PAPER

Cognition in the days following concussion: comparison of symptomatic versus asymptomatic athletes

A Collie, M Makdissi, P Maruff, K Bennell, P McCrory

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See end of article for authors' affiliations

Correspondence to:
Dr A Collie, c/o 92b
Abbeville Road, London
SW4 9NA, UK; acollie@
unimelb.edu.au

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Background: Concussion is a common neurological injury occurring during contact sport. Current guidelines recommend that no athlete should return to play while symptomatic or displaying cognitive dysfunction. This study compared post-concussion cognitive function in recently concussed athletes who were symptomatic/asymptomatic at the time of assessment with that of non-injured (control) athletes.

Methods: Prospective study of 615 male Australian Rules footballers. Before the season, all participants (while healthy) completed a battery of baseline computerised (CogSport) and paper and pencil cognitive tasks. Sixty one injured athletes (symptomatic=25 and asymptomatic=36) were reassessed within 11 days of being concussed; 84 controls were also reassessed. The serial cognitive function of the three groups was compared using analysis of variance.

Results: The performance of the symptomatic group declined at the post-concussion assessment on computerised tests of simple, choice, and complex reaction times compared with the asymptomatic and control groups. The magnitude of changes was large according to conventional statistical criteria. On paper and pencil tests, the symptomatic group displayed no change at reassessment, whereas large improvements were seen in the other two groups.

Conclusion: Injured athletes experiencing symptoms of concussion displayed impaired motor function and attention, although their learning and memory were preserved. These athletes displayed no change in performance on paper and pencil tests in contrast with the improvement observed in asymptomatic and non-injured athletes. Athletes experiencing symptoms of concussion should be withheld from training and competition until both symptoms and cognitive dysfunction have resolved.

Concussion is a common neurological injury in many contact sports.^{1–3} Most sports related concussions fall at the mild end of the spectrum of traumatic brain injury (TBI) and are considered to affect brain function rather than brain structure.^{4–5} The acute consequences of concussion include impaired neurocognitive test performance.^{6–11} There is an emerging pattern of cognitive deficits after concussion, with the most commonly reported impairments in the domains of visual-motor reaction time (RT) and information processing, memory, and attention.^{6–8, 11} Much of our knowledge about cognitive function following >concussion has been generated using “paper and pencil” neuropsychological tests.^{6–8, 12} Recent studies have observed that after a concussion performance on computerised tests of simple, choice, and complex RTs is also impaired.^{13–15}

The time course of recovery after concussion is increasingly well characterised.^{12–14} In uncomplicated cases, symptoms resolve within five to seven days after injury.¹² Although cognitive testing is now considered an important clinical tool,¹⁶ the “golden rule” of management of concussion remains the recommendation that athletes must not return >to play while symptomatic.¹⁶ Despite this, few studies have compared cognitive function after concussion in symptomatic and asymptomatic athletes¹⁷ to determine whether the results of cognitive testing correspond with those of this important component of the clinical evaluation. This study sought to compare the cognitive test performance of non-injured athletes with that of symptomatic (SYMP group) and asymptomatic (ASYMP group) athletes concussed within the previous two weeks.

METHOD

Participants

A total of 615 male Australian Rules footballers participated in this study, which was conducted between 2001 and 2003. During the course of the study, 61 footballers were concussed in game-play. These participants were assigned either to the symptomatic (n = 25) or to the asymptomatic (n = 36) group as described below. A total of 84 footballers who were not concussed were retested after the season and acted as controls (CONT group). The study design was approved by the relevant university human ethics committee, and all participants gave informed consent. Table 1 gives the demographic and clinical information of all the study groups.

Materials

We considered cognitive tests for inclusion in this study on the basis that they had demonstrated sensitivity to the effects of concussion, they were quick to administer (<3 minutes), and that they had minimal practice effects. We used the computerised CogSport (CogSport Ltd, Melbourne, Australia) tasks in this study. A full description of the CogSport battery can be found elsewhere.¹⁸ CogSport is a series of computerised card tasks requiring 15–18 minutes to complete. The test battery includes seven distinct tasks (table 2). The cognitive domains assessed in these tasks were chosen for

Abbreviations: ASYMP, asymptomatic; CHRT, choice reaction time; CONT, control; CXRT, complex reaction time; DIVA, divided attention; DSST, Digit Symbol Substitution Task; LOC, loss of consciousness; LRN, continuous learning; MATCH, matching; OBK, one-back; PTA, post-traumatic amnesia; SRT, simple reaction time; SYMP, symptomatic; TBI, traumatic brain injury; TMT, Trail Making Test—part B; WSD, within subject standard deviation

Table 1 Group-wise demographic and clinical information

	Study group			<i>t</i>	<i>p</i> value
	Control	Asymptomatic	Symptomatic		
No of athletes	84	36	25		
Age in years (mean (SD))	23.4 (3.6)	23.3 (3.9)	22.3 (3.6)	0.85	0.43
Education (secondary/tertiary)	56/28	23/13	23/2	6.84*	0.03
Handedness (right/left)	72/12	32/4	23/2	0.77*	0.68
Prior concussions (mean (SD))	2.0 (2.1)	2.4 (2.3)	3.1 (2.6)	2.12	0.12
Loss of consciousness					
No of athletes (%)	—	7 (19.4)	8 (32.0)	1.11*	0.27
Duration in minutes (mean (SD))	—	1.1 (0.9)	2.0 (1.5)	1.38	0.19
Post-traumatic amnesia					
No of athletes (%)	—	13 (36.1)	9 (36.0)	0.23*	0.82
Duration in minutes (mean (SD))	—	1.4 (3.2)	2.5 (4.3)	0.71	0.48
Symptoms					
At injury (mean (SD))	—	3.3 (1.1)	4.9 (2.0)	3.68	0.002
At test (mean (SD))	—	—	1.8 (0.9)	—	—
Hours to symptom resolution (mean (SD))	—	47.4 (46.8)	79.8 (53.0)	2.36	0.02
Days to return to sport (mean (range))	—	4.3 (2–14)	6.5 (2–12)	2.94	0.007
Days between injury and test (mean (range))	—	3.5 (1–5)	2.2 (1–11)	2.90	0.005
No of athletes (%) missing a game	—	0 (0.0)	10 (40.0)	4.18*	<0.001

*Kruskal–Wallis non-parametric test of significance used.

inclusion in this study on the basis of prior work demonstrating susceptibility to mild TBI and concussion.^{13–23} This computerised test battery has demonstrated sensitivity to mild cognitive changes caused by concussion,⁹ fatigue,²⁴ alcohol,²⁴ early neurodegenerative disease,²⁵ coronary surgery,²⁶ and childhood mental illness.²⁷ The practice effects²⁸ have been documented, as has its correlation with conventional paper and pencil tests.¹⁸ The subtasks within CogSport are highly reliable when administered to healthy young athletes (intraclass correlation coefficients >0.7).¹⁸ Other metric properties of the test have also been reported.²⁹

We also administered two “paper and pencil” neuropsychological tests—Digit Symbol Substitution Test³⁰ (DSST) and the Trail Making Test—Part B³¹ (TMT) (table 2)—to allow comparison with prior studies of concussion conducted in Australian football.^{6–7} In concussed athletes, the presence or absence of symptoms was recorded using a standardised 14 item symptom checklist, which consisted of the most commonly reported symptoms from the Vienna concussion consensus guidelines.¹⁶ Participants were asked to indicate whether each listed symptom was present, but they were not required to rate the severity of each symptom.

Procedure

All participants underwent a baseline neurocognitive assessment before the start of each football season. These cognitive assessments were included opportunistically as part of the medical management programme of the participating clubs. Participation was voluntary but strongly encouraged by the

club medical staff. In total, 848 pre-season assessments were performed over the course of the study, as some footballers were enrolled during consecutive seasons and underwent more than one pre-season assessment. Computerised testing was conducted on laptop computers, with between 4 and 10 participants completing testing at any one time. All testing took place in a quiet, well-lit environment and was supervised by a neuropsychologist or physician. Prior to recording a baseline test, each participant performed a complete practice test during which no data were recorded. Previous research has demonstrated that a single practice test is sufficient to eliminate the majority of the so-called “practice effect” on the computerised tasks administered.²⁸ We also recorded relevant clinical information at the pre-season assessment, such as history of concussion and time since last medically verified concussion.

For the purposes of this study, concussion was defined as head trauma resulting in alteration in mental state or the onset of clinical symptoms or both, and was diagnosed on the basis of a clinical interview conducted by the medical staff of the participating clubs. Club medical staff followed the Vienna consensus guidelines when diagnosing concussion.¹⁶ Details of the injury, including whether the athlete lost consciousness (LOC), experienced post-traumatic amnesia (PTA), and the number and type of symptoms experienced by the athlete were recorded using a standardised assessment form. PTA was defined as memory loss for the events surrounding the injury, with onset occurring soon after the injury, and was diagnosed by clinical interview. No differentiation was made between retrograde and anterograde amnesia. Participants with non-concussive head injuries (cuts, lacerations, etc) were not included in this study.

Post-concussion assessments were undertaken either by club medical staff or by one of the study investigators. All assessments were completed within 11 days of injury. Tests were administered on laptop computers in a controlled, quiet environment. Participants reporting the presence of any symptoms at the time of the cognitive assessment were allocated to the SYMP group, while participants reporting no symptoms at the time of cognitive assessment were allocated to the ASYMP group. Control participants underwent a follow-up assessment at the completion of the season.

Table 2 The assessment battery used in the present study

Task name (abbreviation)	Cognition assessed
Computerised test battery tasks	
Simple reaction time (SRT)	Motor function
Choice reaction time (CHRT)	Decision making
Complex reaction time (CXRT)	Attention
Divided attention (DIVA)	Divided attention
One-back (OBK)	Working memory
Matching (MATCH)	Complex attention
Continuous learning (LRN)	Learning and memory
Paper and pencil neuropsychological tests	
Digit Symbol Substitution Task (DSST)	Information processing
Trail Making Test—part B (TMT)	Information processing

Data analysis

For each participant, anticipatory responses (defined as responses faster than 100 ms) were counted as errors and excluded from further analysis. Inspection of the distributions of RTs indicated a positive skew in all distributions. This is a common feature of RT distributions.³² Data for each participant were therefore logarithmic base 10 ($\log_{10}$) transformed prior to statistical analysis, to ensure that data met the assumptions of normality and heterogeneity of variance. For each participant, the mean RT on each task was used to express the speed of performance. Inspection of accuracy data for all tasks indicated that ceiling effects were evident for SRT, CHRT, CXRT, DIV, and OBK tasks. Consistent with prior analysis using this computerised test battery, we therefore chose to present accuracy data for the MATCH and LRN tasks only.²⁷ All accuracy data were arcsine transformed prior to statistical analysis.³³

Changes between baseline and post-concussion cognitive performance of SYMP athletes were compared with those in ASYMP and CONT athletes using a group (3; SYMP, ASYMP, CONT) by assessment (2; baseline, post-concussion) repeated measures analysis of variance (ANOVA) for each outcome variable. Where significant interactions or main effects of assessment were observed, paired samples *t* tests were used to compare the post-injury performance of each group to its own baseline. Where significant main effects of group were observed, independent samples *t* tests were used to compare the post-concussion test performance of the SYMP and ASYMP groups with the CONT group. For each participant, the magnitude of any observed changes from baseline were expressed using a *z* score, where the mean difference (post-concussion minus baseline) was divided by the within subject standard deviation³⁴ (WSD) of the CONT group.³⁵ The group mean *z* scores are reported in table 3. Statistical significance was defined as $p > 0.05$.

RESULTS

The concussed and control groups were closely matched on age and handedness, although ASYMP and CONT athletes were more highly educated than SYMP participants. A total of 61 concussions were recorded among the 615 athletes enrolled in the study (9.92%). As a group, concussed athletes reported 2.71 (SD 2.44) prior concussions (range 0–10). Fifteen (24.6%) athletes lost consciousness for a mean (SD) of 1.58 (1.31) minutes, whereas 22 (36.1%) reported PTA lasting 1.85 (3.68) minutes. Concussed athletes reported a mean of 3.98 (1.69) symptoms at the time of injury (range 1–10) with the commonest being headache, which occurred in 54 (88.5%) athletes. Time to symptom resolution ranged from 2 to 240 hours (mean 60.6 (51.5) hours). Ten participants

(16.4%) missed the next game, which typically occurred six to eight days after the injury. None of the control athletes were concussed during the study.

Comparison of SYMP and ASYMP groups revealed that the SYMP group had a greater number of symptoms at the time of injury. These symptoms took longer to resolve and resulted in a significant delay in the time taken to return to sport ($p = 0.007$). Further, a greater proportion of symptomatic athletes missed a game. In fact, all 10 athletes who missed a game of football were from the SYMP group. The presence and duration of LOC and PTA did not differ between SYMP and ASYMP groups (see table 1). Baseline (pre-season) level of cognitive test performance did not differ between all three study groups.

Repeated measures ANOVA revealed significant group by assessment interactions for SRT ($F_{2,141} = 3.25$, $p = 0.04$) and DIVA ($F_{2,141} = 4.32$, $p = 0.02$) tasks. Significant main effect of assessment were observed for the TMT ($F_{1,142} = 8.56$, $p = 0.004$), DSST ($F_{1,142} = 15.677$, $p < 0.001$), CHRT ($F_{1,142} = 8.36$, $p = 0.004$), and CXRT ($F_{1,142} = 4.41$, $p = 0.038$) tasks. Significant main effect of group were observed for LRN accuracy ($F_{2,141} = 8.04$, $p < 0.01$), OBK speed ($F_{2,141} = 3.28$, $p = 0.04$), and MATCH accuracy ($F_{2,141} = 3.43$, $p = 0.03$).

Post-hoc *t* tests revealed that the performance of the SYMP group declined after concussion on tests of SRT ($t_{24} = 3.33$, $p = 0.003$), CHRT ($t_{24} = 3.28$, $p = 0.003$), and CXRT ($t_{24} = 2.54$, $p = 0.018$) tasks. The magnitude of these changes, expressed in WSD units, were large according to conventional statistical criteria (SRT = -0.86 ; CHRT = -0.60 , CXRT = -0.61). The performance of the ASYMP group declined after concussion on the DIVA ($t_{35} = 3.23$, $p = 0.003$) but improved on the DSST ($t_{35} = 3.48$, $p = 0.001$) and the TMT ($t_{35} = 2.98$, $p = 0.006$). The magnitude of these changes were large (DIV = -0.73 ; DSST = 0.99 ; TMT = 0.79). Finally, the performance of the CONT group improved at follow up on the DSST ($t_{83} = 4.29$, $p < 0.01$) and the TMT ($t_{83} = 2.61$, $p = 0.011$). These changes were also moderate to large in magnitude (DSST = 0.56 ; TMT = 0.49).

DISCUSSION

When compared with their own baseline test, recently concussed athletes reporting symptoms of their injury displayed statistically large and significant cognitive decline following the injury on computerised tests of motor function and attention (see table 3). These changes are different from those observed in asymptomatic athletes, who displayed post-injury dysfunction on the DIVA only. The performance of the healthy, uninjured athletes did not change between baseline and follow up computerised assessments. The

Table 3 Performance on cognitive tasks (mean (SD)) in concussed and control athletes

	Study group								
	Control			Asymptomatic			Symptomatic		
	Baseline	Follow up	<i>z</i> score	Baseline	Follow up	<i>z</i> score	Baseline	Follow up	<i>z</i> score
No of athletes	84	84		36	36		25	25	
Simple RT speed	2.41 (0.06)	2.42 (0.05)	-0.10	2.43 (0.07)	2.45 (0.06)	-0.30	2.41 (0.06)	2.46 (0.06)	$-0.86\ddagger$
Choice RT speed	2.62 (0.06)	2.64 (0.08)	-0.33	2.64 (0.10)	2.65 (0.06)	-0.07	2.63 (0.08)	2.67 (0.07)	$-0.60\ddagger$
Complex RT speed	2.75 (0.07)	2.75 (0.06)	-0.01	2.76 (0.06)	2.77 (0.07)	-0.16	2.75 (0.07)	2.79 (0.07)	$-0.61\ddagger$
Divided attention speed	2.49 (0.08)	2.49 (0.10)	0.05	2.45 (0.09)	2.51 (0.09)	$-0.73\ddagger$	2.50 (0.08)	2.52 (0.10)	-0.25
One-back speed	2.75 (0.09)	2.77 (0.09)	-0.18	2.77 (0.10)	2.79 (0.09)	-0.16	2.79 (0.10)	2.81 (0.08)	-0.24
Matching accuracy	1.14 (0.22)	1.12 (0.21)	-0.12	1.19 (0.23)	1.23 (0.24)	0.19	1.14 (0.17)	1.23 (0.19)	0.41
Learning accuracy	0.92 (0.12)	0.90 (0.15)	-0.17	0.96 (0.12)	0.99 (0.13)	0.24	0.97 (0.12)	0.97 (0.13)	-0.03
DSST	66.17 (11.28)	68.85 (11.37)	0.56^*	66.42 (12.34)	71.18 (12.63)	0.99^*	61.00 (6.10)	62.41 (8.15)	0.29
Trail Making Test—Part B	52.92 (16.54)	48.33 (15.26)	0.49^*	53.94 (19.55)	46.52 (14.91)	0.79^*	53.81 (13.71)	52.41 (15.02)	0.15

z: change score calculated by dividing the group mean difference score by the within subjects standard deviation (WSD) of the control group.

*Significant improvement in performance from baseline ($p < 0.01$); †Significant deterioration in performance from baseline ($p < 0.01$).

magnitude of cognitive decline observed in symptomatic athletes was large according to conventional statistical criteria, despite these athletes reporting relatively few symptoms at the time of post-injury assessment (mean 1.8 symptoms). These findings are consistent with studies demonstrating post-concussion impairments on computerised tests of simple and choice reaction times^{13–15 19} in the days following injury.

In the present study, impairments after injury in symptomatic athletes were isolated to simple motor and attentional domains of cognition, with no changes observed in cognitive domains of learning and memory. Although no clear pattern of cognitive dysfunction following concussion emerges from the literature, the present findings are consistent with numerous previous studies conducted both in sports concussion and in more severe forms of TBI.^{14 19–23} The asymptomatic athletes in the present study recorded impairment on a test of divided attention only, whereas their motor function and attentional functions returned to baseline. This interesting finding indicates that cognitive recovery from concussion may not be linear in nature, and that some cognitive tests may be differentially sensitive to early and later stages of recovery. Other authors have recorded cognitive impairments in concussed asymptomatic athletes.³⁶ Although the clinical significance of the cognitive test results observed here is difficult to determine, these findings support current recommendations that athletes must not return to play while symptomatic.¹⁶

An interesting feature of many previous neurocognitive studies has been that post-concussion deficits manifest not as a *decline* in performance, such as that observed on the computerised cognitive tests in the present study, but as an *attenuation of practice effects*.^{14 37} For example, the improved performance of 183 concussed athletes assessed 24 hours after injury has been described.⁸ This improvement was surpassed by that observed in control athletes, and hence a significant group difference was observed. This pattern has been observed using the DSST and TMT (for example, see reference 8), two tests commonly employed in studies of concussion,^{6 8 9 12} and has been replicated in the present study. Specifically, we found that both asymptomatic and non-injured control athletes displayed significant improvement on the DSST and TMT, whereas the performance of symptomatic athletes after concussion did not change from their baseline assessment. We have previously argued that this phenomenon makes the clinical application of paper and pencil tests in individual athlete difficult, unless specialist neuropsychological interpretation is available.³⁸ However, the effects of practice may be minimised via the administration of dual baseline tests, a methodological approach that we and other authors have advocated^{28 36} and we have employed in the current study.

Athletes participating in the present study who were symptomatic at the time of medical assessment after concussion, and who displayed large and significant cognitive dysfunction, also recorded a greater burden of symptoms at the time of injury compared with the asymptomatic athletes (see table 1). Symptomatic athletes took longer to return to sport (training or game play), and were significantly more likely to miss the following competitive game than were asymptomatic athletes. These important findings suggest an association between symptom burden at injury, symptom resolution following the injury, cognitive test performance, and time to return to sport. Further work specifically investigating this hypothesis is required. In the present study, time from concussion to post-injury assessment differed significantly between symptomatic and asymptomatic groups. Although this most likely reflects the greater severity of injury in the symptomatic group (as measured by

symptom burden and time to return to sport) and the opportunistic nature of the study design (players were assessed at the discretion of the clubs' medical officers), it is nevertheless a limitation that must be considered when interpreting these results.

Previous studies have suggested that PTA and LOC are useful predictors of the severity of concussion and recovery. For example, numerous concussion grading scales emphasise LOC and/or PTA for grading concussion severity and thus guiding return to play decisions.^{39–41} In the current study, the presence or duration of PTA or LOC did not differentiate the symptomatic and asymptomatic athletes. This finding supports previous research that has challenged the validity of the grading scale approach to management of concussion.^{42 43}

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Authors' affiliations

A Collie, M Makdissi, K Bennell, P McCrory, Centre for Health, Exercise and Sports Medicine, University of Melbourne, Parkville, Victoria, Australia

P Maruff, School of Psychological Science, La Trobe University, Bundoora, Victoria, Australia

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