Acute Effects and Recovery Time Following Concussion in Collegiate Football Players

The NCAA Concussion Study

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Context Lack of empirical data on recovery time following sport-related concussion hampers clinical decision making about return to play after injury.

Objective To prospectively measure immediate effects and natural recovery course relating to symptoms, cognitive functioning, and postural stability following sport-related concussion.

Design, Setting, and Participants Prospective cohort study of 1631 football players from 15 US colleges. All players underwent preseason baseline testing on concussion assessment measures in 1999, 2000, and 2001. Ninety-four players with concussion (based on American Academy of Neurology criteria) and 56 noninjured controls underwent assessment of symptoms, cognitive functioning, and postural stability immediately, 3 hours, and 1, 2, 3, 5, 7, and 90 days after injury.

Main Outcome Measures Scores on the Graded Symptom Checklist (GSC), Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), and a neuropsychological test battery.

Results No player with concussion was excluded from participation; 79 players with concussion (84%) completed the protocol through day 90. Players with concussion exhibited more severe symptoms (mean GSC score 20.93 [95% confidence interval {CI}, 15.65-26.21] points higher than that of controls), cognitive impairment (mean SAC score 2.94 [95% CI, 1.50-4.38] points lower than that of controls), and balance problems (mean BESS score 5.81 [95% CI, –0.67 to 12.30] points higher than that of controls) immediately after concussion. On average, symptoms gradually resolved by day 7 (GSC mean difference, 0.33; 95% CI, –1.41 to 2.06), cognitive functioning improved to baseline levels within 5 to 7 days (day 7 SAC mean difference, –0.03; 95% CI, –1.33 to 1.26), and balance deficits dissipated within 3 to 5 days after injury (day 5 BESS mean difference, –0.31; 95% CI, –3.02 to 2.40). Mild impairments in cognitive processing and verbal memory evident on neuropsychological testing 2 days after concussion resolved by day 7. There were no significant differences in symptoms or functional impairments in the concussion and control groups 90 days after concussion.

Conclusions Collegiate football players may require several days for recovery of symptoms, cognitive dysfunction, and postural instability after concussion. Further research is required to determine factors that predict variability in recovery time after concussion. Standardized measurement of postconcussive symptoms, cognitive functioning, and postural stability may enhance clinical management of athletes recovering from concussion.

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STUDIES IN BASIC NEUROSCIENCE have demonstrated that mild traumatic brain injury (concussion) is followed by a complex cascade of ionic, metabolic, and physiological events that can adversely affect cerebral function for several days to weeks.[1,2] Concussive brain injuries trigger a pathophysiological sequence characterized earliest by an indiscriminate release of excitatory amino acids, massive ionic flux, and a brief period of hyperglycolysis, followed by persistent metabolic instability, mitochondrial dysfunction, diminished cerebral glucose metabolism, reduced cerebral blood flow, and altered neurotransmission. These events culminate in axonal injury and neuronal dysfunction.[2-5] Clinically, concussion eventuates in neurological deficits, cognitive impairment, and somatic symptoms.[6]

Sport-related concussion is now widely recognized as a major public health concern in the United States and worldwide.[3,7-9] Despite rule changes and advances in protective equipment, the incidence rate of concussion in contact

See also pp 2549 and 2604 and Patient Page.

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and collision sports continues to be relatively high.[10] Overall, concussion is one of the most common injuries in many collegiate sports.[11,12] Recent data from the National Collegiate Athletic Association (NCAA) Injury Surveillance System reveal that concussion accounted for a significant percentage of total injuries among athletes participating in collegiate ice hockey (12.2%), football (8%), and soccer (4.8%) during the 2002-2003 season.[11]

Of all sports, football has the highest absolute number of concussions each year because of the large volume of participants at the high school and collegiate levels.[11,13,14] Recent epidemiological and prospective clinical studies estimate that approximately 3% to 8% of high school and collegiate football players sustain a concussion each season.[10,13,15-25] More concerning is the trend toward an increasing rate of concussion in collegiate football over the last 7 years.[11,12]

Despite a growing body of sport-related concussion research, little evidence-based guidance is available on how long it takes for an athlete to recover after concussion and when it is safe to return to competition. A review of the literature reflects estimates of symptom and cognitive recovery ranging anywhere from several hours to several weeks after sport-related concussion.[15,18,19,21-24,26-36] Computerized and clinical tests have detected postural stability deficits at least 3 days after concussion,[37-41] but the course of longer-term recovery in balance functioning has not been extensively studied. It also remains unclear whether all domains affected by concussion (eg, symptoms, cognition, balance) follow the same or different recovery patterns.

Studying the course of recovery of postconcussive abnormalities is a critical step toward determining the interval during which a concussed brain may be most vulnerable to reinjury and establishing evidence-based guidelines for safe return to play by athletes after concussion.[2] The purpose of this NCAA-sponsored study was to prospectively measure the acute effects of concussion and the continuous time course to recovery following concussion in competitive athletes participating in collegiate football.

METHODS

Participants

A total of 1631 football players from 15 NCAA Division I, II, and III member institutions were enrolled in 1 arm of a larger cohort study of the effects of sport-related concussion in the 1999, 2000, and 2001 seasons. In sum, 2410 player-seasons were analyzed; 779 players were enrolled for more than 1 year of the study. A case series of 94 players who sustained a concussion (5.76% of players; 3.90% of player-seasons) were enrolled in an extensive injury assessment protocol.

A noninjured control was selected from each injured player's team; 56 controls matched to injured players on age, years of education, and baseline performance on concussion assessment measures were administered the identical protocol during the first year of the study. A master list of potential controls for each player was formed after preseason baseline testing, which facilitated immediate selection of a matched control in the event of a concussion during competition and allowed follow-up testing of control players under the same conditions and retest intervals as injured players. Limited resources did not allow enrollment of controls in years 2 and 3 of the study, which had a minimal effect on matching characteristics for the complete study sample. As a group, control participants were slightly younger and less educated than injured participants, but there were no statistically significant group differences in history of concussion or other neurological disorders (TABLE 1). There also were no significant differences in baseline performance on assessment measures for injured and control participants (Table 1), with the exception of the Trail-Making Test Part B.[42-47]

This study was approved by the institutional review boards for protection of human research subjects at the

Table 1. Concussion Group and Control Group Characteristics and Baseline Test Results

Characteristics	Concussion Group (n = 94)*	Control Group (n = 56)*	Mean Difference (95% CI)
Demographics			
Age, y	20.04 (1.36)	19.20 (1.45)	0.84 (0.37 to 1.32)
Academic year (collegiate)	2.78 (1.18)	2.02 (1.23)	0.76 (0.35 to 1.16)
Height, in	73.50 (2.94)	72.75 (3.23)	0.75 (–0.28 to 1.78)
Body weight, kg	105.87 (21.10)	98.33 (20.79)	7.54 (0.47 to 14.62)
Self-reported history			
No. of previous concussions in past 7 y	0.58 (0.78)	0.39 (0.68)	0.19 (–0.07 to 0.44)
Concussion (lifetime), No. (%)	41 (43.2)	17 (30.4)	12.8 (0.0 to 28.9)
ADHD, No. (%)	2 (2.30)	1 (1.80)	0.5 (0.0 to 59.2)
Learning disability, No. (%)	2 (2.30)	1 (1.80)	0.5 (0.0 to 58.8)
Baseline test results†			
GSC total score[17]	1.95 (4.94)	0.99 (3.26)	0.96 (–0.49 to 2.43)
SAC total score[42]	27.40 (2.17)	27.43 (1.77)	–0.03 (–0.68 to 0.61)
BESS total score[41]	11.89 (8.09)	12.73 (7.57)	–0.84 (–3.47 to 1.80)
HVLT Immediate Memory[43]	25.03 (4.36)	25.31 (4.05)	–0.28 (–1.70 to 1.13)
HVLT Delayed Recall[43]	8.61 (2.18)	9.15 (2.13)	–0.54 (–1.27 to 0.18)
HVLT Recognition[43]	22.60 (1.97)	22.94 (1.26)	–0.34 (–0.92 to 0.24)
Trail-Making Test Part B[44]	64.42 (22.22)	57.30 (18.69)	7.12 (0.12 to 14.11)
SDMT[45]	55.56 (11.61)	58.90 (12.19)	–3.34 (–7.29 to 0.60)
Stroop Color-Word Test[46]	47.21 (9.23)	48.66 (9.75)	–1.45 (–4.59 to 1.70)
COWAT[47]	40.46 (12.36)	37.15 (10.61)	3.31 (–0.61 to 7.23)

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; BESS, Balance Error Scoring System; CI, confidence interval; COWAT, Controlled Oral Word Association Test; GSC, Graded Symptom Checklist; HVLT, Hopkins Verbal Learning Test; SAC, Standardized Assessment of Concussion; SDMT, Symbol Digit Modalities Test.
*Data are expressed as mean (SD) unless otherwise specified.
†See Table 2 for explanation of total possible range of scores.

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host institutions of the principal investigators. All participants granted written informed consent prior to enrollment in the study.

Study Design

All participants underwent a preseason baseline evaluation on a battery of concussion assessment measures prior to their first year of participation in the study. An extensive health history questionnaire was also administered at baseline to generate a database of demographic information, concussion history, and preexisting neurological and other medical conditions.

Injured players were identified and enrolled in the study protocol by a team physician or certified athletic trainer present on the sideline during an athletic contest or practice. *Concussion* was defined as an injury resulting from a blow to the head causing an alteration in mental status and 1 or more of the following symptoms prescribed by the American Academy of Neurology Guideline for Management of Sports Concussion: headache, nausea, vomiting, dizziness/balance problems, fatigue, difficulty sleeping, drowsiness, sensitivity to light or noise, blurred vision, memory difficulty, and difficulty concentrating.[48,49] Criteria contributing to the identification of a player with a concussion also included the observed mechanism of injury (eg, acceleration or rotational forces applied to the head), symptoms reported or signs exhibited by the player, and reports by medical staff or other witnesses regarding the condition of the injured player. Loss of consciousness, posttraumatic amnesia (eg, inability to recall exiting the field, aspects of the examination), and retrograde amnesia (eg, inability to recall aspects of the play, events prior to injury, score of the game) were documented immediately after injury.

All players identified by the team physician or certified athletic trainer as having a concussion according to the study's injury definition and criteria were tested with a Graded Symptom Checklist (GSC),[17] the Standardized Assessment of Concussion (SAC),[42] and the Balance Error Scoring System (BESS)[41] on the sideline immediately following injury. Follow-up testing on these measures was then conducted 2 to 3 hours after injury (postgame/postpractice) and again on postinjury days 1, 2, 3, 5, 7, and 90. A brief neuropsychological test battery was administered to assess neurocognitive functioning at baseline and on postinjury days 2, 7, and 90. Because research data were collected in the context of direct clinical care delivery, examiners were not blinded to the players' group assignments (injured vs control) at the time of evaluation. Assessments were conducted by certified athletic trainers who were trained by the researchers on administration and scoring of all outcome measures used in the study.

Main Outcome Measures

TABLE 2 summarizes the measures used in this study to assess postconcussive symptoms, cognitive functioning, and postural stability. All of these measures have been used extensively in head injury research, including studies on the effects of sport-related concussion. Several reports have demonstrated the reliability and accuracy of the GSC,[36] SAC,[20,22] BESS,[39-41] and components of the neuropsychological test battery[19] in correctly classifying persons with and without concussion. Clinicians also recorded information on injury mechanism, severity, management, recovery, and return to play.

Statistical Analysis

We initially graphed the recovery curves for symptoms, cognition, and balance

Table 2. Main Outcome Measure Characteristics

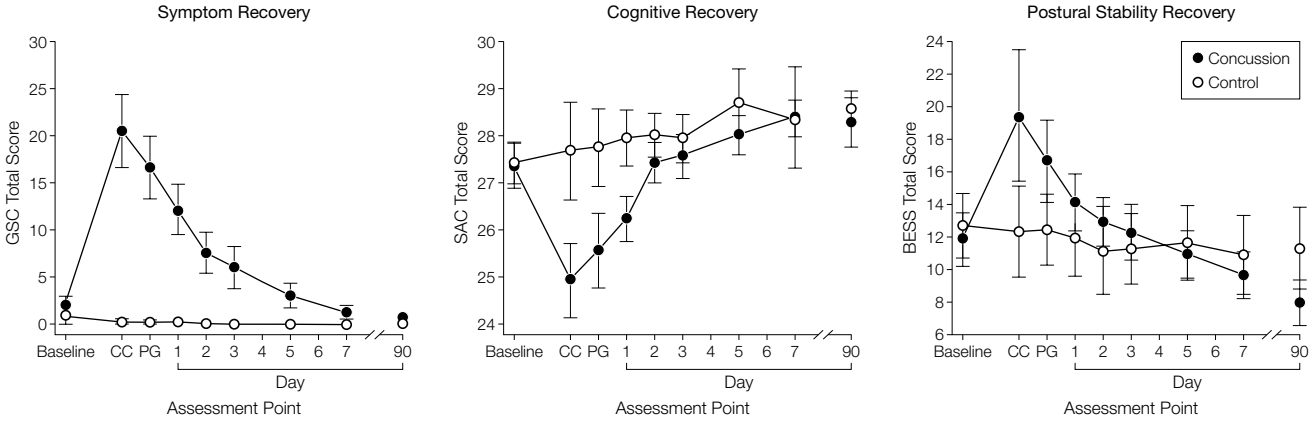
Measure	Functional Domain	Description	Score Range	Time Needed to Administer
Graded Symptom Checklist[17]	Postconcussive symptoms	Self-rated presence and severity of 17 symptoms (eg, headache, dizziness)	Likert scale of 0 (no symptoms) to 6 (severe) per item; total score range, 0-102; higher score indicates more severe symptoms	2-3 min
Standardized Assessment of Concussion[42]*	Cognitive functioning (orientation, immediate and delayed memory, concentration) Neurological screening (strength, sensation, coordination)	Brief neurocognitive assessment and neurological screening; documentation of loss of consciousness, posttraumatic amnesia, retrograde amnesia	Total score range, 0-30; lower score indicates more severe cognitive impairment	5 min
Balance Error Scoring System[41]	Postural stability	Noninstrumented, clinical assessment of postural stability in double-leg, single-leg, and tandem stances on firm and foam surfaces	No defined range; test score equals total number of errors committed by test taker; higher score indicates more severe postural instability	5 min
Neuropsychological test battery[43-47]*	Cognitive functioning (attention, concentration, processing speed, mental flexibility, anterograde memory, verbal fluency)	Hopkins Verbal Learning Test (memory)[43]; Trail-Making Test Part B (cognitive processing)[44]; Symbol Digit Modalities Test (cognitive processing)[45]; Stroop Color-Word Test (mental flexibility)[46]; Controlled Oral Word Association Test (verbal fluency)[47]	Total score range based on individual measures; lower score indicates more severe impairment except for Trail-Making Test (total time to complete)	25 min

*Alternate forms were used to minimize practice effects from repeat testing on the Standardized Assessment of Concussion and the neuropsychological test battery.

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Figure. Symptom, Cognitive, and Postural Stability Recovery in Concussion and Control Participants



Higher scores on the Graded Symptom Checklist (GSC) indicate more severe symptoms; lower scores on the Standardized Assessment of Concussion (SAC) indicate poorer cognitive performance; and higher scores on the Balance Error Scoring System (BESS) indicate poorer postural stability. Error bars indicate 95% confidence intervals. CC indicates time of concussion; PG, postgame/postpractice. On the BESS, multiple imputation was used to estimate means and 95% confidence intervals for control participants for the CC and PG assessments.

across all time points, with 95% confidence intervals. We also fit multivariate regression models to further explore recovery effects and control for potential confounders. Because the data involved longitudinal observations on a set of injured athletes, we fit generalized estimating equation models, with an identity link function, assumed Gaussian residual variation, and independent working correlation matrix.[50,51] We used this model to estimate the mean differences in test scores on each of the main outcome measures between injured players and uninjured controls at each time point. In all analyses, we controlled for baseline scores on the respective tests, history of concussion, and institution. In addition, we controlled for academic year and any self-reported history of a learning disability or attention-deficit/hyperactivity disorder in cognitive and neuropsychological models and for body mass index and height in balance models.

The data collection protocol was time-sensitive; because of clinical workload and logistical constraints, testing could not always be performed at the specified time points, particularly at the time of concussion and at the postgame/postpractice time point. Across all time points for all participants, 86% of data were complete. To examine the potential effect of missing data on the modeling results, we compared the baseline scores for the missing and nonmissing player data at every time point for all outcomes. The baseline scores did not differ between players with missing and nonmissing data, suggesting that the data were missing at random, as described in Diggle et al.[52] We also estimated the missing data using a single imputation model, based on time and player status (injured vs control) and obtained essentially identical results on reanalysis of the imputed data. The sole exception was for data for controls on the BESS balance test at the time of concussion and at the postgame/postpractice time point; baseline scores differed between missing and nonmissing data for this measure at these 2 time points, creating bias in the observed change-from-baseline effect. To overcome this problem, we used multiple imputation to estimate the control means and confidence intervals only for these 2 time points. No imputation was used in any of the generalized estimating equation regression models, since these controlled for baseline test scores. Data were analyzed with SPSS software, version 11.0 (SPSS Inc, Chicago, Ill).

RESULTS

Ninety-four players who had a concussion during a football practice (56.8% of concussions studied) or game were studied. Most injuries were classified as either grade 1 or grade 2 concussions according to the Cantu[53] (98.6%), Colorado[54] (93.3%), and American Academy of Neurology[48] (93.2%) sports-concussion grading scales based on our post hoc review of injury characteristics. A small number of injured players experienced loss of consciousness (6.4%; median duration, 30 seconds) or exhibited posttraumatic amnesia (19.1%; median duration, 90 minutes) or retrograde amnesia (7.4%; median duration, 120 minutes). There was no loss of consciousness, posttraumatic amnesia, or retrograde amnesia associated with 77.8% of injuries. Eleven players exhibited delayed onset of symptoms after concussion (mean [SD] delay, 14.4 [15.5] minutes) and therefore were not evaluated immediately after concussion. No player who sustained a concussion refused to participate or was excluded from the study protocol, but information on unidentified or unreported concussions was not available. Four players had more than 1 concussion during a season. Seventy-nine players with concussion (84%) completed the assessment protocol through the day 90 assessment.

The recovery curves shown in the FIGURE depict the symptoms, cognitive functioning, and postural stabil-

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ity of injured players vs controls across all assessment points. The shape of these curves illustrates a pattern of more severe symptoms, cognitive impairment, and balance problems (postural instability) immediately after injury, followed by a gradual improvement over the first several postinjury days.

After controlling for potential confounders in the multivariate regression models, the recovery patterns depicted in the Figure persist. TABLE 3 provides adjusted mean differences and 95% confidence intervals for the concussion vs control groups, controlling for covariates, on measures of symptoms, cognitive functioning, and balance at each postinjury assessment point. Increased symptoms were very evident during the acute phase immediately following concussion, and strong group differences in symptom scores persisted through postinjury day 5. On average, symptoms in players with concussion resolved by day 7. Ninety-one percent of players with concussion returned to personal baseline symptom levels within 7 days after concussion.

Cognitive impairment in players with concussion was most severe at the time of injury and persisted through postinjury day 2. Milder cognitive deficits appeared to persist up to postinjury day 5 but, on average, resolved by day 7. Balance deficits were most pronounced during the first 24 hours after concussion but appeared to resolve by day 5, slightly earlier than symptoms and cognitive effects resolved.

After plotting raw means for the concussion and control groups on the neuropsychological tests, we fit multivariate regression models to further explore these effects and to control for variations in baseline scores on each test and other potential confounders. TABLE 4 presents raw group means and 95% confidence intervals for the concussion and control groups, and TABLE 5 provides adjusted mean differences and 95% confidence intervals, controlling for covariates, on the neuropsychological test battery at postinjury days 2, 7, and 90. Players with concussion exhibited mild impairment in cognitive processing speed and verbal fluency 2 days and 7 days after concussion. There was also suggestion of a subtle decline from baseline in players with concussion on measures of verbal memory and mental flexibility on postinjury day 2. On day 90, players with concussion performed less well than controls on a

Table 3. Model-Based Adjusted Estimates of Mean Differences Between Concussion and Control Groups in Symptoms, Cognitive Functioning, and Postural Stability*

	Mean Difference (95% Confidence Interval)		
Assessment Point	Symptoms (GSC)	Cognitive Functioning (SAC)	Postural Stability (BESS)
Time of concussion	20.93 (15.65 to 26.21)	–2.94 (–4.38 to –1.50)	5.81 (–0.67 to 12.30)
Postgame/postpractice	16.97 (12.61 to 21.33)	–2.15 (–3.26 to –1.04)	5.66 (1.27 to 10.06)
Postinjury day			
1	11.53 (8.37 to 14.69)	–1.59 (–2.43 to –0.75)	2.72 (–0.14 to 5.57)
2	6.88 (4.17 to 9.59)	–0.72 (–1.51 to 0.08)	2.33 (–0.30 to 4.95)
3	5.08 (2.27 to 7.88)	–0.46 (–1.25 to 0.32)	1.46 (–1.22 to 4.14)
5	2.02 (–0.03 to 4.06)	–0.52 (–1.28 to 0.25)	–0.31 (–3.02 to 2.40)
7	0.33 (–1.41 to 2.06)	–0.03 (–1.33 to 1.26)	–0.55 (–3.19 to 2.09)
90	0.62 (–0.90 to 2.14)	–0.51 (–1.41 to 0.39)	–2.45 (–5.09 to 0.18)

Abbreviations: BESS, Balance Error Scoring System, GSC, Graded Symptom Checklist; SAC, Standardized Assessment of Concussion.
*Estimated mean differences for the GSC are adjusted for baseline GSC score and number of previous concussions; SAC estimates are adjusted for baseline SAC score, academic year, number of previous concussions, history of learning disability and attention-deficit/hyperactivity disorder, and institution; BESS estimates are adjusted for baseline BESS score, height, body weight, number of previous concussions, and institution. Positive mean differences indicate more severe symptoms reported on the GSC and poorer performance on the BESS in the concussion group relative to baseline; negative mean differences indicate poorer performance in the concussion group on the SAC relative to baseline.

Table 4. Neuropsychological Test Battery Results in Concussion and Control Groups at Postinjury Days 2, 7, and 90*

	Mean Score (95% Confidence Interval)					
	Day 2		Day 7		Day 90	
Measure	Concussion Group	Control Group	Concussion Group	Control Group	Concussion Group	Control Group
Memory						
HVLT Immediate Memory[43]	24.41 (23.49-25.34)	25.29 (24.02-26.55)	25.63 (24.74-26.53)	25.85 (24.53-27.17)	26.25 (25.27-27.23)	27.61 (26.15-29.08)
HVLT Delayed Recall[43]	8.07 (7.52-8.61)	8.76 (8.04-9.47)	8.50 (7.94-9.06)	10.22 (8.37-12.06)	9.03 (8.49-9.56)	9.68 (8.97-10.39)
HVLT Recognition[43]	22.18 (21.80-22.57)	22.84 (22.39-23.28)	22.50 (22.18-22.82)	22.65 (21.91-23.39)	23.19 (22.92-23.46)	23.29 (22.94-23.64)
Cognitive processing						
Trail-Making Test Part B[44]	59.99 (55.65-64.32)	53.31 (48.62-58.00)	53.72 (49.44-58.00)	44.87 (40.51-49.24)	51.59 (47.62-55.57)	45.44 (41.10-49.78)
SDMT[45]	54.78 (52.50-57.06)	60.67 (57.09-64.24)	54.84 (52.69-57.00)	59.20 (55.93-62.46)	59.87 (57.42-62.31)	61.42 (57.30-65.54)
Mental flexibility						
Stroop Color-Word Test[46]	48.20 (45.83-50.56)	51.43 (48.73-54.13)	53.47 (51.16-55.78)	55.39 (52.16-58.62)	53.97 (51.65-56.30)	54.32 (50.27-58.37)
Verbal fluency						
COWAT[47]	39.99 (37.75-42.23)	40.29 (37.34-43.23)	41.57 (39.26-43.88)	42.63 (39.56-45.70)	42.65 (40.29-45.01)	44.94 (41.26-48.61)

Abbreviations: COWAT, Controlled Oral Word Association Test; HVLT, Hopkins Verbal Learning Test; SDMT, Symbol Digit Modalities Test.
*Higher scores on the Trail-Making Test indicate slower performance; lower scores indicate poorer performance on all other measures.

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single measure of verbal fluency, but there were no lingering impairments in the concussion group on the other outcome measures.

Table 5. Model-based Adjusted Estimates of Mean Differences Between Concussion and Control Groups on the Neuropsychological Test Battery*

Measure	Mean Difference (95% Confidence Interval)		
	Day 2	Day 7	Day 90
Memory			
HVLT Immediate Memory[43]	−1.02 (−2.84 to 0.81)	−0.57 (−2.38 to 1.23)	−1.22 (−3.32 to 0.88)
HVLT Delayed Recall[43]	−0.59 (−1.62 to 0.44)	−1.63 (−3.62 to 0.35)	−0.02 (−1.04 to 1.00)
HVLT Recognition[43]	−0.50 (−1.24 to 0.24)	0.03 (−0.97 to 1.03)	0.16 (−0.58 to 0.91)
Cognitive processing			
Trail-Making Test Part B[44]	2.25 (−5.38 to 9.88)	4.10 (−3.53 to 11.73)	3.61 (−5.41 to 12.63)
SDMT[45]	−4.99 (−9.88 to −0.11)	−4.03 (−9.29 to 1.24)	0.25 (−4.94 to 5.43)
Mental flexibility			
Stroop Color-Word Test[46]	−2.00 (−5.66 to 1.66)	−0.98 (−4.56 to 2.60)	−0.80 (−4.54 to 2.95)
Verbal fluency			
COWAT[47]	−3.65 (−6.78 to −0.52)	−4.57 (−8.02 to −1.11)	−5.31 (−9.11 to −1.52)

Abbreviations: COWAT, Controlled Oral Word Association Test; HVLT, Hopkins Verbal Learning Test; SDMT, Symbol Digit Modalities Test.
*Estimates are adjusted for baseline scores on each respective measure, academic year, number of previous concussions, history of learning disability/attention-deficit/hyperactivity disorder, and institution.

COMMENT

The findings from this 3-year study indicate that collegiate football players require several days to recover after sport-related concussion. Injured athletes exhibited the most severe symptoms, cognitive dysfunction, and balance problems during the acute phase immediately after concussion, followed by a gradual course of recovery over 5 to 7 days. On average, cognitive functioning returned to normal within 5 to 7 days after concussion, but athletes required a full 7 days for postconcussive symptoms to completely return to baseline and control levels. Players with concussion exhibited a mild decline from baseline and control levels on neuropsychological measures of cognitive processing speed, new learning and memory, and mental flexibility 2 days after concussion; these measures returned to baseline levels by postinjury day 7. Balance testing also returned to normal within 3 to 5 days after concussion. There was no evidence of lingering symptoms, cognitive impairment, or balance problems in the concussion group at postinjury day 90. It is important to note that the rate of recovery after concussion varied from player to player in our study. These findings suggest that clinicians cannot necessarily expect that all collegiate football players will reach a complete recovery within 7 days after a concussion, as approximately 10% of players in this study required more than a week for symptoms to fully resolve. Furthermore, not all players demonstrated the same pattern of recovery in symptoms, cognition, and balance.

Concussion Threshold and Natural Recovery Course

While there is no single biological marker of concussion, data from this study demonstrate a threshold of acute impairments signifying the mildest form of traumatic brain injury. There was clear and consistent evidence of cerebral dysfunction in cases of concussion without classic indicators of mild traumatic brain injury, such as loss of consciousness and posttraumatic amnesia. These data support a movement in the neurosciences toward a revised definition of concussion that emphasizes an *alteration* (as opposed to a loss) of consciousness or mental status as the hallmark of concussion and stresses the potential seriousness of all head injuries, even what has historically been referred to as a simple "ding." Sports medicine professionals especially should be aware that the diagnosis of concussion does not require loss of consciousness, significant amnesia, or other focal neurological abnormalities associated with more severe head injury.

Animal studies have demonstrated a cascade of physiological events that adversely affect cerebral functioning for a period of days to weeks after a concussion.[55,56] The pattern of impairment exhibited by injured players in our study of collegiate athletes provides indirect evidence of the same phenomena in humans through detailed testing of cognitive functioning, postural stability, and subjective symptoms at serial time points following concussion. Injured athletes exhibited significantly increased symptoms and functional impairments during the acute postconcussive phase that gradually resolved along the same neurophysiological course described in animal concussion models.[2] This appears to be the first prospective human study to include preinjury cognitive and motor baseline testing and to plot continuous recovery curves from a point immediately after concussion to several months after injury in a sizable group of persons with concussion.

Our findings contribute to the existing literature on the acute effects of and recovery from sport-related concussion. Interpretation of recovery data from earlier clinical studies has been hampered by varied definitions of concussion, limited follow-up assessment of injured players widely distributed over time, small sample sizes, lack of control groups, and failure to address all domains of postconcussive recovery (eg, neurological, symptomatic, cognitive, postural stability). Few studies have measured symptoms and functional impairments within minutes of injury to establish an early benchmark against which to track recovery.[16,18,23,27] Several studies have reported that a portion of injured participants still exhibited cognitive impairment or postconcussive symptoms at the final assessment point used in the study, precluding any more precise determination of a recovery end point.[26-28,33-36] It has also been unclear from earlier studies whether all do-

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mains affected by concussion follow similar or different recovery courses.

Implications for Sports Concussion Management

Despite recent advances in the science of sports concussion and attempts to reach expert consensus, there remains significant debate over which factors (eg, unconsciousness, amnesia, symptom duration) are most critical in determining concussion severity, expected recovery course, and how long a player should be withheld from competition after injury. Currently, sports concussion grading systems drive injury management strategies, but grading concussion severity is a difficult matter, even with the benefit of extensive standardized assessment data collected within minutes after injury. Grading injury severity assists in acute medical management of concussion but may not independently predict course of recovery or the best plan for safe return to play after injury. Therefore, perhaps less emphasis should be placed on grading concussion, with more emphasis on a standardized approach to measuring recovery in determining when it is safe for an athlete to return to competition. Based on our findings, the use of standardized assessment tools may assist clinicians in determining an athlete's level of recovery and readiness for safe return to competition after a concussion. Further study is required, however, to determine whether the use of these instruments significantly enhances injury management strategies and ultimately reduces the risks associated with sport-related concussion.

Injury surveillance studies have reported that the average length of time players are withheld from competition after concussion in high school and collegiate football ranges from 3 to 8 days, depending on the grade of injury severity.[10,13] We previously found that the largest percentage of collegiate football players were withheld from competition for an average of less than 5 days after concussion.[25] The disparity between our data on average recovery time and concurrent reports on time withheld from play after concussion raises concerns based on the common assumption that resuming competition before reaching full recovery may increase the risks of recurrent injury, cumulative impairment, or even catastrophic outcome. Additional data are required to more precisely determine the risks associated with further injury exposure before reaching a complete recovery after concussion.

Study Limitations

Several limitations to our study warrant consideration. First, most of the concussions studied were of mild to moderate severity. Further study is under way to explore how acute injury severity affects the trajectory and time course of recovery. It is also possible that some players who may have had a concussion during the study were not identified. Whether as part of a research study or in general clinical practice, it has long been thought that the rate of concussion is likely underestimated because of the reluctance of some athletes to report injury or their inability to recognize the signs of injury.[57] Our study is not exempt from this form of potential selection bias in the sample of injured players studied. These data are also subject to the reliability and validity of the main outcome measures we used, which are supported by earlier studies on the accuracy of these measures in detecting the effects of concussion in athletes.[19,20,22,36,39-41] Obtaining a preinjury baseline for all players on these measures provides the most sensitive means to detect reliable change in performance attributable to concussion and track postinjury recovery.[20] Still, our main outcome measures provide indirect evidence of concussion through assessment of symptoms and functional deficits, not cerebral activity directly, and are prone to some degree of error common to all forms of clinical measurement.

While we have attempted to control for potential confounding of postinjury test results by noninjury factors (eg, education, baseline test performance, test practice effects, history of concussion, examiner), we also recognize that further study is required to conclude to what extent injury (eg, unconsciousness, amnesia, previous history of concussion) and noninjury factors may affect recovery time for athletes at all competitive levels. Because our study sample was limited to collegiate athletes, it is unclear if these data can be applied to the expected course of recovery by younger (eg, high school) or older (eg, professional) athletes with a concussion. Concurrent research, however, illustrates a similar pattern of postconcussive recovery in symptoms, cognition, and balance by high school football players.[58] We are also investigating to what extent these data can be generalized to recovery after concussion from other sources of trauma (eg, motor vehicle crashes).

CONCLUSION

Objective data from this study illustrate the natural course of recovery by collegiate football players over a period of several days following concussion and contribute to a shift in the direction of evidence-based guidelines for determining the best time course for young athletes to return to play after injury. These findings also set the stage for randomized research trials to determine the most effective methods for clinical management of athletes recovering from concussion. Further study is necessary to elucidate factors that predict recovery across all functional domains affected by concussion and to determine the recommended duration of a symptom-free waiting period to minimize the risks associated with recurrent concussion or other adverse outcomes resulting from sport-related head injuries.

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Acquisition of data: McCrea, Guskiewicz, Marshall, Onate.
Analysis and interpretation of data: McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Yang, Kelly.
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