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A history of concussions is associated with symptoms of common mental disorders in former male professional athletes across a range of sports

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ABSTRACT

Objective: Recent reports suggest that exposure to repetitive concussions in sports is associated with an increased risk of symptoms of distress, anxiety and depression, sleep disturbance or substance abuse/dependence (typically referred as symptoms of common mental disorders [CMD]) and of later development of neurodegenerative disease, in particular chronic traumatic encephalopathy (CTE). The primary aim of this study was to explore the relationship between sports career-related concussions and the subsequent occurrence of symptoms of CMD among former male professional athletes retired from football (soccer), ice hockey and rugby (union).

Methods: Cross-sectional analyses were performed on baseline electronic questionnaires from three prospective cohort studies among former male professional athletes retired from football (soccer), ice hockey and rugby (union). The number of confirmed concussions was examined through a single question, while symptoms of distress, anxiety and depression, sleep disturbance and adverse alcohol use were assessed using validated questionnaires.

Results: From 1,957 former professional athletes contacted, a total of 576 (29%) completed the questionnaire. Of these, 23% had not incurred a concussion during their career, 34% had two or three, 18% four or five, and 11% six or more concussions. The number of sports career-related concussions was a predictor for all outcome measures ($\beta = 0.072\text{--}0.109$; $P \leq 0.040$). Specifically, former professional athletes who reported a history of four or five concussions were approximately 1.5 times more likely to report symptoms of CMD, rising to a two- to five-fold increase in those reporting a history of six or more sports career-related concussions.

Conclusions: These data demonstrate an association between exposure to sports concussion and subsequent risk of symptoms of CMD in former professional athletes across a range of contact sports. Further work to explore the association between sports concussion and symptoms of CMD is required; in the meanwhile, strategies for effective risk reduction and improved management appear indicated.

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Concussions; sports; mental disorders; epidemiology; athletes

Introduction

Concussion is recognized as a complex pathophysiological process induced by biomechanical forces after a direct or transmitted blow to the head resulting in neurological impairment [1]. In recent years, interest in sports concussion has increased, particularly with regard to its immediate, catastrophic complications (i.e. 'second impact syndrome'), its management, and its association with increased risk of neurodegenerative disease, in particular chronic traumatic encephalopathy (CTE) [2].

At the professional level, the rates of concussion vary across sport and have been consistently rising in recent years. For example, in the comprehensive annual injury surveillance data gathered in English professional rugby, reported concussion incidence has increased from 3 concussions per 1000 player hours in 2005 to 13.4 concussions per 1000 player hours in 2015 [3]. In professional ice hockey, concussion incidence is

recorded at 6.5 concussions per 1000 game hours [4,5]. Among professional footballers, fewer concussions have been reported, with the incidence rate ranging between 0.03 and 0.07 concussions per 1000 players hours in men's European professional football (soccer) [6]. Although the majority of concussions resolve with rest, related symptoms can be prolonged as post-concussion syndrome in about 10–15% of cases [1].

In the longer term, sports career-related concussions have been linked to the occurrence of neurodegenerative diseases among former professional athletes, specifically CTE [7,8]. Of note, studies describing clinical presentation in early stage CTE report behavioral and/or mood disturbance, including depression and suicidality, in the phenotype [9]. Further, retrospective analyses revealed that retired American footballers who reported one or two concussions were 1.5 times more likely to report depression than those with no history of concussion, rising to threefold in

retired players reporting three or more sports career-related concussions [10]. A study among former elite rugby players showed that the risk for depressive disorders increased with the number of sports career-related concussions [11]. Recently, studies have reported that symptoms of distress, anxiety and depression, sleep disturbance, or substance abuse/dependence – typically referred as symptoms of common mental disorders (CMD) – are prevalent in former professional players retired from team sports [12,13]. The question whether the number of concussions sustained during a professional career in wider sports contributes to the occurrence of symptoms of CMD remains unanswered.

Therefore, the primary aim of the study was to explore the relationship between sports career-related concussions and the subsequent occurrence of symptoms of CMD (distress, anxiety and depression, sleep disturbance, adverse alcohol use) among former male professional athletes retired from football, ice hockey, and rugby. A secondary aim was to present the difference across sports in relation to the risk to report symptoms of CMD as a consequence of sports career-related concussions.

Methods

Design

Cross-sectional analyses were conducted on baseline questionnaires from three prospective cohort studies in professional football, ice hockey, and rugby. Results of two of these observational studies (football and rugby) have been presented elsewhere [12–14]. Ethical approval for this study was provided by the board of St. Marianna University School of Medicine (2014/04/16; Kawasaki, Japan), the Faculty of Health Sciences Human Research Ethics Committee of the University of Cape Town (642/2014; Cape Town, South Africa), and the Medical Ethics Review Committee of the Academic Medical Center (W15_060#15.0072, W15_171#15.0207; Amsterdam, The Netherlands). The present research was conducted in accordance with the Declaration of Helsinki [15].

Participants

Participants were former male professional athletes retired from football, ice hockey, and rugby recruited from a range of countries (Finland, France, Ireland, Norway, South Africa, Spain, Sweden, Switzerland). In our study, being a former professional athlete meant (1) to have trained in football, ice hockey, or rugby aiming to improve performance/results; (2) to have participated in the top tier professional leagues in football, ice hockey, or rugby; and (3) to have had football, ice hockey, or rugby training and competition as a major professional activity (way of living) [16]. Inclusion criteria for participants were (1) age 50 years or younger at recruitment; (2) male; (3) able to read and comprehend texts fluently in either English, French, or Spanish; and (4) member as a former professional athlete of their respective national footballers' union, national ice hockey players' association, or national rugby union players' association. In accordance with a sample size calculation for testing the relationship between independent and dependent variables ($N > 50 + 8m$ where m is the number of independent variables), sample size of at least 58 participants was needed [17].

Dependent variables: symptoms of CMD

Distress

Symptoms of distress in the previous 4 weeks were measured using the Distress Screener (3 items scored on a 3-point scale) which is based on the Four-Dimensional Symptom Questionnaire (4DSQ) (e.g. 'Did you recently suffer from worry?') [18,19]. The 4DSQ (i.e. Distress Screener) has been validated in several languages, including English, French, and Spanish (internal consistency: 0.6–0.7; test–retest coefficients: ≥ 0.9 ; criterion-related validity: area under the receiver operating characteristics (ROC) curve ≥ 0.79) [18,19]. A total score ranging from 0 to 6 was obtained by summing up the answers on the three items, a score of 4 or more indicating the presence of distress [18,19].

Anxiety and depression

The 12-item General Health Questionnaire (GHQ-12) was used to assess symptoms of anxiety and depression in the previous 4 weeks (e.g. 'Have you recently felt under strain?') [20]. The GHQ-12 has been validated in several languages, including English, French, and Spanish (internal consistency: 0.7–0.9; criterion-related validity: sensitivity ≥ 0.70 , specificity ≥ 0.75 , area under ROC curve ≥ 0.83) [20,21]. Based on the traditional scoring system, a total score ranging from 0 to 12 was calculated by summing up the answers on the 12 items, with a score of 3 or more indicating signs of anxiety and depression (area under curve = 0.88) [20,21].

Sleep disturbance

Based on the Patient Reported Outcomes Measurement Information System short form (PROMIS), sleep disturbance in the previous four weeks was assessed through four single questions related to sleep quality (e.g. 'Have you recently had problems sleeping?') and scored on a 5-point scale [22,23]. The PROMIS has been validated in several languages, including English, French, and Spanish (internal consistency: >0.9 ; construct validity: product-moment correlations ≥ 0.96) (for detailed information, see www.nihpromis.org). A total score ranging from 1 to 20 is obtained by summing up the answers to the four questions, a score of 13 or more indicating the presence of sleep disturbance [22,23].

Adverse alcohol use

Level of alcohol consumption at the present time was detected using the 3-item of the Alcohol Use Disorders Identification Test Consumption (AUDIT-C; e.g. 'How many standard drinks containing alcohol do you have on a typical day?') [24]. The AUDIT-C has been validated in several languages, including English, French, and Spanish (test–retest coefficients: 0.6 – 0.9; criterion-related validity: area under ROC curve 0.70–0.97) [24,25]. A total score ranging from 0 to 12 was obtained by summing up the answers on the three items, a score of 5 or more indicating the presence of adverse alcohol use [24].

Independent variables: sports career-related concussions

The total number of confirmed concussion incidents occurred during an athlete's career and diagnosed by a medical professional was examined through a single question (e.g. 'How many concussions diagnosed by a medical professional did you have during your professional sports career [training and

competition]?). In our study, concussion was defined as a blow to the head resulting in symptoms such as headache, nausea, vomiting, dizziness/balance problems, fatigue, trouble sleeping, drowsiness, sensitivity to light or noise, blurred vision, difficulty remembering, and difficulty concentrating [1]. This definition of concussion was given to the participants by including it in the questionnaire.

Procedures

Based on all variables included in the study, an electronic questionnaire available in English, French, and Spanish (around 15 min needed to be completed) was set up (FluidSurveys™, Ottawa, Canada). In addition, the following descriptive variables were retrieved: age, height, body mass, duration of professional sports career, duration and nature of retirement, and nature of employment (including number of working hours per week). Information about the study was emailed to potential participants by their respective national footballers' union, national ice hockey players' association, or national rugby union players' association, invitation procedures being blinded to the responsible researchers for reasons of privacy and confidentiality of the former athletes. Participants interested in the study gave their informed consent and were given access to the anonymous online questionnaire that they were asked to complete within 2 weeks. Reminders were sent after 2 and 4 weeks. Once completed, the electronic questionnaires were saved automatically on a secured electronic server that only the lead researcher could access. All former athletes participated voluntarily in the study and did not receive any reward for their participation.

Statistical analyses

All data analyses (statistical software IBM SPSS Statistics 23.0 for Windows) were conducted for the whole group of participants (primary aim) and separately for each sport (secondary aim). Descriptive data analyses (mean, standard deviation, frequency, range) were performed with all variables included in our study.

Box and whisker plot of number of concussions versus presence/absence of symptoms of CMD was drawn from the available data with the boundaries of the box indicating the 25th and 75th percentile, the line within the box marking the median, the whiskers above and below the box indicating the minimum and maximum values (using the Mann-Whitney *U* test for groups comparisons; $P < 0.05$). Logistic regression analyses (expressed as odds ratio [OR] and related 95% CI; adjusted for age and duration of retirement) were used to explore whether former athletes who had sustained one or more concussions (continuous independent variable) during their sports career were more likely to report symptoms of CMD (dichotomous dependent variable) or comorbidity of symptoms of CMD (dichotomous dependent variable: two or more symptoms of CMD) than former athletes who had suffered from none or fewer concussions during their career [26]. In addition, participants were stratified by concussion history (none, 1 concussion, 2 or 3 concussions, 4 or 5 concussions, 6 or more concussions) and logistic regression analyses (expressed as OR and related 95% CI; adjusted for age and duration of retirement) were subsequently conducted (categorical independent variable and dichotomous dependent variables) [26]. With regard to a preferred sample size requirement of 50 times the number of independent variable, intended sample size in our study was set at a minimum 50 participants per sport discipline [26].

Results

Participants

A total sample of 1957 former professional athletes were contacted by their respective national footballers' unions, national ice hockey players' associations, or national rugby union players' associations. Of those, 576 participants gave their informed consent and completed the questionnaire (overall response rate of 29%). Mean age of the participants at recruitment was 37 (range 20–50) years. Participants had competed in professional sports for approximately 10 years (from 9 years in rugby to 12 years in football) and they were retired (41% forced to retire from their sport) from profes-

Table 1. Characteristics of former male professional athletes retired from football, ice hockey, and rugby.

Variables	Total	Football	Ice hockey	Rugby
Number contacted	1957	307	420	1230
Number recruited	576	220	61	295
Age (in years; mean ± SD)	37 ± 7	35 ± 6	38 ± 7	38 ± 6
Height (in cm; mean ± SD)	183 ± 8	181 ± 7	181 ± 5	185 ± 8
Weight (in kg; mean ± SD)	93 ± 16	82 ± 11	90 ± 10	102 ± 16
Years sport career (mean ± SD)	10 ± 5	12 ± 5	11 ± 5	9 ± 4
Years retired (mean ± SD)	7 ± 5	4 ± 3	10 ± 7	7 ± 4
Involuntary retired from sports (%)	41	46	23	41
Currently (self-)employed (%)	88	76	93	95
Working hours per week (mean ± SD)	40 ± 14	35 ± 15	43 ± 10	43 ± 13
<i>Sports career-related concussions (%)</i>				
None	23	25	23	23
Two or three	34	40	29	32
Four or five	18	23	12	17
Six or more	11	3	8	15
<i>Symptoms of CMD (%)</i>				
Distress	21	18	12	25
Anxiety and depression	26	26	18	28
Sleep disturbance	27	28	15	28
Adverse alcohol use	26	25	44	24
Comorbidity: ≥2 CMD symptoms	26	25	21	28

N: Number of participants; SD: standard deviation; cm: centimeters; kg: kilograms; %: percentage; CMD: common mental disorders.

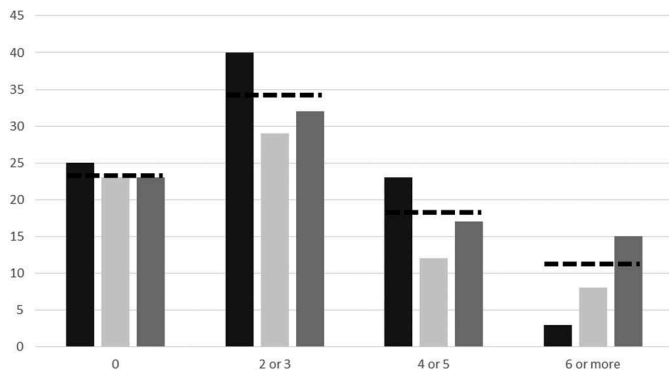


Figure 1. Percentage of former male professional athletes (total cohort in *dash line*, football in *black*, ice hockey in *light grey*, rugby in *dark grey*) reporting sports career-related concussions diagnosed by a medical professional.

sional sports for 7 years (from 4 years in football to 10 years in ice hockey). Around 88% of participants were employed for 40 h per week. All characteristics of the participants (total group and per sport) are presented in Table 1.

Sports career-related concussions

Former athletes reported a mean of 2.7 (SD = 2.7, range 0–15) confirmed concussions during their sports career. Twenty three percent ($n = 110$) had not incurred a concussion during their sports career (23% in ice hockey and rugby, 25% in football), 34% ($n = 158$) reported two or three concussions (29% in ice hockey, 32% in rugby, 40% in football), 18% reported ($n = 84$) four or five concussions (12% in ice hockey, 17% in rugby, 23% in football), and 11% reported ($n = 50$) six or more concussions during their sports career (3% in football, 8% in ice hockey, 15% in rugby (Table 1; Figure 1).

Relationship of concussions with symptoms of CMD

There was a significant difference ($P < 0.05$) in the number of concussions when the group was divided according to the presence/absence of symptoms for distress, sleep disturbance, and anxiety and depression (Figure 2). There was no difference in the number of concussions associated with presence/absence of symptoms of adverse alcohol use. With concussion as a continuous independent variable, the number of sports career-related concussions proved to be a predictor for all outcomes measures, showing that former professional athletes are 7–11% more likely to report symptoms of CMD by every additional sports career-related concussion. With concussion as a categorical independent variable, our analyses showed that former professional athletes reporting a history of four or five concussions were nearly 1.5 times more likely to report symptoms of CMD than former professional athletes reporting no concussions, and participants with a history of six or more sports career-related concussions were two to five times more likely to report symptoms of CMD (Table 2). These relationships were also found across the different sports but most were not statistically significant (Table 2).

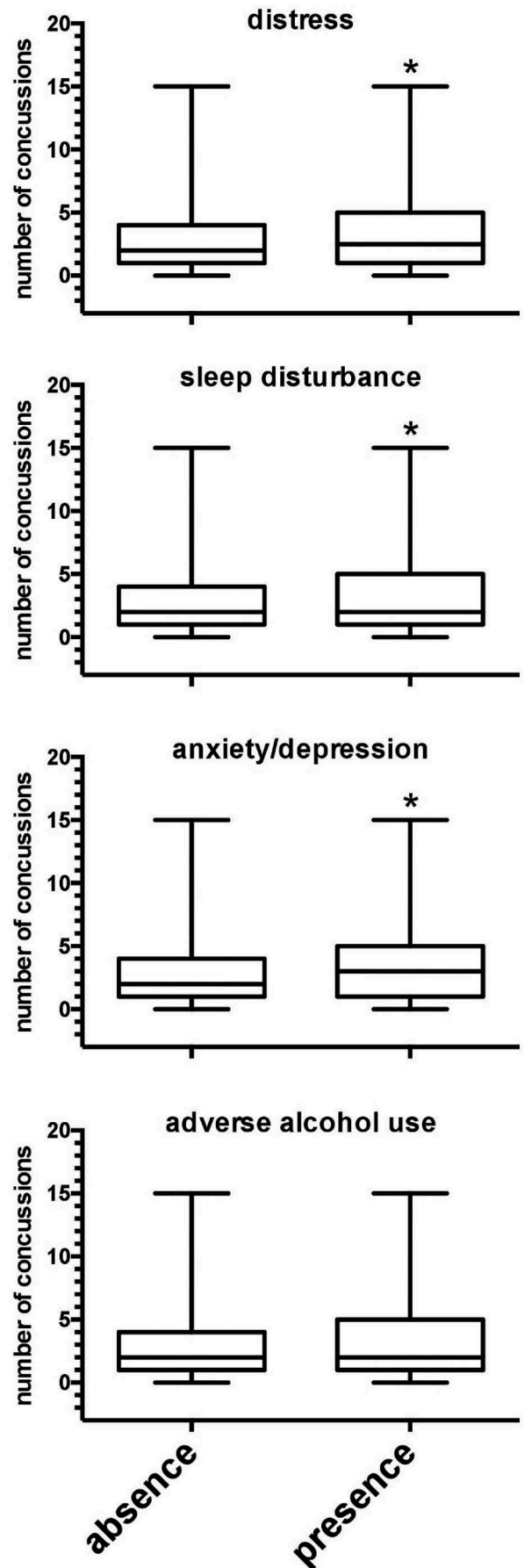


Figure 2. Box and whisker plot of number of concussions versus presence/absence of symptoms of CMD among former male professional athletes (*, $P < 0.05$).

Table 2. Relationship expressed as odds ratio (95% confidence of interval; adjusted for age and duration of retirement) of sports career-related concussions with symptoms of common mental disorders among former male professional athletes retired from football, ice hockey, and rugby.

<i>Distress</i>	Total	Football	Ice hockey	Rugby
0 Concussion	1.0	1.0	1.0	1.0
1 Concussion	0.9 (0.4–2.1)	0.6 (0.1–5.6)	na	1.1 (0.4–3.1)
2 or 3 Concussions	1.3 (0.7–2.4)	0.8 (0.2–3.2)	na	1.4 (0.6–3.0)
4 or 5 Concussions	1.4 (0.7–3.0)	2.6 (0.7–9.5)	na	0.9 (0.4–2.4)
6 or more Concussions	3.2 (1.5–6.9)	1.7 (0.1–20.0)	na	2.8 (1.2–6.8)
<i>Anxiety and depression</i>				
0 Concussion	1.0	1.0	1.0	1.0
1 Concussion	0.8 (0.4–1.8)	na	0.4 (0.1–5.3)	1.4 (0.6–3.4)
2 or 3 Concussions	0.8 (0.4–1.5)	1.6 (0.5–5.0)	0.9 (0.1–9.0)	0.6 (0.3–1.2)
4 or 5 Concussions	1.4 (0.7–2.7)	2.2 (0.7–7.3)	na	1.2 (0.5–2.8)
6 or More concussions	2.4 (1.2–4.9)	9.8 (0.8–116.3)	2.0 (0.1–31.5)	2.0 (0.9–4.7)
<i>Sleep disturbance</i>				
0 Concussion	1.0	1.0	1.0	1.0
1 Concussion	1.8 (0.8–3.9)	0.5 (0.1–5.4)	na	2.7 (1.1–6.9)
2 or 3 Concussions	1.9 (1.0–3.6)	1.5 (0.4–5.0)	na	1.6 (0.7–3.7)
4 or 5 Concussions	2.0 (1.0–4.2)	2.8 (0.8–10.2)	na	1.6 (0.6–4.0)
6 or More concussions	5.2 (2.4–11.2)	4.6 (0.5–42.8)	na	4.9 (2.0–12.2)
<i>Adverse alcohol use</i>				
0 Concussion	1.0	1.0	1.0	1.0
1 Concussion	1.7 (0.8–3.7)	2.4 (0.4–13.5)	2.9 (0.5–17.3)	1.2 (0.4–3.9)
2 or 3 Concussions	1.4 (0.8–2.7)	1.3 (0.4–4.7)	0.3 (0.1–1.9)	2.4 (1.0–5.7)
4 or 5 Concussions	1.2 (0.5–2.4)	1.6 (0.4–6.5)	1.1 (0.1–12.5)	1.4 (0.5–3.8)
6 or More concussions	2.9 (1.3–6.2)	5.5 (0.6–51.4)	0.6 (0.1–14.3)	4.3 (1.7–11.3)
<i>Comorbidity</i>				
0 Concussion	1.0	1.0	1.0	1.0
1 Concussion	1.1 (0.5–2.3)	0.9 (0.2–5.7)	0.4 (0.1–5.7)	1.5 (0.6–4.0)
2 or 3 Concussions	1.7 (0.9–3.0)	1.4 (0.4–4.2)	0.7 (0.1–7.1)	1.9 (0.9–4.2)
4 or 5 Concussions	1.5 (0.7–2.9)	1.4 (0.4–4.9)	na	1.6 (0.7–3.9)
6 or More concussions	3.8 (1.8–8.0)	11.1 (0.9–130.6)	1.6 (0.1–25.4)	3.9 (1.6–9.5)

na: Not applicable because of limited number of cases.

Discussion

In 2001, self-reported data were collected from 2552 retired professional American Football players (mean age of 53 years) to determine the association between prior concussions and the likelihood of being diagnosed with depression [10]. The study showed an association between recurrent concussions and depression, suggesting that the prevalence of depression increases with increasing concussion history [10]. Compared with retired players with no history of concussion, retired players with a history of one or two concussions were 1.5 times more likely to be diagnosed with depression, and those reporting three or more previous concussions were 3 times more likely to be diagnosed with depression [10]. Following this study, 1044 of the participants (i.e. retired professional American Football players) completed a follow-up General Health Survey in 2010 [27]. About 10% of these respondents reported that they had been clinically diagnosed as depressed between 2001 (baseline) and 2010 (follow-up) [27]. The 9-year risk of a depression diagnosis increased with an increasing number of self-reported concussions, ranging from 8% for the group with one or two concussions to 26% for the group with 10 or more concussions [27]. Recently, a study was conducted among 239 French retired high-level rugby players (median age of 52 years) to explore the link between the prevalence of major depressive disorder and mild cognitive disorders and the number of reported concussions [11]. Results showed that major depressive disorder and mild cognitive disorders were associated with the number of reported concussions [11]. Relying on similar cross-sectional analyses, the results of our study are in accordance with these studies. However, besides sports career-related concussion, former professional athletes

might be exposed to other stressors such as adverse life events, poor physical health, and unemployment that are likely to induce symptoms of CMD [12–14].

In our study, former athletes reported a mean of 2.7 confirmed concussions during their sports career, while one out of three reported two or three concussions. Despite that our results concur with recent studies about sports career-related concussions, we believe that concussions remain underreported and/or misdiagnosed in professional sports. Recently, there is also a growing concern in the sports medicine community regarding the immediate and long-lasting effects from subconcussive impacts (below the threshold to cause or elicit any signs of a concussion). Athletes in collision sports, like those involved in our study, are exposed to a large number of impacts that are regularly overlooked, while the short- and long-term consequences of these subconcussive impacts remain poorly understood [28]. With regard to the findings of our study, and under the assumption that subconcussive impacts might be associated with cognitive, motor, and psychiatric deficits, robust and well-powered studies are needed to explore any potential association.

Regarding the long-term consequences of concussions among athletes, increasing attention has been paid to the association between exposure to concussion and proposed increased risk of neurodegeneration among retired athletes, specifically CTE. The first clinical description of the syndrome now recognized as CTE was provided by Martland in his 1928 account of the ‘punch drunk’ syndrome in former boxers [29]. In the years since Martland’s first account, and in particular in the past decade, growing recognition of the pathology of CTE in former athletes from a number of contact sports has led to the understanding that it is exposure to brain injury that is associated with CTE risk, rather than any individual sport [2,8].

Although currently a diagnosis can only be made at autopsy, a clinical syndrome is emerging from the largely retrospective enquiries in confirmed cases of CTE to date that appears distinctive [9]. In particular, in a high proportion of early onset cases, behavioral and/or mood symptoms are reported, including depression and suicidality [2,9,30]. Importantly, however, while our data show high reporting of symptoms of CMD and a direct association between these and incidence of concussion across our cohorts, there is no suggestion that these symptoms are indicative of CTE in our participants, or informative as to incidence of CTE in former athletes.

Limitations and strengths

A potential methodological limitation worth mentioning might be the self-reported character of our study. Participants were asked (single question) to recall the number of diagnosed concussions that had occurred during their sports career. Denial and repression are two defense mechanisms well-known for influencing retrospective recall of unpleasant experiences in the past [31]. This impacts on the validity of the number of diagnosed concussions gathered in our study. However, it is well known that concussions or severe musculoskeletal injuries during a professional sport career can be considered as major life events and it might be assumed that athletes can generally recall quite precisely. In addition, athletes have access to their medical records – remaining their property – in which confirmed concussions should be noted. Therefore, it is likely that recall bias in our study was limited. The different scales used to assess symptoms of CMD are validated in many languages, which is a strength of our study. Even more, the importance and relevance of studies (such as our) relying on Patient Reported Outcome Measures (PROMs) have been very recently empowered in clinical and sports medicine to enable important clinical questions to be answered [32]. Also, the use of PROMs for both independent and dependent variables in our study warranted the involvement of a large number of participants from different sports. This involvement of a large number of professional i.e. elite players retired from football, ice hockey, and rugby can be seen as a strength of our study. By contrast, the cross-sectional design used in our study can be seen as a potential limitation as it does not allow the exploration of a causal association between independent and dependent variables [14]. A prospective study, based on a longitudinal design with a follow-up period of two to three decades and including a large cohort of professional i.e. elite athletes, might have secured a higher methodological quality for an observational study such as ours. However, whether such a prospective study is feasible in professional sports remains very doubtful.

Implications

Considering the number of repetitive concussions that might occur in a career in contact sports such as football, ice hockey, and rugby, our findings endorse the alarming severity of the long-term consequences of repeated concussions among athletes. Consequently, the prevention of concussions should be even more prioritized in professional (and recreational) sports, while continued efforts at improving its management should be

promoted. Preventing the occurrence of concussions (and other injuries) should be the first priority in all contact sports, especially in those sports involving high-speed collisions between players. Existing rules and guidelines might be subject to alterations to minimize (head) collisions, to prevent any concussed athlete from continuing training or competing, and enforcing a conservative Return To Play protocol.

Athletes can also be trained to implement techniques that reduce the risk of injury. For example, in rugby, coaching tackle technique has been introduced in high-level youth rugby with the goal of decreasing the risk of injuries, including concussion [33]. At the professional level in rugby, the application of concussion guidelines has been empowered and monitored by the international and national organizing bodies. The medical support staff and players seem to be embracing these guidelines. Consequently, professional rugby might be regarded as the gold standard when it comes to the prevention and management of concussions. By contrast, the management of concussions in professional football has been under scrutiny. In 2006, the Fédération Internationale de Football Association (FIFA) introduced a rule change by sanctioning any elbow to the head with a mandatory red card. While the number of head injuries during international tournaments decreased after this ruling, the management of concussions in professional football is still discussed and FIFA introduced recently another measure, namely that the referee has the ability to stop the game for 3 min whenever a suspected incident of concussion occurs. Nevertheless, the actual policy related to concussions in professional football remains questioned and should be improved to protect the sustainable health of footballers. In ice hockey, the rule change related to eliminating checking to the head and banning hard plastic elbow pads has been proposed to prevent head injuries and protect players' health [34].

In addition to prevention strategies, particular attention should be applied to the management of a concussion, following the event. The first step in good concussion management is to educate all the stakeholders. In youth sports, parental knowledge and attitudes about concussions and its management should be unequivocally developed and optimized. Nationwide campaigns such as the "If in doubt, sit them out" developed in Scotland might also be effective in reaching the general public and grassroots participants across all sports and in raising their awareness about concussions. In professional and high level sports, while medical staff seem to be properly educated, it is crucial to focus on the education of both coaches and athletes to make them understand and accept concussions' management. Last but not least, a proper support for former professional athletes suffering from mental health should be developed and implemented. Many unions or associations representing athletes have adopted this path recently, but more efforts remain to promote and protect the sustainable health of athletes in the long term.

Conclusions

During the first 10 years after their retirement from contact team sports, former professional athletes retired from football, ice hockey, and rugby are 7–11% more likely to report symptoms of CMD by every additional sports career-related concussion. Former professional athletes reporting a history of four or

five sports career-related concussions are nearly 1.5 times more likely to report symptoms of CMD, and athletes with a history of six or more sports career-related concussions are 2–5 times more likely to report symptoms of CMD. Our findings confirm the urge to protect athletes from concussions during their career and to increase the quality of concussion management at professional sports level.

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Declaration of Interests

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