American Journal of Sports Medicine

http://ajs.sagepub.com

Comparison of Preseason, Midseason, and Postseason Neurocognitive Scores in Uninjured Collegiate Football Players

Jennifer R. Miller, Gregory J. Adamson, Marilyn M. Pink and John C. Sweet

Am. J. Sports Med. 2007; 35; 1284 originally published online Apr 3, 2007;
DOI: 10.1177/0363546507300261

Comparison of Preseason, Midseason, and Postseason Neurocognitive Scores in Uninjured Collegiate Football Players

Jennifer R. Miller,* MD, Gregory J. Adamson,†‡ MD, Marilyn M. Pink,‡ PhD, PT,
John C. Sweet,§ MA, ATC
*From *Idaho Sports Medicine Institute, Boise, Idaho, ‡Congress Medical Foundation, Pasadena, California, and §Occidental College, Los Angeles, California*

Background: College football players sustain an average of 3 subconcussive blows to the head per game. Concussions correlate with decreases in standardized neurocognitive test scores. It is not known whether repetitive, subconcussive microtrauma associated with participation in a full season of collision sport affects neurocognitive test scores.

Hypothesis: No difference exists between preseason, midseason, and postseason Standardized Assessment of Concussion (SAC) and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) scores when collegiate football players sustain subconcussive microtrauma from forceful, repetitive contact activity.

Study Design: Case series; Level of evidence, 4.

Methods: Fifty-eight members of a Division III collegiate football team who had no known concussion during the season voluntarily completed the SAC and ImPACT instruments preseason, midseason, and postseason. A repeated measures analysis of variance was used to compare the scores at the 3 time intervals ($P < .05$).

Results: No statistically significant decreases were found in overall SAC or ImPACT scores or in any of the domains or composites of the tests ($P < .05$) when preseason, midseason, and postseason scores were evaluated.

Conclusions: ImPACT and SAC neurocognitive test scores are not significantly altered by a season of repetitive contact in collegiate football athletes who have not sustained a concussion.

Clinical Relevance: A diminution in SAC or ImPACT scores in concert with clinical symptoms and findings should be interpreted as evidence of a postconcussive event.

Keywords: concussion; athletic injury; neurocognitive tests; head injury

Concussion and its neurocognitive effects in the contact athlete have long been of concern to the sports medicine practitioner. In the United States, football is one of the sports with the highest such potential involvement.[25] The occurrence of football-related concussions has been estimated to be 2.5% to 4% of athletes per season.[17,22,28,31] According to Duma et al,[7] in a Division I college football game there are an average of 3 impacts that exceed 10*g* per player, and in a practice there is half of that. Eighty-nine percent of these impacts measured head accelerations less than 60*g*, whereas the remaining went as high as 200*g*.[7] In a separate study of professional football players, the average peak acceleration in a player who received a concussion was found to be 99 ± 28*g*, whereas the acceleration in an uninjured struck player averaged 60 ± 24*g*.[30]

With this wide range of impact accelerations (1-200*g*), there is likewise a wide range of symptoms. The word *concussion* can include any 1, or a combination, of the following: headache, dizziness, confusion, memory impairment, attention deficit, loss of consciousness (LOC), personality changes, functional language deficits, or sensitivity to light.[2,4] Among the more common deficits are memory, attention, concentration, speed of processing information, reaction time, and visual perceptual processing.[5,12,16,18,23] Greater than 90% of sports-related concussions result in no observable LOC, minimal or no posttraumatic amnesia, and only slight disorientation.[3] Indeed, the American Academy of Neurology defines a grade 1 concussion as no

†Address correspondence to Gregory J. Adamson, MD, Congress Medical Associates, 39 Congress Street, Pasadena, CA 91105 (e-mail: susan@congressmedical.com).

Presented at the 30th annual meeting of the AOSSM, Quebec City, Quebec, Canada, June 2004.

No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 35, No. 8
DOI: 10.1177/0363546507300261

LOC, transient confusion, and mental status changes that resolve within 15 minutes.[22] These more subtle symptoms may go unnoticed or unreported by athletes, thus making the diagnosis more difficult for the team physician. Subtle neurocognitive changes such as these may, however, be identified by neurocognitive testing.[1,19,26,29]

Research has been initiated to study the cognitive effects of prior concussion, multiple concussions, or combined severities of concussion. Most of these studies relied on the subjects to report any historical symptoms of concussion.[5,6,8,9,12,15,16,18,23,32] The majority of these articles are on football players, and the overall conclusion is that there is a significantly deleterious effect of cumulative concussions.[5,6,8,12,26,28]

Numerous neuropsychological tests have been developed to evaluate players suspected of sustaining a concussion and to help determine when it is safe for them to return to play. Within the 11 studies looking at the effect of prior concussions, 53 different measurement tools were used.[5,6,8,9,12,15,16,18,21,23,32] With this large number of different measurement tools, there was relatively little commonality in tests between studies. Of the studies that looked at prior concussions in athletes, including football players, 2 studies measured the concussive effects with the Standardized Assessment of Concussion (SAC),[26,28] 2 quantified the effect with the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) or a portion of the ImPACT,[6,12] and 1 of the studies used 8 other tests.[5]

In that there appear to be cumulative effects of concussions in football,[6,8,12,26] the next logical question is whether there are cumulative effects of subconcussive blows to the head. These blows would be more minor than those leading to findings consistent with a grade 1 classification.[22] Given the frequency and intensity of impacts to the head throughout a season of football, it would be good to know if these subconcussive blows add up and cause any neurocognitive deficit. Also, given the plethora of tests available and given that the on-field clinician must make the initial observation of neurocognitive problems, it appears most appropriate to use tests that the on-field clinician can easily apply and interpret.

It is also frequently the on-field clinician who must make the decision about return to play. Two of the tests more commonly used by clinicians are the SAC and the ImPACT. The SAC is an on-field test that is a useful, quick (approximately 5 minutes), inexpensive assessment of potentially concussed players. The SAC is known to be valid and reliable and to have little ceiling effect.[24,27] Although the SAC is sensitive to changes in cognition early after injury, it has limited sensitivity when used days, weeks, or months after injury. No significant differences have been found between scores obtained during practice or games, suggesting that emotions, distractions, fatigue, and game conditions do not affect test performance.[29]

The ImPACT is a computerized neuropsychological test battery developed specifically to track recovery in the days and weeks after a sports-related concussion (as opposed to the SAC, which is used immediately after injury). The ImPACT has been shown to accurately distinguish between players with mild concussions and controls.[20] It has also been found that comparing players with their own baseline is more accurate than comparing them with age- and sport-matched normative data.[11]

To our knowledge, no study has looked at the effects of a full season of repetitive contact sport on SAC and ImPACT scores when compared with a baseline (preseason) score. The purpose of this study was to compare neurocognitive scores in collegiate football players who had sustained no known concussion throughout a season of repetitive contact activity.

MATERIALS AND METHODS

The study was approved by the college's Investigational Review Board. All athletes involved with that season's football team voluntarily participated in the study.

Seventy-six athletes participated in the preseason data session. These athletes competed in Division III football and completed a season of 9 games. Four players who sustained a concussion (grade 1 or greater[22]) during the season were excluded from the study. Seventy-two players remained eligible for the study and were tested at the midseason data collection session. Fifty-eight of the 72 players (81%) completed all 3 test sessions and were the subjects of this study. Twenty-five of the athletes were on the starting team (ie, relatively high exposure to injury), and 33 athletes were not on the starting team (ie, relatively low exposure to injury). Eight of the 58 athletes self-reported 2 or more concussions before the test season, and 9 self-reported one prior concussion. The average grade point average (GPA) for the original 72 players was 3.36 in high school and 2.78 in college. The mean Scholastic Aptitude Test (SAT) score for this group was 1261.

Data were collected preseason (before the first full-pads practice), midseason (during a bye week, 6 weeks into the season), and postseason (within 2 weeks of the last game). Data collection included the ImPACT (ImPACT Applications Inc, Pittsburgh, Pa) and the SAC (Figure 1).[27] The tests were administered and/or proctored through the college's Athletic Training Department. The players self-administered the ImPACT (version 2.1) on a campus computer, selecting a different version of the test each time. The SAC was administered one-on-one using a different form (A, B, or C) each time. The testing time averaged 20 minutes for the ImPACT and 5 minutes for the SAC.

For the ImPACT, Verbal Memory, Visual Memory, Processing Speed, and Reaction Time were analyzed. All components of the SAC (Immediate Memory, Orientation, Concentration, and Delayed Recall) and Total SAC were used.

Published normative data exist for both the SAC and the ImPACT and demonstrate generalized practice effects on both tests. For the SAC, there are no published correction recommendations for practice effects. Indeed, Barr and McCrea[1] demonstrated no significant retest effect. Iverson et al[14] used the ImPACT to test a group of healthy high school and college students and retested them over a short period of time. These authors found a statistically significant, reliable change index (an index that took into account both the standard error of difference scores and practice effects) averaging 1.7 points for Processing Speed. The

Standardized Assessment of Concussion (SAC)

Form A

Immediate Memory (1 pt. each x 3 trials; max. 15 pts.)
Elbow, Apple, Carpet, Saddle, Bubble

Orientation (1 pt. each; max. 5 pts.)
Month, Date, Day of the Wk., Year, Time (w/in 1 hr)

Concentration (max. 5 pts.)

1. **Reverse Digits** (1 pt. for each string: max. 4 pts.)

4-9-3	6-2-9
3-8-1-4	3-2-7-9
6-2-9-7-1	1-5-2-8-6
7-1-8-4-6-2	5-3-9-1-4-8

2. **Months of the year in reverse order** (1 pt. for entire sequence)
Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan

Delayed Recall (1 pt. each, max. 5 pts)
Elbow, Apple, Carpet, Saddle, Bubble

Total Max. Score = 30 pts

For immediate memory and reverse digits, substitute the following for Form B and Form C

Form B

Candle, Paper, Sugar, Sandwich, Wagon

5-2-6	4-1-5
1-7-9-5	4-9-6-8
4-8-5-2-7	6-1-8-4-3
8-3-1-9-6-4	7-2-4-8-5-6

Form C

Baby, Monkey, Perfume, Sunset, Iron

1-4-2	6-5-8
1-8-3-1	3-4-8-1
4-9-1-5-3	6-8-2-5-1
3-7-6-5-1-9	9-2-6-5-1-4

Figure 1. Standardized Assessment of Concussion (SAC) forms.

1.7-point value was subtracted from our Processing Speed data before statistical analysis and hereafter is referred to as "adjusted data."

Probable ranges of measurement error (the standard error of difference) for ImPACT composite scores have been previously published: Verbal Memory, 6.83 points; Visual Memory, 10.59 points; Reaction Time, 0.05 seconds; Processing Speed, 3.89 points.[14] When a retest score falls outside of the standard error of difference, then the change is most likely attributable to circumstances other than practice effects.

Iverson and Green,[13] Iverson et al,[14] and Barr and McCrea[1] suggested that in clinical circumstances, more liberal statistical criteria should be applied so that real change is more likely to be identified. Confidence intervals for the ImPACT have been reported as 80% confidence intervals, rather than the 90% or 95% that is often used.[14]

Data were checked for normality using Q-plots. Statistical analysis included descriptive and comparative statistics. The data included 5 continuous variables (Verbal Memory, Visual Memory, Processing Speed, Reaction Time, and SAC Total). These data were compared across time using repeated measures analysis of variance, and post hoc t tests were used for those differences that were found to be significant ($P < .05$). The ordinal data included Immediate Memory, Orientation, Concentration, and Delayed Recall and were compared using nonparametric repeated measures components of variance methods using generalized estimating equations (GEE). Post hoc chi-square values were computed under the GEE model ($P < .05$).

TABLE 1
Standardized Assessment of Concussion (SAC) Scores (Means and Standard Deviations of Points) at, and *P* Values When Comparing, Preseason (Pre), Midseason (Mid), and Postseason (Post)

SAC Variable	Time of Season	Mean Score	Standard Deviation
SAC Total	Pre	27.6	2.3
($P = .0003$)	Mid	27.7	1.7
	Post	28.4	1.4
Immediate Memory	Pre	14.4	1.2
($P = .05$)	Mid	14.7	0.7
	Post	14.7	0.7
Orientation	Pre	4.9	0.3
($P = .12$)	Mid	5.0	0.3
	Post	5.0	0.0
Concentration	Pre	4.3	1.0
($P = .0003$)	Mid	4.2	0.8
	Post	4.6	0.6
Delayed Recall	Pre	3.8	1.2
($P = .36$)	Mid	3.8	1.1
	Post	4.1	0.8

Data screening included a comparison of scores for the starting team and the nonstarting team. Additionally, the data were screened by comparing scores for athletes with a prior concussion with those of athletes without such a concussion. There were no significant differences in either of these 2 data screenings. Because of the relatively small sample size in each of these subgroups, the subgroups were combined for further statistical analysis.

RESULTS

Standardized Assessment of Concussion

Standardized Assessment of Concussion scores stayed the same or improved from preseason to midseason to postseason testing for all categories (Table 1). All preseason, midseason, and postseason scores were within 1 unit of measurement to each other. There were no statistically significant decreases in scores for any subsets of the test. There were several statistically significant improvements: SAC Total from preseason to postseason ($P < .001$) and midseason to postseason ($P = .007$), Immediate Memory from preseason to midseason ($P = .046$), and Concentration from preseason to postseason ($P = .0029$) and preseason to midseason ($P < .0001$).

Immediate Post-Concussion Assessment and Cognitive Testing

All of the changes were well within the probable ranges of measurement error for ImPACT composite scores that have been published.[14] All of our composite scores were within the 80% confidence intervals defined in Iverson's study.[14]

TABLE 2
Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Scores (Means and Standard Deviations) at, and *P* Values When Comparing, Preseason (Pre), Midseason (Mid), and Postseason (Post)

ImPACT Composite	Time of Season	Mean Score	Standard Deviation
Verbal Memory, points	Pre	89.93	8.35
($P = .06$)	Mid	89.74	10.02
	Post	92.48	7.55
Visual Memory, points	Pre	78.83	13.24
($P = .04$)	Mid	80.93	11.75
	Post	82.75	12.05
Processing Speed,[a] points	Pre	40.49	7.46
($P = .05$)	Mid	42.98	8.47
	Post	41.13	8.81
Reaction Time, s	Pre	0.55	0.07
($P = .04$)	Mid	0.53	0.06
	Post	0.53	0.07

[a]Adjusted data.

All of the players' ImPACT composite scores for preseason, midseason, and postseason tests were in the average percentile classification (25th to 75th percentile) or high average percentile classification (76th to 90th percentile) ranges. In all categories, the mean scores were either the same or improved at midseason and postseason compared with the mean preseason scores (Tables 2).

There were no significant differences in Verbal Memory ($P = .06$) or in Processing Speed ($P = .05$) when we compared preseason, midseason, and postseason scores. There was a significant improvement as the season progressed in Visual Memory ($P = .04$) and in Reaction Time ($P = .04$). Visual Memory significantly improved from preseason to postseason ($P = .012$), and Reaction Time improved from preseason to midseason ($P = .04$) and from preseason to postseason ($P = .02$).

DISCUSSION

Our study demonstrated no neuropsychological deficits throughout an athletic season in Division III football athletes who had not sustained a concussion. These athletes would have sustained repeated blows to the head on the field week after week throughout the season. Yet they had not received a known concussion as defined by the American Academy of Neurology.[22]

The intensity and frequency of the blows to the head in Division I athletes were defined by Duma et al[7] as 3 impacts per game and 1.5 impacts per practice. Eighty-nine percent of the impacts were less than 60*g*. Likewise, Pellman et al[30] found that uninjured struck professional players had accelerations of $60 \pm 24g$. In that the athletes studied herein were Division III, as opposed to Division I or professional, the results of the study may be more applicable to the large number of community college and high school athletes than would be the results of the Division I or professional athletes.

A few articles have analyzed the effect of exposure to injury and neurocognitive testing. Interestingly, although most of the studies on *cumulative effect of concussions* involved football athletes, most of the studies analyzing the *effect of exposure to injury* involved soccer athletes who "head the ball." Obviously, the study reported herein is unique in that we investigated the effect of exposure throughout a football season.

Of the 6 studies on exposure to injury, 3 found no significant effect of exposure for recreational, collegiate, or elite soccer athletes.[9,15,32] These studies used 17 different tests, of which no test was common to any 2 studies. None of the tests included the SAC or the ImPACT. A fourth study on professional soccer athletes found that the number of "headers" in soccer was related to a decrease in focused attention and a decrease in visual/verbal memory[23]; however, investigators did not use either the SAC or the ImPACT. The remaining 2 studies on exposure did not use the SAC or the ImPACT, and they used athletes from different sports.[16,18]

The relative intensity of impact on the brain with different sports is a variable to consider when interpreting these results. The varying mass at contact in football relative to the known mass of a soccer ball (396-453 g[33]) when heading the ball would obviously lead to different forces at impact. Also, in soccer, an athlete knows when he or she is going to head the ball and thus "fixes" the head by contracting the neck muscles.[10,15,33] This lowers the risk of head injury. On the contrary, a football player does not always know he is going to encounter an impact and thus has less means of protection.

The statistically significant results found in the study herein revealed improvement as the season progressed. The improved results can largely be explained by measurement error, practice effect, and too tight statistical interpretation. As mentioned in Materials and Methods, an 80% confidence interval (rather than a 90% or 95% confidence interval) was suggested for the ImPACT by its developers.[14] An 80% confidence interval would be a more liberal statistical interpretation than the *P* level of .05 that was used in this study and that reveals significant improvements. All of the subjects herein were within the 80% confidence interval and within the boundaries of measurement error for the ImPACT[14] at all 3 testing sessions (preseason, midseason, and postseason). Additionally, a recent study by the developers of the ImPACT specifically attributed an improvement in Reaction Time to the practice effect,[20] and the developers of the SAC demonstrated that when a control group is used, an average increase of up to 1 point can be attributed to practice effect.[1] All of the improvements we found in the SAC were within 1 point.

The subjects in this study had a mean SAT score of 1261, an average college GPA of 2.78, and an average high school GPA of 3.36. Not all prior studies listed SAT or GPA. However, 1 study that did do so reported an average SAT of 929 for the group without any concussions and without learning disabilities.[5] It is of note that the subjects in our study scored 36% better on their SAT score and hence may be relatively good learners on test taking or relatively good test takers. This is in keeping with the significant interaction found by Barr and McCrea,[1] indicating a difference in retest effects observed between college and high school students; the SAC manual notes that there are higher SAC scores at higher educational levels.[28] In that our subjects were college students functioning at a fairly high academic level, the generalized learning effect could have been enhanced.

This study found that there were no statistically significant decreases in SAC or ImPACT scores as the football season progressed. Thus, if an athlete was to score significantly less in a subsequent test session relative to his baseline, that decrease may be clinically relevant.

The results of this study may help to reduce fears that young, unconcussed Division III level football players are causing short-term damage to their brain. This study has shown that repetitive contact activity in sports of this level or less for 1 season should not lead to decreases in SAC and ImPACT scores in the uninjured athlete. Therefore, decreased neurocognitive scores, when considered in conjunction with clinical symptoms, may be valid and should not be dismissed as changes brought on by the effects of the season. The combined use of these tests, when used to supplement, not replace, sound clinical judgment, should lead to safe management of players involved in contact sports.

REFERENCES

1. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *J Int Neuropsychol Soc.* 2001;7:693-702.
2. Bernstein DM. Recovery from mild head injury. *Brain Inj.* 1999;13:151-172.
3. Cantu RC. Head injuries in sports. *Br J Sports Med.* 1996;30:289-296.
4. Capruso DX, Levin HS. Cognitive impairment following closed head injury. *Neurol Clin.* 1992;10: 879-893.
5. Collins MW, Grindel SH, Lovell MR, et al. Relationship between concussion and neuropsychological performance in college football players. *JAMA.* 1999;282:964-970.
6. Collins MW, Lovell MR, Iverson GL, Cantu RC, Maroon JC, Field M. Cumulative effects of concussion in high school athletes. *Neurosurgery.* 2002;51:1175-1181.
7. Duma SM, Manoogian SJ, Bussone WR, et al. Analysis of real-time head acceleration in collegiate football players. *Clin J Sport Med.* 2005;15:3-8.
8. Gronwall D, Wrightson P. Cumulative effect of concussion. *Lancet.* 1975;22;2:995-997.
9. Guskiewicz KM, Marshall SW, Broglio SP, Cantu RC, Kirkendall DT. No evidence of impaired neurocognitive performance in collegiate soccer players. *Am J Sports Med.* 2002;30:157-162.
10. Holbourn AHS. The mechanics of brain injuries. *Br Med Bull*. 1945;3:147-149.
11. Iverson GL, Brooks BL, Collins MW, Lovell MR. Tracking neuropsychological recovery following concussion in sport. *Brain Inj.* 2006;20:245-252.
12. Iverson GL, Gaetz M, Lovell MR, Collins MW. Cumulative effects of concussion in amateur athletes. *Brain Inj.* 2004;18:433-443.
13. Iverson GL, Green P. Measuring improvement or decline on the WAIS-R in inpatient psychiatry. *Psychol Rep.* 2001;89:457-462.
14. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol.* 2003;7:460-467.
15. Janda DH, Bir CA, Cheney AL. An evaluation of the cumulative concussive effect of soccer heading in the youth population. *Inj Control Saf Promot.* 2002;9:25-31.
16. Jordan BD, Matser JT, Zimmerman RD, Zazula T. Sparring and cognitive function in professional boxers. *Phys Sportsmed.* 1996;24:87-98.
17. Kelly JP, Rosenbury JH. The development of guidelines for the management of concussion in sports. *J Head Trauma Rehabil.* 1998;13:53-65.
18. Killam C, Cautin RL, Santucci AC. Assessing the enduring residual neuropsychological effects of head trauma in college athletes who participate in contact sports. *Arch Clin Neuropsychol.* 2005;20:599-611.
19. Lovell MR, Collins MW, Iverson GL, et al. Recovery from mild concussion in high school athletes. *J Neurosurg.* 2003;98:269-301.
20. Lovell MR, Collins MW, Iverson GL, Johnston KM, Bradley JP. Grade 1 or "ding" concussions in high school athletes. *Am J Sports Med.* 2004;32:47-54.
21. Lovell MR, Pardini JE, Collins MW, et al. New advances in sports concussion management: functional brain imaging. *Orthop Tech Rev.* 2006; 8:24-26.
22. Maroon JC, Lovell MR, Norwig J, Podell K, Powell JW, Hartl R. Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery.* 2000;47:659-672.
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.* 2001;23:770-774.
24. McCrea M: Standardized mental status assessment of sports concussion. *Clin J Sport Med.* 2001;11:176-181.
25. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players. The NCAA concussion study. *JAMA.* 2003;290:2556-2563.
26. McCrea M, Kelly JP, Kluge J, Ackley B, Randolph C. Standardized assessment of concussions in football players. *Neurology.* 1997;48:586-588.
27. McCrea M, Kelly JP, Randolph C. *The Standardized Assessment of Concussion (SAC): Manual for Administration, Scoring and Interpretation*. 2nd ed. Waukesha, Wis: CNS Inc; 2000.
28. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L. Immediate neurocognitive effects of concussion. *Neurosurgery.* 2002;50:1032-1042.
29. McCrea M, Kelly JP, Randolph C, et al. Standardized Assessment of Concussion (SAC): on-site mental status evaluation of the athlete. *J Head Trauma Rehabil.* 1998;13:27-35.
30. Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF. Concussion in professional football: reconstruction of game impacts and injuries. *Neurosurgery.* 2003;53:799-814.
31. Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA.* 1999;282:958-963.
32. 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.* 2005;39(suppl 1):i70-i77.
33. Tysvaer AT. Head and neck injuries in soccer: impact of minor trauma. *Sports Med.* 1992;14:200-213.