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Natural History of Concussion in Sport

Markers of Severity and Implications for Management

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Background: Evidence-based clinical data are required for safe return to play after concussion in sport.

Purpose: The objective of this study was to describe the natural history of concussion in sport and identify clinical features associated with more severe concussive injury, using return-to-sport decisions as a surrogate measure of injury severity.

Study Design: Cohort study (prognosis); Level of evidence, 3.

Methods: Male elite senior, elite junior, and community-based Australian Rules football players had preseason baseline cognitive testing (Digit Symbol Substitution Test, Trail-Making Test–Part B, and CogSport computerized test battery). Players were recruited into the study after a concussive injury sustained while playing football. Concussed players were tested serially until all clinical features of their injury had resolved.

Results: Of 1015 players, 88 concussions were observed in 78 players. Concussion-associated symptoms lasted an average of 48.6 hours (95% confidence interval, 39.5–57.7 hours) with delayed return to sport correlated with ≥ 4 symptoms, headache lasting ≥ 60 hours, or self-reported “fatigue/fogginess.” Cognitive deficits using the Digit Symbol Substitution Test and Trail-Making Test–part B recovered concomitantly with symptoms, but computerized test results recovered 2 to 3 days later and remained impaired in 35% of concussed players after symptom resolution.

Conclusion: Delayed return to sport was associated with initially greater symptom load, prolonged headache, or subjective concentration deficits. Cognitive testing recovery varied, taking 2 to 3 days longer for computerized tests, suggesting greater sensitivity to impairment. Therefore, symptom assessment alone may be predictive of but may underestimate time to complete recovery, which may be better estimated with computerized cognitive testing.

Keywords: brain trauma; concussion; sport; injury severity

Concussion is a common problem in many contact sports.^{23,35} In the United States alone, it is estimated that approximately 1.6 to 3.8 million cases of sports-related and recreation-related traumatic brain injury occur each year,²⁴ which represents a significant health problem in active communities.

Determining recovery and guiding safe return to play after a concussive injury is challenging. Premature return to play has been reported to increase the risk of complications such as prolonged concussive symptoms or symptoms

of depression¹⁸ and cumulative cognitive deterioration.^{19,22} Hence, expert consensus guidelines recommend that players should not be allowed to return to competition until they have recovered completely from their concussive injury.^{2,33,34} The main problem with this recommendation is that currently there are no direct objective measures of brain function that can definitively indicate return to normal after concussive injury and guide return-to-play decisions. Consequently, clinicians must rely on indirect measures to inform clinical judgment, such as symptoms and signs of concussion, in addition to the use of brief cognitive tests to estimate recovery of brain function.

An understanding of the typical pattern of recovery of clinical measures used in the assessment of concussion is important in decisions regarding safe return to play after concussive injury. A number of studies in high school and collegiate American football players have demonstrated recovery of symptoms in a majority of concussed athletes within 5 to 10 days of injury.^{19,27,32} Similar findings have also been observed in professional American football players.³⁷ The time-course of recovery of cognitive function,

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One or more of the authors has declared a potential conflict of interest: Drs Darby and Maruff were employees of and held stock in CogState Ltd, the suppliers of the computerized cognitive test battery used in this study. Dr McCrory received research grant support from CogState Ltd.

however, is inconsistently reported in the literature, with some studies revealing transient deficits^{3,27} and others demonstrating prolonged cognitive decline.^{14,38} The common methodological flaw in these studies is that they estimate a player's preconcussion ability and compare postconcussion performance to matched control players. This may reduce the sensitivity for detecting subtle changes, which may still occur within a population-based normative range.¹⁰

Another important component of management relates to the ability of the clinician to identify higher grades of injury severity and potential for poor outcome after concussion in sport. Although loss of consciousness is a traditional marker of more severe head injuries, it does not appear to reflect injury severity or predict time to recovery in concussion or mild traumatic brain injury.^{15,35} The association between posttraumatic amnesia or postconcussive symptoms²⁶ and concussion severity^{17,30} is less clear. Recent studies suggest that the overall burden of postconcussive symptoms,^{15,35} presence of postconcussive headache,¹¹ or self-reported history of concussion,^{12,19} may correlate with time to recovery. However, the outcome measures used were not indicative of complete recovery (return to play on the day of injury, the degree of cognitive impairment at follow-up).

In many elite sports where there is high risk of concussion, experienced doctors oversee concussion management programs. In Australian football, ongoing research and education programs have resulted in a relatively standardized approach to the diagnosis and management of concussive injuries. In this setting, and in the absence of a readily available biomarker for complete recovery, medical clearance to return to play after concussion can be used as a surrogate indicator of resolution of a concussion and provide a common reference point against which the clinical presentation, cognitive sequelae, and injury severity of concussion can be compared. Such information could then be used to assist in the management of concussion in sport and guide safe return-to-play decisions.

The purpose of the current study is to describe the pattern of symptom and cognitive recovery after concussion in Australian football and to investigate the relationship between these features and time to return to play, in order to identify clinical factors that may be useful in classifying injury severity.

METHODS

This prospective cohort study was conducted in Australian football over 4 competitive seasons (2001-2004). Participants were male Australian Rules football players recruited from elite senior, elite junior, and community-based team competitions. All players underwent baseline cognitive testing before the start of each season and were prospectively monitored for concussive injuries during each season they were involved in the study.

All teams chosen to participate in the study were cared for by highly experienced medical staff. Team doctors involved in Australian football are representatives of a group called the Australian Football League Medical

Officers Association. This association holds regular meetings, conducts research projects, and provides ongoing education programs for all members. Consequently, Australian football team doctors have a relatively standardized approach to the diagnosis and management of common problems such as concussion.

The team doctors at each club, who were present at the time of injury, made the diagnosis of concussion in each case according to standard injury definitions.^{2,13} Criteria contributing to the identification of concussed players included symptoms reported by players or signs observed by medical staff after a traumatic injury. Symptoms included (but were not limited to) players reporting feeling dinged, dazed, stunned, woozy, foggy, "head full of cotton wool," or "not quite right," as well as posttraumatic headache, visual disturbance, confusion, memory disturbance, balance disturbance, vertigo, and light headedness. Signs included confusion, loss of consciousness, disorientation, memory disturbance, unsteadiness, attention deficit, and personality change.

The standard approach to return-to-play decisions after concussion in Australian football involves monitoring of symptom recovery and a limited cognitive assessment, using either paper-and-pencil tests or computerized test batteries. The uniform management strategies employed by team doctors are based on long-standing research and education programs dating from the mid-1980s.^{29,35} Furthermore, this clinical approach to return-to-play decisions after concussive injury mirrors the current expert consensus recommendations for the management of concussion in sport.^{2,33,34}

Concussed players were monitored regularly until all clinical features of their concussive injury had resolved. The timing of postconcussion assessments reflected the individual clinical management strategies of experienced team doctors and was designed to be pragmatic rather than being conducted at set time intervals after injury.

Assessment of Clinical Features

A standard postconcussion clinical assessment form was used to record details of the player's concussion history and clinical features, based on previous research.^{2,25} If the player was assessed at the time of injury, the team doctor filled in the forms. All other follow-up assessments were completed by 1 of the authors (M.M.). Postconcussive symptoms experienced after injury were classified as present or absent.

Assessment of Cognitive Function

Cognitive testing included brief paper-and-pencil tests (the Digit Symbol Substitution Test (DSST),⁴⁰ the Trail Making Test—Part B (TMT-B),¹ already in use in Australian football,²⁸ and a commercial computerized cognitive test battery (CogSport, CogState Ltd, Melbourne, Victoria, Australia).⁸ This battery used standard computer hardware, 2 designated keyboard response buttons ("K" and "D" for "YES" or "NO," respectively), simple textual instructions, and game-like playing-card stimuli in 5 tasks assessing psychomotor

processing speed (simple reaction time), decision making (choice reaction time), divided attention (monitoring), memory, and learning. Validation studies for serial evaluation of change have been reported previously,⁷ as has sensitivity to cognitive effects of concussion in sport.⁶ All cognitive tests were performed and scored according to published protocols.^{1,7,40} Cognitive tests were administered before the season, and then repeated during the follow-up assessments. Follow-up scores were compared with the player's individual baseline performance. When a player was assessed at the time of injury, the team doctor administered the tests. All other follow-up tests were administered by 1 of the authors (M.M.).

All players recruited into the study performed the DSST and TMT-B at baseline. Because of the time commitment and resources required for preseason testing, not all teams were able to use the computerized test battery as part of the testing protocol.

Assessment of Recovery

The time taken for the player to return to sport—defined as either full training or competitive playing—was recorded as a measure of clinical recovery. This measure takes into account all facets of clinical recovery including symptom resolution and recovery of cognitive function both at rest and with physical exertion. In each case, the return-to-play decision was made by the team doctor based on his or her usual management protocols. The results of the cognitive testing were made available to team doctors, so it is possible that return-to-sport decisions utilized this information, although this study did not attempt to influence return-to-sport decisions.

Symptom recovery was defined as the time (days from injury) until all reported postconcussive symptoms had resolved. Cognitive recovery was defined for each concussive injury as the time taken (days from injury) for all cognitive deficits to recover (ie, no statistically meaningful deficit in any test domain compared to baseline performance).

Data Analysis

For clinical symptoms, the proportion of players reporting each clinical feature and the mean duration of all clinical features was calculated. For cognitive measures, a reliable change index (RCI) was used to assess return to individual baseline. The RCIs were calculated for the DSST score, TMT-B time (seconds), and individual components of the computerized test battery as previously described.⁹ One-tailed tests were conducted (α level .05), as negative shifts in performance were predicted after concussion.²¹ Given the variable timing of the follow-up cognitive assessment, results were stratified according to the presence or absence of symptoms, to reflect the clinical state of the athlete at the time of testing.⁶

Post hoc sample size calculations were performed to determine if there existed a significant change in cognitive testing on both the pencil-and-paper tests and computerized

test battery. For the pencil-and-paper tests, previous pilot data demonstrated a standard deviation of 7 points with retesting in a normal population, and a change of 10 points to represent a clinically relevant change from baseline. With 5% significance, 21 observations were then required to see this as a significant difference with 90% power, as determined through 1-sample *t* test methodology. Similarly, for the computerized test battery, a clinically relevant change from baseline was considered to be 50 milliseconds (and change to baseline times had a standard deviation of 75 milliseconds). With 5% significance, 24 observations were then required to see this as a significant difference with 90% power.

In preliminary analyses, results were stratified according to age groups (16-18 years of age and >18 years) and level of play (under 18 years of age elite, senior elite [>18 years], and senior community level) with no significant differences identified in any variables assessed (ie, symptom number, severity or duration, cognitive deficits or time to recovery). Consequently, the data were combined to reduce the potential for statistical error associated with analyses of smaller datasets.

The association between clinical features and time to return to sport was investigated using a Cox proportional hazard model. Analyses were performed by comparing each individual clinical variable with time to return to sport (univariate analysis), and by taking into account all other variables assessed (multivariate analysis). The purpose of the multivariate analysis was to determine the impact of each clinical feature on time to return to sport, independent of the influence of other clinical features. Results are interpreted as hazard ratios and statistical significance is defined as the exclusion of the value 1.00 within the 95% confidence interval (α level .05, 2-tailed test).

Analysis of cognitive tests used SPSS software (SPSS-Norusis/SPSS Inc, Chicago, Illinois). Survival analyses were performed using the Stata 7.0 statistical package (StataCorp LP, College Station, Texas).

A number of players suffered repeated concussive injuries during the study period. For the purpose of the study, any player who had not completely recovered from a concussive injury on clinical evaluation was excluded from further analyses. Consequently, all concussive injuries were considered individual events for data analysis.

The Human Research Ethics Committee of the University of Melbourne granted approval for the study. All players provided written informed consent before being recruited into the study.

RESULTS

A sample of 1015 male Australian football players aged between 16 and 35 years were recruited at baseline into the study (675 elite senior players, 272 elite junior players, 68 community-level players). The median age of the overall group was 22 years (interquartile range [IQR], 19-24).

Eighty-eight concussions were observed in 78 players. Two players were concussed 3 times, 6 players were concussed twice, and the remaining 70 players suffered

TABLE 1
Frequency and Duration of Clinical Features Reported After Concussive Injury in Australian Football (N = 88)^a

Clinical Feature	N	N% (95% CI)	Mean Duration (95% CI)	Range
Headache	77	87.5 (80.6-94.4)	44.7 (35.1-54.2)	0-240
Confusion, disorientation	55	62.5 (52.4-72.6)	2.1 (0.3-4.0)	0-48
Visual disturbance	36	40.9 (30.6-51.2)	8.5 (3.4-13.7)	0-48
Dizziness, unsteadiness	35	39.8 (30.0-50.0)	27.6 (16.2-38.9)	0-120
Amnesia	33	37.5 (27.4-47.6)	1.6 (0.5-2.7)	0-12
Fatigue, lethargy, "fogginess"	33	37.5 (27.4-47.6)	58.3 (45.6-70.9)	0-144
Loss of consciousness	32	36.4 (26.4-46.4)	1.1 (0.8-1.5)	0-5
Sleep disturbance	23	26.1 (17.0-35.3)	55.8 (34.5-77.1)	0-240
Nausea	23	26.1 (17.0-35.3)	8.8 (0.0-18.9)	0-120

^aN, number of players reporting clinical feature; N%, percentage of players reporting clinical feature; 95% CI, 95% confidence intervals. Duration of clinical features expressed in hours except for loss of consciousness, which is expressed in minutes.

TABLE 2
Summary of Individual Postconcussion RCIs for Paper-and-Pencil Tests Stratified According to Clinical State of the Player^a

	Symptomatic		Asymptomatic	
	DSST	TMT-B	DSST	TMT-B
Number of tests	40	34	49	48
Mean RCI	-0.03	-0.03	0.50	-0.88
(95% confidence intervals)	(-0.50, 0.44)	(-0.49, 0.45)	(0.18, 0.83)	(-1.24, -0.52)
Number (%) of individual tests with significant deficits	5 (12.5%)	3 (8.8%)	1 (2.0%)	1 (2.0%)
Overall number (%) with ≥ 1 significant deficit in test battery	7 (17.5%)		2 (4.2%)	

^aRCI, reliable change index. Performance deficit is reflected by a decrease in DSST (Digit Symbol Substitution Test) score and increase in TMT-B (Trail-Making Test-Part B) time (log₁₀ [s]); RCI >1.65 for DSST and <-1.65 for TMT-B considered significant.

a single concussive injury over the study period. All concussive injuries were included in the analysis, as all players were considered recovered between concussions. There were 72 concussive injuries in elite senior players (incidence, 3.5 per 1000 player-hours), 6 in elite junior players (incidence, 1.3 per 1000 player hours), and 10 in community-level players (incidence, 3.2 per 1000 player hours). The median age of concussed players was 22 years (IQR, 17-34 years).

Assessment of Clinical Features

Follow-up assessments were conducted at a median of 48 hours (IQR, 18-72 hours), 96 hours (IQR, 72-120), and 120 hours (IQR, 110-126 hours). The numbers of players with symptoms reported at these assessments (of 88 injuries) were 34 (38.6%), 7 (8.0%), and 1 (1.1%), respectively. The latter player ultimately retired because of persistent headache after his concussive injury. No other neurologic abnormalities were reported after concussive injury.

The frequency and duration of clinical features reported after concussive injury are summarized in Table 1.

Overall, the mean number of symptoms reported for each concussive injury was 3.7 (95% confidence interval, 3.4-4.0) and duration of symptoms was 48.6 hours (95% confidence interval, 39.5-57.7 hours). Headache was the most common reported symptom, and fatigue, lethargy, "fogginess," sleep disturbance, and headache lasted the longest.

Assessment of Cognitive Function

All players had DSST testing performed at both preseason and after their injury (n = 88). In 29 concussive injuries, players were assessed twice and 3 required a third follow-up test. For the TMT-B, 8 players did not complete the test at baseline; therefore, postinjury TMT-B results were only included for 80 concussive injuries. Twenty-two of these injuries had TMT-B repeated twice and 3 underwent a third follow-up test. CogSport test results were available in 56 of the 88 concussive injuries recorded during the study period. Of these, 21 underwent a second post-injury assessment, and 3 cases required a third postinjury assessment. The subset of players who underwent computerized cognitive testing did not differ from the overall group with respect to age, level of play (elite versus community-level), history of concussion, clinical presentation, cognitive deficits, and time to recovery.

The results of the cognitive tests stratified according to the clinical state of the athlete at the time of testing are summarized in Tables 2 and 3. For the DSST and TMT-B, 17.5% of the tests performed while the concussed player was still symptomatic revealed a significant decline from baseline. When players were tested after symptoms had recovered, significant decline from baseline was observed in 4.2% of the tests. On the computerized measures, 70.8% of players with concussive injuries revealed significant decline from baseline in 1 or more of the domains when tested while symptomatic, with greatest decline on

TABLE 3

Summary of Individual Postconcussion RCIs for CogSport Test Battery Stratified According to Clinical State of the Player^a

	Simple Reaction Time	Choice Reaction Time	Monitoring	Memory	Learning
Symptomatic					
Number of tests			24		
Mean RCI (95% confidence interval)	2.14 (1.14, 3.13)	1.04 (0.25, 1.84)	0.93 (0.46, 1.40)	0.79 (0.13, 1.44)	0.91 (0.44, 1.37)
Number (%) of individual tests with significant deficits	13 (54.1%)	9 (37.5%)	7 (29.2%)	6 (25.0%)	8 (33.3%)
Overall number (%) with ≥ 1 significant deficit in test battery			17 (70.8%)		
Asymptomatic					
Number of tests			56		
Mean RCI (95% confidence interval)	0.49 (0.05, 0.92)	0.36 (0.06, 0.65)	0.41 (0.12, 0.70)	0.10 (-0.26, 0.46)	0.01 (-0.28, 0.31)
Number (%) of individual tests with significant deficits	11 (19.6%)	5 (9.3%)	6 (11.1%)	3 (5.6%)	3 (5.6%)
Overall number (%) with ≥ 1 significant deficit in test battery			20 (35.7%)		

^aRCI, reliable change index. Performance deficit is reflected by an increase in log mean reaction times for each of the test components; RCI >1.65 considered significant.

the simple reaction test (mean RCI, 2.14). However, even after symptoms had recovered, significant decline from baseline on 1 or more of the domains assessed persisted in 35.7% of concussive injuries, with the largest decline detected for psychomotor and attentional tasks (eg, simple reaction time, monitoring, and choice reaction time).

Assessment of Recovery

Of the 88 concussive injuries, return-to-sport data were unavailable for 6 players. Of these, 4 were concussed at the end of the season and did not return to full training or play until the following season; 1 had an associated cervical spine injury, which prevented his return to training; and the other retired because of persistent headache. For the remaining 82 concussive injuries, the mean time taken to return to full training or sport was 4.8 days (95% confidence interval, 4.3-5.3 days). There was no significant difference in mean time to return to sport for concussive injuries sustained in elite senior, elite junior, and community-level competitions.

Recovery of symptoms, recovery of cognitive deficits, and timing of return to play after concussive injury are summarized in Figure 1. This figure illustrates the percentage of players with concussive injuries who had (1) recovered their symptoms, (2) recovered their cognitive function (on both paper-and-pencil and computerized tests batteries), and (3) had returned to sport, plotted against days from injury. Although the majority of players had returned to play within 7 days of injury, 17.9% of players still displayed significant cognitive decline from baseline

on the computerized test battery at this time. Furthermore, while symptoms and deficits on paper-and-pencil tests appear to recover concomitantly, recovery of cognitive deficits observed on the computerized test battery typically lagged behind symptom recovery by 2 to 3 days.

The association between the clinical features (ie, self-reported symptoms, loss of consciousness, presence of significant cognitive deficit [RCI <-1.65], and self-reported concussion history), and time to return to sport was investigated using a Cox proportional hazard model. The results are summarized in the Appendix (see online Appendix for this article at <http://ajs.sagepub.com/supplemental/>) and demonstrate that prolonged headache (≥ 60 hours); symptoms of fatigue, tiredness, or "fogginess;" or the presence of greater than 3 symptoms at initial presentation are associated with an increased time to return to play after concussive injury. Conversely, headache lasting less than 24 hours was the only factor associated with a shorter time to return to sport. Furthermore, there was no significant association between loss of consciousness, the presence of cognitive deficits, or self-reported history of concussion and prolonged time to return to play.

DISCUSSION

This prospective cohort study investigated the pattern of symptom and cognitive recovery after concussion in Australian football, and identified clinical features that may be associated with higher grades of concussion severity. The results demonstrated that concussed players typically presented

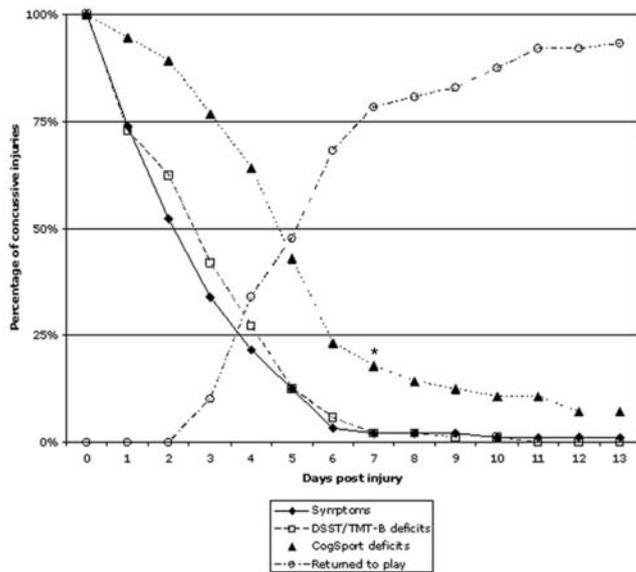


Figure 1. Summary of recovery of symptoms, cognitive deficits, and timing of return to play after concussive injury ($n = 88$). *At day 7 postinjury, when symptoms and cognitive deficits on paper-and-pencil tests had largely resolved, 17.9% of players still displayed significant cognitive decline on the computerized test battery.

with less than 4 symptoms that lasted on average approximately 48 hours. However, in approximately 18% of cases, postconcussive symptoms or cognitive deficits persisted longer than 7 days. The computerized test battery detected cognitive deficits in a greater proportion of concussed players than the paper-and-pencil tests, regardless of the time tested. Furthermore, cognitive deficits resolved independently of symptoms, with the computerized test battery deficits typically outlasting symptoms by an average of 2 to 3 days. Clinical features of concussion in sport that were associated with prolonged time to return to sport included a higher symptom burden at the time of initial presentation (ie, 4 or more symptoms), headache of greater than 60 hours' duration, and self-report of fatigue or "fogginess" after injury.

In the clinical setting, decisions regarding return to play after concussion in sport remain a challenge. Current expert consensus guidelines recommend an individual approach to management of concussed athletes based on clinical assessment of recovery after injury.^{2,33,34} Although there is no direct objective measure of brain function, a multifaceted approach is recommended with a focus on assessment of clinical features (eg, symptoms, balance function) and cognitive performance.^{2,33,34} The results of the current study confirm the importance of clinical monitoring for resolution of symptoms,^{2,33} but also extend prior studies by identifying specific symptoms associated with delayed return to sport. These included prolonged headache (≥ 60 hours) or the presence of fatigue, tiredness, or "fogginess." In addition, more than 4 symptoms at first assessment were associated with delayed return to sport, suggesting that a broad symptom evaluation is likely to be helpful.

However, absence or resolution of symptoms is not necessarily indicative of complete recovery. Although the current study demonstrated that cognitive deficits were most pronounced if players were assessed while still symptomatic, significant cognitive deficits remained in approximately 35% of concussive injuries when players were tested on the computerized test battery after symptoms had resolved. These results are consistent with other studies^{16,39} and suggest that symptoms and cognitive deficits recover at different rates, with cognitive functions recovering more slowly. This supports current expert consensus guidelines that recommend clinical assessment of multiple dimensions in making decisions about recovery and return to play after concussion in sport.^{2,33,34}

The results also demonstrated impairment in a greater proportion of concussed players, both symptomatic and asymptomatic, with the computerized tests compared with the DSST and TMT-B assessments. There was also continued impairment on the computerized test battery despite resolution of DSST and TMT-B impairment, consistent with recent findings in concussed collegiate athletes.⁵ Improved sensitivity of computerized tests likely relates in part to psychometric properties that standardize administration and minimize serial practice effects that may obscure subtle concussion-related decline.²⁷ Whether potentially even more sensitive techniques (eg, imaging or electrophysiologic studies)⁴ will demonstrate even more subtle persisting impairments is yet to be determined, as is the correlation of these with postulated complications of accumulated injuries.

Although the majority of concussed players had recovered within 7 days, 17% still had ongoing symptoms or cognitive deficits. These results suggest that mandatory restriction periods (eg, 3 weeks) are likely to be excessively conservative in the majority of cases of concussion in sport, but also inadequate in the few cases that demonstrate delayed recovery. Ultimately, an individualization of monitoring provides the best approach for return-to-sport decisions.

The strength of the current study relates to the use of a large-scale prospective cohort design in a sport such as Australian football. The advantage of this setting is that concussive injuries are common³¹ and that experienced team doctors have a consistent approach to management because of ongoing research and education programs. Moreover, strategies used by team doctors in Australian football reflect current consensus management guidelines for concussion in sport,^{2,33,34} and have previously been demonstrated to result in safe and appropriate return to play after concussion in this sport.³¹

There are a number of limitations of the current observational study. First, medical decisions regarding return to sport were based on the judgment of team doctors on an individual basis. Guidelines at the time stressed resolution of symptoms prior to graded return to training or play.^{2,33} Hence, it is not surprising that symptoms were correlated with return-to-play decisions. In addition, it is also likely that if available, computerized test results might influence clinical decisions and would have prolonged return to sport in those with more severe symptoms. Second, the study cohort consisted of young, male Australian footballers, and

the results may not be generalizable to other demographic or sporting groups. However, the presentation of clinical features and time to recovery was consistent with prospective studies performed in other groups of athletes,^{20,37} suggesting that the cases in the current study are representative. Third, this study only used the DSST and TMT-B as representative paper-and-pencil tests because this was common practice in professional Australian football at the time. It is likely that more extensive paper-and-pencil test batteries³⁶ may allow greater detection of impairment in this setting; however, this remains to be demonstrated.

CONCLUSION

The current study uses a prospective design in a large cohort of Australian footballers to investigate the recovery of clinical features of concussion in sport and to investigate the relationship between clinical features and time to return to sport. The results suggest that sole reliance on symptom reports is unreliable in determining persistence of impairment, as recovery of symptoms can precede cognitive recovery on computerized testing. In addition, computerized testing appears more sensitive to persisting impairment than the DSST and TMT-B tests. The results of this study confirm that in the absence of direct objective measures of brain function, an individualized approach based on assessment of multiple clinical domains should be used to guide decisions regarding return to play following concussion in sport. Clinical features that suggest a more severe injury include a higher symptom burden, prolonged headache, and the presence of fatigue or "fogginess" following injury. These features should be actively sought in any athlete presenting after a concussive injury.

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