Effects of heading exposure and previous concussions on neuropsychological performance among Norwegian elite footballers

T M Straume-Naesheim, T E Andersen, J Dvorak, R Bahr

Background: Cross-sectional studies have indicated that neurocognitive performance may be impaired among football players. Heading the ball has been suggested as the cause, but recent reviews state that the reported deficits are more likely to be the result of head injuries.

Objective: To examine the association between previous concussions and heading exposure with performance on computer-based neuropsychological tests among professional Norwegian football players.

Methods: Players in the Norwegian professional football league (Tippeligaen) performed two consecutive baseline neuropsychological tests (Cogsport) before the 2004 season (90.3% participation, n = 271) and completed a questionnaire assessing previous concussions, match heading exposure (self-reported number of heading actions per match), player career, etc. Heading actions for 18 players observed in two to four matches were counted and correlated with their self-reported values.

Results: Neither match nor lifetime heading exposure was associated with neuropsychological test performance. Nineteen players scored below the 95% confidence interval for one or more subtasks, but they did not differ from the rest regarding the number of previous concussions or lifetime or match heading exposure. The number of previous concussions was positively associated with lifetime heading exposure (exponent (B) = 1.97(1.03–3.75), p = 0.039), but there was no relation between previous concussions and test performance. Self-reported number of headings correlated well with the observed values (Spearman’s r = 0.77, p < 0.001).

Conclusion: Computerised neuropsychological testing revealed no evidence of neuropsychological impairment due to heading exposure or previous concussions in a cohort of Norwegian professional football players.

Head in football was previously considered to be ludicrous and “not football”. However, it has developed to become not only a natural feature of the game, but also an important part of defensive and offensive play. Today football is the only contact sport exposing a large number of participants to purposeful use of the head for controlling and advancing the ball. In 1992, on the basis of a series of cross-sectional studies using neurological examinations, neuropsychological tests, computer tomography scanning, and electroencephalography in active and older retired Norwegian footballers, Tysvaer proposed that, as seen in boxing, encephalography in active and older retired Norwegian footballers, Tysvaer proposed that, as seen in boxing, accidents such as American football and boxing, as well as in non-athletes. Among injuries related to football, 4–22% are head injuries. The reported incidence during matches—1.7 injuries per 1000 player hours—incorporates all types of head injuries including facial fractures, contusions, lacerations, and eye injuries. The estimated incidence of concussion—0.5 injuries per 1000 match hours—probably represents a minimum estimate due to the problem of defining and grading concussions. Although most athletes with head injuries recover uneventfully following a single concussive episode, repetitive mild head trauma may be implicated in the development of cumulative cognitive deterioration. Based on paper and pencil tests, cumulative effects of repeated concussions have been found to cause deterioration in neuropsychological function among athletes in other sports such as American football and boxing, as well as in non-athletes.

The consensus at the first International Conference on Concussion in Sport, held in Vienna in 2001, recognised neuropsychological tests as one of the cornerstones of concussion evaluation, and emphasised the benefits of the computerised cognitive function testing programs that have been developed during the past decade—for example, CogSport (CogState Ltd, Melbourne, Australia), ImPACT (ImPACT Inc., Pittsburgh, PA), ANAM (Automated Neuropsychological Assessment Metrics; developed by the...
Effects of heading exposure and previous concussions on neuropsychological performance

US Department of Defense, and CRI (conclusion resolution index; HeadMinder Inc., New York, NY).

Conventional paper and pencil tests were designed primarily for assessment of cognitive dysfunction caused by neuronal or psychiatric disorders and not for the assessment of mild changes in cognitive functions over time. These tests have therefore often poor psychometric properties for serial study, including limited range of possible score, floor and ceiling effects, learning effects, and poor test–retest reliability. Computerised testing, using infinitely variable test paradigms, may overcome these concerns and is therefore recommended for monitoring consequences of concussion in sport. Studies suggest that computerised tests may be particularly sensitive to the cognitive consequences of sports related concussions, and also that conventional paper and pencil tests do not share this sensitivity. In addition, computer based neuropsychological tests have demonstrated sensitivity to cognitive changes caused by fatigue, alcohol, early neurodegenerative diseases, coronary surgery, and childhood mental illnesses. Studies indicating impaired neuropsychological performance due to heading exposure and/or previous concussions in football were based on conventional paper and pencil neuropsychological tests. Therefore the present study sought to investigate whether these impairments could be reproduced among professional Norwegian footballers when assessed by the new and more sensitive computer based neuropsychological tests. To that end, we examined the association between previous concussions and heading exposure with computer based neuropsychological test performance among professional Norwegian football players.

METHODS

Participants

The Norwegian professional men’s football league (Tippeligaen) has 14 clubs. We invited all the clubs with their A-squad contract players (about 300) to participate in the study. A total of 289 players (96.3%) agreed to take part. The Regional Ethics Committee for Southern Norway approved the project and we obtained written informed consent from all the participating players. Every year in February/March, the teams meet at the Norwegian Football Association training centre at La Manga, Spain, for the La Manga Cup and pre-season training camp. We collected data on 13 of the 14 Tippeligaen teams at La Manga prior to the 2004 season in a test lab set up within the hotel. The neuropsychological tests were administered and supervised by trained personnel. The players undertook the tests in groups of three in the same quiet room to allow rapid data collection. We used the computer based neuropsychological test CogSport (versions 2.2.0 and 2.2.1). Norwegian speaking players were tested with the Norwegian language version of the test, while instructions for each subtask were in Norwegian, and all others used the English language version. The test is described in detail elsewhere. The stimulus for all tasks consists of playing cards with responses given using the keyboard, with the d key indicating “no” and the k key “yes”, or vice versa for left handed players. No other keys were used. The CogSport test battery includes seven subtasks testing different cognitive brain functions:

- Simple reaction time (motor function)
- Choice reaction time (decision making)
- Congruent reaction time (simple attention)
- Monitoring (divided attention)
- One-back (working memory)
- Matching (complex attention)
- Learning (learning and memory)

All subtasks include between 15 and 40 trials, and for all subtasks the data are reported by the CogSport program as the mean reaction time with corresponding standard deviation, accompanied by accuracy data for all tasks except simple reaction time and monitoring. Anticipatory responses (reaction times <100 ms) and abnormally slow responses (reaction times >3500 ms) are recorded as errors and excluded from the analyses. Accuracy data are calculated as the number of true positive responses divided by the number of trials. The test was stopped if a player had more than 40 incorrect responses on one task. Since previous studies on CogSport have indicated a slight learning effect between the first two tests performed, in this study two consecutive tests

Neuropsychological testing

The neuropsychological tests were administered and supervised by trained personnel. The players undertook the tests in groups of three in the same quiet room to allow rapid data collection. We used the computer based neuropsychological test CogSport (versions 2.2.0 and 2.2.1). Norwegian speaking players were tested with the Norwegian language version of the test, while instructions for each subtask were in Norwegian, and all others used the English language version. The test is described in detail elsewhere. The stimulus for all tasks consists of playing cards with responses given using the keyboard, with the d key indicating “no” and the k key “yes”, or vice versa for left handed players. No other keys were used. The CogSport test battery includes seven subtasks testing different cognitive brain functions:

- Simple reaction time (motor function)
- Choice reaction time (decision making)
- Congruent reaction time (simple attention)
- Monitoring (divided attention)
- One-back (working memory)
- Matching (complex attention)
- Learning (learning and memory)

All subtasks include between 15 and 40 trials, and for all subtasks the data are reported by the CogSport program as the mean reaction time with corresponding standard deviation, accompanied by accuracy data for all tasks except simple reaction time and monitoring. Anticipatory responses (reaction times <100 ms) and abnormally slow responses (reaction times >3500 ms) are recorded as errors and excluded from the analyses. Accuracy data are calculated as the number of true positive responses divided by the number of trials. The test was stopped if a player had more than 40 incorrect responses on one task. Since previous studies on CogSport have indicated a slight learning effect between the first two tests performed, in this study two consecutive tests
We used the measures of mean reaction time for all seven subtasks as the main dependent variables, as these measures have shown the highest reproducibility and sensitivity.32 33 Prior to all calculations, the mean reaction times and number of potential confounding variables (age, alcohol consumption, use of other central stimulants, previous narcosis, exposure to solvents, learning difficulties, level of education, and neurological diseases) were entered in the model using backward methodology. Logistic regression was performed for the association between previous concussions (yes or no) and the two heading exposure variables. To increase the power of the logistic regression we rearranged the number of heading actions per match to form the three categories: “0–5 times”, “6–10 times”, and “>11 times”. The lowest and the highest two categories of heading frequency (“0–5 times” v. “>11 times”) and total number of previous concussions (“never concussed” v those with three previous concussions or more) were examined for differences in neuropsychological performance using independent sample t tests. A Bland–Altman plot was constructed to examine the association between self-reported and manually counted number of headings per match, in addition to a non-parametric correlation test (Spearman’s ρ). We set the level of significance as p<0.05, and we did not make any corrections for multiple testing (for example, Bonferroni). SPSS (version 11) was used for all statistical analyses.

RESULTS

Of the 289 players consenting to take part, 18 did not report for neuropsychological testing and were excluded, resulting in a final sample of 271 players. A total of 137 players (50.6%) reported having had one or more previous concussions (55 reported one previous concussion, 43 two, 17 three, and 22 more than four) and 112 players (41.3%) reported a football related concussion—20.8% having experienced a concussion within the previous year (one player did not report his concussion history). The participating players’ characteristics within the previous year (one player did not report his concussion history). The participating players’ characteristics within the previous year (one player did not report his concussion history). The participating players’ characteristics (yes or no) and the two heading exposure variables. To increase the power of the logistic regression we rearranged the number of heading actions per match to form the three categories: “0–5 times”, “6–10 times”, and “>11 times”. The lowest and the highest two categories of heading frequency (“0–5 times” v. “>11 times”) and total number of previous concussions (“never concussed” v those with three previous concussions or more) were examined for differences in neuropsychological performance using independent sample t tests. A Bland–Altman plot was constructed to examine the association between self-reported and manually counted number of headings per match, in addition to a non-parametric correlation test (Spearman’s ρ). We set the level of significance as p<0.05, and we did not make any corrections for multiple testing (for example, Bonferroni). SPSS (version 11) was used for all statistical analyses.

RESULTS

Of the 289 players consenting to take part, 18 did not report for neuropsychological testing and were excluded, resulting in a final sample of 271 players. A total of 137 players (50.6%) reported having had one or more previous concussions (55 reported one previous concussion, 43 two, 17 three, and 22 more than four) and 112 players (41.3%) reported a football related concussion—20.8% having experienced a concussion within the previous year (one player did not report his concussion history). The participating players’ characteristics (yes or no) and the two heading exposure variables. To increase the power of the logistic regression we rearranged the number of heading actions per match to form the three categories: “0–5 times”, “6–10 times”, and “>11 times”. The lowest and the highest two categories of heading frequency (“0–5 times” v. “>11 times”) and total number of previous concussions (“never concussed” v those with three previous concussions or more) were examined for differences in neuropsychological performance using independent sample t tests. A Bland–Altman plot was constructed to examine the association between self-reported and manually counted number of headings per match, in addition to a non-parametric correlation test (Spearman’s ρ). We set the level of significance as p<0.05, and we did not make any corrections for multiple testing (for example, Bonferroni). SPSS (version 11) was used for all statistical analyses.

RESULTS

Of the 289 players consenting to take part, 18 did not report for neuropsychological testing and were excluded, resulting in a final sample of 271 players. A total of 137 players (50.6%) reported having had one or more previous concussions (55 reported one previous concussion, 43 two, 17 three, and 22 more than four) and 112 players (41.3%) reported a football related concussion—20.8% having experienced a concussion within the previous year (one player did not report his concussion history). The participating players’ characteristics (yes or no) and the two heading exposure variables. To increase the power of the logistic regression we rearranged the number of heading actions per match to form the three categories: “0–5 times”, “6–10 times”, and “>11 times”. The lowest and the highest two categories of heading frequency (“0–5 times” v. “>11 times”) and total number of previous concussions (“never concussed” v those with three previous concussions or more) were examined for differences in neuropsychological performance using independent sample t tests. A Bland–Altman plot was constructed to examine the association between self-reported and manually counted number of headings per match, in addition to a non-parametric correlation test (Spearman’s ρ). We set the level of significance as p<0.05, and we did not make any corrections for multiple testing (for example, Bonferroni). SPSS (version 11) was used for all statistical analyses.
followed by attackers (38.5% in the 11–20 category, 10.3% in the >20 category). The manual count, which included 18 players observed in two to four matches, showed that the number of headings per player per match averaged 8.5 (range 0–26). Data on these 18 players revealed a slight over-estimation of the number of headings per match compared with the self-reported figures, at least for the frequent headers. However, the correlation between the self-reported number of headings and the manual count was good (Spearman's $r = 0.77$, $p<0.001$), and the majority defined themselves in the same quartiles as those created by the observed values.

The estimated lifetime heading exposure was significantly positively associated with the number of previous concussions on logistic regression (exponent (B) = 1.97(1.03–3.75), $p = 0.039$) and the self-reported number of headings per match showed the same trend (fig 1, exponent (B) = 1.67, $p = 0.12$) between the medium frequency (6–10 headings) and the high frequency heading group (>11 headings).

However, the multiple linear regression analyses did not reveal any relation between the total number of previous concussions and neuropsychological performance on any of the seven subtasks (fig 2). In addition, there was no relations between the number of headings per match and the neuropsychological test score on any of the subtasks (fig 3), nor between estimated lifetime heading exposure and test scores (fig 4). These results did not change if we excluded players with potential language problems (3%).

There was also no difference in the neuropsychological test results of players with the lowest heading frequency (0–5 times per match) and those heading most frequently (>11 times per match). The mean difference in performance on the seven subtasks between the groups ranged from −0.24% to 0.68% ($p$ values ranging from 0.27 to 0.99). Comparison of
neuropsychological test performance. When the two groups of players with the highest self-reported heading frequency (defensive players and attackers) were compared with the group of players playing other positions (excluding goalkeepers) there were no differences in neuropsychological test performance. When the two groups of players with the highest self-reported heading frequency both independently and together in a multiple regression model in this study but without finding any significant relation. The apparent discrepancy between the current findings and previous studies is not easily explained. In general, the present study was based on similar methodology as the preceding studies in the field, including cross-sectional neuropsychological testing, and heading and concussion exposure based on self-report. In a recent comprehensive review of studies addressing the neuropsychological consequences of heading and head trauma in football, Rutherford et al concluded that there was no definitive evidence that football, and heading in particular, caused deterioration in neuropsychological function among football players. Furthermore, they stated that all the neuropsychological studies conducted so far suffer from methodological problems and that, at best, a few of these studies may be regarded as exploratory. The principal methodological limitations include small and/or inappropriate subject groups,
low or unknown response rates, inappropriate statistical methods (type 1 errors, not adjusting for multiple comparisons or potential confounders). For instance, Matser et al’s study suggesting neuropsychological impairments in amateur football players is generally criticised for conducting up to 283 statistical tests without proper adjustment of the level of significance. When planning the current study, we sought to rectify some of these limitations.

Conventional v computerised tests
All the previous studies have used conventional paper and pencil tests. It has been argued that these tests have problems with normal ranges, sensitivity and specificity, and practise and learning effects. Recent studies of reliability of computerised neuropsychological testing have suggested that measures of response speed are more reliable than measures of response accuracy in healthy young adults. This may be important, since the output from conventional neuropsychological tests used to study cognitive deficits from heading and concussion exposure is typically either an accuracy score or a gross measure of the total time to perform the task. In contrast, we used exact measures of reaction time from computer based tests.

We were not able to include conventional paper and pencil tests in the current study, but other studies suggest that computerised tests may be particularly sensitive to the cognitive consequences of sports related concussions, although both methods have been shown to be sensitive for detection of post-concussive neurocognitive changes. Nevertheless, a meta-analytic review of neuropsychological studies addressing persisting brain damage after minor head trauma suggested that conventional neuropsychological assessment had a positive predictive value of less than 50%. In contrast in several studies computerised reaction time measures show evidence of persisting impairment after sports concussion, even in the presence of normal performance on traditional clinical neuropsychological measures. However, even if there were differences in sensitivity between conventional and computerised neuropsychological tests in favour of the latter, this does not explain why the potentially less sensitive method (paper and pencil) would detect differences that are not identified using the more sensitive method (computer).

Readministration of tests
To minimise variability, we asked the athletes to perform two consecutive neuropsychological tests. For computerised tests, a practise effect is seen between the first and second administration with only smaller non-significant improvements with further serial testing. Macciocchi conducted repeated testing of 110 athletes with conventional neuropsychological tests and showed that the athletes had a definite capacity to improve performance with only one readministration of the test. For instance, the widely used Trail Making Test showed a mean improvement of 20% (p = 0.008). Thus, the results from a second administration of a neuropsychological test, both conventional and computerised, provide a more reliable description of the group’s neuropsychological performance. In the previous studies which showed neuropsychological deficits among footballers neither the footballers nor the control groups performed a practise test.

Control group
There is yet another distinction between the current and previous studies that may be more important. We chose not to include a non-football control group, based on the principle that participants should differ only on the variable under examination (such as heading and concussion). For example in Downs and Abwender’s study, the young footballers and control group had different proportions of men and women, and the older groups consisted exclusively of men. Consequently, any difference might have been due to sex rather than an aspect of football play. This issue was thoroughly discussed by Rutherford et al.

Our approach enabled us to investigate the effects of heading and concussion more specifically compared with the studies of Tysvaer and Lochen, or Matser et al where the main comparison was between the footballers and the non-football controls. Furthermore, we found no evidence of cognitive impairment even when we compared the test results to the normal range defined by the test manufacturers. Only a handful of players qualified as outliers for one or more subtasks and they did not differ from the others regarding history of previous concussions or heading exposure.

Response rate
Finally, the current study is the largest study conducted on football players to date and with a high response rate. Among the previous studies, only Webbe and Ochs reported response rates. In their study, which showed an association between heading recency and neurocognitive performance, 48% of the players invited declined, most citing the reason as insufficient time to accommodate testing. Even so, there is a potential for a selection bias. We invited all the players in the Norwegian top league and 90.3% agreed to participate, minimising selection bias and securing a group of players all playing at the same level.

Many previous studies were performed on amateur level players or on a mixture of amateur, professional, and former professional players.

LIMITATIONS OF THE PRESENT STUDY

Some methodological issues must be considered when interpreting the results of the current study. In particular, these are related to the accuracy of the main independent variables, concussion history and heading exposure, which were self-reported as in most previous studies.

Heading frequency
The ability of players to self-report heading frequency is debated in the literature. Heading frequency may also be subject to great variability among different playing cultures and styles, between continents, countries, different teams and even matches against different opponents. Matser et al claimed that players usually underestimate the number of headers per match in an interview setting, even though their players reported an average of 16 headings per match ranging from 0 to 42. In contrast, studies based on direct observation showed that across the whole team, the average number of headers is between 6 and 16 per match. This is the basis for the grading scale used in the present study to group the participating players according to heading frequency: never, 1–5, 6–10, 11–20 and >20 times per match. Although based on a limited number of games, our observations suggest that the players rated their heading frequency quite well, even though the absolute values were slightly high. Thus it is not likely that the results are biased by misclassification of heading exposure. As mentioned above we also compared the upper and lower extremes of heading frequency groups to minimise this effect—still without detecting any differences in neuropsychological performance. Even so, heading frequency may be questioned as a valid measure of brain impacts. To reduce angular or rotational acceleration, good heading technique requires good timing and coordination of the muscles of the neck to stabilise the head. A more frequent header may be more likely to have a superior heading.
Lifetime heading exposure

Our measure of lifetime heading exposure might have been biased, since it does not consider the level of play for all the years incorporated in the variable. As all our participants were selected from the top league it is reasonable to assume that they had played top level football since the age of 16. As players specialise early, it is also highly likely that they have played the same playing position throughout their careers, with a similar relative frequency of involvement in heading situations. The heading frequency and risk of injury may have increased when progressing from junior to senior ranks even for these elite players, which would lead to an error in the absolute numbers estimated. However, a gradual increased exposure to heading situations would not have influenced a player’s relative rank with respect to heading frequency within the group.

Concussion history

Our measure of concussion history is also based on self-recall, and therefore subject to considerable recall bias, most likely resulting in an underestimation. In a study on a group of US college football players and grid iron football players, Delaney et al showed that four of five concussions were not recognised by the player, even if the player remembered having symptoms on the field when examined retrospectively. These results can only partly be explained by recall bias, and probably also reflect the many different grading systems and definitions of head trauma and concussions. Until recently, the approach to concussion management in Norway has been uniform and conservative, using to the old definition requiring loss of consciousness and/or amnesia. This definition was therefore also used in the player questionnaire. Based on the system of injury registration established in 2000 for Tippeligaen, the doctors for 12 of the included teams registered eight concussions during the 2001 season (0.09 per 1000 players hours of exposure, including matches and training) (TE Andersen, personal communication). This figure is lower than the 24 concussions reported by the players during the same time period (14 teams)−19 during a football match or training (1 January 2003 to 31 December 2003). This comparison indicates that player recall was not a major problem, at least for concussions resulting in amnesia and/or loss of consciousness during the previous season. However, a recent study from Tippeligaen using video analysis to document the injury mechanisms of head injuries showed that only about 10% of all incidents involving impacts to the head were reported by the team doctors as concussions.2 Given the definition used for previous concussions in the present study, we were not able to take such minor head trauma into consideration in the regression model. Guskiewicz et al defined concussion as injury resulting from a blow to the head that may have resulted in one more of the following conditions: headache, nausea, vomiting, dizziness or balance problems, fatigue, trouble sleeping, drowsiness, blurred vision, difficulty remembering or difficulty concentrating.

Yet they found a similar prevalence of concussions as in our study (49.5% reporting a history of one or more concussions compared with 49.1% in our study), and the concussion history was not associated with depressed neurocognitive performance. Even though that study was performed on college soccer players (average age 19 years), the results were similar to the current study. Guskiewicz et al also revealed a higher prevalence of concussions among the footballers, but did not demonstrate any difference in neurocognitive performance compared to the non-football athletes or students.

On the other hand the vast majority of head impacts and concussions in football happen in heading duels, where a hit from the opponent’s arm or head to head collisions represent the most frequent mechanisms of injury.11 Frequent headers are more frequently involved in heading duels. Consequently, they may be exposed to head trauma more often than less frequent headers. This hypothesis is supported by the significant association shown between estimated lifetime heading exposure and the number of previous concussions. This makes it difficult to separate the effects of heading exposure from previous concussions in studies based on self-reported retrospective data. It could be argued that heading frequency is just as good a measure for previous concussions and minor head impacts during football as the self-reported numbers of concussions.

CONCLUSION

This study does not support the hypothesis that concussive and/or subconcussive trauma caused by heading has a cumulative effect causing neuropsychological impairments among football players.

What this study adds

- Computer based neuropsychological testing of Norwegian professional footballers did not show any neuropsychological impairment compared with normative control data among the vast majority of the players (98.5%) and revealed no evidence of cognitive impairment associated with heading exposure or number of previous concussions
- Heading frequency and concussions are weakly associated, identifying heading duels as risk situations for head injuries

What is already known on this topic

- Based on neuropsychological paper and pencil test studies have suggested a higher frequency of cognitive impairments among football players compared with controls
- The evidence that such impairment occurs as a result of general football play, concussions on the football field, or normal football heading is limited
Effects of heading exposure and previous concussions on neuropsychological performance

ACKNOWLEDGEMENTS
This study was paid for by a grant from FIFA. In addition, financial support came from the Oslo Sports Trauma Research Center, which has been established at the Norwegian University of Sport and Physical Education through generous grants from the Eastern Norway Regional Health Authority, the Royal Norwegian Ministry of Culture and Church Affairs, the Norwegian Olympic Committee and Confederation of Sports, Norsk Tipping AS, and Pfizer AS. CogState Ltd. provided the necessary software and technical support free of charge. A special thanks to Astrid Junge from the FIA Medical Assessment and Research Centre (F-MARC) for her collaboration during the development of the study protocol and Alex Collie for technical support. The authors thank Jostein and Grete Steene-Johannessen for test supervision, Ingar Holme and Lars Bo Andersen for statistical assistance, and the players, team physicians, physiotherapists, and coaches for their cooperation.

Authors’ affiliations
T M Straume-Naesheim, T E Andersen, Oslo Sports Trauma and Research Center, Oslo, Norway
J Dvorak, FIFA Medical Assessment and Research Centre, Zurich, Switzerland
R Bahr, Norwegian University of Sport and Physical Education, Oslo, Norway

Competing interests: none declared

REFERENCES
14. CogState Ltd. provided the necessary software and technical support free of charge.