



Pergamon

Archives of Clinical Neuropsychology
18 (2003) 397–417

Archives
of
CLINICAL
NEUROPSYCHOLOGY

Soccer heading frequency predicts neuropsychological deficits[☆]

Adrienne D. Witol, Frank M. Webbe*

School of Psychology, Florida Institute of Technology, Melbourne, FL 32901, USA

Accepted 13 April 2002

Abstract

This study investigated the presence of neuropsychological deficits associated with hitting the ball with one's head (heading) during soccer play. A neuro-cognitive test battery was administered to 60 male soccer players, high school, amateur and professional level, and 12 nonplaying control participants. The effects of currently reported heading behavior as well as that of estimated lifetime heading experience on neuropsychological test performance were examined. Players with the highest lifetime estimates of heading had poorer scores on scales measuring attention, concentration, cognitive flexibility and general intellectual functioning. Players' current level of heading was less predictive of neuro-cognitive level. Comparison of individual scores to age-appropriate norms revealed higher probabilities of clinical levels of impairment in players who reported greater lifetime frequencies of heading. Because of the worldwide popularity of the game, continued research is needed to assess the interaction between heading and soccer experience in the development of neuropsychological deficits associated with soccer play. © 2002 National Academy of Neuropsychology. Published by Elsevier Science Ltd. All rights reserved.

Keywords: Soccer; Neuropsychological deficits; Soccer heading; Injury

1. Introduction

Soccer, long the most popular sport in the rest of the world, rapidly has grown in popularity in the United States. Unfortunately, as the total number of soccer participants increases, so

[☆] This Paper was presented in part at the 1993 annual meeting of The National Academy of Neuropsychology. This paper was based in part on Adrienne D. Witol's master's thesis at Florida Institute of Technology. She is now at the Glenrose Rehabilitation Hospital, Edmonton, Alberta.

* Corresponding author. Tel.: +1-321-674-8104; fax: +1-321-674-7105.

E-mail address: webbe@fit.edu (F.M. Webbe).

does the number of injuries. The game has always been associated with a high injury rate (Ekstrand, 1990), although its introduction into youth sports in the United States often involved descriptions of the game as “safe” in comparison to American football (Dailey & Barsan, 1992). Head injuries, while less frequent than other injuries incurred during soccer play (e.g., sprains of the ankle and knee, and fractures of the tibia), are equally, if not more important, because the symptomatology associated with a blow to the head can include cognitive deficits ranging from mild memory impairment to dementia or even death (Cantu, 1996; Smodlaka, 1981).

Soccer-related head injuries may occur in at least four ways: head contact with the ball (heading), contact with another player (head, foot, arm), contact with the ground, and contact with stationary objects (goal posts). Normal play of the game calls for use of the head to propel or redirect the flight of the ball. When two players leave their feet, in a mutual attempt to head the ball (a common occurrence), the risk for head and neck injuries increases. For example, a player who is challenged on his blind side may be unprepared for the resulting collision between two heads. Or, a defender challenging from behind, may receive severe injuries if his opponent’s head is jerked backwards into his face. Other head injuries may occur when players use their arms and hands illegally and when goalkeepers fall at the feet, and boots, of an onrushing attacker. Fields (1989), in a review of case reports, suggested that improper head-to-ball and head-to-head contact was responsible for many of the reported soccer-related head injuries between 1960 and 1980.

Although some studies have reported that the position played related to the incidence of injury generally (Hunt & Fulford, 1990), no clear conclusions about the incidence of head injury as a function of position can be made (Sandelin, Santavirta, & Kiviluoto, 1985). Sandelin et al. (1985) analyzed the soccer injuries that occurred during a 1-year period in Finland. Head and neck injuries accounted for 13% of all soccer injuries, with 7% diagnosed as concussions. Playing position did not seem to influence the type of injury received. Instead, most head injuries occurred through physical contact with another player. In 5% of the cases, injuries were caused by a direct blow from the ball. Similarly, Tysvaer (1992) reported that head and neck injuries accounted for 4–22% of all soccer injuries in the multiple samples that he studied. Recent reports of injury occurrences among American collegiate soccer players show that concussions accounted for 10 and 13% of all injuries for men and women, respectively (The NCAA News, 2001).

Injury rates may also change as a function of age. Backous, Friedl, Smith, Parr, and Carpine (1988) assessed injuries in 1,139 children and young adults during a series of 1-week summer camp programs. The injury rate for the 14–17-year-old group was twice as high as that for the younger players. Head and nose contusions accounted for approximately 7% of all injuries. No information was provided regarding injury severity or criteria used to diagnose concussion.

Unfortunately, the above studies only analyzed injuries that required medical attention. Dailey and Barsan (1992) have also proposed that soccer-related minor head injuries are under diagnosed. Two factors probably contribute to such an effect. First, players themselves may minimize or deny injury to avoid being held out of play. Second, soccer has not enjoyed the same level of medical supervision at games and practices as has football (Green & Jordan, 1998). These two factors have made it exceedingly difficult to study adequately the prevalence and sequelae of soccer-related mild traumatic brain injury (TBI).

1.1. Mild traumatic brain injury

Reflecting the controversy surrounding the prevalence of neurobehavioral sequelae following mild TBI, disagreement exists about the degree of impairment athletes may experience following seemingly minor head injuries. The literature contains many reports that relate nausea, vomiting, headache, visual field defects, confusion, personality changes, paresthesia and hemiparesis following seemingly minor blows to the head while playing soccer (Harrison, 1990; Mathews, 1972). Investigators have reported on soccer players who have sustained short- and long-term difficulties from mild TBI (Dailey & Barsan, 1992; Fields, 1989). Furthermore, there have been accounts of serious injury and poor outcome in persons, primarily young adults, who have experienced repeated mild brain injury over short periods of time (Fekete, 1968; Kelly et al., 1991; McQuillen, McQuillen, & Morrow, 1988; Saunders & Harbaugh, 1984; Shell, Carico, & Patton, 1993). Wilberger and Maroon (1989) have provided evidence that performance on neuropsychological measures declines relative to the number of mild injuries experienced. Neuropsychological examination of athletes with three, four, or five incidents of mild TBI revealed performance declines on information processing tasks of 25, 33 and 40%, respectively.

In contrast, Lehman (1988) stated that mild to moderate head injuries are usually associated with transient or evanescent loss of consciousness, and only rarely produce focal or lateralizing neurologic findings. Additionally, headache, nausea and seizure activity following these minor head injuries are uncommon. However, the absence of neurobehavioral sequelae should not be considered as an indicator of a negligible or insignificant injury (Barth et al., 1989; Gronwall & Wrightson, 1975; Lunberg, 1986; Ross, Cole, Thompson, & Kim, 1983).

1.2. Heading techniques and impact

Properly performed, heading, due to speed and impact forces, may be conceptualized as repeated subconcussive blows to the head. Ball speeds up to 51 mph have been measured (Smoldaka, 1984), although most balls are propelled at considerably slower speeds. The accepted technique for heading requires the player to contact the oncoming ball at the frontal hairline fringe, with shoulder and neck muscles tensed. The head may or may not be moving relative to the trunk (and ball), depending upon the circumstances of play. Heading with feet off the ground usually ameliorates the shock to the skull and spinal column. The angle of contact with the ball varies with the circumstance of play. For defenders, balls are more likely to approach in a path perpendicular to the forehead. For attackers nearer the opponents goal, the ball is likely to approach in a path that is more nearly parallel to the forehead. Thus, some headings will result in a summation of the velocity of the ball with the velocity of the player (coming head on), whereas others, coming more obliquely, will produce less force from velocity but more from rotational effects on the head. Of Lambert and Hardman's (1984) four mechanisms for neuropathological change in acute brain damage, three clearly describe the effects of head to ball and ball to head impacts in soccer. These are rotational, linear acceleration and deceleration of the head upon impact. As early as 1941 in their monograph on experimentally-induced concussion, Denny-Brown and Russell (1941) proposed a model of concussion injury that detailed how changes in the momentum of the head are critical factors in such injuries. Fields

(1989) elaborated Denny–Brown and Russell’s (1941) model to argue that players are at an increased risk of injury when heading with the neck flexed or extended. Interestingly, heading technique performed correctly has been shown to result in reduced impact forces to the head (Tysvaer & Lochen, 1991). However, there are reports of players who complain of persistent headache even when using seemingly proper heading techniques (Ashworth, 1985; Smodlaka, 1984). Mathews (1972) noted that 5 of 10 athletes who had been demonstrating heading for up to 15 min periods also developed headaches.

It has been suggested that repeated subconcussive blows to the head can cause equivalent if not greater damage than a single mild concussive event (Tysvaer & Lochen, 1991; Unterharnscheidt, 1970). Furthermore, there is a risk of TBI when heading is performed improperly or results in a head-to-head contact with another player. The implications of subconcussive events and the possibility, however arguable (see McCrory, 2001), of second impact syndrome must be considered by soccer players who, in the course of their career, receive hundreds or thousands of blows to the head.

During a soccer game all players are likely to head the ball eventually, though with varying degrees of skill, frequency, and neurologic outcome. While statistics on heading frequency for amateur soccer players are currently being developed, the heading practices of professional athletes have been examined. Tysvaer and Storli (1981) observed the total number of headings in 10 first division games, six English games and four international games. The average number of headings for all players was 111, that is, an average of six per player per game. If one plays 300 top division games, a player may expect to receive at least 2,000 lifetime head blows (Tysvaer & Storli, 1981; consider also that this estimate does not include any practice headings). This is a significant number of potential brain insults, and given the knowledge accrued regarding varying risks due to heading technique, it is imperative that athletes be sufficiently skilled in proper techniques, possibly reduce the frequency of heading, and obtain the best possible knowledge about heading and cognitive function.

1.3. Neurological and neuropsychological evaluation of soccer players

Younger players seem to be at the highest risk of injury, given their less developed skills, experience and less developed brains (Tysvaer, Storli, & Bachen, 1989). Tysvaer and Storli (1989) noted abnormal EEGs in 35% of the active soccer players in their study (ages 15–34), compared to 12% of the control subjects. Older, retired players (ages 35–64) exhibited EEG abnormalities in a similar ratio to their control group (Tysvaer, 1992). Tysvaer notes that when players from both the active and retired samples were examined as a group, EEG abnormalities occurred most frequently in the players younger than age 24. EEG changes following MTBI appear to be very evanescent. Tysvaer suggests that this is because such changes arising from minor cerebral trauma can normalize within minutes to hours, due to complete remission (or possibly destruction of the involved tissue) following the injury. Tysvaer and Storli (1989) suggested that an unknown number of their subjects may have suffered transient changes that had normalized by the time of examination, increasing the value of their findings in regard to young soccer players.

Sortland and Tysvaer (1989) also examined the 33 former soccer players described in Tysvaer and Storli (1989) by cerebral computed tomography. Approximately one third of

these athletes had slight to moderate atrophy which the authors attributed to a widening of the lateral ventricles. Players who described themselves as “headers” demonstrated significantly more cortical atrophy; however, they were also significantly older than the other athletes in the sample. Cortical atrophy is positively correlated with age and the incidence of increased atrophy in the “headers” also could have been due to this factor.

Regarding the EEG studies summarized above, players who described themselves as “headers” did not exhibit any higher incidence of abnormality than the other players. This could suggest that amount of heading had no bearing on the alarming number of neurological abnormalities. However, Kraus, Ohler, and Barolin (1983) reported that 2 of 10 players manifested EEG abnormalities after 15 min of heading practice. Although this study is suggestive of a significant heading effect, the evidence was far from conclusive, and Tysvaer (1992) noted that no changes in EEG correlated with immediacy of testing following heading/play.

The investigation of neuropsychological deficits associated with soccer play has recently accelerated. Research with both amateur and professional players, active and retired, men and women, now has been reported. In one of the earliest neuropsychological investigations, assessment of 37 former soccer players revealed significant deficits in attention, concentration, memory and judgment in 81% of the athletes (Tysvaer & Lochen, 1991). When compared to the control group, the athletes had a significantly larger verbal and performance IQ split and lower scores in parts A and B of the Trail Making Test. Differences in performance between the “headers” and “nonheaders” were not significant. The results suggest diffuse organic impairment quite similar to that found in minor head injury patients.

Murelius and Haglund (1991) compared amateur Swedish boxers to first and second division soccer players and track and field athletes. All athletes completed a comprehensive neuropsychological and neurological evaluation. Only scores on measures of motor speed and dexterity (finger tapping) differentiated the groups. Soccer players performed better than boxers, and more poorly than the track and field athletes. For the boxers and soccer players, tapping performance for both dominant and nondominant hands was correlated with the length of the athlete’s career. No relationship was found between age and motor performance. No information was provided regarding incidence of TBI or heading practices.

Caution must be used when generalizing the results from the above neurological and neuropsychological results to today’s athletes, particularly those playing in the United States. Tysvaer et al. (1989) assessed older, retired players, many of whom used the older, heavier, leather ball. This raises the question of relevancy to today’s athletes who tend to use a somewhat lighter ball. However, those authors have responded to this criticism and believe that the difference is ameliorated by current players’ more intense and frequent play. Additionally, American soccer is still in a developmental stage in comparison to the sport in most of the rest of the world. Skill and technique in all phases of the game are more variable in US, at all levels of play. Finally, very little neuropsychological testing was done in these studies, so the presence of neurobehavioral abnormalities was not assessed. Thus, Tysvaer et al.’s findings, while useful in generating further research, must be applied to US athletes, active or retired, with some measure of caution.

Abreau, Templer, Schuyler, and Hutchison (1990) compared the cognitive and perceptual performance of 31 active US college soccer players to an equal number of tennis players and found no difference between the sport groups on the Paced Auditory Serial Addition

Task, the Symbol Digit Modalities Test, the Perceptual Speed Test, or the Raven Progressive Matrices. A significant negative correlation between number of soccer games played and performance upon the PASAT was obtained. The remainder of the tests did not significantly differentiate between the soccer and tennis players, nor did estimates of heading relate to test performance. Because of the many limitations in their approach, the authors viewed their study as a pilot, but nevertheless, they concluded that the risk of cognitive impairment in soccer players was real and deserved further research. More recently, [Matser, Kessels, Jordan, Lezak, and Troost \(1998\)](#) assessed neurobehavioral changes in 53 active professional soccer players. In comparison to a control group of noncontact athletes, the soccer players exhibited impaired performances in memory, planning, and visuospatial processing. Specific tests on which impairment was shown included the Complex Figure Test, the Facial Recognition Test, and the Logical Memory and Visual Reproduction tests of the Wechsler Memory Scale—Revised. No differences were shown with the Trail Making Test, the Stroop, or the PASAT, among others. These impairments varied inversely with number of documented concussions and estimated frequencies of heading the ball. [Matser, Kessels, Lezak, Jordan, and Troost \(1999\)](#) conducted a similar study with Dutch regional-level amateur soccer players. Similar deficits in performance were noted with this sample in comparison to the same group of control athletes used in the 1998 study. Planning and memory functions appeared to be most affected by the history of soccer play, presumably due to a combination of documented concussions and heading. Since concussion and head injury frequency tended to vary with frequency estimates of heading in these two studies, the role of heading, per se, as a factor in producing neurobehavioral impairments was not clear. However, their overall conclusion captured the data well. That is, there is no necessary cognitive impairment that *must* occur as a result of a lifetime playing soccer, but the stark conclusion is that cumulative time spent playing (and heading) predicts a higher risk of such an outcome.

Much of the literature that has examined neuropsychological performance in soccer players has addressed the issue of cognitive deficits from the perspective of the contribution of known sources of brain injury, such as collision of the head with fixed objects or parts of other players' bodies, versus the intentional heading of the ball during play. [Matser et al. \(1999\)](#) contended that heading played a role, as did the present authors in a brief presentation of some of the results from the current study ([Witol & Webbe, 1994](#)). Other researchers who studied high-level men and women players concluded to the contrary that heading did not relate either to structural damage to the brain ([Jordan, Green, Galanty, Mandelbaum, & Jabour, 1996](#)), to concussion incidence ([Boden, Kirkendall, & Garrett, 1998](#)), or to neuro-cognitive deficits ([Putukian, Echemendia, & Mackin, 2000](#)). These latter conclusions have been adopted by most recent reviewers of the literature ([Broglio & Guskiewicz, 2001](#); [Green & Jordan, 1998](#); [Kelly, 1999](#); [Kirkendall, Jordan, & Garrett, 2001](#)).

The present study examined the effects of cumulative and current heading experience on neuropsychological test performance. Players with a documented or reported history of moderate to serious head injury, or alcohol or drug history were eliminated from the study. The weight of previous studies reviewed above led to the prediction that players who headed the ball most frequently over their career would display more impaired test scores than nonplaying control participants as well as players who had headed the ball less frequently. Moreover, the suggestion that heading the ball could be viewed as successive subconcussive blows to the head

led to the prediction that players who currently headed the ball at the highest frequencies would perform more poorly on the neuropsychological tests than nonplaying control participants and players who headed less frequently.

2. Method

2.1. Participants

Sixty male—high-school, college, adult amateur, and professional level—soccer players were recruited from the central Florida area as were 12 nonsoccer playing control subjects. The control participants were predominantly college students who volunteered to participate in response to an announcement of the study in the psychology building of the campus of Florida Institute of Technology. Although the control group was not a true matched sample, the final control participants were chosen from an 18–29-year-old population that was similar to the soccer players in other key demographic respects; that is, they were Caucasian, were almost all single, and most had completed some college work. They had no history of head injury, minimal or no soccer experience (i.e., they had not played any soccer during the last 10 years and never played on any league or organized team), and were held to the same exclusion criteria as the soccer players. The proportion of high school students in the control group was the same as for the group of soccer players.

The soccer players were currently active in the sport, that is, involved in at least one game or practice per week, and had typically begun the sport in childhood and had been playing consistently from about age nine or ten. Participants were solicited through personal contacts of the experimenters with managers or coaches of the various teams. The teams represented included two very competitive high school sides, two colleges including a recent national champion, one premier-league amateur team, and one professional side. Participants were excluded from participation in this study if they: (a) admitted current use of any illicit/recreational drugs, (b) had a history of learning disabilities or attention deficit/hyperactivity disorder, (c) had a history of recent (within the past 10 years) head trauma that could not be attributed to soccer play, (d) incurred head injuries, during soccer play, which resulted in post traumatic amnesia lasting more than 24 h, (e) had a history of open head injuries, (f) experienced a loss of consciousness for more than 20 min following a soccer related head injury. The first three exclusion factors were chosen so as to prevent confounding of neuropsychological deficit due to extraneous circumstances. The last three factors ensured that players with other than mild traumatic brain injury were excluded. The final sample contained no one with a known or history of serious head injury from soccer or other causes.

Testing occurred in the midst of playing seasons for the high school and adult participants, and within one month following the completion of the college season for the collegiate players (some of the collegiate players had already begun practicing/playing with amateur club teams).

The nature and procedure of the study was described in detail to all prospective participants. Volunteers completed a consent form before participating in any data collection, as prescribed by the Institutional Review Board for Human Experimentation. The final sample of participants were those who volunteered and who also met the inclusion criteria. Players and controls who

declined to participate commonly excused themselves because of a lack of time in their schedule to accommodate the testing.

2.2. Instruments

A structured interview preceded all neuropsychological testing. Demographic, historic, academic, vocational, and sports history information was collected at this time. Volunteers who affirmed any of the exclusion criteria were thanked for their time and not used further. As part of the standard questionnaire participants were asked if they had ever experienced dizziness, headaches or confusion during or immediately after soccer play. For players who recalled such symptoms, additional details regarding the incident, onset and course of symptoms were obtained.

Following the interview, players and nonplayer controls completed six cognitive/neuropsychological tests: The Shipley Institute of Living Scale, Trail Making Test Parts A and B, Paced Auditory Serial Addition Test (PASAT), Facial Recognition Test (FRT), Rey–Osterreith Complex Figure Test (CFT), and Rey Auditory Verbal Learning Test (RAVLT). Tests were selected based upon demonstrated sensitivity to brain injury as well as ability to provide information regarding participants general cognitive functioning. An attempt was made to assess the functioning of both hemispheres as well as the frontal and temporal lobes, which are at maximal risk in many impact injuries (Bigler, 1988).

2.2.1. Shipley Institute of Living Scale

The 60-item Shipley Institute of Living Scale provides an intellectual quotient based upon responses to vocabulary items, and a conceptual quotient based upon concept formation and abstract verbal and arithmetic problems ((Shipley, 1940)). The Shipley was used as a brief, general measure of intellectual functioning (Zachary, 1986; Zachary, Crumpton, & Spiegel, 1985).

2.2.2. Trail Making Test Parts A and B

This is a two-part test of visual scanning, visuomotor tracking, motor speed, attention and mental flexibility (Reitan, 1955). This test reliably differentiates between brain injured and other types of groups (Lezak, 1995, p. 383). In the present study, the Trail Making Test was used to assess for the effects of diffuse brain injury.

2.2.3. Paced Auditory Serial Addition Test (PASAT)

The PASAT is a sensitive measure of auditory-based information processing (Gronwall, 1977). The PASAT presents 60 pairs of random numbers and requires the subject to add the next number to the one immediately preceding. Four series are conducted, each at a different rate of number presentation (range: 1.2–2.4 s). The PASAT was used because of its sensitivity to deficits in information processing skills which are commonly associated with minor head injuries (Gronwall & Wrightson, 1981).

2.2.4. Test of Facial Recognition (FRT)

The FRT assesses visual perceptual accuracy by way of comparisons of front and profile pictures (Benton & Van Allen, 1968). No memory component is assessed. The short form of

the test was used here (Levin, Hamsher, & Benton, 1975). The rationale for the use of FRT in this study was its sensitivity to brain damage within the nondominant parietal area (Dricker, Butters, Berman, Samuels, & Carey, 1978).

2.2.5. *Rey Osterreith Complex Figure Test (CFT)*

This test assesses visuospatial constructional ability, incidental learning and visual memory (Rey, 1941). Planning and organizational skill and problem-solving strategies also may be assessed (Spreen & Strauss, 1991). The CFT was used in the present study because of its sensitivity to impairments in figural memory and visuospatial constructional abilities (Taylor, 1969).

2.2.6. *Rey Auditory Verbal Learning Test (RAVLT)*

The RAVLT (Rey, 1964) assesses short-term verbal memory, verbal learning, postinterference recall and recognition of visually presented material (Rosenberg, Ryan, & Prifitera, 1984). Scores on Trial I, the sum of Trials I–V, and delayed recall (Trial VII) were analyzed. The RAVLT was used because of its sensitivity to impairments in verbal memory and learning abilities (Lezak, 1979).

Thus, various parameters of cognitive functioning were assessed including general intellectual functioning, abstract reasoning abilities, visual scanning, attention, mental flexibility, information processing, visuospatial constructional ability, and nonverbal and verbal memory.

2.3. *Procedure*

The test battery was administered at one sitting, individually to each subject. The order of administration of tests was as follows: RAVLT; CFT; Trail Making Test Parts A and B; Shipley, part II; RAVLT, recall; Shipley, part I; CFT, recall; FRT; and PASAT. This order was developed to minimize the effects of interference on visual and verbal delayed memory tasks. Experienced graduate students and trained psychometrists administered all tests, which then were scored by the first author.

Two questions from the interview provided information regarding heading practices: (1) did the player consider himself to be a “header” and (2) estimation of how often he headed the ball during a typical game. To describe current heading practices, participants were divided into four heading groups: control (#1; no heading), low (#2; zero to four times per game), moderate (#3; five to eight times per game), and high (#4; nine or more times per game). This current measure was garnered from the participants’ self-reports. A cumulative heading measure was devised to provide an estimate of lifetime propensity for heading. This cumulative measure multiplied the current heading estimate by the years of experience in competitive soccer. This latter measure assumes a constant number of games and practices per year, and admittedly is a gross measure. However, in discussions with players and coaches, no better estimate could be conceptualized. The cumulative groups were formed by keeping together the 12 control participants to form Group 1, and forming Groups 2, 3, and 4 by creating break points for the three remaining quartiles in the distribution of the cumulative heading measure.

In addition to assessing the role of heading in determining cognitive performance, level of impairment was calculated based upon comparisons with the normative data for the respective

tests, corrected for age and education when such tables were available. Test scores that exceeded two standard deviations below the mean (e.g., 2nd percentile) were considered impaired for the purposes of this study. The manual for the FRT provides actual cut-off score information for determining level of impairment, and those scores were used here.

3. Results

3.1. Current heading frequency

The first set of analyses examined between-group differences in the current heading groups. Players' self-reports of current heading frequencies dictated their inclusion into a group. Key demographic characteristics along with the means and standard deviations for the various neuro-cognitive tests are presented in Table 1. Comparison of group differences for each measure were accomplished through MANOVA for the four PASAT trials and through ANOVA for the other measures.

As expected, a player's self-attribution of being a "header" tracked their assignment into heading groups based upon their frequency estimates of headings per game. Years of playing experience varied positively with likelihood of being a "header" ($r(58) = .41, P < .01$). Education and age did not differ significantly between groups. Significant differences between

Table 1
Demographics and mean (S.D.) test scores for current heading groups

	Control	Heading groups		
		Low	Moderate	High
<i>N</i>	12	17	24	19
Age	22.92 (3.55)	20.47 (4.42)	21.46 (5.80)	22.00 (4.50)
Education	14.92 (1.08)	13.12 (2.62)	13.12 (2.54)	13.32 (2.54)
Years played	0	9.06 (5.03)	12.12 (5.26)	13.89 (6.53)
"Headers" (%)	0	17.6	60.9	78.9
FRT	47.25 (1.91)	45.82 (3.66)	47.79 (3.74)	46.26 (5.47)
PASAT 1.2	46.08 (7.51)	45.41 (9.55)	46.67 (9.59)	40.89 (13.42)
PASAT 1.6	45.17 (7.08)	37.35 (12.75)	44.38 (9.25)	38.58 (11.67)
PASAT 2.0	38.92 (10.90)	33.76 (9.60)	38.67 (10.20)	36.32 (11.37)
PASAT 2.4	28.33 (8.80)	25.53 (9.12)	30.29 (8.13)	27.84 (8.17)
PASAT total	158.50 (29.45)	142.06 (32.44)	160.00 (34.55)	143.63 (41.68)
RAVLT I	6.08 (1.31)	6.83 (1.51)	6.29 (1.46)	7.42 (1.61)
RAVLT total	46.75 (8.97)	51.41 (8.56)	48.91 (8.78)	53.63 (5.88)
RAVLT VII	9.82 (3.12)	10.00 (3.28)	10.13 (2.92)	10.79 (3.24)
R-CFT copy	33.00 (3.46)	33.56 (1.90)	32.83 (2.79)	32.84 (2.91)
R-CFT recall	23.71 (7.54)	22.74 (7.06)	21.52 (5.97)	22.45 (4.53)
Shipley IQ	112.42 (8.32)	108.47 (9.98)	108.83 (7.21)	104.53 (8.06)
Shipley CQ	112.17 (8.32)	110.71 (13.26)	110.25 (12.94)	105.11 (11.71)
Trails A	20.75 (4.47)	24.65 (8.32)	21.79 (4.82)	29.79 (11.19)
Trails B	45.92 (13.42)	58.59 (30.22)	50.42 (15.58)	63.42 (33.04)

groups were found only on part A of the Trail Making Test, $F(3, 68) = 4.82, P < .004$. Fisher's LSD test ($P < .05$) showed that Group 4, those athletes with the most estimated headers per game, took significantly longer to complete Part A of the Trail Making Test than the other three groups. Although the mean time to completion for the high heading group (Group 4) on part B of the Trail Making Test was numerically greater than the other groups, this difference was not significant. The considerable variance in the low and high heading groups resulted from one player in each group reaching the maximum allowable time for completion of Trails B. No other participants were close to this maximum. The Shipley estimated IQ (but not CQ) score differences were near significant, $F(3, 68) = 2.51, P < .06$. Group 4 had lower estimated mean scores than the other groups. No significant outcomes were found for the PASAT, RAVLT, FRT or CFT. Scores only on the RAVLT were superior for the high heading group.

3.2. Estimated lifetime heading as the independent variable

In order to more clearly assess the contribution of the career history of heading the ball, the four heading groups were re-formed, based upon the estimate of cumulative lifetime heading events, described previously. Key demographic characteristics for these re-formed groups along with the means and standard deviations for the various tests are presented in Table 2. This restructuring caused some shuffling of players among the groups. For example, a young high school player who was a high-frequency header would have been in the high heading

Table 2
Demographics and mean (S.D.) test scores for lifetime heading groups

	Heading groups			
	Control	Low	Moderate	High
<i>N</i>	12	19	20	21
Age	22.92 (3.55)	20.63 (4.19)	19.10 (3.99)	24.14 (5.38)
Education	14.92 (1.08)	13.47 (2.32)	11.85 (2.48)	14.19 (2.27)
Years played	0	6.79 (4.29)	10.95 (3.19)	17.19 (4.46)
"Headers" (%)	0	33.3	55.0	71.4
FRT	47.25 (1.91)	46.58 (2.52)	46.85 (4.74)	46.81 (5.37)
PASAT 1.2	46.08 (7.51)	44.79 (8.66)	48.55 (11.22)	40.33 (11.72)
PASAT 1.6	45.17 (7.08)	37.79 (11.65)	44.65 (10.35)	39.14 (11.44)
PASAT 2.0	38.92 (10.90)	32.79 (8.34)	41.50 (11.25)	35.19 (9.95)
PASAT 2.4	28.33 (8.80)	24.89 (8.02)	32.20 (8.09)	27.29 (8.17)
PASAT total	158.50 (29.45)	140.26 (32.91)	166.90 (38.52)	141.95 (37.97)
RAVLT I	6.08 (1.31)	6.42 (1.39)	6.90 (1.37)	7.05 (1.88)
RAVLT total	46.75 (8.97)	50.11 (9.98)	50.45 (7.88)	52.57 (6.12)
RAVLT VII	9.82 (3.12)	10.00 (3.51)	9.80 (2.93)	11.05 (2.84)
R-CFT copy	33.00 (3.46)	33.34 (2.26)	32.98 (3.04)	32.83 (2.50)
R-CFT recall	23.71 (7.54)	23.74 (7.14)	22.08 (4.98)	20.81 (5.14)
Shipley IQ	112.42 (8.32)	110.00 (8.79)	108.05 (7.66)	104.33 (8.20)
Shipley CQ	112.17 (8.32)	110.68 (12.91)	110.00 (9.32)	105.81 (15.11)
Trails A	20.75 (4.47)	21.84 (5.44)	23.45 (7.71)	29.71 (10.53)
Trails B	45.92 (13.42)	53.47 (19.63)	51.35 (26.20)	65.14 (31.20)

group in the analysis of *current* heading, but could have placed in the low or moderate *lifetime* heading group based upon his fewer years of experience relative to other players. Similarly, an older players who headed infrequently might have moved from the low to the moderate group simply by virtue of the total years playing and heading. These were the most likely changes from the current to the lifetime groups composition, and is evident by the change in average years played as shown in [Table 2](#).

Although the control participants still exhibited a somewhat higher absolute mean for years of education, it was not much different from the high heading participants. Regardless, the lifetime estimate groups did not differ significantly with respect to education or age. Years of playing experience varied positively with likelihood of being a “header” ($r(58) = .61$, $P < .01$).

A pattern of graded decrease in scores with an increase in estimated heading was apparent in the Trail Making Test and the Shipley Scales. A significant difference between groups was found for part A of the Trail Making Test, $F(3, 68) = 4.95$, $P < .004$. Similar to the current heading analysis, the high lifetime heading group took significantly longer to complete Trails A than the three other groups. Although the means on Trails B were widely separated from the control to the high heading group, the variance in the moderate and high groups was again very large. No significant difference was found. The Shipley IQ estimate, though not the CQ, differed significantly between groups, $F(3, 68) = 3.15$, $P < .03$. The LSD comparison revealed that the high heading group scored significantly lower than the control group. Although a significant multivariate effect was found for the four trials of the PASAT, $F(3, 68) = 2.45$, $P < .04$, no significant differences between groups were found when the PASAT univariate F scores were examined. This apparent contradiction occurs since the MANOVA examines all the dependent variables together when determining the multivariate F . Because statistical power may be affected when the number of dependent variables increases, it is possible to find no differences when the variables are evaluated individually ([Van De Geer, 1971](#)). In order to assess more succinctly the meaning of the MANOVA findings, the four PASAT trials at the different durations were summed to create a total PASAT score for each group. A significant difference between groups was obtained, $F(3, 68) = 2.53$, $P < .05$; however, the significant differences were between Groups 2 and 4 versus Groups 1 and 3. Examination of individual results revealed that 2 players in Group 3 had the highest level of performance on the test for all 72 participants. This outcome muddied any conclusions that could be derived from the PASAT data. No significant differences between groups were found for the RAVLT, CFT, or FRT. As with the current heading analysis, although not significant, the high heading group performed the best of all groups on the RAVLT.

Although the lifetime estimate of heading revealed more instances where the high heading group performed significantly weaker than controls or other heading groups, the changes were generally not large. Moreover, even when the high heading group did have significantly weaker performance, the absolute means were within normal ranges of variability for the test.

3.3. Clarification of the role of age and education

Because the significant decrease in IQ scores across cumulative heading groups was unexpected, and because it had already been found that years of experience correlated positively

Table 3
Percentage of impaired scores in lifetime heading groups

	<i>N</i>	Trails A (%)	Trails B (%)	PASAT (%) ^a	RAVLT (%) ^b	CFT (%) ^c	FRT (%)
Control	12	0	0	4	10	8	0
Low	19	0	0	12	14	21	5
Moderate	20	5	5	14	9	20	5
High	21	14	10	20	8	33	10

^a The PASAT score represents the sum across all four trials.

^b The RAVLT score represents the sum across Trials I–V.

^c The CFT score represents the sum of copy and recall scores.

with the self-report of being a “header,” all ANOVAs were repeated with age and education inserted into the formula as covariates to assess any age or education related confounding. No changes in the original findings were revealed.

3.4. Relationship between heading and somatic complaints

In collecting the demographic information from the players, questions were asked about the physical and medical history that could relate to frequent heading. Since the exclusion criteria used in forming the sample ruled out players with a history of serious head injury, the remaining variables for analysis were representative of “softer” signs, such as dizziness during or after games and problems with memory. Players who identified themselves as “headers” were significantly more likely to have experienced game-related dizziness, $X^2(1, N = 60) = 4.62$, $P < .03$. Similarly, there was a significant relationship between time spent on the sidelines during games because of dizziness and (1) the current frequency of heading, $r(58) = .44$, $P < .01$, and (2) the lifetime estimate of heading, $r(58) = .45$, $P < .01$.

3.5. Impaired scores for all tests for cumulative heading groups

Tables 3 and 4 describe the distribution of impaired scores on all cognitive/perceptual tests for all subjects, categorized according to cumulative heading frequency. A score in the impaired range on the normative tables for a test, or one that was two or more standard deviations below

Table 4
Percentage of impaired scores in current heading groups

	<i>N</i>	Trails A (%)	Trails B (%)	PASAT ^a (%)	RAVLT ^b (%)	CFT ^c (%)	FRT (%)
Control	12	0	0	4	10	8	0
Low	17	6	6	13	13	24	10
Moderate	24	0	4	15	9	22	0
High	19	16	5	18	9	30	10

^a The PASAT score represents the total score for all four trials.

^b The RAVLT score represents the sum across Trials I–V.

^c The CFT score represents the combination of copy and recall scores.

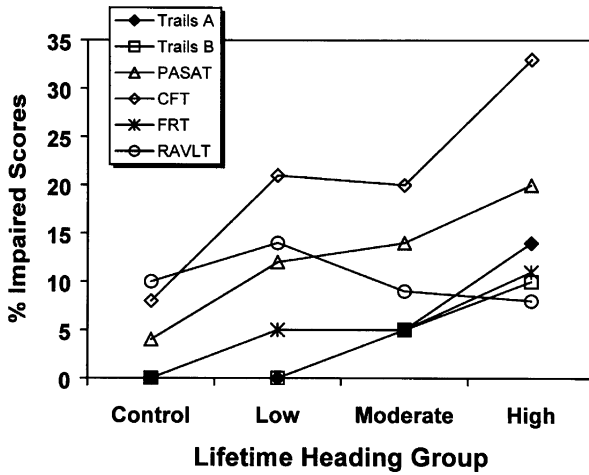


Fig. 1. Percentages of players who scored in an impaired range on the listed tests related to the lifetime estimated headings. Impairment was based upon comparison to established norms or scores more than two standard deviations below the mean for that test, if no norms were available.

the mean when no normative tables were available, was judged impaired. With the exception of the RAVLT, the frequency of impaired scores clearly differentiated the high heading group from the others, even when the group data had not revealed any change as a function of the heading variable. For example, with the Complex Figure Test, only one score from the control group was in the impaired range, but one-third of all scores produced by the high headers were at an impaired level. A graphic portrayal of these data, shown in Figure 1, captures effectively how impairment and heading were related.

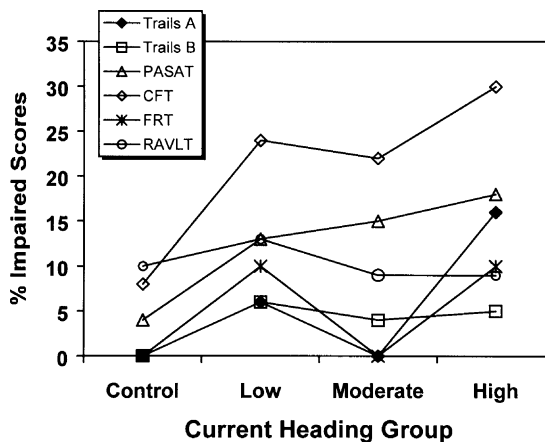


Fig. 2. Percentages of players who scored in an impaired range on the listed tests related to the currently reported heading behavior. Impairment was based upon comparison to established norms or scores more than two standard deviations below the mean for that test, if no norms were available.

For the current heading estimates, the differential between impaired scores within the control group versus all heading groups was naturally still present. However, impaired scores were distributed more evenly throughout the heading groups. More still occurred among those who headed most frequently as [Figure 2](#) shows.

4. Discussion

4.1. Conclusions from comparison of mean test scores

The group data from the present study provide evidence that cumulative heading experience may result in significantly weaker performance on some but not all tests in a neuro-cognitive battery, supporting previous findings or suggestions of such effects ([Abreau et al., 1990](#); [Matser et al., 1999](#); [Tysvaer & Lochen, 1991](#)). Because players with a reported history of moderate to severe head injuries were excluded from the present study, the role of heading was assessed more clearly than in previous reports. However, there was no actual control *during* the study for new head injuries nor was there control for historical mild head injuries from non-ball-related contacts. A player's estimated career incidence of heading predicted a graded decrease in performance on the Trail Making Test and the Shipley Scales. This finding supports the role of heading, *per se*, as a factor in predicting weaker neuropsychological test performance. The PASAT results, though suggestive of a heading effect, were too variable for any clear conclusion to be drawn. Lack of clear or significant change in the FRT, CFT and RAVLT suggests that any heading effect may be weak, circumscribed within particular neuro-cognitive functions, or part of an interactive relationship involving other factors.

Players who reported heading the ball very frequently took significantly longer to complete the Trail Making Test Part A, suggesting difficulties with visual search, attention, and mental flexibility. Even though the average performance by the frequent heading group was still within a range that is standard for the normal population, one might have expected high level, competitive soccer players to perform in the upper range on tests that measure visual search and attention, and cognitive processing time. Increasing the load of such cognitive characteristics has been shown in real-world situations to differentiate experienced from novice soccer players ([Smith & Chamberlain, 1992](#)). Although the results from the PASAT are less clear due to anomalies in the moderate heading group, the frequent headers performed more poorly on the PASAT than the control subjects, indicating some difficulty with information processing.

Frequent headers also achieved lower estimated IQ scores based upon the Shipley Institute of Living Scale. Though lower than the other groups, these estimated IQs still were within a normal range. The CQ portion of the Shipley did not differentiate significantly among the heading groups, although the pattern of scores across heading groups was similar to that seen with the IQ measure. The higher variance in the CQ measure may have obscured an effect if one were to be found. An historical use of the Shipley Scales was to determine brain deterioration when the CQ was considerably lower than the IQ, under the assumption that the verbal declarative knowledge measured by the vocabulary scale of the IQ portion should be more resistant to impairment ([Lezak, 1995](#), p. 734). No such differences were found here.

The neuropsychological tests of generalized function (Trails A and B, Shipley IQ, and to a lesser degree, PASAT) tended to differentiate those players who headed more vs. less frequently. Tests that assessed more specialized functions (FRT, CFT and RAVLT) did not significantly differentiate groups based upon the heading variable, even though these tests often are sensitive to the effects of mild traumatic brain injuries. This lack of consistency within all the measures has been reported in previous studies (Abreau et al., 1990; Maser et al., 1999) and may reflect (1) limitations of the heading variable as a key predictor of neuropsychological performance, (2) an interaction with other, extraneous variables, or (3) large within-group variability.

4.2. *Conclusions from analysis of impairment percentages*

A much clearer picture emerged from analysis of impaired scores than with the group comparisons of average test scores. Players with the highest estimated frequency of heading (either current or lifetime estimates) produced more impaired scores than did control participants or players who headed the ball much less. This pattern emerged with all tests (except the RAVLT) regardless of whether there had been a difference in the mean scores of the tests across groups. As with the average test score analysis, this effect was more pronounced when the lifetime estimates of heading were used.

In many ways, these results appear to skip around the individuals, tests, and groups, a phenomenon that mirrors the sketchy effects across tests and groups that have been observed in individuals who suffered sports-related MTBI. For example, Echemendia, Putukian, Mackin, Julian, and Shoss (2001) examined athletes who had suffered MTBI using both a battery of neuropsychological tests and clinical interview/examination. The test data were superior to the subjective data in correctly identifying injured players versus controls. However, formidable within-group variability occurred within the athlete group and also within individual tests from the battery. For this reason, the authors cautioned that observation of the entire test batteries as opposed to performance on any one individual test should be the standard for conclusions from such examinations.

There is a need to assess the predictive relationship that these impaired test scores have upon the soccer player's daily functioning. Neither the present study nor previous studies have reported practical examples of impairment, although they may have been present. It is uncertain whether low scores on neuropsychological tests translated to functional differences in daily living. Indeed, from a positive standpoint, one of the most frequent headers in this study was a two-time All American who had maintained a 3.9 grade point average in a very demanding major. From a negative standpoint, several players in the frequent heading group complained of inability to concentrate and attend to important information in class or at work. Moreover, it was the frequent headers who were most likely to complain of dizziness during or after games.

4.3. *Limitations*

Our cumulative measure of lifetime heading was a gross estimate, and may have led to over or under estimation of heading across individuals. Sources for bias also included individual

differences and intensity differences related to level of play. Probably the most significant factor that was not estimated was the frequency of heading in practice. During actual high school and college playing seasons, daily practices are common. The senior amateur and professional players in our study practiced fewer times per week but performed in leagues with longer playing seasons. Players in all categories tended to play for multiple teams in multiple leagues which further confused the issue of practice. However, frequency of actual matches played per year appeared to be similar across ages and experience, based upon the interviews with players. Although one could argue the relative importance of games versus practices in contributing to heading effects, we believe that both are important and that both should be considered in future studies.

There was no simple relationship between the heading effects and the experience effects. Certainly lifetime heading experience and lifetime playing experience correlated positively. However, current heading frequency did not fit into such a relationship. Thus, young players who headed frequently were likely to perform more poorly than less frequent headers of the same age/level, and older players who did not head frequently were less likely to exhibit weak or impaired performance. Since all the athletes were assessed on a one-time basis and were also currently active soccer players, the present study was unable to discern the longevity of effect or of differences among the groups in this regard. Differences between groups may be minimal during the off season or once a player retires. However, Tysvaer et al.'s (1989) study of the former athletes contraindicates the likelihood of full recovery. Thus, there is a legitimate need for future research to clarify relevant variables that determine impairment (such as playing position, heading skill and/or frequency of play) and to determine whether any of these deficits will ameliorate with time off from playing (and heading). Future research should investigate the presence of any interaction effects between age groups and heading frequency in determining impairments, and also in assessing the relative permanence of such impairments. In their investigation of the permanence of neuropsychological impairment following mild head injury in American college football players, [Macciocchi, Barth, Alves, Rimel, and Jane \(1996\)](#) found that most symptoms were resolved within a few days. Although any concussive or subconcussive effects of heading the soccer ball could similarly be expected to be resolved quickly, the routine nature of heading and the nearly continuous playing season for serious soccer athletes may suggest the maintenance of chronic, low levels of neurological and neuropsychological symptoms. For example, in the present study, the college athletes had just finished their NCAA season, but still were working out together on a nonsupervised basis. Within 2 months of testing, many of them had begun practice and play in spring/summer amateur leagues. Most of the adult players participated in two or more leagues, indoor and outdoor, during the course of the year.

The current study examined only male players. The generalizability of results to female soccer players is unclear. However, [Boden et al. \(1998\)](#) and the [NCAA Injury Surveillance System \(2001\)](#) found fairly similar head injury and concussion rates for male and female college soccer players, so it is reasonable to postulate that similar neuropsychological effects might occur in a chronic setting. Because of their smaller body mass (with a resulting reduced ability to absorb impact to the head and greater incidence of injury) and historically less opportunities for training and education in the sport, female players may actually be at greater risk for traumatic brain injury and cortical impairment.

In the present investigation self-report data regarding soccer experience was a limitation. Testing whole teams who share coaching, practice, and game experience, and having several examiners attend the games and practices to count accurately players' heading behavior can validate the information gathered from self-report. A prospective, longitudinal study with a larger number of participants, measures of neuropsychological abilities taken at successive intervals, and comparative measures of subjects who head the ball frequently may best be able to determine permanency of impaired scores on neuropsychological measures. Such observational data also could clarify the incidence of head injuries that resulted from other than ball to head events. Clearly, players suffer arm to head, leg and foot to head, and head to head injuries on all too frequent a basis (Tysvaer, 1992). This study did not rule out the potential deleterious effects of such contacts. The obtaining of relationships between reported amount of heading and level of cognitive performance (and impairment) argues strongly that heading plays an important role. However, the contribution of subconcussive ball to head impacts versus subconcussive or concussive impacts with other players during the heading process is very difficult to determine. The question is not trivial since the issue of subconcussive effects lays at the heart of the heading debate.

The variability of the scores within groups clearly impacted the obtaining of significant differences. For example, even though some of the tests of specialized function such as the FRT revealed greater percentages of impaired scores in the high heading group, no significant differences in scores across groups overall were found. This was most noticeable in Part B of the Trail Making Test. Considerable differences across groups were noted, but the high variance obviated any statistical significance of these differences. Such variability has been commented on by Lezak (1995, p. 383) as an extant problem in interpreting group results on Trails B with MTBI patients. In follow-up studies, it is recommended that every effort be made to provide a uniform testing environment that minimizes nonexperimental variability. Several players were tested at their convenience in other locations to maximize the number of participants. This deviation from our desired standard appeared to produce no obvious systematic effect, but probably did result in higher within group variance. Motivation versus malingering appeared to play no role with the soccer players, who adopted a very competitive approach to the testing. They appeared to be more highly motivated to perform well than (for example) typical college students whom we have tested, including some of the control participants in the present study. Importantly, no test data were included in the study where validity was in question.

As soccer becomes a more popular sport in the United States, future research will be essential to help determine the specific effects soccer play has upon cognitive functioning. Although the incidence of head injury is lower in soccer than in American football, wrestling, and rugby (Dailey & Barsan, 1992; The NCAA News, 2001), players who head the ball frequently may carry a higher risk of neurobehavioral sequelae. While the results of the present study do not provide unambiguous evidence that ball-to-head contacts are responsible for impaired functioning, they certainly show more than previous studies that the *behavior* of heading does relate to such impairment. Certainly, it is not premature to consider development of standards to limit heading practices, at least in the short term, by persons who are recovering from a documented head injury. Finally, the present findings should remind the scientific and soccer communities that the book is not closed on the potential role of heading (and subconcussive incidents in general) as a causative agent in neurobehavioral impairment.

References

- Abreau, F., Templer, D. I., Schuyler, B. A., & Hutchison, H. T. (1990). Neuropsychological assessment of soccer players. *Neuropsychology*, *4*, 175–181.
- Ashworth, B. (1985). Migraine, head trauma, and sport. *Scottish Medical Journal*, *30*, 240–242.
- Backous, D. D., Friedl, K. E., Smith, N. J., Parr, T. J., & Carpine, W. D., Jr. (1988). Soccer injuries and their relation to physical maturity. *American Journal of Diseases of Children*, *142*, 839–842.
- Barth, J., Alves, W., Ryan, T., Macciocchi, S., Rimel, R., Jane, J., & Nelson, W. (1989). Mild head injury in sports: Neuropsychological sequelae and recovery of function. In H. Levin (Ed.), *Mild head injury* (pp. 257–275). New York: Oxford University Press.
- Benton, A. L., & Van Allen, M. W. (1968). Impairment in facial recognition in patients with cerebral disease. *Cortex*, *4*, 344–358.
- Bigler, E. (1988). *Diagnostic clinical neuropsychology—Revised edition*. Austin: University of Texas Press.
- Boden, B. P., Kirkendall, D. T., & Garrett, W. E., Jr. (1998). Concussion incidence in elite college soccer players. *The American Journal of Sports Medicine*, *26*, 238–241.
- Broglio, S. P., & Guskiewicz, K. M. (2001). Soccer heading: Are there risks involved? *Athletic Therapy Today*, *6*, 28–32.
- Cantu, R. C. (1996). Head injuries in sport. *British Journal of Sports Medicine*, *30*, 289–296.
- Dailey, S. W., & Barsan, W. G. (1992). Head injuries in soccer: A case for protective headgear? *The Physician and Sportsmedicine*, *20*, 779–785.
- Denny-Brown, D., & Russell, R. (1941). Experimental cerebral concussion. *Brain*, *64*, 93–164.
- Dricker, J., Butters, N., Berman, G., Samuels, I., & Carey, S. (1978). The recognition and encoding of faces by alcoholic Korsakoff and right hemisphere patients. *Neuropsychologia*, *16*, 683–695.
- Echemendia, R. J., Putukian, M., Mackin, R. S., Julian, L., & Shoss, N. (2001). Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sports Medicine*, *11*, 23–31.
- Ekstrand, J. (1990). Normal course of events amongst Swedish soccer players: An 8-year follow-up study. *British Journal of Sports Medicine*, *24*, 117–119.
- Fekete, J. F. (1968). Severe brain injury and death following minor hockey accidents: The effectiveness of the “safety helmets” of amateur hockey players. *Journal of the Canadian Medical Association*, *99*, 1234–1239.
- Fields, K. B. (1989). Head injuries in soccer. *The Physician and Sportsmedicine*, *17*, 69–73.
- Green, G. A., & Jordan, S. E. (1998). Are brain injuries a significant problem in soccer. *Clinics in Sports Medicine*, *17*, 795–809.
- Gronwall, D. M. A. (1977). Paced Auditory Serial-Addition Task: A measure of recovery from concussion. *Perceptual and Motor Skills*, *44*, 367–373.
- Gronwall, D., & Wrightson, P. (1975). Cumulative effect of concussion. *Lancet*, *ii*, 995–997.
- Gronwall, D., & Wrightson, P. (1981). Memory and information processing capacity after closed head injury. *Journal of Neurology, Neurosurgery, and Psychiatry*, *44*, 889–8895.
- Harrison, D. W. (1990). Blindness following minor head trauma in children: A report of two cases with a review of the literature. *Journal of Emergency Medicine*, *8*, 21–24.
- Hunt, M., & Fulford, S. (1990). Amateur soccer: Injuries in relation to field position. *British Journal of Sports Medicine*, *24*, 265.
- Kelly, J. P. (1999). Traumatic brain injury and concussion in sport. *Journal of the American Medical Association*, *282*, 989–991.
- Kelly, J. P., Nichols, J. S., Rilley, C. M., Lillehel, K. O., Rubinstein, D., & Kleinschmidt-DeMasters, B. K. (1991). Concussion in sports: Guidelines for the prevention of catastrophic outcome. *Journal of the American Medical Association*, *266*, 2867–2869.
- Kirkendall, D. T., Jordan, S. E., & Garrett, W. E. (2001). Heading and head injuries in soccer. *Sports Medicine*, *31*, 369–386.
- Kraus, R., Ohler, K., & Barolin, G. S. (1983). Balleinwirkung auf den kopf-eine quantifizierende EEG-untersuchung bei fußballern. *Zeitschrift EEG-EMG*, *14*, 209–212.

- Jordan, S. F., Green, G. A., Galanty, H. L., Mandelbaum, B. R., & Jabour, B. A. (1996). Acute and chronic brain injury in United States national team soccer players. *The American Journal of Sports Medicine*, 24, 205–210.
- Lambert, P. W., & Hardman, J. M. (1984). Morphological changes in brains of boxers. *Journal of the American Medical Association*, 251, 2676–2683.
- Lehman, L. B. (1988). Preventing and anticipating neurologic injuries in sports. *American Family Practitioner*, 38, 181–184.
- Levin, H. S., de Hamsher, K. S., & Benton, A. L. (1975). A short form of the Test of Facial Recognition for clinical use. *Journal of Psychology*, 91, 223–228.
- Lezak, M. D. (1979). Recovery of memory and learning functions following traumatic brain injury. *Cortex*, 15, 63–70.
- Lezak, M. D. (1995). *Neuropsychological assessment* (3rd ed.). New York: Oxford University Press.
- Lunberg, G. D. (1986). Boxing should be banned in civilized countries-round 3. (Editorial). *Journal of the American Medical Association*, 255, 2483–2485.
- Macciocchi, S. N., Barth, J. T., Alves, W., Rimel, R. W., & Jane, J. A. (1996). Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery*, 39, 510–514.
- Mathews, W. B. (1972). Footballer's migraine. *British Medical Journal*, 2, 327–327.
- Matser, J. T., Kessels, A. G. H., Jordan, B. D., Lezak, M. D., & Troost, J. (1998). Chronic traumatic brain injury in professional soccer players. *Neurology*, 51, 791–796.
- Matser, J. T., Kessels, A. G. H., Lezak, M. D., Jordan, B. D., & Troost, J. (1999). Neuropsychological impairment in amateur soccer players. *Journal of the American Medical Association*, 282, 971–973.
- McCrory, P. (2001). Does second impact syndrome exist? *Clinical Journal of Sport Medicine*, 11, 144–149.
- McQuillen, J. B., McQuillen, E. N., & Morrow, P. (1988). Trauma, sports, and malignant cerebral edema. *American Journal of Forensic Medicine and Pathology*, 9, 12–15.
- Murelius, O., & Haglund, Y. (1991). Does Swedish amateur boxing lead to chronic brain damage? A retrospective neuropsychological study. *Acta Neurologica Scandinavica*, 83, 9–13.
- Reitan, R. (1955). The relation of the Trail Making Test to organic brain damage. *Journal of Consulting Psychology*, 19, 393–395.
- Rey, A. (1941). Psychological examination of traumatic encephalopathy. *Archives de Psychologie*, 28, 286–340; *The Clinical Neuropsychologist*, 1993, 4–9 (J. Corwin, & F. W. Bylisma, Trans.).
- Rey, A. (1964). *L'examen clinique en psychologie*. Paris: Presses Universitaires de France.
- Rosenberg, S. J., Ryan, J. J., & Prifitera, A. (1984). The Auditory-Verbal Learning Test: Performance of patients with and without memory impairment. *Journal of Clinical Psychology*, 40, 785–787.
- Ross, R. J., Cole, M., Thompson, J. S., & Kim, K. H. (1983). Boxers—computer tomography, EEG and neurological evaluation. *Journal of the American Medical Association*, 249, 211–213.
- Sandelin, J., Santavirta, S., & Kiviluoto, O. (1985). Acute soccer injuries in Finland in 1980. *British Journal of Sports Medicine*, 19, 30–33.
- Shell, D., Carico, G. A., & Patton, R. A. (1993). Can subdural hematoma result from repeated minor head injury? *The Physician and Sportsmedicine*, 21, 74–84.
- Shipley, W. C. (1940). A self-administered scale for measuring intellectual impairment and deterioration. *Journal of Psychology*, 9, 371–377.
- Smith, M. D., & Chamberlain, C. J. (1992). Effect of adding cognitively demanding tasks on soccer skill performance. *Perceptual and Motor Skills*, 75, 955–961.
- Smoldlaka, V. N. (1981). Death on the soccer field and its prevention. *The Physician and Sportsmedicine*, 9, 100–107.
- Smoldlaka, V. N. (1984). Medical aspects of heading the ball in soccer. *The Physician and Sportsmedicine*, 12, 127–131.
- Sortland, O., & Tysvaer, A. (1989). Damage in former association football players: An evaluation by cerebral computed tomography. *Neuroradiology*, 31, 44–48.
- Spren, O., & Strauss, E. (1991). *A compendium of neuropsychological tests: Administration, norms, and commentary*. New York: Oxford University Press.
- Taylor, L. B. (1969). Localization of cerebral lesions by psychological testing. *Clinical Neurosurgery*, 16, 269–287.
- The NCAA News*. (2001, March 12). Latest fall sports study spotlights head and player contact injuries.

- Tysvaer, A. (1992). Head and neck injuries in soccer. Impact of minor trauma. *Sports Medicine*, *14*, 200–213.
- Tysvaer, A., & Lochen, E. (1991). Soccer injuries to the brain: A neuropsychologic study of former soccer players. *The American Journal of Sports Medicine*, *19*, 56–60.
- Tysvaer, A., & Storli, A. (1981). Association football injuries to the brain: A preliminary report. *British Journal of Sports Medicine*, *15*, 163–166.
- Tysvaer, A., & Storli, V. (1989). Soccer injuries to the brain: A neurologic and electroencephalographic study of active players. *The American Journal of Sports Medicine*, *17*, 573–578.
- Tysvaer, A., Storli, V., & Bachen, N. (1989). Soccer injuries to the brain: A neurologic and electroencephalographic study of former players. *Acta Neurologica Scandinavica*, *80*, 151–156.
- Unterharnscheidt, F. (1970). About boxing: A review of historical and medical aspects. *Texas Representative Biological Medicine*, *28*, 421–495.
- Van De Geer, J. P. (1971). *Introduction to multivariate analyses for the social sciences*. San Francisco: Freeman.
- Wilberger, J. E., Jr., & Maroon, J. C. (1989). Head injuries in athletes. *Clinical Sports Medicine*, *8*, 1–9.
- Witol, A., & Webbe, F. (1994). Neuropsychological deficits associated with soccer play [abstract]. *Archives of Clinical Neuropsychology*, *9*, 204–205.
- Zachary, R. A. (1986). *Shipley Institute of Living Scale—Revised manual*. Los Angeles: Western Psychological Services.
- Zachary, R. A., Crumpton, E., & Spiegel, D. E. (1985). Estimating WAIS–R IQ from the Shipley Institute of Living Scale. *Journal of Clinical Psychology*, *41*, 532–540.