

Do Minor Head Impacts in Football (Soccer) cause Concussive Injury? – A Prospective Case Control Study

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Abstract

Objective: To determine whether minor head trauma in elite football (soccer) matches causes measurable impairment in brain function.

Method: Baseline neuropsychological testing was completed by professional football players in the Norwegian elite league, Tippeligaen, prior to the 2004 or 2005 seasons (N=462). A player who experienced a head impact during a league match completed a follow-up test the following day (Head Impact Group). Video tapes of all the impacts were collected and reviewed. A group of players without head impacts were also tested after a league match to serve as controls (Match Control Group, N=47).

Results: A total of 228 impacts were identified and 44 of these were followed up with a CogSport test (19.3%, i.e. shift towards more severe, but only 6 cases with loss of consciousness). The Head Impact Group had a greater change in reaction time from baseline to follow-up compared to the Match Control Group with regard to the three simplest tasks. The largest deficits were seen among the players reporting acute symptoms after the impact, but deficits were also demonstrated among asymptomatic players. Players who experienced one or more head impacts during the 2004 season showed a reduction in neuropsychological performance when tested prior to the 2005 season. However, none of these footballers were impaired when compared to the test manufacturer's normative data.

Conclusion: A reduced neuropsychological performance was found after minor head impacts in football, even in allegedly asymptomatic players. However, the long-term cognitive consequences are uncertain.

Introduction

Football (soccer) is a vigorous sporting activity, where one event having an injury potential occurs every sixth second of a competitive game, resulting in approximately one injury every 45 minutes (30). Between 6% and 15% of these injuries are head injuries (2, 14) which mainly result from aerial challenges for the ball with an unprotected head (1, 14).

Results from cross-sectional studies performed in the nineties suggested that repetitive sub-concussive head impacts, including heading, could cause cognitive impairment among footballers (11, 22, 23, 37-39). However, a comprehensive review of the literature on this topic raised several concerns regarding the methods and study designs used, finding that there was no conclusive evidence that cognitive impairment occurred as a result of general football play or normal heading (31). This is consistent with biomechanical studies of linear and angular head acceleration during normal heading (4, 27). A study from the Norwegian football elite league, revealed an incidence of events with a head injury potential of 22.0 per 1000 playing hours (1), compared to a reported concussion incidence of 0.3 per 1000 playing hours. Thus, it has been suggested that four out of five concussions are not recognized by the players themselves (10). There are also concerns regarding the potential consequences of repetitive head impacts during football play (18).

The main objective of our study was therefore to determine whether minor head impacts caused measurable brain function impairment among elite football players. A secondary objective was to investigate whether there was any change in neuropsychological test performance from one year to the next for players who had experienced one or more minor head impacts during the course of the previous season.

Methods

Study Design and Participants

A prospective case-control study was undertaken. Players contracted at the start of the 2004 and 2005 seasons in all 14 teams in the Norwegian elite football league, Tippeligaen, were invited to participate. Written informed consent was obtained at baseline for all participants. The study design was approved by the Regional Committee for Medical Research Ethics, Helse Sør, and the Data Inspectorate.

Baseline testing was performed for all players prior to the 2004 and the 2005 seasons. Players suffering a head impact during a regular league match were asked to participate in a follow-up test the next morning (Head Impact Group). These were compared to a league players who experienced no head impact (Match Control Group). A one-year follow-up was conducted where the cases, defined as players who had experienced one or more head impacts, were compared to the players in the cohort without any recorded head impacts.

Assessments

At baseline the participants were asked to complete a questionnaire to document their history of head injuries, neurological disease, age at which they started organized football training, mean number of headings per match, learning disabilities, activity disorders, alcohol intake and use of other drugs. In addition, a symptom assessment (Post Concussion Symptom Scale) (19) was completed at baseline and at all follow-ups.

Neuropsychological performance was assessed using a commercially available computer-based test battery (CogSport, CogState Ltd, Charlton South, Victoria, Australia). The test battery consists of six different tasks (Psychomotor function, Decision making, Simple attention, Divided attention, Working memory, and Learning & Memory). The tasks and the

sensitivity and reliability of the test is described elsewhere (6, 8, 9, 12, 21, 32, 33). Only the reaction time measurements were considered in this study.

At baseline two consecutive CogSport tests were performed and the first was regarded as a practice run and discarded from further analyses (12, 33).

Head Impact Cases - Sampling and Evaluation

The participants were observed during all regular league matches and all 'head impacts' were recorded by local medical personnel present at the football arena (the team's medical personnel or other medical personnel with a background in football recruited by the administrators of the study). The study's definition of a head impact was: 1) the player appeared to have received an impact to the head (including the face and the neck), irrespective of the match situation, 2) the match was interrupted by the referee, and 3) the player laid down on the pitch for more than 15 seconds (1).

Players who met the head impact definition, irrespective of whether or not he was taken out of play, were evaluated clinically by the local medical personnel immediately post match.

Follow-up testing was performed the following day supervised by a member of the team's medical staff.

Video of all matches, provided by the Norwegian Broadcasting Corporation (NRK), were reviewed the morning after the match. If one or more head impacts were identified, the respective team's medical personnel were contacted by phone to check on the follow-up status and, if possible, arrange for follow-up testing. Video images of all head impacts were copied to a computer and saved for more detailed analysis.

Details of head impacts that resulted in actual time-loss injuries (13) were collected from the injury surveillance system in Tippeligaen (TISS) administrated by Oslo Sports Trauma Research Centre (2).

Match Control Group

Players from the same cohort were recruited as controls (Match Control Group). After playing a regular league match in which they did not experience a head impact (as per the study definition) or other injuries, they completed the same follow-up regime as the Head Impact Group with post-match symptom assessment and neuropsychological testing the following day.

One Year Follow-up

The group of players who had experienced one or more head impacts during the 2004 season, irrespective of the follow-up status of these impacts, were defined as the Season One Head Impact Group and compared to players who had not experienced any head impacts during the 2004 season (Season One Control Group).

Video Analysis

All head impact cases were analyzed independently on video by two of the authors (TMSN and AM) according to the predefined general and specific impact severity assessments presented in table 2. The results were then compared and disagreements were re-reviewed in a consensus group meeting (TMSN, AM and TEA), where a final decision was made. Both AM and TEA were blinded to the injury outcome of the head impact cases.

To assess whether there was any selection bias with respect to follow up status and impact severity, the severity of head impacts that were followed up with neuropsychological testing were compared with head impacts with no follow up.

Effect Variables and Statistical Methods

The main effect variable was the global change in neuropsychological test performance from baseline to follow-up for the head impact groups (Head Impact and Season One Head Impact) compared to the controls (Match Control and Season One Control, respectively). If a

significant difference was found, a post-hoc test was performed to identify potential differences on each of the six sub-tasks. A within-person comparison was also performed to identify individual players with significant deteriorations from baseline to follow-up.

The test-retest differences in reaction times (delta values) for all six subtests were divided by their corresponding mean baseline reaction time to create a percentage change score. The global changes in neuropsychological performance between the groups were assessed using a (multivariate linear) model where the percent change for all six subtasks were entered at the same time (Multivariate Analysis of Variance, MANOVA). Post-hoc pair-wise t-test comparisons with Bonferroni-corrected p-values were performed to reveal significant differences between the examined groups for any of the six subtasks.

All statistics were performed using the Statistical Package for the Social Sciences (SPSS, SPSS Inc. Chicago, USA).

Results

Sample Population

Due to the considerable turnover of players within each team in the pre-season (transfer) period, the exact number of the players in the A-squad at the time of testing was difficult to assess (Table 1). A total of 326 players played in at least one regular match in Tippeligaen in 2004 and 334 players in 2005 (League players in Table 1). The cohort comprised 455 individuals and 660 “player seasons” (one player playing one season, 326 + 334, Table 1). The mean age was 25.2 (18 to 34) years and 317 (79.1%) of the players were Norwegian or Scandinavian. Preseason neuropsychological testing was completed for 68.3% (452 of the 660 one season league players).

A total of 205 of these players were active in both seasons, and 144 (70.2%) of them completed the preseason neuropsychological testing both years (2004 and 2005) and were thus available for one year follow-up..

Table 1 The compliance with the test protocol for the prospective league study

	Pre-season Baseline		Season Follow up				
	N*	Cog-Sport	League players [§]	Head Impact Group N [†]	Cog-Sport	Match Control Group N	Cog-Sport
2004 cohort	300	271 (90%)	326	105	17 (16%)	53	47 (89%)
2005 cohort							
Players from 2004	205	37 (18%) (Impact) [†] 107 (52%) (Control) [†]	205	59	18 (31%)	-	-
New 2005	181	133 (73%)	129	64	9 (14%)	-	-
Total 2005	386	277 (72%)	334	123	27 (22%)	-	-
Totals for both seasons	686	548 (80%)	660	228	44 (19%)	53	47 (89%)

*In the pre-season period there was considerable turnover within each team, and thus the exact number of the players in the A-squad in this period is difficult to assess. Consequently, some players who were tested at baseline did not play any matches the following season. [§]The term league players represent all players who have been registered in the official match statistics for that particular season, including those who joined the teams after the baseline testing. [†]Head impacts identified on video review of the league matches.

Head Impact Identification and Video Evaluation

A total of 228 head impacts to 141 players that met the inclusion criteria were identified on video from the 352 matches observed (i.e. 19.6 incidents per 1000 playing hours). Of these, 44 (19.3%) were followed up with neuropsychological testing the following day (Head Impact Group). A player removed from the match due to a head impact was more likely to be followed up than a player who returned to play (RR=5.1; 95% confidence interval: 2.7 to 9.5). Of the incidents followed up, 29.5% (N=13) were characterized as “severe” on the global impression of impact severity, compared to 13.6% (25) of the missed incidents (RR=2.2; 95% confidence interval: 1.2 to 3.9) (Table 2).

Table 2 Distribution of risk factors for the head impact which were followed up and the impacts that were not followed up. Distributions were compared using chi square test.

		Head impact follow-up status		p
		Followed up (N=44, 19.3%)	Not followed up (N=184, 80.7%)	
General assessments				
Classification of the impact	Definite	35 (79.5%)	144 (78.3%)	0.27
	Doubtful	2 (4.5%)	21 (11.4%)	
	Could not be assessed	7 (16.0%)	19 (10.3%)	
Global impression of severity	Severe	13 (29.3%)	25 (13.6%)	0.04
	Not severe	30 (68.2%)	154 (83.7%)	
	Could not be assessed	1 (2.3%)	5 (2.7%)	
Returned to play	No	17 (38.6%)	12(6.5%)	<0.001
	Yes	27 (61.4%)	172 (93.5%)	
Specific impact severity assessment				
Horizontal speed and direction	No relative speed	10 (23.3%)	61 (34.1%)	0.15
	Low speed (towards)	21 (48.8%)	87 (47.8%)	
	High speed (same direction)	9 (20.9%)	30 (16.5%)	
	High speed (towards)	3 (7.0%)	3 (1.6%)	
Head movement contribution	No head movement	26 (59.1%)	127 (69.1%)	0.64
	One player	6 (13.6%)	21 (11.4%)	
	Both	8 (18.2%)	24 (13.0%)	
	Could not be assessed	4 (9.1%)	12 (6.5%)	
Location	Frontal	3 (6.8%)	13 (7.1%)	0.45
	Temporal/parietal	11 (25.0%)	31 (16.8%)	
	Other	30 (68.2%)	140 (76.1%)	
Striking body part	Head	15 (34.1%)	41 (22.3%)	0.36
	Shoulder	3 (6.8%)	12 (6.5%)	
	Elbow	5 (11.4%)	34 (18.5%)	
	Other	21 (47.7%)	97 (52.7%)	

The 228 impacts resulted in 13 (5.7%) “time-loss” injuries (13) that were reported through TISS. Six of these were superficial cuts or facial fractures, while 7 (3.1%) were reported as concussions (0.6 per 1000 playing hours). Six of these concussions were included among the 44 cases in the Head Impact Group including 5 with loss of consciousness and two of these

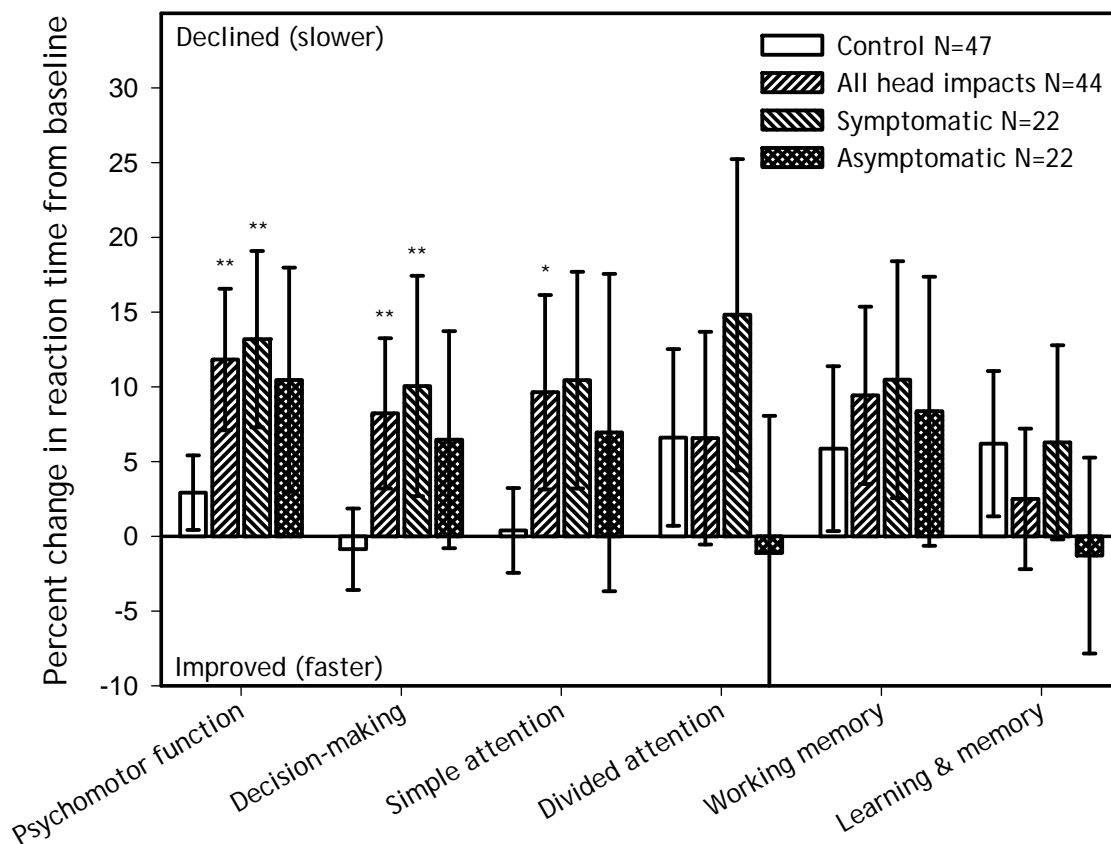
had also post-traumatic amnesia. In two of the cases, where ultimately a “time-loss” concussion was reported, the player had returned to play in the same game after the head impact.

Neuropsychological Testing

Global testing of the reaction time change from baseline to follow-up for all six neuropsychological test variables revealed a significant difference between the Head Impact Group and the Match Control Group (Wilks’ lambda 0.82, $p=.008$).

Post-hoc tests revealed that the Head Impact Group had a significant decline in performance on the follow-up test for the two simplest tasks; Psychomotor function and Decision-making compared to the Match Control Group (Fig. 1).

Figure 1:



A total of 22 (50%) of the players in the Head Impact Group reported one or more symptoms at the time of the incident. Headache was the most common symptom and was reported by 17 (38.6%) of the players in the Head Impact group, followed by dizziness (N=12, 27.3%) and concentration problems (N=8, 36.4%).

Both the symptomatic and the asymptomatic players were significantly different from the Match Control Group on the global test (Wilks' lambda: Symptomatic =.76, $p=.008$, Asymptomatic =.78, $p=.016$). Even though performance on the three simplest tasks was reduced among the asymptomatic and symptomatic players compared to the Match Control Group, significant differences were only demonstrated for the two simplest tasks, and for the symptomatic group only (Figure 1).

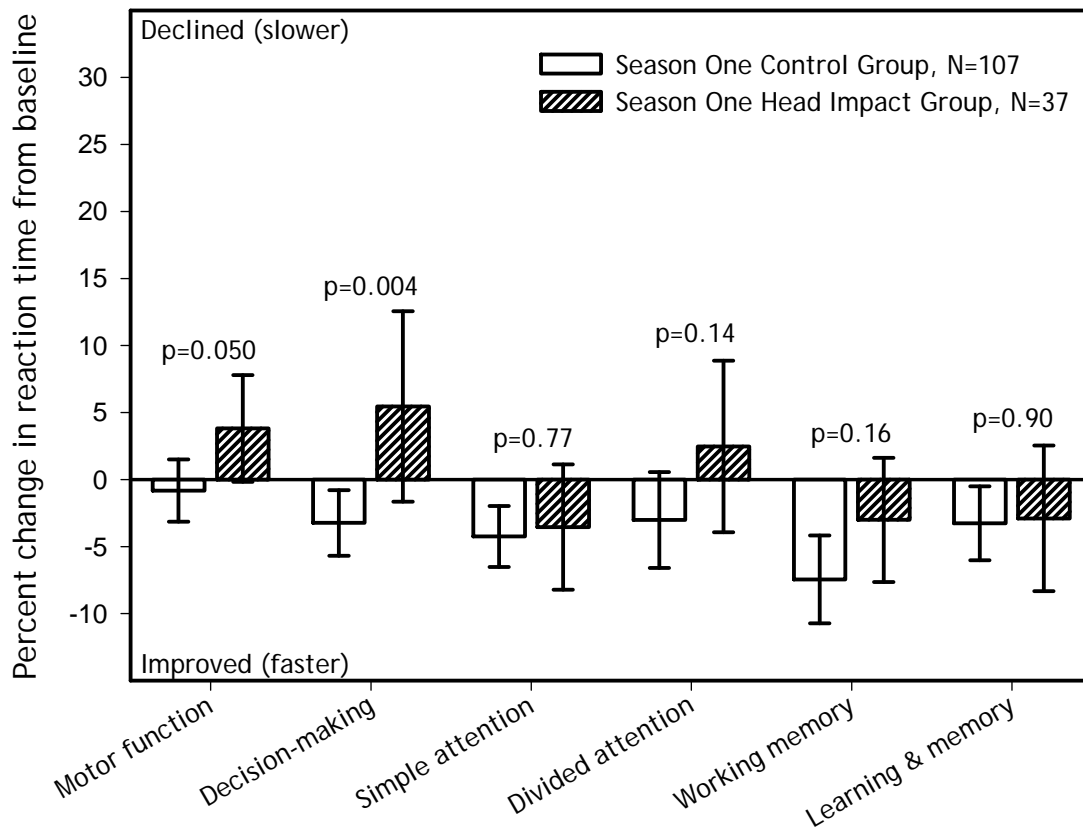
Among the 27 cases from the Head Impact Group who returned to play (RTP Group), a total of eleven reported playing with one or more symptoms. The RTP Group was significantly slower than the Match Control Group on the follow-up test (Wilks' lambda: .76, $p=.004$). The post-hoc analyses of each subtest revealed the same trend as for the whole Head Impact Group.

Neuropsychological Performance at One-year Follow-up

From the 144 players that completed the preseason neuropsychological testing both years we identified 107 (74.3%) players who did not experience any head impacts in the 2004 season (Season One Control Group) and 37 (25.7%) players who had experienced at least one impact (Season One Head Impact Group). Most players (N=31, 83.7%) only experienced one impact. The Season One Head Impact Group also had a higher proportion of players playing in a position with an increased risk of experiencing a head trauma and headed more frequently compared to the Season One Control Group.

At the one-year follow-up (baseline 2005), the Season One Head Impact Group showed a larger increase in reaction times compared to the Season One Control Group (Wilks' lambda = 0.91, p = 0.043). Figure 2 shows the change for the six subtests for the two groups. The post-hoc tests revealed that the Decision-making task was the only task that was significantly different between the two groups, while there was a trend in the same direction for the Psychomotor function task.

Figure 2:



Discussion

This prospective study was designed to assess acute neuropsychological effects of minor head impacts in football. Players who had experienced a minor head impact showed significantly poorer performance as a group compared to controls, when tested the following day. Still, 50% of the followed-up cases claimed to be initially asymptomatic, 61% returned to play

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directly after the impact and only six concussions were diagnosed by the teams themselves. However, the differences were limited to the two simplest subtasks in the test battery, and deficits were mainly found among the players reporting to be symptomatic directly after the head impact.

Limitations of the Study

In spite of the presence of observers at every venue and contacting all teams the day after the match if a head impact was identified on the video review of the match, only 19.3% of the head impacts were followed up with neuropsychological testing. In general, the video analyses revealed that the impacts that appeared to be more severe, and where the player did not return to play, were more likely to be followed up. The main reason for the low compliance was that players were reluctant to be tested after these impacts, which they regarded as trivial. As reflected by the lack of symptoms and the low concussion rate, the vast majority of the followed-up impacts were benign, and thus representative of the minor head impacts that occur in competitive football. Nevertheless, the low compliance with follow-up testing represents the main limitation of this study, and must be kept in mind when interpreting the findings.

Interpretation of the Neuropsychological Performance

This study is the first to assess prospectively neuropsychological changes after head impacts during regular football matches, irrespective of whether the impacts were diagnosed as concussions or not. On the other hand, several studies have assessed initially concussed athletes where the symptoms had resolved after a few minutes or by the time of testing (7, 20, 28). Consistent with the findings in our study, there seems to be an agreement that the largest deficits in neuropsychological performance are found for the players who are symptomatic at the time of testing (15). Other studies have revealed electrophysiological changes (40) as well

as neuropsychological deficits (10) among concussed athletes where the symptoms have allegedly resolved. Our study is the first to demonstrate neuropsychological deficits after minor head impacts where the player did not report any acute concussive symptoms.

The participants in the Head Impact Group and the Match Control Group did not differ with respect to the mean number of headers per player per match, and thus, the main difference between the two groups were the head impacts. This is in contrast to the previous studies, where a retrospective design makes it difficult to separate the effects of heading versus sub-concussive head trauma (26).

The study protocol included assessment of S100B as a serum marker for brain cell injury, and in line with the neuropsychological findings, the blood sample analyses did not reveal any evidence of significant brain cell injury after these minor head impacts (35). Nevertheless, some deficits in cognitive function were observed in the Head Impact Group when compared to footballers that had played a match without experiencing any head impacts.

Long-term Effects

Neuropsychological impairments from concussions have been shown to resolve within 3-7 days after the incident (5, 24). In contrast, this study found that the players who experienced a head impact during the 2004 season exhibited a significant, albeit small, reduction in neuropsychological performance from one year to the next. These players both headed more frequently and had a larger proportion of players playing in a position with an increased risk of injury, compared to their uninjured colleagues. However, the 2004 baseline assessment of the same cohort, revealed no effects of heading frequency and concussion history on neuropsychological performance (34). Pre-post test comparisons for each individual have been suggested as more sensitive than control group comparisons for detecting head injury related neuropsychological effects (36), and this could partly explain this discrepancy. Putting

the Season One Head Impact group results in context, all 37 follow-up tests were within the normal range defined by the test manufacturer and only 4 (10.8%) showed a declined performance on two or more subtests. Consequently, the clinical significance of the statistical deficits demonstrated for the Season One Head Impact Group compared to the Season One Controls is not known.

Clinical Implications

These findings support the suggestion that concussive symptoms are often not recognized by the players (25) and that, if recognized, symptoms are often not reported (17). Even though the footballers in the RTP Group were allegedly asymptomatic and considered fit to play the rest of the match, many reported at the time of testing that they had indeed experienced symptoms of concussion directly after the impact or experienced a delayed onset of such symptoms.

There is currently no consensus in the literature whether returning to play in the same match when asymptomatic after a concussion involves a risk of prolonged symptoms or further damage to the brain (3, 16, 29). However, these athletes *do* exhibit reduced reaction time, perceptual skills etc. that might make the player susceptible of experiencing an injury to other parts of the body as well.

Of all the 228 incidents verified, only 7 concussions were reported. Five players had experienced loss of consciousness and two of them had also post-traumatic amnesia. Thus it seems obvious that the team's medical personnel still refers to the pre-Vienna (3) concussion criteria, where loss of consciousness or amnesia was mandatory. In this respect, our findings emphasize the need for an increased awareness of concussion signs and symptoms, not only among the teams' medical personnel, but also among the players themselves.

Conclusion

A reduced neuropsychological performance was found after minor head impacts in football, even in allegedly asymptomatic players. However, the followed-up impacts represented the more severe spectrum of the head impacts in football. Still, only six of these impacts were reported as concussions. In addition, pre-season test performance was somewhat reduced from one year to the next in footballers who had experienced one or more head impacts during the season, although not when compared to the test manufacturer's normal range. Consequently, the clinical significance of this finding is uncertain.

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References

1. Andersen TE, Árnason A, Engebretsen L, Bahr R: Mechanisms of head injuries in elite football. **Br J Sports Med** 38:690-696, 2004.
2. Andersen TE, Tenga A, Engebretsen L, Bahr R: Video analysis of injuries and incidents in Norwegian professional football. **Br J Sports Med** 38:626-631, 2004.
3. Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Johnston K, Kelly J, Lovell M, McCrory P, Meeuwisse W, Schamasch P: Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. **Br J Sports Med** 36:6-10, 2002.
4. Babbs CF: Biomechanics of heading a soccer ball: implications for player safety. **ScientificWorldJournal** 1:281-322, 2001.
5. Belanger HG, Vanderploeg RD: The neuropsychological impact of sports-related concussion: a meta-analysis. **J Int Neuropsychol Soc** 11:345-357, 2005.
6. Collie A, Maruff P, McStephen M, Darby D: CogSport, in Echemendia RJ (ed): *Sports Neuropsychology: A clinical primer*. New York, Guilford Publications, 2005.
7. Collie A, Makdissi M, Maruff P, Bennell K, McCrory P: Cognition in the days following concussion: comparison of symptomatic versus asymptomatic athletes. **J Neurol Neurosurg Psychiatry** 77:241-245, 2006.

8. Collie A, Maruff P, Makdissi M, McCrory P, McStephen M, Darby D: CogSport: reliability and correlation with conventional cognitive tests used in postconcussion medical evaluations. **Clin J Sport Med** 13:28-32, 2003.
9. Darby D, Maruff P, Collie A, McStephen M: Mild cognitive impairment can be detected by multiple assessments in a single day. **Neurology** 59:1042-1046, 2002.
10. Delaney JS, Lacroix VJ, Leclerc S, Johnston KM: Concussions among university football and soccer players. **Clin J Sport Med** 12:331-338, 2002.
11. Downs DS, Abwender D: Neuropsychological impairment in soccer athletes. **J Sports Med Phys Fitness** 42:103-107, 2002.
12. Falletti MG, Maruff P, Collie A, Darby D, McStephen M: Qualitative similarities in cognitive impairment associated with 24 h of sustained wakefulness and a blood alcohol concentration of 0.05%. **J Sleep Res** 12:265-274, 2003.
13. Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, Hagglund M, McCrory P, Meeuwisse WH: Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. **Clin J Sport Med** 16:97-106, 2006.
14. Fuller CW, Junge A, Dvorak J: A six year prospective study of the incidence and causes of head and neck injuries in international football. **Br J Sports Med** 39 Suppl 1:i3-i9, 2005.

15. Gosselin N, Theriault M, Leclerc S, Montplaisir J, Lassonde M: Neurophysiological anomalies in symptomatic and asymptomatic concussed athletes. **Neurosurgery** 58:1151-1161, 2006.
16. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, Onate JA, Kelly JP: Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. **JAMA** 290:2549-2555, 2003.
17. Kelly JP, Rosenberg JH: The development of guidelines for the management of concussion in sports. **J Head Trauma Rehabil** 13:53-65, 1998.
18. Kirkendall DT, Garrett WE: Heading in Soccer: Integral Skill or Grounds for Cognitive Dysfunction? **J Athl Train** 36:328-333, 2001.
19. Lovell MR, Collins MW: Neuropsychological assessment of the college football player. **J Head Trauma Rehabil** 13:9-26, 1998.
20. Lovell MR, Collins MW, Iverson GL, Johnston KM, Bradley JP: Grade 1 or "ding" concussions in high school athletes. **Am J Sports Med** 32:47-54, 2004.
21. Makkissi M, Collie A, Maruff P, Darby DG, Bush A, McCrory P, Bennell K: Computerised cognitive assessment of concussed Australian Rules footballers. **Br J Sports Med** 35:354-360, 2001.
22. Matser JT, Kessels AG, Jordan BD, Lezak MD, Troost J: Chronic traumatic brain injury in professional soccer players. **Neurology** 51:791-796, 1998.

23. Matser JT, Kessels AG, Lezak MD, Troost J: A dose-response relation of headers and concussions with cognitive impairment in professional soccer players. **J Clin Exp Neuropsychol** 23:770-774, 2001.
24. McCrea M, Guskiewicz KM, Marshall SW, Barr W, Randolph C, Cantu RC, Onate JA, Yang J, Kelly JP: Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. **JAMA** 290:2556-2563, 2003.
25. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K: Unreported concussion in high school football players: implications for prevention. **Clin J Sport Med** 14:13-17, 2004.
26. Moriarity J, Collie A, Olson D, Buchanan J, Leary P, McStephen M, McCrory P: A prospective controlled study of cognitive function during an amateur boxing tournament. **Neurology** 62:1497-1502, 2004.
27. Naunheim RS, Bayly PV, Standeven J, Neubauer JS, Lewis LM, Genin GM: Linear and angular head accelerations during heading of a soccer ball. **Med Sci Sports Exerc** 35:1406-1412, 2003.
28. Pellman EJ, Lovell MR, Viano DC, Casson IR, Tucker AM: Concussion in professional football: neuropsychological testing--part 6. **Neurosurgery** 55:1290-1303, 2004.

29. Pellman EJ, Viano DC, Casson IR, Arfken C, Feuer H: Concussion in professional football: players returning to the same game--part 7. **Neurosurgery** 56:79-90, 2005.
30. Rahnama N, Reilly T, Lees A: Injury risk associated with playing actions during competitive soccer. **Br J Sports Med** 36:354-359, 2002.
31. Rutherford A, Stephens R, Potter D: The neuropsychology of heading and head trauma in Association Football (soccer): a review. **Neuropsychol Rev** 13:153-179, 2003.
32. Silbert BS, Maruff P, Evered LA, Scott DA, Kalpokas M, Martin KJ, Lewis MS, Myles PS: Detection of cognitive decline after coronary surgery: a comparison of computerized and conventional tests. **Br J Anaesth** 92:814-820, 2004.
33. Straume-Naesheim TM, Andersen TE, Bahr R: Reproducibility of computer based neuropsychological testing among Norwegian elite football players. **Br J Sports Med** 39 Suppl 1:i64-i69, 2005.
34. Straume-Naesheim TM, Andersen TE, Dvorak J, Bahr R: Effects of heading exposure and previous concussions on neuropsychological performance among Norwegian elite footballers. **Br J Sports Med** 39 Suppl 1:i70-i77, 2005.
35. Straume-Naesheim TM, Andersen TE, Jochum M, Dvorak J, Bahr R: Minor Head Trauma in Football and Serum Levels of S100B. **Neurosurgery** Submitted: 2007.

36. Sundstrom A, Marklund P, Nilsson LG, Cruts M, Adolfsson R, Van BC, Nyberg L: APOE influences on neuropsychological function after mild head injury: within-person comparisons. **Neurology** 62:1963-1966, 2004.
37. Tysvaer AT: Head and neck injuries in soccer. Impact of minor trauma. **Sports Med** 14:200-213, 1992.
38. Tysvaer AT, Lochen EA: Soccer injuries to the brain. A neuropsychologic study of former soccer players. **Am J Sports Med** 19:56-60, 1991.
39. Tysvaer AT, Storli OV: Soccer injuries to the brain. A neurologic and electroencephalographic study of active football players. **Am J Sports Med** 17:573-578, 1989.
40. Warden DL, Bleiberg J, Cameron KL, Ecklund J, Walter J, Sparling MB, Reeves D, Reynolds KY, Arciero R: Persistent prolongation of simple reaction time in sports concussion. **Neurology** 57:524-526, 2001.

Figure legends

Figure 1 Change (%) in reaction time from baseline to follow-up for the Head Impact Group and the Match Control Group. Data are also shown for symptomatic and asymptomatic players in the Head Impact Group. * $p < .05$ vs. the Match Control Group; ** $p < .01$.

Figure 2 Change (%) in reaction time from baseline 2004 to baseline 2005 for players with (Season One Head Impact) and without (Season One Control) a registered head impact during the 2004 season (N=144).