Intelligence and educational level as risk factors for concussion: A population study of young males

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Article Summary

Article focus:	The role of intelligence and educational level in the occurrence of concussions.
Key messages:	Lower intelligence and, in particular, lower EL appear to be risk factors for sustaining a concussion. This risk increases with the severity of the injury
Strengths and weaknesses	Strengths: The data are derived from a large, well-defined, population cohort. Weaknesses: The data are limited to young men only and lack information on the severity of the injury other than whether it was treated in an accident and emergency unit or with admission to a hospital.

Abstract:

Objectives: To investigate the association of concussion with intelligence and educational level.

Design: Epidemiological: Cross-linkage of national computer registers

Setting: Denmark

Participants: 130,420 young men appearing before the Danish draft board in the period 2006-2010. Primary and secondary outcome measures: Intelligence test scores (IQ), educational level (EL) and occurrence of concussion in the period 2004-2009, treated either in an Accident & Emergency (A&E) unit or with admission to a hospital ward.

Results: The 3.067 men who had suffered a concussion had lower IQs (mean=96.5, 95%CI=95.0-

97.0) than the total cohort and they were lower for the 1,452 who were admitted to a hospital ward (mean IQ=95.8, 95%CI=95.1-96.6) than for the 1,615 who were treated only at an A&E unit (mean IQ=97.1, 95%CI=96.3-98.0). Multiple logistic regression revealed that the effects for educational level were stronger than for IQ. Among the 127,353 men not sustaining a concussion, 48% attended a 'gymnasium' (sixth-form college), among men treated for a concussion at an A&E unit, this falls to 36% and, among men hospitalized for a concussion to 30%. Transfer to a gymnasium, if it happens, almost invariably does so typically before the 18th birthday. Among 701 men suffering a concussion and admitted to a hospital department after this date, only 26% (n=182) had previously transferred to a gymnasium. Among the 804 men treated at an A&E unit after their 18th birthday, 33% (n=265) had done so. These two percentages are significantly below the corresponding non-concussed population (48%), and they differed significantly from each other (OR=1.40, 95%CI=1.12-1.75).

Conclusions: taken together, the results suggest that lower intelligence and, in particular, lower EL are risk factors for sustaining a concussion, the risk increasing with the severity of the injury.

INTRODUCTION

A concussion is defined as "a trauma-induced alteration in mental status that may or may not involve loss of consciousness"[1], whereas mild traumatic brain injury (mTBI) is defined as "a traumatically induced physiological disruption of brain function" [2]. In both cases the definition is characterized by symptoms such as loss of consciousness, amnesia for events immediately preceding or following the injury, and/or feelings of confusion and dizziness.

The consequences of concussion vary from transient symptoms, as described above, to rarer instances of Post-Concussional Syndrome with lasting physical, emotional, cognitive, or behavioural symptoms [2 3]. Studies typically find that the cognitive effects of a concussion resolve themselves within days or at most weeks [4-6]. According to one meta-analysis of 21 studies, all symptoms of neuropsychological impairment cease within seven days, with the exception of impairments in delayed memory which are found to persist beyond this period [7]. A recent study reports significant effects on neurocognitive tests at 1, 6 and 12 months follow up in children with mTBI and also in a control group of children with other minor injuries, but specifically states that "when controlling for pre-injury factors, there is no evidence of long-term neurocognitive impairment in this group relative to another injury control group." [8]. Sustaining repeated concussions is associated with declines in delayed memory and executive functioning [9], and gender has been found to influence cognitive performance after two or more concussions [10].

Severity of the trauma has been found to correlate positively with especially memory problems at follow up [11], and very young age at injury is a risk factor for impairments in executive functioning following traumatic brain injury (TBI) [12]. Injury sustained at a young age leads to a more generalized impairment in executive functioning than injury sustained in adulthood [13]. Yet, young age, as well as premorbid high functioning, also seems to be a protective factor leading to better cognitive recovery following moderate to severe TBI [14]. However, children sustaining complicated mTBI, i.e. those with intra-cranial abnormalities [15] appear to be more vulnerable to developing mild chronic cognitive dysfunction following injury than adults with similar injuries [16,17].

According to a meta-analysis by Cassidy et al. 70-90 percent of all treated TBIs are mild, and about 100-300 per 100,000 per annum in a population are treated in hospital for mTBI [18]. As many mTBIs are not reported, however, the total population-based rate is estimated to be at least 600/100,000 [18]. Approximately two million people sustain a TBI each year in the US [19], and an estimate of 50.000-300.000 college athletes in the US experience mTBI each year [20]. In Denmark, Engberg & Teasdale [21] reported a decline in the incidence of concussions leading to hospital admissions between 1979 and 1993 from 227 to 131 per 100,000, a decline which appeared to result from a decreasing practice of admission to a hospital ward from an Accident and Emergency (A&E) unit, for observation, patients whose only apparent complaint was the concussion itself.

A number of risk factors for concussion have been identified. One of the major factors appears to be participation in sports [22], and, indeed, most studies about concussions concern sports-related injuries. Annual incidence rates have been found to be between 9.36 and 33.09 per 100,000 American high school athletes, depending on the particular sport [23]. Participants in contact sports are particularly likely to sustain concussion, with ice hockey and rugby players having the highest incidence rates during games, and male boxers and female taekwondo participants being most likely to sustain concussion in their leisure time [24]. Furthermore, duration of the game is also a risk factor for sustaining concussion: the longer into the game, the greater the chance of injury [25]. In absolute numbers, males outweigh females in terms of sustaining sports-related concussion [18], but female athletes appear to be at a proportionally greater risk for concussion than their male counterparts [22,26 27,28].

Having previously sustained a concussion is a risk factor in itself [23], and the effects appear to be correspondingly cumulative [29]. Athletes who suffer multiple concussions are significantly more likely to experience yet another concussion, about four to six times more according to some studies [30].

Gender and age are significant risk factors for concussions including those which are not the result of sports injuries. Concussions from all causes occur more often for males than for females and their incidences are particularly high among adolescents and young adults, but also peaking again amongst the elderly [21].

Alcohol intoxication is an immediate risk factor for concussion. One study of patients treated at an A&E unit reported almost 50% of concussion patients to be under the influence of alcohol [31]. Sustaining a concussion while under the influence of alcohol has been identified as a risk factor for sustaining further alcohol-related concussions [32].

Although there has been extensive research investigating the cognitive effects of concussions, there has been relatively little research investigating the possible influence of education and cognitive functioning as risk factors. Ewing-Cobbs et al. [33] found academic skill deficiencies to be present among adolescents prior to injury. Similarly, Teasdale & Engberg [34] reported cognitive test performance to be reduced among young adults who subsequently sustained a concussion, even some years later.

Four major difficulties with the extant studies have been the selectiveness of sampling, small samples, variability in the severity of the concussion (in particular, that many concussions sustained in sporting activities are comparatively quite mild) and the lack of good controls or test norms. The present study has attempted to overcome these difficulties. Our data are derived from a national medical database from which a large sample has been drawn and the concussions involved were medically diagnosed as such (ICD-10, S.060) and were of a severity sufficient to warrant at the least attendance at an A&E unit. Specifically, as an indication of severity, we have been able to compare patients who were only treated at an A&E unit with patients who were admitted to a hospital ward. Furthermore, for purposes of comparison, we have available full cognitive test scores and educational levels for a complete population cohort: it is worth noting that this represents a considerable advance on the limited data available to us in previous studies where we had only cognitive test scores reduced to a dichotomy and no information on educational level [34,35]. Unusually, we are also able to report on the cognitive functioning and educational level (EL) of concussion patients either before or after the concussion occurred.

On the basis of the evidence reviewed we have formed three hypotheses: first, that concussion patients will prove to have lower than average scores on the cognitive test, and to have lower ELs than the general population, this irrespective of the temporal relationship between the date of cognitive testing and the date of the concussion. An exception to this forms our second hypothesis, namely that cognitive functioning is particularly reduced where testing has taken place less than a month following the concussion. The third hypothesis is that lower cognitive functioning and EL are more marked for patients admitted to a hospital ward than for patients treated at A&E clinics, this because lower cognitive functioning and EL is a stronger risk factor for more serious injuries. In addition we wished to explore the possible role of the cause of injury, specifically accident versus violence.

METHODS

Draft Board Data.

The starting point for the present study was a database comprising all 159,402 men processed by the Danish draft board in the five-year period 2006-2010. Denmark maintains military conscription for which all men become liable at age 18. The procedure entails, inter alia, a 45-minute test for cognitive abilities, the Børge Prien's Prøve (BPP) which comprises four subtests for logical, verbal, numerical and spatial reasoning, each having about 20 items none of which are multiple-choice. All of the subtests are measures of 'fluid' rather than 'crystallized' intelligence [36] and all are timed; thus, mental speed is at a premium. The test result is the number of correct answers across subtests and out of 78, but this has here been converted to IQ scaling with a mean of 100 and a standard deviation of 15 in order to give a more familiar indication of effect size. The BPP has been reported to correlate .82 with the Wechsler Adult Intelligence Scale [37] and to have a test-retest reliability of .77 [38]. Further details are reported elsewhere [39].

Also recorded by the draft board is educational level (EL) on an 8-13 scale primarily reflecting the highest school class attained. The most critical point on this scale is the divide between the values 8 through 10, which indicate just grade school, possibly followed by occupational training, and the values 11 through 13 which indicate that the individual has entered a 'gymnasium', equivalent to a three-year sixth-form college and leading to a 'studentereksamen', akin to a baccalaureate and requisite for higher education. Entry to a gymnasium is contingent on examination results and teachers' recommendations.

In some cases, personal appearance before the board is not required and neither BPP nor EL are obtained. This occurs for men who in advance can document an illness which would disqualify them from military service, e.g. chronic asthma, severe myopia, and curvature of the spine. In the present cohort 28,982 men (18.2%) did not appear before the draft board. We obtained BPP and EL, together with the exact date of the draft board appearance, for the remaining 130,420 (81.8%) men. The average age for this appearance was 19.5 years (SD 1.3). Similarly to what has been reported elsewhere [38] the correlation between BPP and EL was .52. It is worth observing parenthetically that only a small proportion of the men who are processed by the draft board are thereafter called upon to perform military service, this being largely determined by the draw of a lottery number once suitability has been established.

Hospital Registration Data

In Denmark, all hospital admissions and, since 2004, all treatments at A&E units are centrally recorded in a National Hospitalization Register [40]. Dates of admission or A&E treatments are recorded. ICD-10 diagnoses are used and in most cases the cause of an injury is recorded using the Nordic Medico-Statistical Committee (NOMESCO) system [41]. Primary among these causes in Denmark are accidents and, to a much lesser extent, violence.

For the 159,402 men in our Draft Board database we searched this register for persons who, in the period 2004 through 2009, had been admitted to hospital, typically to an orthopaedic or neurological ward, or were treated at A&Es, in all cases with the sole discharge diagnosis of concussion (ICD-10 S.060). Cross-linking the two registers is made possible since both employ a national Central Person Registration number. For those admitted to hospital we restricted the period involved to not more than two days. The search identified 3,847 men of whom 1,830 had been admitted to hospital and 2,017 had been treated at an A&E unit. The approximately 4% of men who had sustained more than one concussion in the time period, were recorded with the first of these. The hospitalization register does not include information on loss of consciousness or post-traumatic amnesia. Amongst the two groups, respectively 1,452 (79.3%) and 1,615 (80.1%) had appeared before the draft board and for whom BPP and EL were thus available. It is worth noting that these percentages differ significantly (χ^2 (2) = 12.0, p < .01) but only slightly from the above noted overall rate of 81.8%. The mean age at injury for all patients was 17.9 years (s.d. 2.5). The ages ranged between 11 and 31 but 90% were between 14 and 22 years. For those injured prior to testing the average interval was 2.4 years (s.d. 1.6).

Among those for whom BPP and EL were available 1,887 cases (62%) were coded as 'accident' and 447 cases (15%) were coded as 'violence'. These codes were lacking for the remaining 733 (24%).

Table 1 shows age at injury and age at testing, separately for admitted patients and for A&E patients in relation to the injury occurring before or after draft board testing, together with age at testing for the non-patient group. It can be seen that there are no differences between the five defined groups in age at testing. Age at injury was (necessarily) earlier for those injured before testing and later for those injured after testing. Among the four patient groups a significantly higher proportion of those injured before testing were admitted to hospital rather than treated in A&E (49.5%) than among those injured after testing (40.5%) ($\chi^2(1) = 18.5$, $p < .001$). Among those injured before testing the median time interval was 819 days for admitted patients and 797 days for A&E patients (Mann-Whitney U, z = 0.64, n.s.)

Table 1

Mean ages and frequencies as a function of concussion pre- or post-testing and without concussion

	Age at Injury Mean (SD)	Age at Testing Mean (SD)	n
Admitted patients			
Concussion pre-testing	17.2 (2.0)	19.6 (1.3)	1152
Concussion post-testing	20.5 (1.4)	19.4 (1.1)	300
A&E patients			
Concussion pre-testing	17.1 (2.0)	19.5 (1.4)	1174
Concussion post-testing	20.6 (1.5)	19.4 (1.1)	441

Non-patients	19.5 (1.3)	127353

Statistics

The data were analyzed with SPSS20, using t-tests, analyses of variance, logistic regression, and odds ratios.

RESULTS

Means and standard deviations for IQ and EL as a function of patient type and being tested post- or pre-concussion, together with the non-concussed group are shown in Table 2. Overall t-tests showed that concussion patients had significantly lower IQs (t(130,418) = 13.2, p<.001) and significantly lower ELs (t(130,418) = 18.8, p<.001) than the non-patient population. The IQ difference was 3.6 points, corresponding to an effect size of .24 (Cohen's d, [42]) and the effect size for EL was .35

Table 2

IQ and Educational Level (EL) as a function of concussion pre- or post-testing and without concussion

	IQ Mean (SD)	EL Mean (SD)
Admitted patients		
Concussion pre-testing	95.5 (14.9)	10.2. (1.7)
Concussion post-testing	97.1 (14.9)	10.2 (1.7)
A&E patients		
Concussion pre-testing	96.3 (14.8)	10.4 (1.8)

Concussion post-testing	99.0 (14.9)	10.6 (1.8)
All patients	96.5 (14.9)	10.3 (1.8)
Non-patients	100.1 (15.0)	11.0 (1.8)

In order to examine for effects of hospital admission versus A&E treatment and of sequence of injury and testing we conducted analyses of variance for IQ and EL in which the non-patient group was excluded and pre-or-post injury and patient type were included as independent variables. For IQ there were significant main effects of pre-post injury (F(1,3063)=11.1, p=.001) and of patient type (F(1,3063)=4.5, p=.033). The interaction was not, however, significant (F(1,3063)=0.7, n.s.). Overall, men injured before testing had IQs on average 2.3 points below those of men injured after testing, an effect size of d=.15. Those who were admitted to hospital had IQs on average 1.2 points below those who were treated in A&E units, an effect size of d=.08. Taken together, 60% of men suffering a concussion had a below average IQ (OR=1.50, 95%CI=1.39-1.61).

For EL there was no main effects of pre-post injury (F(1,3063)= .8, n.s.) but there was a significant effect of patient type (F(1,3063)=15.6, p<.001). The interaction was not significant (F(1,3063)=.7, n.s.). Patients admitted to hospital had lower EL than those treated in A&E units (effect size, d = .15).

In order to investigate the degree to which IQ and EL are independently related to the occurrence of a concussion we included both variables, transformed to z-scores to enable comparison of their respective contributions, in a logistic regression predicting concussion. The Nagelkerke R^2 was .014. The resulting model is shown in Table 3 where it can be seen that both EL and IQ predict concussion significantly, but that the contribution of EL is markedly and significantly greater than that of IQ.

Table 3

Logistic regression of IQ and Educational Level (both standardized to z-scores) in relation to concussion

	B	S.E.	Wald	df	Sig.	OR	OR 95% C.I.	
							Lower	Upper
IQ	-.072	.021	12.43	1	p<.001	.930	.893	.968
EL	-.315	.022	198.57	1	p<.001	.730	.698	.762
Constant	-3.786	.019	38293	1	p<.001	.023		

We have explored further the potential role of educational level as a risk factor for concussion. As stated above, within the educational level scale from 8 to 13, the most salient dichotomy is between 8-10, representing those who only attended grade school ('folkeskole', typically leaving at age 15 or 16 and pursuing non-academic further education) and 11-13, representing those who went on to the academically oriented gymnasium. Since we do not know the exact age at which an individual transferring to a gymnasium actually did so, we selected men whose injuries occurred after their 18^{th} birthday since transfer would almost certainly have happened before that date. The numbers of these men were compared with a baseline of those of men in the present sample who did not sustain a concussion and who did attend a gymnasium (61,645 out of 127,353 = 48.4%).

Among the 701 men who sustained a concussion after their 18^{th} birthday and for which they were admitted to a hospital, 26% (n=182) had entered a gymnasium, this being significantly below the baseline (OR=2.7, 95%CI=2.26-3.17). Among the 804 men who sustained a concussion after their 18th birthday and for which they were treated at an A&E department, 33% (n=265) had entered a gymnasium, this again being significantly below the baseline (OR=1.91, 95%CI=1.65-2.21). The percentage of men attending gymnasium within these two concussion groups was significantly higher for men admitted to a hospital than for men treated at an A&E unit (OR=1.40, 95%CI=1.12-1.75).

Given previous evidence of cognitive dysfunction for a period following a concussion we examined IQ scores for 26 patients who were tested within 30 days after being injured. This group had a mean IQ of 95.3 (SD 15.3) which did not differ significantly from all others who were injured prior to being tested, mean IQ = 95.9, (SD 14.8) (($t(2327) = 0.2$, n.s.).

The two main causes of injury were 'accident' (n=1,905, (62%)) and 'violence' (458, 15%). Mean IQs and Els for these two groups are shown in Table 4. The majority of the remaining causes of injury were either not coded or recorded as 'other'. Patients with injuries associated with violence had significantly lower IQs ($t(2334) = 2.02$, $p<.05$) and significantly lower ELs ($t(2361) = 3.61$, $p<.001$) than patients with accidental injuries. Again, the effect size is greater for EL ($d = .24$) than for IQ ($d = .11$).

Table 4

IQ and Educational Level (EL) as a function of cause of injury

	IQ	EL
	Mean (SD)	Mean (SD)
Accident	96.6 (15.0)	10.4 (1.8)
Violence	95.0 (14.6)	10.0 (1.6)

DISCUSSION

The main finding of the present study is that lower intelligence and, in particular, lower EL appear to be risk factors for sustaining a concussion, the risk increasing with the severity of the injury. It is, however, recognized that the study has a number of limitations. First, we have only had data available on males and it is therefore uncertain whether the present findings would apply also for females. It should be added, however, that males account for a much greater incidence of concussions than do females [18,21]. A second limitation is the narrow age range of our sample which, for reasons related to the available databases, was limited to concussions occurring predominantly between the ages of 14 and 22. Again it could be added that the age range to which we perforce have been limited to is exactly a high risk period for concussions [21]. A third limitation is the lack of conventional measures of the severity of a concussion, such as depth of coma or duration of post-traumatic amnesia.

These limitations notwithstanding, a number of conclusions can be drawn. The major conclusion, and a confirmation of our first hypothesis, is that both relatively low IQ and educational level are associated with the occurrence a concussion. We found lower levels of IQ and educational level for men who had suffered a concussion both when the concussion had occurred prior to testing, and when it occurred subsequent to testing. Confirming the third of our hypotheses, the effect was more marked among men who had been admitted to a hospital ward than among men who were treated only in an accident & emergency unit.

The fact that the effect for IQ was also greater for men who had suffered a concussion prior to being tested by the draft board, than among those whose concussion occurred after testing, was unexpected and contrary to an earlier finding of the reverse pattern [34]. It should, however, be noted that the age range for injuries is much narrower, and the sample size much larger in the present study. Furthermore, that the earlier study used a very limited dichotomous scoring of the BPP test and did not include a measure of educational level.

Whatever accounts for this pre- and post-testing IQ effect it seems unlikely that it is largely attributable to a direct causal effect of the injury on IQ test scores. The average pre-testing interval in the present sample was 2.4 years, whereas most studies finding direct effects of concussion on cognitive functioning report much shorter intervals [4-6,34]. A further reason to discount a direct effect of the concussion is that, in a failure to confirm our second hypothesis, we did not find reduced test performance in those patients for whom the concussion-to-testing interval was within a range more commonly reported, i.e. one month. However, the possibility should not be discounted that some proportion of the men injured prior to testing have been suffering Post-Concussional Syndrome in which, amongst other symptoms, poor attention and fatigue can continue for long after the injury [4,43-45]. Such cases would depress both the IQ scores and educational levels. The consistency with which the associations of concussion are greater with educational level than with IQ may in part result from the lower reliability of the BPP test.

It is, however, particularly striking that among the young men who had suffered a concussion after attaining the age of 18, by which time any transfer to higher education (gymnasium) would have occurred, substantially fewer in fact had done so. Whereas about 48% of men in general had attended a gymnasium, only 26% of men admitted to a hospital for a concussion had done so and only 33% of men treated at an A&E unit had done so. This strongly implicates educational level as a risk factor for sustaining a concussion and the difference between hospital admission and A&E

treatment further suggests that the risk is greater for more severe injuries. It is tempting to speculate that both IQ and educational level in this context are indicators for broader social environmental factors.

It is beyond the scope of the present study to investigate such factors more closely; but the frequent involvement of alcohol in incidences of concussion [31,32], and our finding that violence as a cause of injury is is more strongly associated with lower educational level and IQ than is accident, also suggests that social factors are operating [47].

Declarations

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No competing interests are involved.

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Contributorship

TWT was responsible for the acquisition of data. Both authors made substantial contributions to the conception and design, and the interpretation of results. TWT bore primary responsibity for the statistical analyses and AJF bore primary responsibility for reviewing the relevant literature. Both authors have collaborated in drafting the article and both have given final approval of the version to be published.

Data Sharing

No additional data available

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1 YES	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2 YES	Explain the scientific background and rationale for the investigation being reported
Objectives	3 YES	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4 YES	Present key elements of study design early in the paper
Setting	5 YES	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6 YES	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed
Variables	7 YES	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8 YES	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9 YES	Describe any efforts to address potential sources of bias
Study size	10 YES	Explain how the study size was arrived at
Quantitative variables	11 YES	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12 YES	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses
Results		
Participants	13 YES	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14 YES	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data	15 YES	Report numbers of outcome events or summary measures over time

Main results	16 YES	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17 YES	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18 YES	Summarise key results with reference to study objectives
Limitations	19 YES	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20 YES	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21 YES	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22 YES	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

Cognitive ability and educational level in relation to concussion: A population study of young males

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Research Article: Cognitive ability and educational level in relation to concussion: A population study of young males

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Keywords Concussion, Cognitive ability, Educational Level, Risk Factors

3256 words

ABSTRACT

Objectives: To investigate the association of concussion with cognitive ability and educational level.

Design: Epidemiological: Cross-linkage of national computer registers

Setting: Denmark

Participants: 130,420 young men appearing before the Danish draft board in the period 2006-2010.

Primary and secondary outcome measures: cognitive ability test scores (CA), educational level (EL) and occurrence of concussion in the period 2004-2009, treated either in an Accident & Emergency (A&E) unit or with admission to a hospital ward.

Results: The 3.067 men who had suffered a concussion had lower CAs (mean=96.5, s.d.=15, 95%CI=95.0-97.0) than the total cohort and they were lower for the 1,452 who were admitted to a hospital ward (mean CA=95.8, s.d.=15, 95%CI=95.1-96.6) than for the 1,615 who were treated only at an A&E unit (mean CA=97.1, s.d.=15, 95%CI=96.3-98.0). Multiple logistic regression revealed that the effects for educational level were stronger than for CA. Among the 127,353 men not sustaining a concussion, 48% attended a 'gymnasium' (sixth-form college), among men treated for a concussion at an A&E unit, this falls to 36% and, among men hospitalized for a concussion to 30%. Transfer to a gymnasium, if it happens, almost invariably does so before the 18th birthday. Among 701 men suffering a concussion and admitted to a hospital department after this date, only 26% (n=182) had previously transferred to a gymnasium. Among the 804 men treated at an A&E unit after their 18th birthday, 33% (n=265) had done so. These two percentages are significantly below the corresponding non-concussed population (48%).

Conclusions: taken together, the results suggest that lower CA and, in particular, lower EL are risk factors for sustaining a concussion, the risk increasing with the severity of the injury.

Article summary

Article focus:	The role of cognitive ability and educational level in the occurrence of concussions.
Key messages:	Lower cognitive ability and, in particular, lower EL appear to be risk factors for sustaining a concussion, being found in individuals prior to sustaining a concussion. This risk increases with the severity of the injury.
Strengths and weaknesses	Strengths: The data are derived from a large, well-defined, population cohort. Weaknesses: The data are limited to young men only and lack information on the severity of the injury other than whether it was treated in an accident and emergency unit or with admission to a hospital.

INTRODUCTION

A concussion, also often termed a Mild Traumatic Brain Injury, is defined as "a trauma-induced alteration in mental status that may or may not involve loss of consciousness" (1). It typically involves temporarily reduced consciousness and/or feelings of confusion and dizziness together with amnesia for events immediately preceding or following the injury. The consequences of concussion vary from transient symptoms to rarer instances of Post-Concussional Syndrome with lasting physical, emotional, cognitive, or behavioural symptoms (2) (3). Most studies, however, typically find that the cognitive effects of a concussion resolve themselves within days or at most weeks (4-6).

A number of risk factors for concussion have been identified. One of the major factors appears to be participation in sports (7), and, indeed, most studies about concussions concern sports-related injuries. (8) (9)(10). Having previously sustained a concussion is a risk factor in itself (8), and the effects appear to be correspondingly cumulative (11)(12).

Gender and age are also significant risk factors for concussions, including those which are not the result of sports injuries. Concussions from all causes occur more often for males than for females and their incidences are particularly high among adolescents and young adults, but also peaking again amongst the elderly (13). Alcohol intoxication is an immediate risk factor for concussion (14) and sustaining a concussion while under the influence of alcohol has also been identified as a risk factor for further alcohol-related concussions (15).

Although there has been extensive research investigating the cognitive effects of concussions, there has been relatively little research investigating the possible influence of education and cognitive functioning as risk factors. Ewing-Cobbs et al. (16) found academic skill deficiencies to be present among adolescents prior to injury. Similarly, Teasdale & Engberg (17) reported cognitive test performance to be reduced among young adults who subsequently sustained a concussion, even some years later. A relationship of educational and cognitive functioning with concussions could plausibly be expected given the pervasive association of social class related characteristics with injuries in general (18).

Four major difficulties with the extant studies have been the selectiveness of sampling, small samples, variability in the severity of the concussion (in particular, that many concussions sustained in sporting activities are comparatively quite mild) and the lack of good controls or test norms. The present study has attempted to overcome these difficulties. Our data are derived from a national medical database from which a large sample has been drawn and the concussions involved were medically diagnosed as such (ICD-10, S.060) and were of a severity sufficient to warrant at the least attendance at an Accident &Emergency unit (A&E). Specifically, as an indication of severity, we have been able to compare patients who were only treated at an A&E unit with patients who were admitted to a hospital ward. Furthermore, for purposes of comparison, we have available full cognitive test scores and educational levels for a complete population cohort: it is worth noting that this represents a considerable advance on the limited data available to us in previous studies where we had only cognitive test scores reduced to a dichotomy and no information on educational level (17;19). Unusually, we are also able to report on the cognitive ability (CA) and educational level (EL) of concussion patients either before or after the concussion occurred.

The present study thus examines the relationship of cognitive ability and educational level with concussion, particularly with regard to the temporal order of events and the severity of concussion. In addition we wished to explore the possible role of the cause of injury, specifically accident versus violence.

METHODS

Draft Board Data.

The starting point for the present study was a database comprising all 159,402 men processed by the Danish draft board in the five-year period 2006-2010. Denmark maintains military conscription for which all men become liable at age 18. The procedure entails, inter alia, a 45-minute test for cognitive abilities, the Børge Prien's Prøve (BPP) which comprises four subtests for logical, verbal, numerical and spatial reasoning, each having about 20 items none of which are multiple-choice. All of the subtests are measures of 'fluid' rather than 'crystallized' intelligence (20) and all are timed; thus, mental speed is at a premium. The test result is the number of correct answers across subtests and out of 78, but this cognitive ability (CA) score has here been converted to parallel conventional IQ scaling, viz. with a mean of 100 and a standard deviation of 15, in order to give a more familiar metric of effect size. The BPP has been reported to correlate .82 with the Wechsler Adult Intelligence Scale (21) and to have a test-retest reliability of .77 (22). Further details are reported elsewhere (23).

Also recorded by the draft board is educational level (EL) on an 8-13 scale primarily reflecting the highest school class attained. The most critical point on this scale is the divide between the values 8 through 10, which indicate just grade school, possibly followed by occupational training, and the values 11 through 13 which indicate that the individual has entered a 'gymnasium', equivalent to a three-year sixth-form college and leading to a ‘studentereksamen’, akin to a baccalaureate and requisite for higher education. Entry to a gymnasium is contingent on examination results and teachers’ recommendations and typically occurs about age 16.

In some cases, personal appearance before the board is not required and neither BPP nor EL are obtained. This occurs for men who, in advance, can document an illness which would disqualify them from military service, e.g. chronic asthma, severe myopia, and curvature of the spine. In the present cohort 28,982 men (18.2%) did not appear before the draft board. We obtained BPP and EL, together with the exact date of the draft board appearance, for the remaining 130,420 (81.8%) men. The average age for this appearance was 19.5 years (SD 1.3). Similarly to what has been reported elsewhere (22) the correlation between the BPP and EL was .52. It is worth observing parenthetically that only a small proportion of the men who are processed by the draft board are thereafter called upon to perform military service, this being largely determined by the draw of a lottery number, once suitability has been established.

Hospital Registration Data

In Denmark, all hospital admissions and, since 2004, all treatments at A&E units are centrally recorded in a National Hospitalization Register (24). Dates of admission or A&E attendance are recorded. ICD-10 diagnoses are used and, in most cases, the cause of an injury is recorded using the Nordic Medico-Statistical Committee (NOMESCO) system (25). Primary among these causes in Denmark are accidents and, to a much lesser extent, violence.

For the 159,402 men in our Draft Board database we searched this register for persons who, in the period 2004 through 2009, had been admitted to hospital, typically to an orthopaedic or neurological ward, or were treated at A&Es, in all cases with the sole discharge diagnosis of concussion (ICD-10 S.060). Cross-linking the two registers is made possible since both employ a national Central Person Registration number. For those admitted to hospital we restricted the period involved to not more than two days. The search identified 3,847 men of whom 1,830 had been admitted to hospital and 2,017 had been treated at an A&E unit. The approximately 4% of men who had sustained more than one concussion in the time period, were recorded with the first of these. The hospitalization register does not include information on loss of consciousness or post-traumatic amnesia. Amongst the two groups, respectively 1,452 (79.3%) and 1,615 (80.1%) had appeared before the draft board and for whom BPP and EL were thus available. It is worth noting that these percentages differ significantly, (χ^2 (2) = 12.0, p < .01) but only slightly, from the above noted overall rate of 81.8%. The mean age at injury for all patients was 17.9 years (s.d. 2.5). The ages ranged between 11 and 31 but 90% were between 14 and 22 years. Among those for whom BPP and EL were available 1,887 cases (62%) were coded as 'accident' and 447 cases (15%) were coded as 'violence'. These codes were lacking for the remaining 733 (24%).

Table 1 shows age at injury and age at testing, separately for admitted patients and for A&E patients, in relation to the injury occurring before or after draft board testing, together with age at testing for the non-patient group. It can be seen that there are no differences between the five defined groups in age at testing. Age at injury was (necessarily) earlier for those injured before testing and later for those injured after testing. Among the four patient groups a significantly higher proportion of those injured before testing were admitted to hospital rather than treated in A&E (49.5%) than among those injured after testing (40.5%) (χ^2 (1) = 18.5, p < .001). Among those injured before testing the median time interval was 819 days for admitted patients and 797 days for A&E patients (Mann-Whitney U, z = 0.64, n.s.)

Table 1

Mean ages and frequencies as a function of concussion pre- or post-testing and without concussion

	Age at Injury	Age at Testing	
	Mean (SD)	Mean (SD)	n
Admitted patients			
Concussion pre-testing	17.2 (2.0)	19.6 (1.3)	1152
Concussion post-testing	20.5 (1.4)	19.4 (1.1)	300
A&E patients			
Concussion pre-testing	17.1 (2.0)	19.5 (1.4)	1174
Concussion post-testing	20.6 (1.5)	19.4 (1.1)	441
Non-patients		19.5 (1.3)	127353

Statistics

The data were analyzed with SPSS20, using t-tests, analyses of variance including a priori contrasts, logistic regression, and odds ratios.

RESULTS

Means and standard deviations for CA and EL as a function of patient type and being tested post- or pre-concussion, together with the non-concussed group are shown in Table 2. Overall t-tests showed that concussion patients had significantly lower CA ($t(130,418) = 13.2$, $p<.001$) and significantly lower EL ($t(130,418) = 18.8$, $p<.001$) than the non-patient population. The CA difference was 3.6 points, corresponding to an effect size of .24 (Cohen's d, (26)) and the effect size for EL was .35. With the single exception of the CA score for individuals suffering a concussion subsequent to testing and treated at an A&E unit, all comparisons between the individual concussion groups shown in Table 2 and the non-patient group are statistically significant p<.01

Table 2

Cognitive Ability (CA) and Educational Level (EL) as a function of concussion pre- or post-testing and without concussion

	CA		EL	
	Mean (SD)		Mean (SD)	
Admitted patients				
Concussion pre-testing	95.5 (14.9)	*	10.2. (1.7)	*
Concussion post-testing	97.1 (14.9)	*	10.2 (1.7)	*
A&E patients				
Concussion pre-testing	96.3 (14.8)	*	10.4 (1.8)	*
Concussion post-testing	99.0 (14.9)		10.6 (1.8)	*
All patients	96.5 (14.9)	*	10.3 (1.8)	*
Non-patients	100.1 (15.0)		11.0 (1.8)	

* Differs significantly from the corresponding Non-patients mean (p<.01, a priori contrast)

In order to examine for effects of hospital admission versus A&E treatment and of sequence of injury and testing we conducted analyses of variance for CA and EL in which the non-patient group was excluded and pre-or-post injury and patient type were included as independent variables. For CA there were significant main effects of pre-post injury ($F(1,3063)=11.1$, $p=.001$) and of patient type ($F(1,3063)=4.5$, $p=.033$). The interaction was not, however, significant ($F(1,3063)=0.7$, n.s.). Overall, men injured before testing had CAs on average 2.3 points below those of men injured after testing, an effect size of $d=.15$. Those who were admitted to hospital had CAs on average 1.2 points below those who were treated in A&E units, an effect size of $d=.08$. For EL there was no main effects of pre-post injury ($F(1,3063)= .8$, n.s.) but there was a significant effect of patient type ($F(1,3063)=15.6$, $p<.001$). The interaction was again not significant ($F(1,3063)=.7$, n.s.). Patients admitted to hospital had lower EL than those treated in A&E units (effect size, $d = .15$).

In order to investigate the degree to which CA and EL are independently related to the occurrence of a concussion we included both variables, transformed to z-scores to enable comparison of their respective contributions, in a logistic regression predicting concussion. The Nagelkerke R^2 was .014. The resulting model is shown in Table 3 where it can be seen that both EL and CA predict concussion significantly, but that the contribution of EL is markedly and significantly greater than that of CA.

Table 3

Logistic regression of Cognitive Ability (CA) and Educational Level (EL) (both standardized to z-scores) in relation to concussion

	B	S.E.	Wald	df	Sig.	OR	OR 95% C.I.	
							Lower	Upper
CA	-.072	.021	12.43	1	p<.001	.930	.893	.968
EL	-.315	.022	198.57	1	p<.001	.730	.698	.762
Constant	-3.786	.019	38293	1	p<.001	.023		

We have explored further the potential role of educational level specifically as a risk factor for concussion. As stated above, within the educational level scale from 8 to 13, the most salient dichotomy is between 8-10, representing those who only attended grade school ('folkeskole', typically leaving at age 15 or 16 and pursuing non-academic further education) and 11-13, representing those who went on to the academically oriented gymnasium. Since we do not know the exact age at which an individual transferring to a gymnasium actually did so, we selected men whose concussions occurred after their 18th birthday since transfer would almost certainly have happened before that date. The numbers of these men were compared with a baseline of those of men in the present sample who did not sustain a concussion and who did attend a gymnasium (61,645 out of 127,353 = 48%).

Among the 701 men who sustained a concussion after their 18th birthday and for which they were admitted to a hospital, 26% (n=182) had entered a gymnasium, this being significantly below the baseline (OR=.37, 95%CI=.32-.44). Among the 804 men who sustained a concussion after their 18th birthday and for which they were treated at an A&E department, 33% (n=265) had entered a gymnasium, this again being significantly below the baseline (OR=.52, 95%CI=.45-.61). The percentage of men attending gymnasium within these two concussion groups was significantly lower for those admitted to a hospital than for those treated at an A&E unit (OR=.71, 95%CI=.57-.89).

Given previous evidence of cognitive dysfunction for a comparatively short period following a concussion we examined CA scores for 26 patients who were tested within 30 days after being injured. However, this group had a mean CA of 95.3 (SD 15.3) which did not differ significantly from all others who were injured prior to being tested, mean CA = 95.9, (SD 14.8) (($t(2327) = 0.2$, n.s.).

The two main causes of injury were 'accident' (n=1,905, 62%) and 'violence' (458, 15%). Mean CA and EL for these two groups are shown in Table 4. The majority of the remaining causes of injury were either not coded or recorded as 'other'. Patients with injuries associated with violence had significantly lower CAs ($t(2334) = 2.02$, $p<.05$) and significantly lower ELs ($t(2361) = 3.61$, $p<.001$) than patients with accidental injuries. Again, the effect size is greater for EL ($d = .24$) than for CA ($d = .11$).

Table 4

Cognitive Ability (CA) and Educational Level (EL) as a function of cause of injury

	CA	EL
	Mean (SD)	Mean (SD)
Accident	96.6 (15.0)	10.4 (1.8)
Violence	95.0 (14.6)	10.0 (1.6)

DISCUSSION

The main finding of the present study is that lower cognitive ability and, in particular, lower educational level appear to be risk factors for sustaining a concussion, the risk increasing with the severity of the injury. It is, however, recognized that the study has a number of limitations. First, we have only had data available on males and it is therefore uncertain whether the present findings would apply also for females. It should be added, however, that males account for a much greater incidence of concussions than do females (13;27). A second limitation is the narrow age range of our sample which, for reasons related to the available databases, was limited to concussions occurring predominantly between the ages of 14 and 22. Again it could be added that the age range to which we perforce have been limited to is exactly a high risk period for concussions (13). A third limitation is the lack of conventional measures of the severity of a concussion, such as duration of unconsciousness or post-traumatic amnesia.

These limitations notwithstanding, a number of conclusions can be drawn. The major conclusion is that both relatively low CA and EL are associated with the occurrence of a concussion. We found lower levels of CA and EL for men who had suffered a concussion both when the concussion had occurred prior to testing, and, importantly, when it occurred subsequent to testing. The fact, however, that the effect for CA was also greater for men who had suffered a concussion prior to being tested by the draft board, than among those whose concussion occurred after testing was contrary to an earlier finding of the reverse pattern (17). It should, however, be noted that the age range for injuries is much narrower, and the sample size much larger in the present study.

Furthermore, the earlier study used a very limited dichotomous scoring of the BPP test and did not include a measure of educational level.

Whatever accounts for this pre- and post-testing CA effect it seems unlikely that it is largely attributable to a direct causal effect of the injury on later CA test scores. The average pre-testing interval in the present sample was 2.4 years, whereas most studies finding direct effects of concussion on cognitive functioning report much shorter intervals (4-6;17). A further reason to discount a direct effect of the concussion is that we did not find reduced test performance in those patients for whom the concussion-to-testing interval was within a range more commonly reported, i.e. one month. It is rrecognised that the possibility cannot be discounted that some proportion of the men injured prior to testing have been suffering Post-Concussional Syndrome in which, amongst other symptoms, poor attention and fatigue can continue for long after the injury (4;28-30). Such cases would depress both the CA scores and EL. However, it should be observed that Post-Concussional Syndrome is more characteristic of women than men and of older rather than younger persons (31).

The consistency with which the associations of concussion are greater with EL than with CA may in part result from the lower reliability of the BPP test. It is, however, particularly striking that among the young men who had suffered a concussion after attaining the age of 18, by which time any transfer to higher education (gymnasium) would have occurred, substantially fewer in fact had done so. Whereas about 48% of men in general had attended a gymnasium, only 26% of men admitted to a hospital for a concussion had done so and only 33% of men treated at an A&E unit had done so. This strongly implicates educational level as a risk factor for sustaining a subsequent concussion and the difference between hospital admission and A&E treatment further suggests that the risk is greater for relatively more severe injuries.

It is tempting to speculate that both cognitive ability and educational level in the present study are indicators for broader social environmental factors which appear to contribute to injury risks in wider contexts (18) . It is beyond the scope of the present study to investigate such factors more closely, but the frequent involvement of alcohol in incidences of concussion [31,32], and our finding that violence as a cause of injury is more strongly associated with lower educational level and cognitive ability than is accident, also suggests that social factors are operating (32).

Declarations

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

No competing interests are involved.

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Contributorship

TWT was responsible for the acquisition of data. Both authors made substantial contributions to the conception and design, and the interpretation of results. TWT bore primary responsibility for the statistical analyses and AJF bore primary responsibility for reviewing the relevant literature. Both authors have collaborated in drafting the article and both have given final approval of the version to be published.

No additional data available

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Research Article: ~~Intelligence~~ Cognitive ability and educational level ~~as risk factors~~in relation to ~~for~~ concussion:

A population study of young males

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Keywords Concussion, ~~Intelligence~~ Cognitive ability, Educational Level, Risk Factors

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ABSTRACT

Objectives: To investigate the association of concussion with ~~intelligence~~ cognitive ability and educational level.

Design: Epidemiological: Cross-linkage of national computer registers

Setting: Denmark

Participants: 130,420 young men appearing before the Danish draft board in the period 2006-2010.

Primary and secondary outcome measures: ~~Intelligence~~ cognitive ability test scores (CA~~IQ~~), educational level (EL) and occurrence of concussion in the period 2004-2009, treated either in an Accident & Emergency (A&E) unit or with admission to a hospital ward.

Results: The 3.067 men who had suffered a concussion had lower CA~~IQ~~s (mean=96.5, s.d.=15, 95%CI=95.0-97.0) than the total cohort and they were lower for the 1,452 who were admitted to a hospital ward (mean ~~IQ~~CA=95.8, s.d.=15, 95%CI=95.1-96.6) than for the 1,615 who were treated only at an A&E unit (mean ~~IQ~~CA=97.1, s.d.=15, 95%CI=96.3-98.0). Multiple logistic regression revealed that the effects for educational level were stronger than for CA~~IQ~~. Among the 127,353 men not sustaining a concussion, 48% attended a 'gymnasium' (sixth-form college), among men treated for a concussion at an A&E unit, this falls to 36% and, among men hospitalized for a concussion to 30%. Transfer to a gymnasium, if it happens, almost invariably does so ~~typically~~ before the 18th birthday. Among 701 men suffering a concussion and admitted to a hospital department after this date, only 26% (n=182) had previously transferred to a gymnasium. Among the 804 men treated at an A&E unit after their 18th birthday, 33% (n=265) had done so. These two percentages are significantly below the corresponding non-concussed population (48%)~~, and they differed significantly from each other (OR=1.40, 95%CI=1.12-1.75)~~.

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Conclusions: taken together, the results suggest that lower ~~intelligence~~ CA and, in particular, lower EL are risk factors for sustaining a concussion, the risk increasing with the severity of the injury.

Article summary

Article focus:	The role of ~~intelligence~~ cognitive ability and educational level in the occurrence of concussions.
Key messages:	Lower ~~intelligence~~cognitive ability and, in particular, lower EL appear to be risk factors for sustaining a concussion, being found in individuals prior to sustaining a concussion. This risk increases with the severity of the injury.
Strengths and weaknesses	Strengths: The data are derived from a large, well-defined, population cohort. Weaknesses: The data are limited to young men only and lack information on the severity of the injury other than whether it was treated in an accident and emergency unit or with admission to a hospital.

INTRODUCTION

A concussion, also often termed a Mild Traumatic Brain Injury, ~~-~~is defined as "a trauma-induced alteration in mental status that may or may not involve loss of consciousness" (1)~~[1], whereas mild traumatic brain injury (mTBI) is defined as "a traumatically induced physiological disruption of brain function" [2]~~. It typically involves ~~In both cases the definition is characterized by symptoms such as loss of~~temporarily reduced consciousness and/or feelings of confusion and dizziness together with~~consciousness,~~ amnesia for events immediately preceding or following the injury~~, and/or feelings of confusion and dizziness~~.

The consequences of concussion vary from transient symptoms~~, as described above,~~ to rarer instances of Post-Concussional Syndrome with lasting physical, emotional, cognitive, or behavioural symptoms (2)~~[2]~~ (3)~~[3]~~. Most studies, however, ~~Studies~~ typically find that the cognitive effects of a concussion resolve themselves within days or at most weeks (4-6)~~[4-6]~~. ~~According to one meta-analysis of 21 studies, all symptoms of neuropsychological impairment cease within seven days, with the exception of impairments in delayed memory which are found to persist beyond this period [7].~~

~~A recent study reports significant effects on neurocognitive tests at 1, 6 and 12 months follow up in children with mTBI and also in a control group of children with other minor injuries, but specifically states that "when controlling for pre-injury factors, there is no evidence of long-term neurocognitive impairment in this group relative to another injury control group." [8]. Sustaining repeated concussions is associated with declines in delayed memory and executive functioning [9], and gender has been found to influence cognitive performance after two or more concussions [10].~~

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Severity of the trauma has been found to correlate positively with especially memory problems at follow up [11], and very young age at injury is a risk factor for impairments in executive functioning following traumatic brain injury (TBI) [12]. Injury sustained at a young age leads to a more generalized impairment in executive functioning than injury sustained in adulthood [13]. Yet, young age, as well as premorbid high functioning, also seems to be a protective factor leading to better cognitive recovery following moderate to severe TBI [14]. However, children sustaining complicated mTBI, i.e. those with intra-cranial abnormalities [15] appear to be more vulnerable to developing mild chronic cognitive dysfunction following injury than adults with similar injuries [16,17].

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According to a meta-analysis by Cassidy et al. 70-90 percent of all treated TBIs are mild, and about 100-300 per 100,000 per annum in a population are treated in hospital for mTBI [18]. As many mTBIs are not reported, however, the total population-based rate is estimated to be at least 600/100,000 [18]. Approximately two million people sustain a TBI each year in the US [19], and an estimate of 50.000-300.000 college athletes in the US experience mTBI each year [20]. In Denmark, Engberg & Teasdale [21] reported a decline in the incidence of concussions leading to hospital admissions between 1979 and 1993 from 227 to 131 per 100,000, a decline which appeared to result from a decreasing practice of admission to a hospital ward from an Accident and Emergency (A&E) unit, for observation, patients whose only apparent complaint was the concussion itself.

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A number of risk factors for concussion have been identified. One of the major factors appears to be participation in sports (7)[22], and, indeed, most studies about concussions concern sports-related injuries. Annual incidence rates have been found to be between 9.36 and 33.09 per 100,000 American high school athletes, depending on the particular sport (8)[23]. Participants in contact sports are particularly likely to sustain concussion, with ice hockey and rugby players having the highest

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incidence rates during games, and male boxers and female taekwondo participants being most likely to sustain concussion in their leisure time (9)[24]. Furthermore, duration of the game is also a risk factor for sustaining concussion: the longer into the game, the greater the chance of injury (10)[25]. In absolute numbers, males outweigh females in terms of sustaining sports-related concussion [18], but female athletes appear to be at a proportionally greater risk for concussion than their male counterparts [22,26] [27,28].

Having previously sustained a concussion is a risk factor in itself (8)[23], and the effects appear to be correspondingly cumulative (11)[29]. Athletes who suffer multiple concussions are significantly more likely to experience yet another concussion, about four to six times more according to some studies (12)[30].

Gender and age are also significant risk factors for concussions, including those which are not the result of sports injuries. Concussions from all causes occur more often for males than for females and their incidences are particularly high among adolescents and young adults, but also peaking again amongst the elderly (13)[21].

Alcohol intoxication is an immediate risk factor for concussion. One study of patients treated at an A&E unit reported almost 50% of concussion patients to be under the influence of alcohol (14)[31] and. S sustaining a concussion while under the influence of alcohol has also been identified as a risk factor for sustaining further alcohol-related concussions (15)[32].

Although there has been extensive research investigating the cognitive effects of concussions, there has been relatively little research investigating the possible influence of education and cognitive

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functioning as risk factors. Ewing-Cobbs et al. (16)[33] found academic skill deficiencies to be present among adolescents prior to injury. Similarly, Teasdale & Engberg (17)[34] reported cognitive test performance to be reduced among young adults who subsequently sustained a concussion, even some years later. A relationship of educational and cognitive functioning with concussions could plausibly be expected given the pervasive association of social class related characteristics with injuries in general (18).

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Four major difficulties with the extant studies have been the selectiveness of sampling, small samples, variability in the severity of the concussion (in particular, that many concussions sustained in sporting activities are comparatively quite mild) and the lack of good controls or test norms. The present study has attempted to overcome these difficulties. Our data are derived from a national medical database from which a large sample has been drawn and the concussions involved were medically diagnosed as such (ICD-10, S.060) and were of a severity sufficient to warrant at the least attendance at an Accident &Emergency unit (A&E). Specifically, as an indication of severity, we have been able to compare patients who were only treated at an A&E unit with patients who were admitted to a hospital ward. Furthermore, for purposes of comparison, we have available full cognitive test scores and educational levels for a complete population cohort: it is worth noting that this represents a considerable advance on the limited data available to us in previous studies where we had only cognitive test scores reduced to a dichotomy and no information on educational level (17;19)[34,35]. Unusually, we are also able to report on the cognitive ability (CA)functioning and educational level (EL) of concussion patients either before or after the concussion occurred.

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On the basis of the evidence reviewed we have formed three hypotheses: first, that concussion patients will prove to have lower than average scores on the cognitive test, and to have lower Els than the general population, this irrespective of the temporal relationship between the date of cognitive testing and the date of the concussion. An exception to this forms our second hypothesis, namely that cognitive functioning is particularly reduced where testing has taken place less than a month following the concussion. The third hypothesis is that lower cognitive functioning and EL are more marked for patients admitted to a hospital ward than for patients treated at A&E clinics, this because lower cognitive functioning and EL is a stronger risk factor for more serious injuries.The present study thus examines the relationship of cognitive ability and educational level with concussion, particularly with regard to the temporal order of events and the severity of concussion. In addition we wished to explore the possible role of the cause of injury, specifically accident versus violence.

METHODS

Draft Board Data.

The starting point for the present study was a database comprising all 159,402 men processed by the Danish draft board in the five-year period 2006-2010. Denmark maintains military conscription for which all men become liable at age 18. The procedure entails, inter alia, a 45-minute test for cognitive abilities, the Børge Prien's Prøve (BPP) which comprises four subtests for logical, verbal, numerical and spatial reasoning, each having about 20 items none of which are multiple-choice. All of the subtests are measures of 'fluid' rather than 'crystallized' intelligence (20)[36] and all are timed; thus, mental speed is at a premium. The test result is the number of correct answers across subtests and out of 78, but this cognitive ability (CA) score has here been converted to parallel conventional IQ scaling, viz. with a mean of 100 and a standard deviation of 15, in order to give a more familiar indication metric of effect size. The BPP has been reported to correlate .82 with the Wechsler

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Adult Intelligence Scale (21)[37] and to have a test-retest reliability of .77 (22)[38]. Further details are reported elsewhere (23)[39].

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Also recorded by the draft board is educational level (EL) on an 8-13 scale primarily reflecting the highest school class attained. The most critical point on this scale is the divide between the values 8 through 10, which indicate just grade school, possibly followed by occupational training, and the values 11 through 13 which indicate that the individual has entered a 'gymnasium', equivalent to a three-year sixth-form college and leading to a 'studentereksamen', akin to a baccalaureate and requisite for higher education. Entry to a gymnasium is contingent on examination results and teachers' recommendations and typically occurs about age 16.

In some cases, personal appearance before the board is not required and neither BPP nor EL are obtained. This occurs for men who, in advance, can document an illness which would disqualify them from military service, e.g. chronic asthma, severe myopia, and curvature of the spine. In the present cohort 28,982 men (18.2%) did not appear before the draft board. We obtained BPP and EL, together with the exact date of the draft board appearance, for the remaining 130,420 (81.8%) men. The average age for this appearance was 19.5 years (SD 1.3). Similarly to what has been reported elsewhere (22)[38] the correlation between the BPP and EL was .52. It is worth observing parenthetically that only a small proportion of the men who are processed by the draft board are thereafter called upon to perform military service, this being largely determined by the draw of a lottery number, once suitability has been established.

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Hospital Registration Data

In Denmark, all hospital admissions and, since 2004, all treatments at A&E units are centrally recorded in a National Hospitalization Register (24)[40]. Dates of admission or A&E ~~treatments~~ attendance are recorded. ICD-10 diagnoses are used and, in most cases, the cause of an injury is recorded using the Nordic Medico-Statistical Committee (NOMESCO) system (25)[41]. Primary among these causes in Denmark are accidents and, to a much lesser extent, violence.

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For the 159,402 men in our Draft Board database we searched this register for persons who, in the period 2004 through 2009, had been admitted to hospital, typically to an orthopaedic or neurological ward, or were treated at A&Es, in all cases with the sole discharge diagnosis of concussion (ICD-10 S.060). Cross-linking the two registers is made possible since both employ a national Central Person Registration number. For those admitted to hospital we restricted the period involved to not more than two days. The search identified 3,847 men of whom 1,830 had been admitted to hospital and 2,017 had been treated at an A&E unit. The approximately 4% of men who had sustained more than one concussion in the time period, were recorded with the first of these. The hospitalization register does not include information on loss of consciousness or post-traumatic amnesia. Amongst the two groups, respectively 1,452 (79.3%) and 1,615 (80.1%) had appeared before the draft board and for whom BPP and EL were thus available. It is worth noting that these percentages differ significantly, (χ^2 (2) = 12.0, p < .01) but only slightly, from the above noted overall rate of 81.8%. The mean age at injury for all patients was 17.9 years (s.d. 2.5). The ages ranged between 11 and 31 but 90% were between 14 and 22 years. ~~For those injured prior to testing the average interval was 2.4 years (s.d. 1.6).~~

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Among those for whom BPP and EL were available 1,887 cases (62%) were coded as 'accident' and 447 cases (15%) were coded as 'violence'. These codes were lacking for the remaining 733 (24%).

Table 1 shows age at injury and age at testing, separately for admitted patients and for A&E patients, in relation to the injury occurring before or after draft board testing, together with age at testing for the non-patient group. It can be seen that there are no differences between the five defined groups in age at testing. Age at injury was (necessarily) earlier for those injured before testing and later for those injured after testing. Among the four patient groups a significantly higher proportion of those injured before testing were admitted to hospital rather than treated in A&E (49.5%) than among those injured after testing (40.5%) (χ^2 (1) = 18.5, p < .001). Among those injured before testing the median time interval was 819 days for admitted patients and 797 days for A&E patients (Mann-Whitney U, z = 0.64, n.s.)

Table 1

Mean ages and frequencies as a function of concussion pre- or post-testing and without concussion

	Age at Injury	Age at Testing	
	Mean (SD)	Mean (SD)	n
Admitted patients			
Concussion pre-testing	17.2 (2.0)	19.6 (1.3)	1152
Concussion post-testing	20.5 (1.4)	19.4 (1.1)	300
A&E patients			
Concussion pre-testing	17.1 (2.0)	19.5 (1.4)	1174
Concussion post-testing	20.6 (1.5)	19.4 (1.1)	441

Non-patients	19.5 (1.3)	127353

Statistics

The data were analyzed with SPSS20, using t-tests, analyses of variance including a priori contrasts, logistic regression, and odds ratios.

RESULTS

Means and standard deviations for IQ CA and EL as a function of patient type and being tested post- or pre-concussion, together with the non-concussed group are shown in Table 2. OOverall t-tests showed that concussion patients had significantly lower IQs CA (t(130,418) = 13.2, p<.001) and significantly lower ELs (t(130,418) = 18.8, p<.001) than the non-patient population. The IQCA difference was 3.6 points, corresponding to an effect size of .24 (Cohen's d, (26)[42]) and the effect size for EL was .35. With the single exception of the CA score for individuals suffering a concussion subsequent to testing and treated at an A&E unit, all comparisons between the individual concussion groups shown in Table 2 and the non-patient group are statistically significant p<.01

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Table 2

IQ Cognitive Ability (CA) and Educational Level (EL) as a function of concussion pre- or post-testing and without concussion

	IQCA	EL
	Mean (SD)	Mean (SD)
Admitted patients		
Concussion pre-testing	95.5 (14.9) *	10.2. (1.7) *

Concussion post-testing	97.1 (14.9) *	10.2 (1.7) *
A&E patients		
Concussion pre-testing	96.3 (14.8) *	10.4 (1.8) *
Concussion post-testing	99.0 (14.9)	10.6 (1.8) *
All patients	96.5 (14.9) *	10.3 (1.8) *
Non-patients	100.1 (15.0)	11.0 (1.8)

* Differs significantly from the corresponding Non-patients mean (p<.01, a priori contrast)

In order to examine for effects of hospital admission versus A&E treatment and of sequence of injury and testing we conducted analyses of variance for ~~IQ~~ CA and EL in which the non-patient group was excluded and pre-or-post injury and patient type were included as independent variables. For ~~IQ~~ CA there were significant main effects of pre-post injury (F(1,3063)=11.1, p=.001) and of patient type (F(1,3063)=4.5, p=.033). The interaction was not, however, significant (F(1,3063)=0.7, n.s.). Overall, men injured before testing had ~~IQs~~ CAs on average 2.3 points below those of men injured after testing, an effect size of d=.15. Those who were admitted to hospital had ~~IQs~~ CAs on average 1.2 points below those who were treated in A&E units, an effect size of d=.08. ~~Taken together, 60% of men suffering a concussion had a below average IQ (OR=1.50, 95%CI=1.39-1.61).~~

For EL there was no main effects of pre-post injury (F(1,3063)= .8, n.s.) but there was a significant effect of patient type (F(1,3063)=15.6, p<.001). The interaction was again not significant

(F(1,3063)=.7, n.s.). Patients admitted to hospital had lower EL than those treated in A&E units (effect size, d = .15).

In order to investigate the degree to which IQCA and EL are independently related to the occurrence of a concussion we included both variables, transformed to z-scores to enable comparison of their respective contributions, in a logistic regression predicting concussion. The Nagelkerke R^2 was .014. The resulting model is shown in Table 3 where it can be seen that both EL and IQCA predict concussion significantly, but that the contribution of EL is markedly and significantly greater than that of IQCA.

Table 3

Logistic regression of IQ Cognitive Ability (CA) and Educational Level (EL) (both standardized to z-scores) in relation to concussion

	B	S.E.	Wald	df	Sig.	OR	OR 95% C.I.	
							Lower	Upper
IQCA	-.072	.021	12.43	1	p<.001	.930	.893	.968
EL	-.315	.022	198.57	1	p<.001	.730	.698	.762
Constant	-3.786	.019	38293	1	p<.001	.023		

We have explored further the potential role of educational level specifically as a risk factor for concussion. As stated above, within the educational level scale from 8 to 13, the most salient dichotomy is between 8-10, representing those who only attended grade school ('folkeskole', typically leaving at age 15 or 16 and pursuing non-academic further education) and 11-13, representing those who went on to the academically oriented gymnasium. Since we do not know the exact age at which an individual transferring to a gymnasium actually did so, we selected men whose injuries concussions occurred after their 18th birthday since transfer would almost certainly have happened before that date. The numbers of these men were compared with a baseline of those of men in the present sample who did not sustain a concussion and who did attend a gymnasium (61,645 out of 127,353 = 48.4%).

Among the 701 men who sustained a concussion after their 18th birthday and for which they were admitted to a hospital, 26% (n=182) had entered a gymnasium, this being significantly below the baseline (OR=~~2~~.37, 95%CI=.32-~~2.26~~.44-~~3.17~~). Among the 804 men who sustained a concussion after their 18th birthday and for which they were treated at an A&E department, 33% (n=265) had entered a gymnasium, this again being significantly below the baseline (OR=~~1.91~~.52, 95%CI=.45~~1.65~~-.61~~2.21~~). The percentage of men attending gymnasium within these two concussion groups was significantly ~~higher~~ lower for ~~men~~ those admitted to a hospital than for ~~men~~ those treated at an A&E unit (OR=.71~~1.40~~, 95%CI=.57~~1.12~~-.89~~1.75~~).

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Given previous evidence of cognitive dysfunction for a comparatively short period following a concussion we examined ~~IQ~~ CA scores for 26 patients who were tested within 30 days after being injured. However, t~~T~~his group had a mean ~~IQ~~ CA of 95.3 (SD 15.3) which did not differ significantly from all others who were injured prior to being tested, mean CA~~IQ~~ = 95.9, (SD 14.8) ((t(2327) = 0.2, n.s.).

The two main causes of injury were 'accident' (n=1,905, ~~(~~62%~~)~~) and 'violence' (458, 15%). Mean ~~IQs~~ CA and ELL~~ls~~ for these two groups are shown in Table 4. The majority of the remaining causes of injury were either not coded or recorded as 'other'. Patients with injuries associated with violence had significantly lower ~~IQ~~CAs (t(2334) = 2.02, p<.05) and significantly lower ELs (t(2361) = 3.61, p<.001) than patients with accidental injuries. Again, the effect size is greater for EL (d = .24) than for ~~IQ~~ CA (d = .11).

Table 4

~~IQ~~ Cognitive Ability (CA) and Educational Level (EL) as a function of cause of injury

	CA~~IQ~~	EL
	Mean (SD)	Mean (SD)
Accident	96.6 (15.0)	10.4 (1.8)

Violence	95.0 (14.6)	10.0 (1.6)

DISCUSSION

The main finding of the present study is that lower intelligencecognitive ability and, in particular, lower EL educational level appear to be risk factors for sustaining a concussion, the risk increasing with the severity of the injury. It is, however, recognized that the study has a number of limitations. First, we have only had data available on males and it is therefore uncertain whether the present findings would apply also for females. It should be added, however, that males account for a much greater incidence of concussions than do females (13;27)[18,21]. A second limitation is the narrow age range of our sample which, for reasons related to the available databases, was limited to concussions occurring predominantly between the ages of 14 and 22. Again it could be added that the age range to which we perforce have been limited to is exactly a high risk period for concussions (13)[21]. A third limitation is the lack of conventional measures of the severity of a concussion, such as depth of coma or duration of unconsciousness or post-traumatic amnesia.

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These limitations notwithstanding, a number of conclusions can be drawn. The major conclusion, and a confirmation of our first hypothesis, is that both relatively low IQCA and ELeducational level are associated with the occurrence of a concussion. We found lower levels of IQCA and educational levelEL for men who had suffered a concussion both when the concussion had occurred prior to testing, and, importantly, when it occurred subsequent to testing. Confirming the third of our hypotheses, the effect was more marked among men who had been admitted to a hospital ward than among men who were treated only in an accident & emergency unit.

The fact, however, that the effect for ~~IQ~~CA was also greater for men who had suffered a concussion prior to being tested by the draft board, than among those whose concussion occurred after testing~~,~~ was contrary ~~was unexpected and contrary~~ to an earlier finding of the reverse pattern (17)[34]. It should, however, be noted that the age range for injuries is much narrower, and the sample size much larger in the present study. Furthermore, ~~that~~ the earlier study used a very limited dichotomous scoring of the BPP test and did not include a measure of educational level.

Whatever accounts for this pre- and post-testing ~~IQ~~CA effect it seems unlikely that it is largely attributable to a direct causal effect of the injury on later ~~IQ~~CA test scores. The average pre-testing interval in the present sample was 2.4 years, whereas most studies finding direct effects of concussion on cognitive functioning report much shorter intervals (4-6;17)[4-6,34]. A further reason to discount a direct effect of the concussion is that~~, in a failure to confirm our second hypothesis,~~ we did not find reduced test performance in those patients for whom the concussion-to-testing interval was within a range more commonly reported, i.e. one month. It is rrecognised that ~~However, t~~the possibility ~~should not~~cannot be discounted that some proportion of the men injured prior to testing have been suffering Post-Concussional Syndrome in which, amongst other symptoms, poor attention and fatigue can continue for long after the injury (4;28-30)[4,43-45]. Such cases would depress both the ~~IQ~~CA scores and EL~~educational levels~~. However, it should be observed that Post-Concussional Syndrome is more characteristic of women than men and of older rather than younger persons (31).

The consistency with which the associations of concussion are greater with ~~educational level~~EL than with ~~IQ~~CA may in part result from the lower reliability of the BPP test.

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_It is, however, particularly striking that among the young men who had suffered a concussion after attaining the age of 18, by which time any transfer to higher education (gymnasium) would have occurred, substantially fewer in fact had done so. Whereas about 48% of men in general had attended a gymnasium, only 26% of men admitted to a hospital for a concussion had done so and only 33% of men treated at an A&E unit had done so. This strongly implicates educational level as a risk factor for sustaining a subsequent concussion and the difference between hospital admission and A&E treatment further suggests that the risk is greater for relatively more severe injuries.

-It is tempting to speculate that both cognitive abilityIQ and educational level in the present studyis context are indicators for broader social environmental factors which appear to contribute to injury risks in wider contexts (18) .

_It is beyond the scope of the present study to investigate such factors more closely,; but the frequent involvement of alcohol in incidences of concussion [31,32], and our finding that violence as a cause of injury is is more strongly associated with lower educational level and cognitive abilityIQ than is accident, also suggests that social factors are operating (32)[47].

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Declarations

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

No competing interests are involved.

Licence for Publication

Contributorship

TWT was responsible for the acquisition of data. Both authors made substantial contributions to the conception and design, and the interpretation of results. TWT bore primary responsibility for the statistical analyses and AJF bore primary responsibility for reviewing the relevant literature. Both authors have collaborated in drafting the article and both have given final approval of the version to be published.

No additional data available

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation
Title and abstract	1 YES	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2 YES	Explain the scientific background and rationale for the investigation being reported
Objectives	3 YES	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4 YES	Present key elements of study design early in the paper
Setting	5 YES	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6 YES	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed
Variables	7 YES	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8 YES	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9 YES	Describe any efforts to address potential sources of bias
Study size	10 YES	Explain how the study size was arrived at
Quantitative variables	11 YES	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12 YES	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses
Results		
Participants	13 YES	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14 YES	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) Summarise follow-up time (eg, average and total amount)
Outcome data	15 YES	Report numbers of outcome events or summary measures over time

Main results	16 YES	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17 YES	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18 YES	Summarise key results with reference to study objectives
Limitations	19 YES	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20 YES	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21 YES	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22 YES	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.