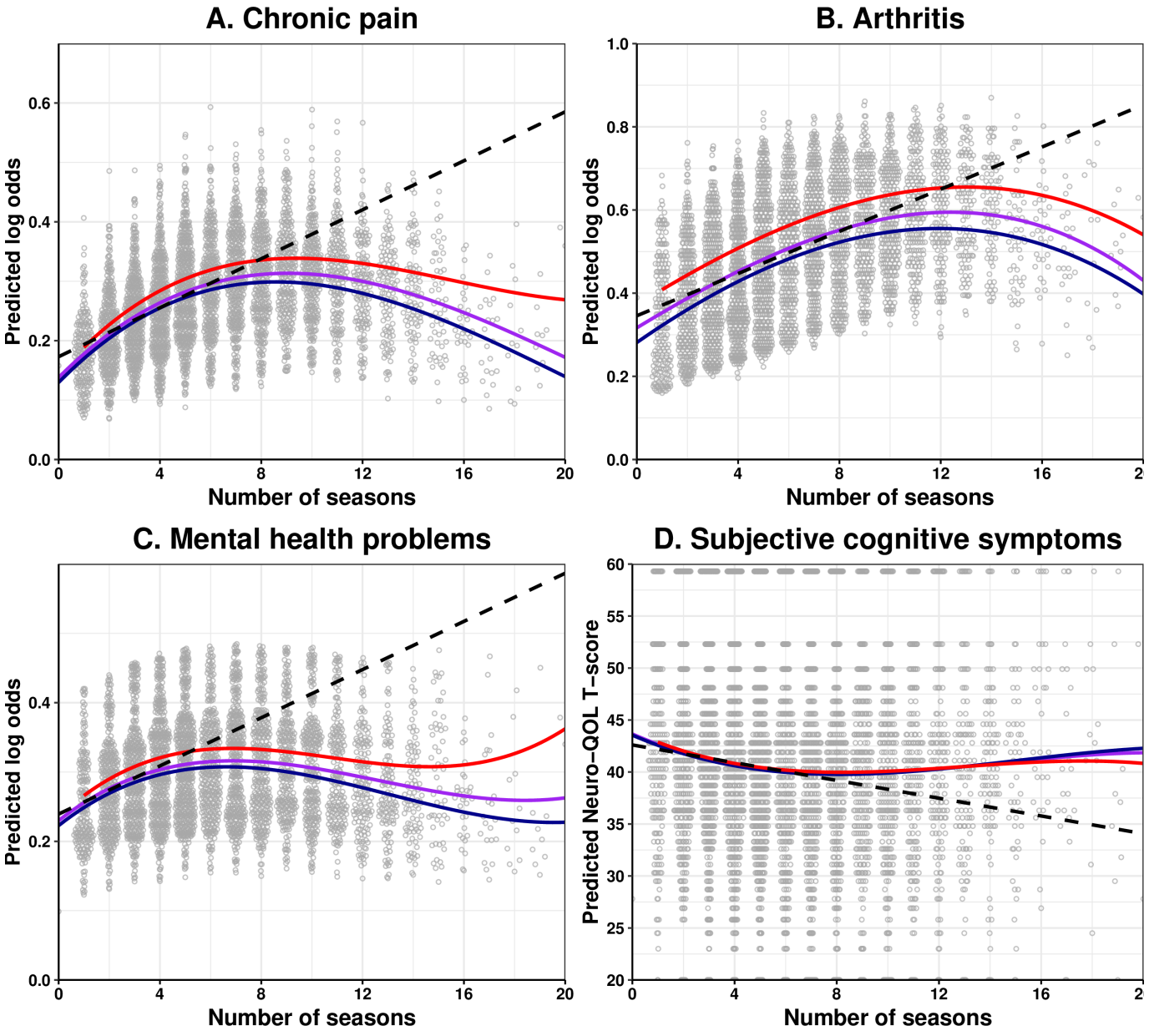


**Figure 2** Spline regression models of number of professional seasons in relation to (A) chronic pain, (B) arthritis, (C) mental health problems (anxiety or depression) and (D) subjective cognitive symptoms for all positions (purple), and stratified by linemen (red) and non-linemen (blue). All models were adjusted for age, race and linemen status (unless stratified by this variable). Dashed line extrapolates the trend using the first slope and intercept identified by the piecewise linear regression for each outcome. X-axis visuals are limited to 20 seasons to protect participant identity.

among ASF athletes with relatively longer playing careers, which is unlikely. Despite the fact that our cohort size and participation rate are equal or exceed other studies,[40] possible bias could occur depending on the exposure and health profiles of the players who joined our study. However, selection conditions that could have produced the results we found seem somewhat unlikely. Specifically, there would have had to be underparticipation by those with outcomes and longer careers. While differential participation among those with an outcome may be likely, that it would also depend on career duration seems less so. This issue seems even less likely with respect to the level of football-specific exposures.

It is important to note that comparisons between the FPHS cohort and publicly available professional football data show that the FPHS was representative across age, height, weight, career duration and position.[24] Data on factors that likely predict survivorship including cognitive reserve, social determinants of health, genomics and epigenomics, playing and coaching styles, health-related behaviours during the game, individual personality traits and postcareer health-care delivery were not measured. Finally, average snaps per game estimations for players with longer careers may reflect the fact that players with longer careers played fewer snaps in later years, thus reducing estimates specifically for that group. Collecting data on cumulative snaps over players' careers may better reflect exposures that could be tied to health outcomes.

In conclusion, our data illustrate non-linear inverse U-shaped relationships between professional ASF career duration and later life health outcomes and football-specific exposures. This finding, likely explained at least in part by survivor bias, reveals a limitation of using career duration to

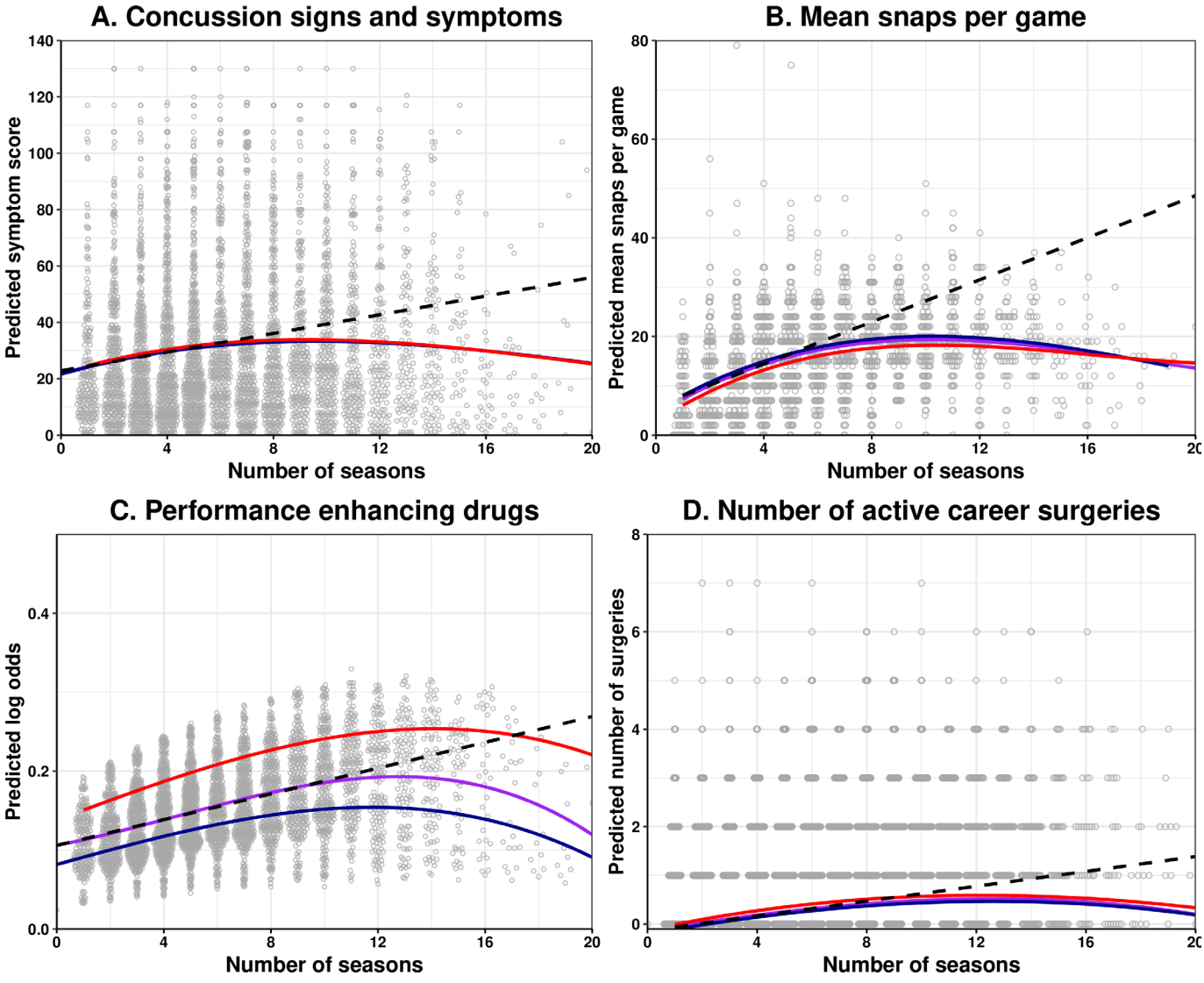


**Figure 3** Spline regression models of number of professional seasons in relation to (A) concussion signs and symptoms score, (B) mean snaps per game, (C) use of performance enhancing drugs and (D) number of active career surgeries. Splines shown for all positions (purple) and stratified by linemen (red) and non-linemen (blue). All models were adjusted for age, race and linemen status (unless stratified by this variable). Dashed line extrapolates the trend using the first slope and intercept identified by the piecewise linear regression for each outcome. X-axis visuals are limited to 20 seasons to protect participant identity.

predict long-term health among former athletes. More data are needed to understand biopsychosocial factors related to career longevity to assist in making causal inferences for specific play population subgroups. It is also important to note that some metrics of football-specific exposures include career duration although it may not be obvious, such as the Cumulative Head Impact Index[13] and the Professional Football Cumulative Head Impact Index.[18] More work is needed to identify and most accurately use sporting exposure metrics in postcareer health studies with former athletes.

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**Acknowledgements** The authors wish to acknowledge the study participants, advisors and staff of the Football Players Health Study for their time and effort.

**Contributors** RG, ALB, DM, MGW, JDT and COT contributed to study proposal development. RG, ALB, RSR, COT, JDT, DPT, RDZ, HL, MGW and HD contributed to data collection and analyses. RG, ALB, DPT, SRE and GLI contributed to writing the manuscript. HD, RDZ, MGW, RSR and ALB led acquisition of funding and oversight of the larger research initiative. All authors critically reviewed the manuscript for submission. RG serves as guarantor of the data.

**Funding** The Football Players Health Study is supported by the NFL Players Association (grant number: N/A). The NFL Players Association did not contribute to the design and conduct of the study; collection, management, analysis and interpretation of the data; preparation, review or approval of the manuscript; and decision to submit the manuscript for publication. This work received support from Harvard Catalyst | The Harvard Clinical and Translational Science Center (National Center for Advancing Translational Sciences, National Institutes of Health Award UL1 TR002541) and financial contributions from Harvard University and its affiliated academic healthcare centers.

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**Competing interests** ALB has received funding from the National Institute of Health/National Heart, Lung and Blood Institute, the National Football Players Association and the American Heart Association and receives compensation for his role as team cardiologist from the US Olympic Committee/US Olympic Training Centers, US Soccer, US Rowing, the New England Patriots, the Boston Bruins, the New England Revolution and Harvard University. GLI has a clinical and consulting practice in forensic neuropsychology, including expert testimony, involving individuals who have sustained mild TBIs (including former athletes). He has received past research support or funding from several test publishing companies, including ImPACT Applications, CNS Vital Signs and Psychological Assessment Resources (PAR). He receives royalties from the sales of one neuropsychological test (WCST-64). He has received research funding as a principal investigator from the National Football League, and subcontract grant funding as a collaborator from the Harvard Integrated Program to Protect and Improve the Health of National Football League Players Association Members. He has received research funding from the Wounded Warrior Project. He acknowledges unrestricted philanthropic support from ImPACT Applications, the Mooney-Reed Charitable Foundation, the National Rugby League, Boston Bolts and the Schoen Adams Research Institute at Spaulding Rehabilitation. RDZ reported receiving royalties from Springer/Demos publishing for serving as coeditor of the text Brain Injury Medicine; serving on the scientific advisory board of Myomo, and onecare.ai; evaluating patients in the Massachusetts General Hospital Brain and Body–TRUST Programme, which is funded by the NFL Players Association and receiving grants from the NIH. MGW reported receiving grants from the NFL Players Association and the NIH during the conduct of the study. DPT serves on the Scientific Advisory Board for HitIQ and previously consulted for REACT Neuro. JDT serves as CEO of Mastery Development, Chief Health Innovation and Performance officer NESTRE Health and Performance, as Vice President of the Society for Sports Neuroscience, RG, HD, AJW and DM received grant funding from the NFL Players Association. No other disclosures were reported.

**Patient consent for publication** Not applicable.

**Ethics approval** This study involves human participants and was approved by Harvard T. H. Chan School of Public Health Institutional Review Board (#IRB18-1365). Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; internally peer reviewed.

**Data availability statement** No data are available. Due to the high profile nature of the participants, data are not publicly available.



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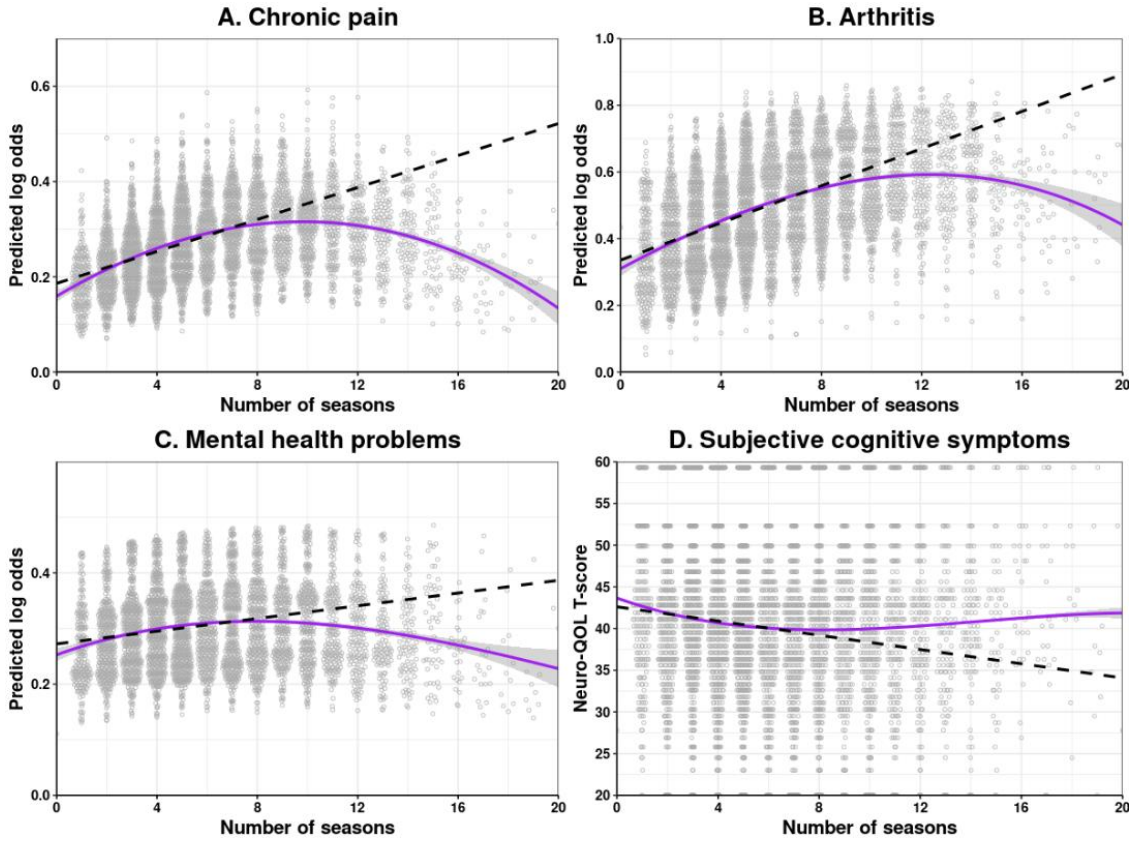
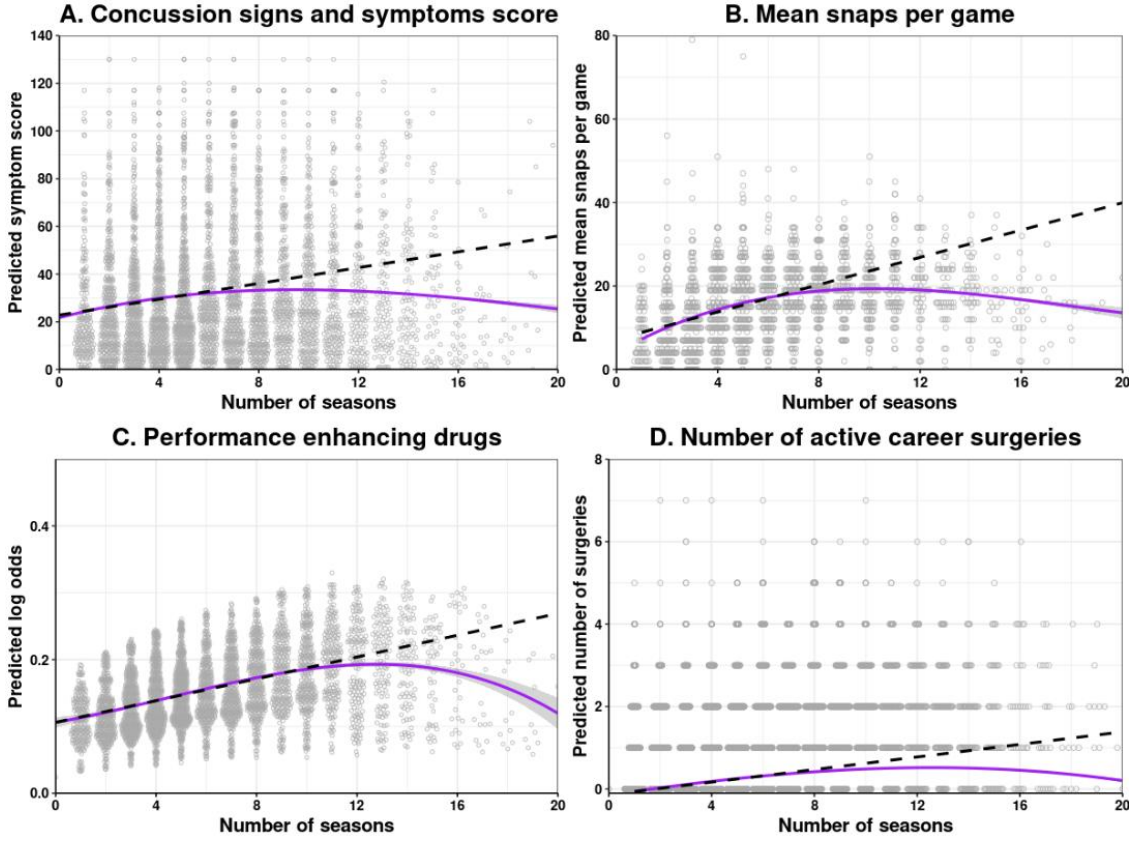
**Online Supplementary Material**




**Supplemental figure 1**. Spline regression models of number of professional seasons in relation to (A) chronic pain, (B) arthritis, (C) mental health problems (anxiety or depression), and (D) subjective cognitive symptoms for all positions (purple). Models including all positions adjusted for age, race, and linemen status. Models stratified by linemen status adjusted for age and race. Gray shading indicates 95% confidence intervals. Dashed line extrapolates from the first slope and intercept identified by piecewise linear regression for each outcome out to longer career lengths. X-axis visuals are limited at 20 seasons to protect participant identity.




**Supplemental figure 2. S**pline regression models of number of professional seasons in relation to (A) concussion signs and symptoms score, (B) mean snaps per game, (C) use of performance enhancing drugs, and (D) number of active career surgeries. Splines shown for all positions (purple). Models including all positions adjusted for age, race, and linemen status. Models stratified by linemen status adjusted for age and race. Gray shading indicates 95% confidence intervals. Dashed line extrapolates from the first slope and intercept identified by piecewise linear regression for each exposure out to longer career lengths. X-axis visuals are limited at 20 seasons to protect participant identity.