The effects of concussion dosage, gender, reported symptoms and expectations on long-term outcomes following sport-related concussion

Submitted by James William Broughton, to the University of Exeter
as a thesis for the degree of Doctor of Clinical Psychology

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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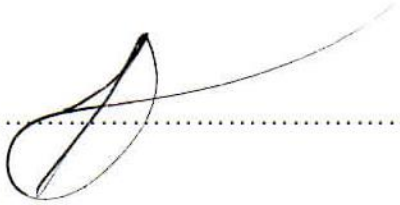

Table of Contents

List of Tables

Literature Review

Empirical Paper

List of Figures

Literature Review

Empirical Paper

SCHOOL OF PSYCHOLOGY

DOCTORATE IN CLINICAL PSYCHOLOGY

LITERATURE REVIEW

The application of psychological theories of etiology in post-concussive symptom reporting/recovery in sport-related concussion: A systematic review

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Abstract

Objective: Psychological factors are increasingly considered in clinical settings when diagnosing/treating mild traumatic brain injury (MTBI). However, there appears to have been limited high-quality research on etiological theories within sport-related concussion (SRC) outcome. This review aimed to investigate the extent to which psychological theories of etiology have been investigated within SRC.

Method: A systematic review was conducted of all literature to date on the OvidSP (MEDLINE, PsycINFO, PsycARTICLES), NICE Healthcare, and Web of Science databases.

Results: Eight relevant articles were identified, consisting of cross-sectional and prospective research. The articles indicated that athlete post-concussive outcomes can be significantly affected by their expectations and understanding of their injury, symptom severity and expectations around recovery. There were few high-quality longitudinal articles, and causality was difficult to establish. The overall quality of the articles was rated as weak to moderate.

Conclusions: Expectation influences athlete recovery following SRC. Psychological factors such as expectations need consideration when assessing athletes for SRC and persisting symptoms. Care should be taken with the terminology and assessment methodology used, as these can alter outcomes and subsequent decisions around diagnosis or treatment. There is limited high-quality research linking psychological theories of etiology and SRC outcome. Recommendations for future research were made.

Keywords: *mild traumatic brain injury, mild head injury, expectation as etiology, good-old-days, post-concussion syndrome*

Introduction

Rationale

Psychological theories of etiology (herein referred to as etiological theories) are models of psychological factors that lead to changes in function and symptomology. Though psychological factors are increasingly considered in clinical settings when assessing mild traumatic brain injury (MTBI), there appears to have been limited high-quality research on etiological theories within sport-related concussion (SRC) outcomes. This review is the first to investigate the extent to which etiological theories of MTBI outcome have been investigated within SRC, in order to more clearly understand the influence of psychological factors on an often "high-risk" population (Cantu, 1996; Gardner et al., 2014).

Traumatic Brain Injury (TBI)

TBI is one of the leading causes of death and disability of young people in the developed world (Thurman, Alverson, Dunn, Guerrero, & Sniezek, 1999; Yates, Williams, Harris, Round, & Jenkins, 2006). A TBI is an injury caused through impact to the head, or other mechanisms of rapid movement or displacement of the brain within the skull. TBI is regarded as a neurocognitive disorder within the diagnostic and statistical manual of mental disorders, fifth-edition (American Psychiatric Association, 2013). Symptoms can include loss of consciousness (LOC), amnesia, a range of cognitive deficits, disorientation/confusion, seizures, sensory deficits, hemiparesis, and/or neuroimaging evidence of injury (American Psychiatric Association, 2013; National Institute of Neurological Disorders and Stroke, 2016).

Mild Traumatic Brain Injury (MTBI)

Approximately 70-80% of TBI cases can be classified as "mild" (Arciniegas, Anderson, Topkoff, & McAllister, 2005). There is inconsistency between diagnostic criteria for commonly used definitions of injury (i.e. MTBI; mild head injury [MHI];

sport-related concussion [SRC]), lack of specificity of symptoms, and a lack of clarity over etiology/pathogenesis (Bigler, 2008; Williams, Potter, & Ryland, 2010). MTBI has historically been described as a temporary condition with symptoms usually resolving within hours or days (Cassidy et al., 2004; Concussion in Sport Group, 2013; Williams et al., 2010). However, as part of a post-concussion syndrome (PCS), some symptoms can persist for months or years post-injury (Alves, Macciocchi, & Barth, 1993; Ruff, Camenzuli, & Mueller, 1996; Williams et al., 2010).

Psychological Theories of Etiology in MTBI Outcome

Pre-morbid factors can be important predictors of persisting symptoms at 3-6 months post-injury (Barlow, 2016). Poorer outcome is known to be associated with psychological factors such as depression, trauma or patient expectations (Broshek, De Marco, & Freeman, 2015; Ferguson, Mittenberg, Barone, & Schneider, 1999; Gunstad & Suhr, 2001; Losoi et al., 2016; Uomoto & Fann, 2004). However, psychological factors can be difficult to identify, and PCS can be difficult to accurately diagnose (Bender & Matusewicz, 2013). Two accepted theories describing how some psychological factors can influence PCS are “expectation as etiology” (EE; Mittenberg, DiGiulio, Perrin, & Bass, 1992) and the “good-old-days” bias (GODB; Gunstad & Suhr, 2001).

Expectation as etiology (EE). EE states that long-term symptom presence is associated with the individual’s beliefs and expectations about their head injury, causing reattribution of common complaints/symptoms to their injury, making them more difficult to treat (Whittaker, Kemp, & House, 2007). For example, headaches occur naturally within non-head-injured populations, yet following MTBI, all of an individual’s headaches may be blamed on the injury, with pre-injury headache prevalence being ignored/underestimated (Mittenberg et al., 1992). Focusing on the “severity” of their symptoms as consequences of their injury, results in the individual

experiencing the injury and symptoms as more severe and disabling. Underestimating premorbid symptoms strengthens the belief that symptom "increases" result from the head injury (Hilsabeck, Gouvier, & Bolter, 1998; Mittenberg et al., 1992). The extent to which symptoms are attributed to MTBI can be a significant predictor of PCS severity (Belanger, Barwick, Kip, Kretzmer, & Vanderploeg, 2013).

"Good-old-days" bias (GODB). Gunstad and Suhr (2001) expanded EE beyond head injury symptoms with the GODB. Both EE and GODB can operate in tandem, but are distinctly different: Rather than the focus being on individual's beliefs about the *current* consequences of their injury or illness (EE), GODB focuses on an individual's tendency following an injury or illness to view themselves as being healthier in the past (pre-injury) than they are in the present (post-injury). Gunstad and Suhr suggested that any negative life event (e.g. an injury) can become a salient landmark for viewing current physical or psychological states or abilities in a negative perspective compared to how things were before that event. For example, the individual may think that they never used to experience headaches prior to their injury, when in reality pre-injury headaches may actually have been present.

Symptoms are therefore experienced as a direct result of expectations, termed the "nocebo" effect (Hahn, 1999), which negatively impacts the individual's perception of current problems and expected likelihood of recovery (Iverson, Lange, Brooks, & Rennison, 2010). However, whilst some studies have demonstrated significant differences between head-injured participants and healthy controls (Gunstad & Suhr, 2001), other studies have found similar underestimations of premorbid symptoms for both healthy and head-injured groups (Panayiotou, Crowe, & Jackson, 2011), leading to suggestions that all individuals are prone to remembering the past more favourably. Some studies have demonstrated limited or

no effect differences between current and retrospective symptom reports in non-clinical participants (Sullivan & Edmed, 2012a). However, Sullivan et al. note that further research is required to compare clinical and non-clinical groups.

Psychological Factors Influencing Sport-related Concussion (SRC) Outcome

There is mixed evidence for athletes responding differently to SRC compared to non-athletes, with the context of their sport or expectations around injury recovery appearing to be important factors (Whitfield, 2013). Despite a large body of research focusing on the role of expectations in MTBI injuries in the general population, it is unclear whether there has been such a focus on outcome expectations in the sporting arena.

Athlete personality profiles can differ from non-athletes (Filho, Ribeiro, & García, 2005; Mokhtari & Haghi, 2014). Within athletes, profiles can differ when comparing contact verses non-contact (Sohrabi, Atashak, & Aliloo, 2011), high-versus low-risk (Kajtna, Tušak, Barić, & Burnik, 2004), or team verses individual (Nia & Besharat, 2010). PCS symptom reports can be greater in recreational or retired athletes than current competitive athletes (Thornton, Cox, Whitfield, & Fouladi, 2008). Injury expectations may be influenced by the perceived (un)desirability of the injury condition (Gunstad & Suhr, 2002; Mulhern & McMillan, 2006): SRC may be less negatively perceived and associated with fewer negative expectations for recovery than non-sporting MTBI (Edmed & Sullivan, 2014).

Review Objectives

When considering the variations in personality profiles of athletes compared to non-athletes and potential differences in expectations/perceptions of head injury severity, it is reasonable to expect that athletes may exhibit different response patterns or expectations in response to SRC/MTBI than non-athletes. This review therefore initially aims to explore the extent to which etiological theories have been

researched within the context of SRC. The review will also consider the identified differences between athlete and non-athlete expectations around head injury and any association with outcomes.

Review questions. The research questions are:

1. To what extent have etiological theories been considered in the context of athletes and SRC outcome?
2. Do athletes experience patterns of symptoms or recovery following SRC that differ from the general population and can be explained by etiological constructs, such as EE or GODB?

Method

This systematic review was conducted using the 2009 Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) protocol (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). The PRISMA protocol is a widely used protocol for structuring systematic review reports. Using an established reporting protocol enables a standardised, non-biased approach to be employed, and facilitates the appraisal of the review methods (Moher et al., 2015).

PECO – Population, Exposure, Comparison, Outcomes of Interest

The “PECO” method can aid the formulation and structure of systematic reviews, as it helps a reviewer to identify the features of interest in the articles they are reviewing:

1. **Population of interest:** Adult players of sports (athletes) who have experienced MTBI or “SRC” as a result of sporting participation.
2. **Exposure:** Cross-sectional or longitudinal observation studies assessing or following individuals post-injury (also pre-injury if available).
3. **Comparison groups:** Non-athletes who have experienced MTBI, or “control” populations with no history of MTBI. Self-reports of “pre-injury performance”.

4. **Outcomes of interest:** Reported symptoms, expectations about injuries and symptoms, perceptions of recovery pathways, comparisons between pre- and post-injury symptoms/performance.

Eligibility Criteria

Table 1 details the eligibility criteria used during the search and subsequent review of the search results.

Table 1

Inclusion and Exclusion Criteria for Systematic Review.

Inclusion criteria	Exclusion criteria
Primary research (quantitative and qualitative)	Book reviews, conference presentations, meetings, letters, commentaries, expert opinions, review articles, meta-analyses
Full text available in English	Full text not available in English
Published in a peer reviewed journal	Non-peer reviewed publications
	Does not include mild severity (e.g. moderate or severe TBI only)
	Where participants have genetic or developmental cognitive difficulties, e.g. autism, learning disability
	Where participants have degenerative conditions, e.g. Alzheimer's disease or other dementing illnesses
	Where participants have other neurological conditions such as non-traumatic acquired brain injury, e.g. arising from stroke, tumours, substance abuse
	Where participants have diagnosed mental health conditions not associated with MTBI or PCS (e.g. schizophrenia)
	Where participants/subjects are aged under 16 years old or where MTBI occurred under 16 years old
	Where article does not identify, define or categorise sample in relation to a sporting activity (e.g. focus on

Inclusion criteria	Exclusion criteria
	military-personnel only)
	Where article does not identify, define or categorise MTBI or PCS etiology in relation to sporting activities (e.g. focusing only on military blast-injuries, assaults, vehicular accidents)

Information Sources and Search Strategy

The following databases were used: Web of Science, NICE Healthcare Database (HDAS), and OvidSP databases (Medline PubMed, PsycINFO, and PsycARTICLES). Titles, abstracts and key words were searched from the beginning of each database up to 19th March, 2016, using the following search terms:

1) "good old days" OR "good-old-days" OR "expectation as *etiology" OR "expectation *etiology" AND
2) "src" OR "sport* related concussi*" OR "athlete*" OR "rugby" OR "football" OR "box*" OR "jockey*" OR "sport*" OR "contact sport*" OR "exercis*" OR "concussi*" OR "post concussi*" OR "tbi" OR "mtbi" OR "traumatic brain injur*" OR "brain injur*" OR "head injur*" OR "postconcussi*" OR "pcs" OR "symptom" OR "performance" OR "perception" OR "perceiv*"

Searches were conducted for articles that cited the articles identified as relevant through the main search. A search for Cochrane reviews was conducted and reference lists of relevant articles were also examined to identify further articles of interest.

Data Extraction and Quality Assessments

Titles and abstracts of the initial search findings were screened individually for relevance to the review aims. The full contents of shortlisted papers were then scanned and assessed for inclusion, as per the eligibility criteria (Table 1). Articles that did not meet review criteria at each stage were rejected (Figure 1, based on

PRISMA 2009 flow chart [Moher et al., 2009]). No difficulties were encountered obtaining access to full texts of relevant articles.

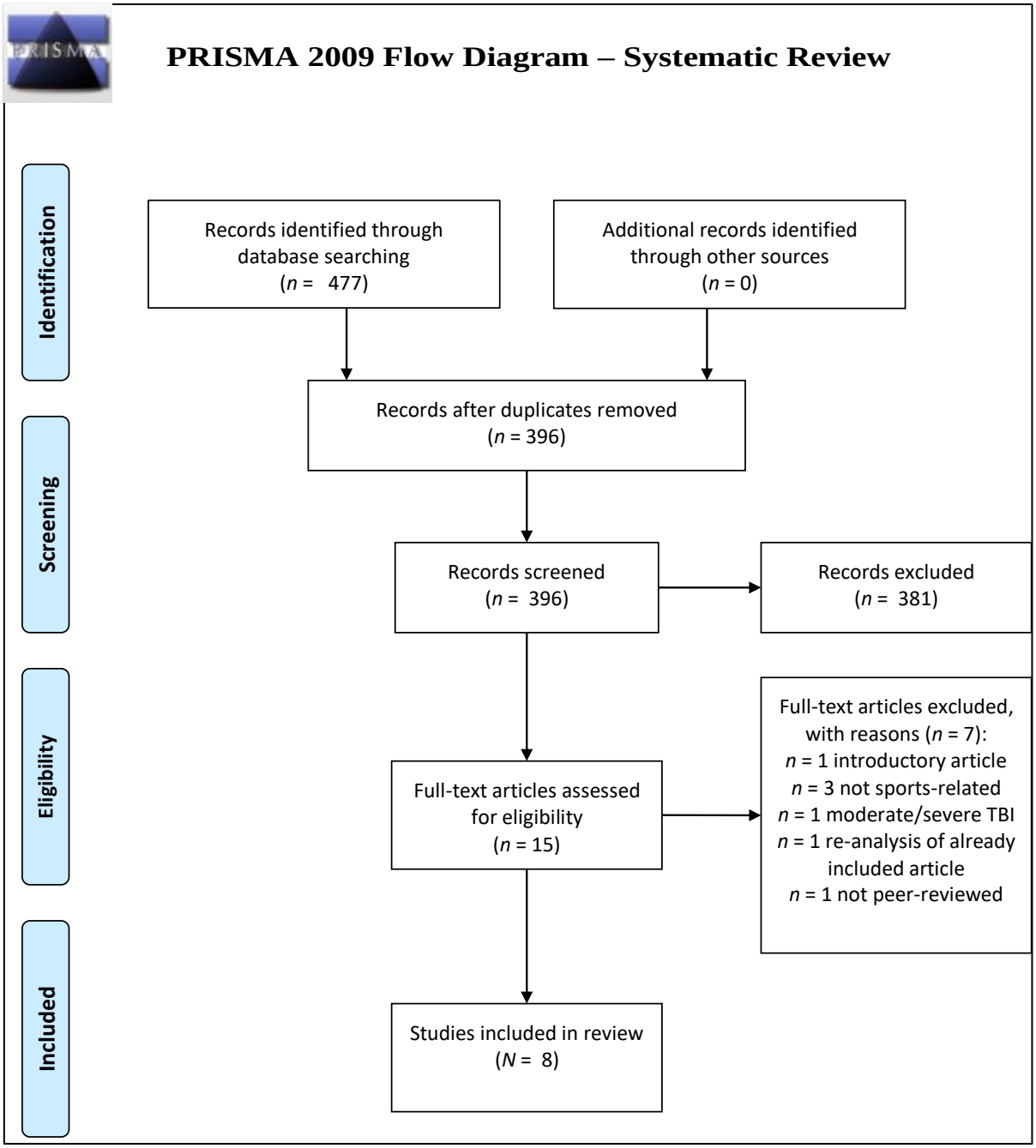

Figure 1. Search strategy used to determine eligibility for the systematic review, based on the PRISMA 2009 flowchart.

Each article was reviewed in detail using an extraction form to summarise key information (Appendix A). Article quality was assessed using the Effective Public Health Practice Project (EPHPP)'s "Quality Assessment Tool" (Effective Public Health Practice Project, 1998; Thomas, Ciliska, Dobbins, & Micucci, 2004). The

Quality Assessment Tool has higher inter-rater reliability for individual domains and overall grading than the Cochrane Collaboration Risk of Bias tool (Armijo-Olivo, Stiles, Hagen, Biondo, & Cummings, 2012). Articles were graded on selection bias, study design, confounders, blinding, data collection methods, withdrawals/drop-outs, intervention integrity, and analysis. Based on these ratings, global ratings of "weak", "moderate", or "strong" were awarded.

All searches, screening, data extraction and EPHPP quality assessments were all conducted by a single reviewer, as DClinPsy time and financial constraints meant a lack of resources available to recruit additional reviewers to allow for inter-rater reliability checks.

Results

The systematic search outlined above revealed 477 results. Duplicates were removed, leaving 396 unique articles. Titles and abstracts were screened individually against eligibility criteria, leaving fifteen articles (Figure 1). Full texts were reviewed and eight articles were retained (Table 2). Head injury definitions used by the articles are available in Appendix B. Results are discussed using the terminology used within each article to describe the head injuries under investigation (MTBI; MHI; SRC; concussion).

Table 2

Summary of Aims, Design and Participants, Lists of Measures Used, Main Findings Related to SRC, and EPHPP Evaluations for Reviewed Articles.

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
1. Blaine, Sullivan, and Edmed (2013)	To determine the effect of exposure to instructions aimed at inducing or reducing diagnosis threat, on a range of outcomes.	**Research location** Australia **Design** Cohort design, single-blind. Randomly allocated experimental conditions and control group. **Sampling method** Opportunity sampling **Sample characteristics** Undergraduate population. *N* = 45 (SRC *n* = 26). M_{age} = 24.08, *SD* = 5.56. 62% female. $M_{post\text{-}injury}$ = 4 years **TBI severity in sample** Mild **Inclusion criteria**	-Brief Symptom Inventory 18 -Controlled Oral Word Association Test -Illness Perception Questionnaire, Revised -Neurobehavioural Symptom Inventory -Post-experimental questionnaire -Rey Auditory Verbal Learning Test -Screening questionnaire -Test Of Memory Malingering -Trail Making Test -WAIS-III Digit Span	Diagnosis threat did not significantly affect performance on outcome measures. The authors query whether diagnosis threat should remain in biopsychosocial model as a predictor of poor-outcome following MTBI.	**Stated strengths** -Not stated. -Findings consistent with recent literature. **Stated limitations** -Self-reported MTBI not verified. -Very small sample size. -Sports injuries can be perceived as less negative so participants may therefore respond differently. -Instructions were not representative of clinical practice. **Global EPHPP quality rating:** Weak

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		-MTBI -English language proficiency. -Passed memory malingering effort test **Exclusion criteria** -Injury <3months -Psychological or neurological disorder diagnosed or requiring treatment <12 months -Neuropsychological assessment <12 months	-WAIS-III Symbol Coding -WAIS-III Symbol Search		
2. Ferguson et al. (1999)	To examine the role of expectations in the symptom reports of athletes who sustained mild head injury (MHI) in contact sports.	**Research location** USA **Design** Between-group cross-sectional design. Matched groups. Control group. **Sampling method** Opportunity sampling **Sample characteristics** Male athletes enrolled in collegiate, postgraduate and high	-Demographic questionnaire -Symptom checklist -Variable instructions	MHI sustained in contact sports did not significantly affect post-concussion symptoms. Symptom incidence did not differ significantly between matched groups of concussed and uninjured athletes. Athletes with MHI underestimated premorbid symptom experiences in the face of no objective post-injury symptom increase. This indicates a	**Stated strengths** -Not stated. -Some findings consistent with previous research. **Stated limitations** -Rating symptom presence on a binary scale may produce different results to using e.g. Likert scales. -Potential recruitment bias, with a risk that more symptomatic

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		school amateur collision sports programs. *N* = 209 (SRC *n* = 50, M_{age} = 20.22 years, *SD* = 3.41, $M_{post\text{-}SRC}$ = 6 months, *SD* = 4.9 months). **TBI severity in sample** None, mild **Inclusion criteria** **-**Non-head-injured athletes criteria: (a) no prior sport-related head trauma, (b) no prior non-sport-related head trauma (e.g., motor vehicle accident) **Exclusion criteria** -Female. -Head injury from motor vehicle accident or other non-sport-related accident. -SRC greater than 1 year prior to participation.		subjective overestimation of pre- to post-injury symptom change consistent with their symptom expectations	individuals did not complete the questionnaire, resulting in a lower level of symptom reporting in the sample than in athletic populations overall. -The chronicity and severity of concussion imagined by uninjured participants may have differed from that experienced by MHI participants. -Post-concussive memory impairment could have affected recall of pre-morbid symptoms for MHI participants. -Expectations of MHI participants were not measured. -Longitudinal assessment of pre-injury expectations would be appropriate.

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
					Global EPHPP quality rating: Weak
3. Gunstad and Suhr (2001)	To examine the contribution of malingering, emotional state, expectations, and chronic pain in the reporting of PCS symptoms across a range of demographic groups, including concussed and non-concussed athletes. To explore the "expectation as etiology" hypothesis and establish whether instead there is a general response bias for all individuals to view	**Research location** USA **Sampling method** Opportunity sampling **Design** Between-group cross-sectional design. Control group. **Sample characteristics** University undergraduate population. *N* = 141, 27.7% male (SRC *n* = 25, M_{age} = 18.8, 46.2% male. Average 2.1 years following injury). **TBI severity in sample** None, mild **Inclusion criteria** Not stated	-Demographic questionnaire -Headache Screening Questionnaire, revised -Inventory of Depressive Symptomatology -Postconcussion Syndrome Symptom Scale -Structured Diagnostic Interview for Headache, Brief Version -Vignettes	No differences between premorbid symptoms of head-injured athletes and healthy controls. Head injured athletes did not report any more current PCS symptoms than other groups. Depressed participants reported more symptoms than head-injured athletes, suggesting PCS symptoms are not specific to PCS. Healthy athletes expected fewer memory or cognitive problems, somatic complaints, distractor items, affective symptomatology, and less reliance on memory compensation devices than other groups, consistent with "expectation as etiology" hypothesis. Head injured athletes reported	**Stated strengths** -Not stated. -Results provide support for EE and GODB theories. **Stated limitations** -Head-injured athletes were assessed an average of 2.1 years following their injury. Symptom and distress levels may therefore have reduced to near normal levels, resulting in lower rate of symptoms reported. -Depressed individuals in the sample were not seeking any form of treatment, which may result in different

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
	themselves as healthier in the past.	**Exclusion criteria** -More than 1 migraine headache per month -Cluster headaches -Concurrent pain disorder -TMD (acronym not defined by authors) or occlusional disorders -Major pain -Psychiatric medication use -Excessive analgesic use -Currently seeking psychological treatment for pain. -Headache sufferers excluded if reported history of head injury.		significantly more current symptoms than premorbid symptoms. Athletes may have a general expectation of health and recovery, and that symptoms may be related to their perception of the event that caused the injury. The "expectation as etiology" hypothesis may be too specific, and people may attribute all symptoms to their injury, consistent with the "good old days" hypothesis.	presentations to clinical samples. **Global EPHPP quality rating:** Weak
4. Gunstad and Suhr (2004)	To determine the relative contribution of uncomplicated head injury, depression, headache pain, and athletic participation in PCS reports.	**Research location** USA **Design** Cross-sectional design. Control group. Group-testing for data collection. **Sampling method** Opportunity sampling	-Demographic questionnaire -Headache Screening Questionnaire, revised -Inventory of Depressive Symptomatology -Postconcussion Syndrome Symptom Scale	Head-injured, and headache groups underestimated premorbid symptom rates, consistent with "expectation as etiology" hypothesis. However, head-injured athletes did not underestimate premorbid symptoms or report elevated rates of current symptoms	**Stated strengths** -Clear definition between groups – head-injured participants were screened for factors associated with elevated PCS reports (depression, chronic headaches).

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		Sample characteristics university undergraduates population. *N* = 190 (SRC *n* = 25, M_{age} = 18.76, *SD* = 0.37, 60% female, Average 2.1 years post=injury, *SD* = 1.52 years). **TBI severity in sample** None, mild **Inclusion criteria (see Appendix C)** Participants must meet one of the following: -Non-athletes with history of head injury (one incident only). -Non-athletes with no history of head injury, and not meeting any depression or tension headache criteria (control group). -Athlete status (participation at the intercollegiate or intramural level for the	-Structured Diagnostic Interview for Headache, Brief Version -Variable instructions -Vignettes	relative to controls. Head-injured athletes did not report a lasting change in PCS symptom rate following their head injury, suggesting a lack of specificity to head injury. Non-neurological factors influenced symptom reporting, and may be more closely related to PCS symptom report than head injury status. A combination of both "expectation as etiology" and the "good old days" hypotheses could account for PCS symptom patterns.	-Results provide evidence for the influence of non-neurological factors in PCS symptom report. **Stated limitations** Head-injured participants were an average of two years post-injury so may have recovered. -Strict eligibility criteria means very limited sample size and groups will not be representative of typical clinical presentations. **Global EPHPP quality rating:** Weak

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		previous three years) with history of head injury as a result of athletic participation. Athlete status with no history of head injury. -Depression (scores greater than 18 on the Inventory of Depressive Symptomatology) and treatment seeking (current receipt of psychological or pharmacological intervention for depression or headaches within the previous 3 weeks). -Depression and not treatment seeking. -Tension headache and treatment seeking -Tension headache and not treatment seeking. **Exclusion criteria (see Appendix C)** **-**Any participant meeting inclusion criteria for more than one group. -Chronic medical			

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		problems. -Substance misuse. -Athletes suffering a head injury from non-sporting events. -Head injury with LOC >10 minutes. -More than one episode of LOC or concussion. -Previous history of psychological treatment (defined as any history of participation in counselling, psychotherapy, or prescription of psychoactive medication). Exclusionary criteria for headache group: presence of a concurrent pain disorder, TMJ (acronym not defined by authors), head trauma, headaches related to alcohol consumption, recent history of antidepressant medication, excessive analgesic use,			

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		symptoms of multiple or non-tension headaches. It is not stated whether there was any overlap between participants in Article 4 and Article 3.			
5. Snell, Siegert, Hay-Smith, and Surgenor (2011)	To examine the demographic and clinical characteristics associated with good and poor outcomes three months following MTBI. To examine whether a theoretically-derived self-regulation model of health behaviour such as Leventhal's CSM (illness perceptions, distress and coping) could be used to extend current understandings	**Research location** New Zealand **Design** Between-groups cross-sectional design. Baseline for article 6. Mixture of face-to-face, telephone and postal questionnaires for data collection. **Sampling method** Opportunity sample **Sample characteristics** *N* = 147. M_{age} = 41.8 years, *SD* = 15.7. 44.2% male. SRC *n* = 28. **TBI severity in sample** Mild	-The Brief COPE Inventory -Demographic questionnaire -Dichotomous outcome rating scale -Hospital Anxiety and Depression Scale -Illness Perception Questionnaire-revised (modified) -Rivermead Head Injury Follow Up Questionnaire -Rivermead Post-concussion Symptoms Questionnaire	Subjective understandings about MTBI can affect outcome: Participants with poor outcomes endorsed more symptoms, greater social or functional problems, greater distress and stronger beliefs and expectations about their condition, severity and predictability of symptoms, and poorer overall understanding of their condition. Theoretical frameworks such as CSM have clinical applicability for predicting those at risk of poor outcome, and in identifying potential treatment targets.	**Stated strengths** -Broad inclusion and exclusion criteria were used in an effort to ensure that the study sample was clinically representative. **Stated limitations** -Recruitment methods meant potential selection bias. -Self-report could have meant reporting bias. -Possible influences of litigation factors. -Cross-sectional design. Injury perceptions likely to be influenced by

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
	about MTBI outcomes and recovery.	**Inclusion criteria** -Sustained a MTBI within the preceding 3 months -Aged 16 or older -No previous history of severe traumatic brain injury or significant comorbid health conditions such as cardiovascular disease or neurological disorder **Exclusion criteria** -If there had been significant additional injuries sustained in the same accident which might make it difficult for participants to discriminate between their various injury symptoms -If retrospectively reported post-traumatic amnesia was the only criterion used for determining MTBI			presence or absence of symptoms at time of data collection. -Significant proportion of the target population did not respond – primarily younger males, who are less likely to present for treatment. **Global EPHPP quality rating:** Weak
6. Snell, Hay-Smith,	To examine the demographic and clinical	**Research location** New Zealand	-Brief COPE Inventory	Participants endorsing unhelpful perceptions of their injury (attribution of	**Stated strengths** -Low attrition rate

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
Surgenor, and Siegert (2013)	characteristics associated with good and poor outcomes three months following MTBI and at six month follow up. Specifically, to explore the extent to which components of Leventhal's CSM (injury perceptions, coping and distress) are associated with clinical MTBI outcomes over time.	**Design** Cohort study, two-stage longitudinal design (follow-up to article 5). Face-to-face, telephone and questionnaires. **Sampling method** Opportunity sample **Sample characteristics** *N* = 147. M_{age} = 41.8 years, *SD* = 15.7. 44.2% male. SRC *n* = 28. **TBI severity in sample** Mild **Inclusion criteria** -Sustained a MTBI within the preceding 3 months -Aged 16 or older -No previous history of severe traumatic brain injury or significant comorbid health conditions such as cardiovascular disease or neurological disorder	-Demographic questionnaire -Dichotomous outcome rating scale -Hospital Anxiety and Depression Scale -Illness Perception Questionnaire-revised (modified) -Rivermead Head Injury Follow Up Questionnaire -Rivermead Post-concussion Symptoms Questionnaire	many symptoms to MTBI, stronger beliefs about the injury identity, severity of expected consequences, expected duration of symptoms and emotional impact) had greater odds of poor outcome six months later. This is consistent with Leventhal's CSM model. Over time, participants changed their perception of the impact of MTBI and appeared to see the injury as more serious than they did earlier following injury, regardless of outcome. Recovery following MTBI can be influenced by psychological factors during both the sub-acute recovery period, and also over time.	(though not explicitly stated). **-**Longitudinal design. **Stated limitations** -Potential for recruitment bias and underestimation of mild injuries. -Results may be specific to MTBI and not be generalised to wider trauma groups. -Self-report could have meant reporting bias. -Possible influences of litigation factors. -Measures used may not have been appropriate. -Iatrogenic effects may have confounded results over time. **Global EPHPP**

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		Exclusion criteria -If there had been significant additional injuries sustained in the same accident which might make it difficult for participants to discriminate between their various injury symptoms -If retrospectively reported post-traumatic amnesia was the only criterion used for determining MTBI			**quality rating:** Moderate
7. Weber and Edwards (2010)	To investigate the influence of the terms concussion, mild traumatic brain injury and minor head injury on injury outcome expectations, familiarity and actual symptom reporting in university athletes.	**Research location** UK **Design** Between-group design. Pseudo-random group allocation. Group-testing for data collection. Control group mentioned but not clear. **Sampling method** Opportunity sampling **Sample**	-Hospital Anxiety and Depression Scale -Pain scale -Positive and Negative Affectivity Scale -Rivermead Post Concussion Symptoms Questionnaire -Terminology questionnaire	Terminology was significantly associated with familiarity and understanding of symptoms associated with sport concussion, MTBI or MHI. The term MTBI was less familiar to participants, with more negative associated injury outcome expectations. However, MTBI-related expectations were more accurate than those for	**Stated strengths** -Not stated. **-**Findings represent potentially important implications for athletic education in sport brain-injury. **Stated limitations** -Participants who did not identify with an injury terminology may have subsequently

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		characteristics University students from university sports teams or School of Sport and Exercise Sciences. Primarily undergraduate students. *N* = 224, M_{age} = 19.9, *SD* = 2.34, 58% female. Estimated 57.6% of sample contact sport players. Estimated 34.8% of sample experienced MTBI (not stated - calculated from figures in article). **TBI severity in sample** Not clearly stated. "None" and "mild" groups mentioned in text. **Inclusion criteria** Not stated **Exclusion criteria** Not stated		the term concussion. There are implications on the use of different terminology in educational programmes. No significant effect of terminology on psychological measures of subjective symptoms, anxiety, depression, positive affect, negative affect and pain for participants with or without a self-reported history of sport concussion, MTBI or MHI.	failed to self-report accurate injury history. -Participants who reported MTBI may have possessed superior knowledge than other participants. **Global EPHPP quality rating:** Weak
8. Edmed and	To determine the influence of	**Research location** Australia	-Demographic questionnaire	Perceptions of injury cause can play a	**Stated strengths** -Not stated.

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
Sullivan (2014)	cause of injury, personal knowledge, and expectations of symptoms on beliefs and expectations around MTBI recovery in contact and non-contact sports players	**Design** Between-groups cross-sectional design. Random group allocation **Sampling method** Opportunity sampling **Sample characteristics** Undergraduate university students. *N* = 224. *n* = 185 non-contact sport (M_{age} = 21.89, *SD* = 6.00, 81.5% female). *n* = 59 contact-sport (M_{age} = 20.75, *SD* = 4.59, 69.5% female) **TBI severity in sample** None. **Inclusion criteria** Not stated. **Exclusion criteria** Four medical history criteria. Answering "Yes" = excluded.	-Illness Perception Questionnaire-revised -Mild Brain Injury Atypical Symptoms Scale -MTBI experience questionnaire -Neurobehavioural Symptom Inventory -Perceived undesirability scale -Post-experimental questionnaire -PTSD Checklist-Civilian -Vignettes	significant role in expectations of symptoms or recovery processes. Contact sport participation did not account for variability in MTBI beliefs or expectations. Personal knowledge of MTBI may account for some variability in MTBI beliefs or expectations.	-Provides further evidence for the need to consider the contribution of non-injury-related factors in MTBI. **Stated limitations** -Sample may not generalise to the general population or clinical samples. -Samples were disproportionately composed of females. -Small sample size for contact-sports players, who may not be represented enough in the overall sample. -Vignettes used may not represent typical sports concussions -Did not compare other MTBI causes (e.g. falls, assaults, blasts). -Risk of confounding

Article	Article aims	Design and Participants	Measures used	Main findings related SRC	Evaluation and quality assessment
		1) History of concussion (also known as minor head injury, mild traumatic brain injury, etc.). 2) Diagnosis of mental or intellectual impairment such as severe brain injury, seizures, or other neurological problems. 3) Received treatment for mental health problems by a mental health provider within 12 months 4) Received medication for a mental health problem within 12 months			variables affecting vignette responses. **Global EPHPP quality rating:** Weak

Notes. WAIS-III = Wechsler Adult Intelligence Scale, third edition
TOMM = Test Of Memory Malingering
MHI = Mild head injury
CSM = Common Sense Model (of self regulation)
M_{age} = Mean participant age
TMD and TMJ = Not specifically defined by authors. However, further searches suggest that in both cases the authors were referring to temporomandibular joint disorders

Design

Article 1 used a cohort design with pre- and post-intervention testing conducted during one sitting. Article 6 used a longitudinal cohort design. All other articles used cross-sectional designs with single testing phases and between-group analyses.

Participants

TBI severity varied across the articles: Articles 1, 5, and 6 included only mild severity. Articles 2, 3, and 4 included athletes with no head injury and athletes with MTBI. Article 7 does not clearly state severity, though indicates that participants with and without head injury history were included. Articles 2, 7 and 8 were the only articles to exclusively recruit athletes. Articles 6 conducted a six-month follow-up of article 5's sample. Article 8 used non-head-injured athletes only.

Participants were tested at a range of time-points post-injury. The earliest testing was by article 5 (within three months of injury). The latest testing was by article 1, (participants averaging four years post-injury). Articles 4 and 7 tested participants in small groups. All other articles tested participants individually.

Measures Used

Across the eight articles, 37 different measures were used, with little consistency between research groups (Table 3). All articles used self-reporting of symptoms and injury history. The authors of articles 3, 4 and 8 used unvalidated measures developed by themselves in previous studies. Articles 3, 4 and 8 used vignettes of hypothetical injuries instead of real incidents. Most articles conducted the main assessments face-to-face, with the exception of articles 5 and 6, who conducted some baseline assessments remotely (telephone or postal questionnaires).

Table 3

Measures Used in Reviewed Articles, with Descriptions of Each Measure and Supporting References as Cited by Article Authors.

Measure used	Articles	Key references provided	Summary of measure	Validated? *
Brief COPE Inventory	5, 6	Carver (1997); Carver, Scheier, and Weintraub (1989)	A modified and shortened version of the 60 item COPE Inventory, assessing different coping strategies. Instructions were modified slightly to encourage participants to consider what their usual response would be to a stressful situation	Not stated*
Brief Symptom Inventory 18	1	Derogatis (2001)	Measures psychological distress and psychiatric disorders, and provide an overall psychological distress level to monitor change	Derogatis (1994); Spitzer et al. (2011)
Controlled Oral Word Association Test	1	Benton and Spreen (1961); Sumerall, Timmons, James, Ewing, and Oehlert (1997)	Measures a participant's ability to make verbal associations with specified letters. Measures word association fluency. Participations must name words beginning with specified letters within a time limit	Ruff, Light, Parker, and Levin (1996)
Demographic questionnaire$_1$	2	Not stated	Measured demographic and head injury history	Not stated*
Demographic questionnaire$_2$	3, 4	Not stated	Demographic information, relevant medical history, and psychological history. Assesses history of head injury, psychological treatment, athletic status, chronic medical conditions, current medications, and substance use disorders	Not stated*
Demographic questionnaire$_3$	5, 6	Not stated	Collected demographic, injury and medical information, litigation or compensation problems, injury severity	Not stated*

Measure used	Articles	Key references provided	Summary of measure	Validated? *
			indicators such as GCS score, duration of post-traumatic amnesia, and imaging results (e.g. MRI or CT) if available, any other injuries sustained concurrently with MTBI, history of treatment for a psychiatric condition and/or comorbid psychiatric diagnosis, and substance use	
Demographic questionnaire[4]	8	Not stated	Collected demographic information and medical history to apply exclusions and characterise the sample	Not stated*
Dichotomous outcome rating scale	5, 6	Decision to use based on Whittaker et al. (2007), Heitger et al. (2009), Stulemeijer, Van der Werf, Borm, and Voc (2008) and Kashluba, Paniak, and Casey (2008)	Outcome following MTBI defined dichotomously (good or poor)	Not stated*
Headache Screening Questionnaire, Revised	3, 4	Lipchik (1996); Holm (1983) – unpublished	Screens for chronic headache. Used in articles with headache and depressed groups only	Not stated*
Hospital Anxiety and Depression Scale	5, 6, 7	Zigmond and Snaith (1983)	A measure of anxiety, depression and psychological distress following TBI	New Zealand Guidelines Group (2006); Whelan-Goodinson, Ponsford, and Schonberger (2009) in articles 5 and

Measure used	Articles	Key references provided	Summary of measure	Validated? *
				6. Not stated for article 7
Illness Perception Questionnaire-Revised	1, 5, 6, 8	Moss-Morris et al. (2002)	Assesses participant perceptions and beliefs about their condition/injury. Questionnaire modified for articles	Not stated*
Inventory of Depressive Symptomatology	3, 4	Rush et al. (1986)	Self-report version. Designed to assess the severity of depressive symptoms. Participants are asked to rate the severity and frequency of specific symptoms over the previous 7 days	Not stated*
Mild Brain Injury Atypical Symptoms Scale	8	Cooper, Nelson, Armistead-Jehle, and Bowles (2011)	Uses a 5-point Likert scale with five uncommon MTBI symptoms to detect symptom over-reporting	Not stated*
MTBI experience questionnaire	8	Not stated	Assesses prior knowledge of MTBI through four “yes/no” questions	Not stated*
Neurobehavioural Symptom Inventory	1, 8	Wilde et al. (2010); Cicerone and Kalmar (1995)	A self-report measure of symptoms commonly associated with PCS following MTBI	Wilde et al. (2010) in article 1. Not stated in article 8
Pain scale	7	McDowell and Newell (2003)	An 11-point analogue scale to measure pain, modified for article	Not stated*
Perceived undesirability scale	8	Sullivan and Edmed (2012b)	A 5-point Likert scale to measure a participant’s perception of the undesirability of an injury	Not stated*. Measure designed by authors of article

Measure used	Articles	Key references provided	Summary of measure	Validated? *
Positive and Negative Affectivity Scale	7	Watson, Clark, and Tellegen (1988)	Self-report measure of current feelings or average feelings over a period of time. Measures both positive and negative affect.	Watson et al. (1988)
Postconcussion Syndrome Symptom Scale	3, 4	Compiled from: Alves et al. (1993), Bohnen, Twijnstra, and Jolles (1992), Fox, Lees-Haley, Earnest, and Dolezal-Wood (1995), Gouvier, Uddo-Crane, and Brown (1988), Iverson and McCracken (1997), Mittenberg et al. (1992), Rattan, Strom, and Dean (1987), and Wong, Regennitter, and Barrios (1994)	A 97 item checklist of common neuropsychological symptoms and distractor items. Items categorised under cognitive/memory, mood/affect, somatic, metamemory, and distractor headings	Not stated*. Measure compiled by authors of article
Post-experimental questionnaire$_1$	1	Not stated	Measured whether the participants had read, understood, and “acted in a way that was consistent with” their experimental instructions	Not stated*
Post-experimental questionnaire$_2$	8	Sullivan and Edmed (2012b)	A measure of six experimental manipulation checks designed to ensure that participants have adequately understood and complied with experiment instructions	Not stated*. Measure designed by authors of article
PTSD Checklist-Civilian	8	Weathers, Litz, Herman, Huska, and Keane (1993, October)	A measure of PTSD symptoms that map onto the criteria for PTSD in the Diagnostic and Statistical Manual of	Weathers et al. (1993, October)

Measure used	Articles	Key references provided	Summary of measure	Validated? *
			Mental Disorders–Fourth Edition, Text Revision's (DSM–IV–TR)	
Rey Auditory Verbal Learning Test	1	Rey (1941); Rey (1964)	Measures short-term auditory-verbal memory, rate of learning, learning strategies, retroactive, and proactive interference, presence of confabulation of confusion in memory processes, retention of information, and differences between learning and retrieval. Participants repeat a list of 15 unrelated words. Another list of 15 unrelated words are presented. Participants must then repeat the original list, and then repeat the lists again after 30 minutes.	Delaney, Prevey, Cramer, and Mattson (1992); McMinn, Wiens, and Crossen (1988)
Rivermead Head Injury Follow Up Questionnaire	5, 6	Crawford, Wenden, and Wade (1996)	Measures functional and social outcomes following TBI. Participants rate perceived changes compared to before their injury on 10 items of everyday activities and aspects of participation such as work, leisure and social interaction	Crawford et al. (1996)
Rivermead Post-concussion Symptoms Questionnaire	5, 6, 7	King, Crawford, Wenden, Moss, and Wade (1995)	Self-report symptom inventory comprising of 16 common symptoms following MTBI. Participants rate the presence and problem status of each symptom on a scale of 0-4.	King et al. (1995)
Screening questionnaire	1	Not stated	Online screening questionnaire for inclusion and exclusion criteria	Not stated*
Structured Diagnostic Interview for Headache, Brief Version$_1$	3	Holroyd and French (1995) – unpublished	Not stated. Screens for chronic headache. Used in article with headache groups only	Not stated*

Measure used	Articles	Key references provided	Summary of measure	Validated? *
Structured Diagnostic Interview for Headache, Brief Version[2]	4	Penzien and Holroyd (1991)	Identifies prodromal symptoms, location and onset of pain, duration and frequency of headaches, associated symptoms, medication, and relevant medical history. Used in articles with headache groups only	Not stated*
Symptom checklist[1]	2	Mittenberg et al. (1992)	A 30 item checklist of symptoms related to post-concussion complaints including memory difficulties, affective and somatic symptoms, and difficulties with attention and concentration	Mittenberg et al. (1992)
Terminology questionnaire	7	Not stated	Three versions, differing only in key condition terminology (concussion, mild traumatic brain injury or minor head injury). Measured familiarity with terminology used, outcome expectations, and indicators of injury	Not stated*
Test Of Memory Malingering	1	Tombaugh (1996)	A visual recognition test designed to distinguish between malingered and true memory impairments	Greve, Ord, Curtis, Bianchini, and Brennan (2008); Wisdom, Brown, Chen, and Collins (2012)
Trail Making Test	1	Reitan (1958); Bowie and Harvey (2006)	Measures visual search speed, scanning, speed of processing, mental flexibility, and executive functioning. Participants are required to draw lines to sequentially connect letters or numbers on a page, depending on instructions	Not stated*

Measure used	Articles	Key references provided	Summary of measure	Validated? *
Variable instructions	2, 3, 4	N/a	Variable instructions given to participants depending on treatment condition.	N/a
Vignettes$_1$	3, 4	Mittenberg et al. (1992)	Written vignette describing an automobile accident. Participants asked to imagine they were in the accident	Not stated*
Vignettes$_2$	8	Sullivan, Edmed, and Cunningham (2013) based on Mittenberg et al. (1992)	Written vignettes describing an automobile accident and a sporting accident. Participants asked to imagine they were in the accident	Not stated*. Measure designed by authors of article
WAIS-III Digit Span (forward and backward)	1	Wechsler (1997a); Wechsler (1997b)	Measures working memory, attention, encoding, and auditory processing. Participants must recall a series of numbers in order	Tulsky and Zhu (1997)
WAIS-III Symbol Coding and Symbol Search	1	Wechsler (1997a); Wechsler (1997b)	Symbol search measures processing speed. Participants must indicate the presence or absence of specific symbols from rows of symbols within a time limit Symbol coding measures processing speed, associative memory, and graphomotor speed. Participants must identify and write down specific symbols corresponding to specific digits, within a time limit. Based on the digit symbol substitution test	Tulsky and Zhu (1997)

Note: *Validation references are those cited as additional articles by author regarding validation/reliability statistics. Where articles did not provide reference to validation statistics, these are listed as “not stated”. Validation/reliability statistics may be available in the literature.

Method of Analysis

Articles 1-6 and 8 used parametric statistical measures, including t-tests and analysis of variance (ANOVA). All articles used some nonparametric tests, including chi-square, Mann-Whitney *U* and Kruskal-Wallis tests. Associations were mainly evaluated using Pearson's correlations. Article 6 also used logistic regression. Article 7 used nonparametric measures only (chi-square and Munzel-Brunner test). Articles 5 and 6 did not differentiate SRC data from non-sporting head injury data.

Power calculations were not presented by any articles. Article 6 stated that "a priori power analysis estimates suggested adequate power", but no values were presented.

Results of Individual Articles

Article 1 (Blaine et al., 2013) gave groups of athletes differing questionnaire instructions to induce or minimise diagnosis threat to explore associations with MTBI and PCS outcomes. No effects were found of diagnosis threat on performance on a battery of tests, leading the authors to query the usefulness of considering diagnosis threat as a predictor of poor-outcome following sporting MTBI.

Article 2 (Ferguson et al., 1999) aimed to identify whether head-injured athletes underestimated pre-injury symptoms to maintain perceptions of post-injury deficits. Head-injured participants were asked to imagine current symptoms and symptoms prior to their injury. Controls estimated "pre-injury symptoms", as if they had experienced SRC six months previously. The results suggested that SRC history did not significantly affect current PCS symptom reports. However, head-injured athletes underestimated premorbid symptoms even with no objective post-injury symptom increase. The authors concluded that this was

indicative of a subjective overestimation of pre- to post-injury symptom change, consistent with the athletes' injury expectations.

Articles 3 and 4 were conducted by the same research team to explore the predictive powers of EE and GODB on PCS. In article 3 (Gunstad & Suhr, 2001), non-head-injured athletes, depressed participants and controls read a motor-vehicle-accident vignette and reported expected symptoms. Head-injured athletes, headache sufferers and additional controls were asked about historical symptoms. Non-head-injured athletes expected fewer symptom increases than controls or depressed individuals, and endorsed fewer current symptoms than depressed individuals. Headache sufferers and head-injured athletes reported fewer premorbid symptoms than current, though at the same rate as controls. This was inconsistent with Mittenberg et al. (1992) and Ferguson et al. (1999; article 2), suggesting EE may be too specific to be relied on to explain symptom differences, and that GODB may be a more accurate explanation.

In Article 4 (Gunstad & Suhr, 2004), participants rated their symptoms, read article 3's vignettes, then re-rated their symptoms. Depressed, depressed-and-seeking-treatment and headache-and-seeking-treatment groups reported more symptoms than controls, in contrast to head-injured athletes and head-injured non-athletes. Head-injured non-athletes, depressed, depressed-and-seeking-treatment, headache, and headache-and-seeking-treatment groups all reported more current than historical symptoms, in contrast to head-injured athletes and athlete controls. Head-injured non-athletes and headache groups both underestimated historical symptoms, supporting GODB, though head-injured athletes did not underestimate premorbid symptoms. Gunstad and Suhr (2004) concluded that non-neurological factors may be more related to PCS symptom reporting than head injury status and that both EE and GODB

hypotheses could account for the symptom reports.

Articles 5 and 6 consider Leventhal's Common Sense Model (Leventhal, Leventhal, & Cameron, 2001) as an alternative method of understanding MTBI outcomes. In Article 5, Snell et al. (2011) establish baseline data for Article 6 (Snell et al., 2013). Participants completed a battery of psychometric tests and were rated for "good"/"poor" injury outcome. Participants with poor outcomes endorsed more symptoms, greater social and functional problems, greater distress, stronger beliefs about symptom severity and predictability, and poorer overall understanding of their injury. Article 6 presents a six-month follow-up of the sample. Participants who endorsed unhelpful perceptions/expectations about their injury at baseline had poorer outcome at follow-up. The authors concluded that Leventhal's Common Sense Model could have clinical applicability for predicting individuals at risk of poor outcome. Recovery following MTBI can be influenced by psychological factors during sub-acute recovery, and also over time. SRC and non-SRC injuries were both represented in the sample, but not analysed separately so similarities or differences between injury-types are unknown.

Article 7 (Weber & Edwards, 2010) used questionnaires varying in terminology to examine the influence of the terms concussion, MTBI, and MHI on injury outcome expectations, familiarity and symptom reporting in athletes. Terminology was not found to significantly influence symptom reporting, but significantly influenced expected outcomes and injury familiarity. MTBI (the least familiar term) was associated with poorer outcome expectations than MHI or concussion. MHI was endorsed as being more "part of contact sports" than concussion or MTBI. The authors recommended further research and increased educational programmes around the symptoms/effects of brain injury.

Article 8 (Edmed & Sullivan, 2014) was conducted by the same research team as Article 1. Contact- and non-contact-sport athletes with no history of head injury read vignettes about a sport-related MTBI and a motor-vehicle-accident-related MTBI, before rating their beliefs about the injury. The motor-vehicle-accident-related MTBI was associated with significantly more negative beliefs, expectations of greater post-traumatic-stress-disorder and greater PCS affective symptomology, suggesting perceptions of injury cause can play a significant role in symptom expectations or recovery processes. Contact-sport participation did not affect outcomes.

Article Quality (EPHPP)

Article 6 (Snell et al., 2013) received an EPHPP global quality rating of “moderate”. The other seven articles were rated as “weak”. Weaknesses were mainly related to selection bias, study design, and/or data collection method.

Risk of Article Bias

All articles used self-reporting of symptoms and history from participants. Self-reporting in MTBI is known to be influenced by treatment-seeking behaviour, or litigation procedures, which could have affected participant self-reports, resulting in inaccurate data (Lange, Iverson, & Rose, 2010). The research teams behind articles 2, 4 and 8 used their own measures, which may have increased the risk of supporting the accuracy and validity of their measures. Article 6 followed up from Article 5, which had already been published. This could have created pressure to maintain consistency with the original results.

Discussion

This review is the first to investigate the extent to which psychological theories of etiology in MTBI outcome have been investigated within SRC. Clear associations have been identified between athlete expectations around their

injury recovery and perceived/observed symptoms. However, a number of methodological issues and inconsistent results across the reviewed articles highlights the need for further research with athletes in order to more clearly understand how these factors affect this high-risk population. Due to the lack of longitudinal studies that met inclusion criteria, it is difficult to draw causal relations in the literature.

Review Question 1: To what extent have etiological theories been considered in the context of athletes and SRC outcome?

In non-sporting MTBI, there is growing acceptance into the utility of using psychological etiology models. In sports this focus is relatively sparse considering the amount of research into SRC and PCS. Psychological theories such as EE, GODB or CSM have clear applications in aiding our understanding of recovery patterns post-MTBI, and from the limited research available they appear to provide a potential understanding of SRC-recovery. There does not appear to be any further development of the theories that specifically measure athlete/sporting populations. Further longitudinal research is needed.

Review Question 2: Do athletes experience patterns of symptoms or recovery following SRC that differ from the general population and can be explained by etiological constructs, such as EE or GODB?

The reviewed articles indicate that expectation is a factor in symptom etiology within the sporting population. However, the effects of expectations on outcomes can be variable and similarities/differences are inconsistent when compared to non-sporting populations. Though athletes may experience different perceptions or expectations of the effects of SRC, actual symptom reports may not significantly differ from non-SRC or control reports (Gunstad & Suhr, 2001). The tendency to view oneself as healthier prior to your injury, in line with GODB,

is observable in athletes following SRC (Ferguson et al., 1999; Gunstad & Suhr, 2004). However, athletes can present different psychological profiles to non-athletes and the influence of these factors or other motivations on expectations and recovery patterns is not clear from the reviewed articles. Reliance on self-reports for diagnosis is also problematic and may lead to misdiagnosis (Gunstad & Suhr, 2004). Perceptions and expectations of SRC appear to be less negative for some athletes than non-sporting MTBI (Edmed & Sullivan, 2014). An athlete's expectations during the post-acute period regarding their potential longer-term recovery are predictive of their actual longer-term outcome/recovery (Snell et al., 2013; Snell et al., 2011). For example, athletes expecting poorer recovery are linked to actual poorer recovery, when compared to athletes expecting a good recovery. With limited longitudinal research into the potentially cyclical relationship between factors such as expectations and self-reported symptoms, causality and specific features of this relationship remain unclear.

Strengths and Weaknesses of the Literature

Strengths and weaknesses identified by article authors are described in Table 2. Article 7 identified how terminology can have a significant effect on athletes' self-identification with injuries, and expectations of symptoms and recovery outcomes (Weber & Edwards, 2010). Across the eight articles reviewed, four different head injury definitions were used, with varying terminology. Articles 3, 7 and 8 did not identify the definition/diagnostic criteria they were using. The inconsistencies in definition could mean that the articles were actually investigating and measuring different constructs (Wills & Leathem, 2001). Due to the limited number of articles that have investigated etiological theories of SRC outcome, it is important to maintain as much consistency in the field of study as possible (i.e. terminology used, assessment materials, diagnostic criteria). With

such fundamental methodological inconsistencies, quantitative comparison between articles could have limited value (Wills & Leathem, 2001).

The majority of the articles used cross-sectional designs, limiting their ability to infer causality. Due to issues with design and data collection methods, the majority of the articles were rated as “weak” using the EPHPP criteria (Effective Public Health Practice Project, 1998). The articles covered post-injury time-points ranging from under three months to over four years. Direct comparison between studies is therefore difficult, as distinctly different points of the post-injury recovery process were targeted. Exploration of similarities or differences in outcomes across the time-points could help identify a clearer map of an athlete’s recovery process. This could enable greater understanding of the appropriateness of different interventions/treatments at discrete time-points post-injury.

Strengths and Weaknesses of This Review

A potential weakness of this review is the restrictive nature of the search terms used in the original literature search, which may have limited results. Preliminary searches identified that inclusion of search terms such as “expect*” returned over 200,000 results. The search was therefore narrowed to articles utilising the most common expectation-based models. To minimise the effects of the restricted search, article reference lists and lists of articles citing key review articles were also manually searched. The Cochrane library was searched to identify any additional articles referenced through review papers. No additional articles were identified, inferring that the original search strategy may have been adequate.

Another weakness of the review is the lack of additional reviewers when performing literature searches, screening, data extraction and quality

assessments. Using only one reviewer increases the risk of bias, as it means you cannot no conduct inter-rater reliability checks. For example, reviewer bias could have meant that this review did not ascribe the appropriate degree of strength to the reviewed articles.

The majority of participants in the articles reviewed were in their late teenage years or early twenties. It is unclear whether paediatric MTBI was adequately controlled for in the reviewed articles, which may have influenced the interpretations of the review. It is also unclear whether there was any overlapping between the samples in Articles 3 and 4. A significant overlap could reduce the literature base for the research findings. If a significant overlap exists, then the literature base may be smaller than implied by the review, limiting implications and potential generalisability of the review findings.

Suggestions for Future Research

Identifying people who have experienced MTBI can difficult, and open to misinterpretation or misunderstanding of terminology. This can be complicated further in sports where knowledge and expectations around injuries may differ to the general population. Future research may wish to focus more on individual symptom-based descriptions over diagnostic labels/norms to improve identification of head-injury histories. Developing and utilising standardised methodologies across SRC assessments would aid comparison between articles or clinical cases.

Further research is recommended into the role of psychological factors in recovery from SRC, and the differences between sporting populations and general populations. SRC may be associated with fewer expected symptoms than non-sporting MTBI (Edmed & Sullivan, 2014). Further evidence is required to explore whether this is due to player perceptions, inaccurate self-reports,

methodological biases, or misconceptions in assessment. EE and GODB both imply that the injury-causing event was a negative event. However, if injuries occur within the context of a sporting event, the perception of the injury may not be as negative compared to non-sporting MTBI causes (Kit, Mateer, Tuokko, & Spencer-Rodgers, 2014). Further understanding of the differences in how athletes respond to SRC compared to non-athletes could also justify re-analysis of historical data where injury-causes were not analysed separately.

Conclusions

This review has highlighted the lack of research into the influence of expectations on SRC outcome. Expectation appears to be a key psychological factor within the sporting population. However, the effects of expectations can be variable and similarities/differences are inconsistent when compared to non-sporting populations. Etiological theories could be further developed within sports research to explain outcomes in athlete populations. With no identified high-quality longitudinal research into expectations and subjective symptom experiences, the strength of this relationship and any causality cannot be established. Caution is advised against unnecessary overestimation or over-assessment of symptoms. Further research is required in this area in order to more clearly understand the influence of psychological factors such as expectations on this high-risk population.

In clinical healthcare settings, reports of symptom type, frequency and severity are known to be affected by assessment methods (Edmed, Sullivan, Allan, & Smith, 2015; Iverson, Brooks, Ashton, & Lange, 2010). This review has highlighted that athlete perceptions of their injury and their expectations around recovery can also affect their expected and reported symptoms. When assessing athletes for SRC, care should be taken to the terminology used, and assessment

methodology, as seemingly minor variations could significantly alter outcomes and subsequent clinical decisions around diagnosis or treatment.

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Appendix A: Data extraction form

Data extraction form

Author(s):

Year: Title:

Journal: Volume: Pages:

Aim(s) of the study:

Study Design:

Sampling method (random, opportunity):

Where recruited from:

Population characteristics:

Sport-related: n =

Total: n =

TBI severity from sample: mild moderate severe

Control group? Yes/No

Matched controls: Yes/No

Inclusion criteria:

Exclusion criteria:

Power calculations presented: Yes/No Power:

Measures

Assessments/measures used (list all):

Were measures validated?

Results

Method(s) of analysis:

Adequate reporting of data, parametric assumptions:

Sports MTBI and expectation results:

Conclusions

Conclusions in relation to sports MTBI and expectations:

Conclusions in relation to expectation as aetiology:

Conclusions in relation to good-old-days bias:

Stated strengths:

Stated limitations:

Appendix B: MTBI Definitions in Articles

Table B1

Definitions of Head Injury Used by Reviewed Articles

Article	Definition source	Definition of head injury used
1. Blaine et al. (2013)	Author defined	A forceful blow to the head or any acceleration or deceleration force (i.e. whiplash) that resulted in one of the following: confusion or disorientation, loss of consciousness (< 30 minutes), posttraumatic amnesia not exceeding 24 hours, and/or other temporary neurological abnormalities (i.e. intracranial lesion not needing surgery)
2. Ferguson et al. (1999)	Head-injured group selection criteria adapted from Cook (1969)	Selection criteria: (a) Athletes responding "yes" to the screening question, "During the course of a game or match, have you ever been knocked unconscious or received a blow on the head which resulted in your being unable to remember part of the game or match?" (b) The sport-related injury occurred within 1 calendar year of completing the questionnaire (c) Post-traumatic amnesia was reported as no greater than 24 hr; and (d) Individuals must not have suffered a

		non-sport-related MHI (e.g., motor vehicle or other non-sport-related accident)
3. Gunstad and Suhr (2001)	Not defined	N/a
4. Gunstad and Suhr (2004)	Mild Traumatic Brain-injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine	One of the four following criteria needs to be met: (1) any period of loss of consciousness (2) any loss of memory for events immediately before or after the accident (3) any alteration in mental state at the time of the accident (4) focal neurological deficits (may be transient) not exceeding 30 minutes, loss of consciousness, Glasgow Coma Scale of 13–15 after 30 minutes, and post-traumatic amnesia not greater than 24 hours
5. Snell et al. (2011) and 6. Snell et al. (2013)	New Zealand Guidelines Group definition, based on WHO Collaborating Centre Task Force definition	MTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces. Operational criteria for clinical identification include one or more of the following: (1) Confusion or disorientation. (2) Loss of consciousness (for 30 minutes or less).

		(3) Post-traumatic amnesia (less than 24 hours). (4) Other transient neurological abnormalities such as focal neurological signs, seizure and intracranial lesion not requiring surgery. (5) The Glasgow Coma Scale (GCS) [31] score should be 13 or greater, 30 minutes after injury (or later upon presentation for healthcare). In addition these manifestations of MTBI must not be due to drugs, alcohol, medications, caused by other injuries (e.g. systemic injuries, facial injuries or intubation), caused by other problems (e.g. psychological trauma, language barrier, co-existing medical conditions) or caused by penetrating cranio-cerebral injury
7. Weber and Edwards (2010)	Three terms of interest are presented, but not defined.	N/a
8. Edmed and Sullivan (2014)	Not defined	N/a

Appendix C: Inclusion and Exclusion Criteria for Article 4 (Gunstad & Suhr, 2004)

Table C1

Inclusion and Exclusion Criteria for Each Respective Group, as Presented in Gunstad and Suhr (2004)

Group	Selection criteria/method	Exclusion criteria
Head Injury	HI[a]	ATH[b], DEP[c], HA[d]
Head-injured Athletes	HI, ATH	DEP, HA
Athletes	ATH	HI, HA, DEP
Depressed Treatment	DEP, TX[e]	HI, HA, ATH
Depressed No Treatment	DEP, TX	HI, HA, ATH, TX
Tension Headache Treatment	HA, TX	HI, DEP, ATH
Tension Headache No Treatment	HA	HI, DEP, ATH, TX
Controls		HI, HA, DEP, ATH

Note. Any individual reporting chronic medical problems or substance misuse was excluded from analyses.

[a] Reported history of head injury. Participants were excluded if they reported more than one episode of LOC or concussion.

[b] Athlete status was defined as participation at the intercollegiate or intramural level.

[c] Depression was defined as scores greater than 18 on the IDS.

[d] Tension Headaches were defined using the Headache Screening Questionnaire and the Diagnostic Interview for Headaches.

[e] Treatment seeking was defined as current receipt of psychological/pharmacological intervention for depression or headaches.

Appendix D: Instructions for Contributors: Journal of the International Neuropsychological Society

Aims and Scope The *Journal of the International Neuropsychological Society* is the official journal of the *International Neuropsychological Society*, an organization of over 4,500 international members from a variety of disciplines. The *Journal of the International Neuropsychological Society* welcomes original, creative, high quality research papers covering all areas of neuropsychology. The focus of articles may be primarily experimental, applied, or clinical. Contributions will broadly reflect the interest of all areas of neuropsychology, including but not limited to: development of cognitive processes, brain-behavior relationships, adult and pediatric neuropsychology, neurobehavioral syndromes (such as aphasia or apraxia), and the interfaces of neuropsychology with related areas such as behavioral neurology, neuropsychiatry, genetics, and cognitive neuroscience. Papers that utilize behavioral, neuroimaging, and electrophysiological measures are appropriate.

To assure maximum flexibility and to promote diverse mechanisms of scholarly communication, the following formats are available in addition to *Regular Research Articles: Brief Communications* are shorter research articles; *Rapid Communications* are intended for ‘‘fast breaking’’ new work that does not yet justify a full length article and are placed on a fast review track; *Neurobehavioral Grand Rounds* are theoretically important and unique case studies; *Critical Reviews* and *Short Reviews* are thoughtful considerations of topics of importance to neuropsychology, including associated areas, such as functional brain imaging, genetics, neuroepidemiology, and ethical issues; *Dialogues* provide a

forum for publishing two distinct positions on controversial issues in a point-counterpoint format; *Symposia* consist of several research articles linked thematically: *Letters to the Editor* respond to recent articles in the *Journal of the International Neuropsychological Society*; and *Book Reviews*. *Critical Reviews, Dialogues,* and *Symposia* are typically invited by the Editor-in-Chief or an Associate Editor. *Book Reviews* are considered but are no longer solicited.

Originality and Copyright To be considered for publication in the *Journal of the International Neuropsychological Society*, a manuscript cannot have been published previously nor can it be under review for publication elsewhere. Papers with multiple authors are reviewed with the assumption that all authors have approved the submitted manuscript and concur with its submission to the *Journal of the International Neuropsychological Society*. A Copyright Transfer Agreement, with certain specified rights reserved by the author, must be signed and returned to the Editor-in-Chief by the corresponding author of accepted manuscripts, prior to publication. This is necessary for the wide distribution of research findings and the protection of both author and the society under copyright law. If you plan to include material that has been published elsewhere and is under copyright of a third party, you will need to obtain permission to re-use this material in your article. A form may be provided for this purpose by the editorial office. Alternatively, many publishers use an online system for such requests. It is the responsibility of the authors to obtain permissions to re-use material from elsewhere. For information regarding rights and permissions concerning the *Journal of the International Neuropsychological Society*, please contact Marc Anderson (manderson@cambridge.org) or Adam Hirschberg (ahirschberg@cambridge.org).

Disclosure Potential conflicts of interest include funding sources for the reported study (e.g., a test validation study financially supported by a test publisher, a study supported by an insurance company), personal or family financial interest in a test or product or with a company that publishes a test that is being investigated in the manuscript or competes with a test that is being investigated in the manuscript. Other conflicts include employment, consultancies, stock ownership or medicolegal work. For the latter, information about whether the author's medicolegal work is largely for one side should be reported. This list of potential conflicts is not all inclusive, and it is the responsibility of each author to ensure that all of their ''potential conflicts'' are reported in the Acknowledgment section of the paper.

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SCHOOL OF PSYCHOLOGY

DOCTORATE IN CLINICAL PSYCHOLOGY

EMPIRICAL PAPER

Do concussion dosage, gender or reported symptoms affect long-term cognitive performance and stop-signal reaction times following sports-related concussion/MTBI in university rugby players?

Trainee Name:	**James Broughton**
Primary Research Supervisor:	**Professor Huw Williams** Associate Professor of Clinical Neuropsychology, Co-Director – Centre for Clinical Neuropsychology Research (CCNR), University of Exeter
Secondary Research Supervisor:	**Dr Philip Yates** Chartered Clinical Psychologist and Clinical Neuropsychologist, University of Exeter
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Abstract

Objective: The long-term cognitive effects of mild traumatic brain injury (MTBI) and sport-related concussion (SRC) are not always clear. Higher-level longer-term cognitive difficulties can indicate enduring neurological damage, as part of a post-concussion syndrome (PCS). This study aimed to investigate whether cognitive performance and self-reported PCS symptoms of athletes (rugby players) relate to SRC and whether gender moderates these effects.

Method: Eighty-six participants completed a questionnaire detailing SRC history (frequency and severity) and rated long-term symptoms using the Sport Concussion Assessment Tool 3 (SCAT3) symptom evaluation scales, before completing the CogState Brief Battery and STOP-IT (stop-signal response inhibition task).

Results: No significant relationships between SRC dosage (frequency/severity), self-reported PCS symptoms, and cognitive test performance were identified. A greater proportion of males reported SRC compared to females, but no effect of gender was found on any of the cognitive outcome measures or self-reports of PCS symptoms.

Conclusions: The results show that SRC has no observable long-term effects on cognitive test performance or PCS symptom self-reports. The analysis may have lacked power to detect effects. Analysis of individual performance over time against baseline scores may be more relevant for accurate diagnosis than relying on normative test scores. Recommendations for future research were made.

Keywords: *mild traumatic brain injury, mild head injury, expectation as etiology, good-old-days, post-concussion syndrome*

Introduction

Historically, mild traumatic brain injury (MTBI) has been understood as a temporary condition with symptoms usually resolving within hours or days (Williams, Potter, & Ryland, 2010). Research evidence is increasingly suggesting that MTBI could be a chronic condition, with links to longer-term conditions such as post-concussion syndrome (PCS), chronic-traumatic encephalopathy (CTE) and dementia (American Psychiatric Association, 2013). MTBI can result in long-term neurological changes and disruption to brain networks (Bonnelle et al., 2012; Mayer et al., 2012). However, evidence for long-term cognitive effects is often mixed, particularly within sports-based research. There is also limited investigation into gender effects in MTBI (Cancelliere, Donovan, & Cassidy, 2016). Therefore, in this study we aim to investigate whether cognitive performance and self-reported PCS symptoms of athletes (rugby players) relate to sport-related concussion (SRC) and whether these effects are moderated by gender.

Traumatic Brain Injury (TBI)

A TBI is an injury to the brain caused through a sudden impact to the head or body that results in rapid movement or displacement of the brain within the skull. TBI is regarded as one of the leading causes of death and disability in the developed world (Thurman, Alverson, Dunn, Guerrero, & Sniezek, 1999; Yates, Williams, Harris, Round, & Jenkins, 2006). Symptoms following TBI can vary significantly between individuals who survive the injury, but can include loss of consciousness (LOC), headaches, dizziness, visual deficits, attention or memory difficulties and other cognitive impairments, difficulties with mood or anxiety, behavioural problems such as apathy or impulsivity, and/or movement disorders such as muscle weakness or paralysis (American Psychiatric Association, 2013;

Arciniegas, Anderson, Topkoff, & McAllister, 2005). Incidence rates of TBI in Western countries are 180-250 per 100,000 people (Yates et al., 2006).

Mild Traumatic Brain Injury (MTBI)

Classification of TBIs can vary depending on the diagnostic criteria used, with approximately 70-80% of TBI cases being classified as “mild” injuries (Arciniegas et al., 2005). However, within the literature there are inconsistencies regarding the terms used (i.e. MTBI; SRC; mild head injury [MHI]), and disagreement over diagnostic criteria, symptoms and etiology (Bigler, 2008; Williams et al., 2010). Common causes include motor-vehicle-accidents, falls, assaults, and sports. Contact sports such as rugby, hockey, boxing, and American football expose players to high SRC risk (Brooks, Fuller, Kemp, & Reddin, 2005; Cantu, 1996; Gardner et al., 2014; Tommasone & Valovich McLeod, 2006).

MTBI can be seen as a spectrum disorder and measured by injury “dosage”; the number of concussive-incidents experienced, or severity of key acute symptoms (e.g. post-traumatic or retrograde amnesia, or LOC duration). LOC duration is often used by clinical tools as a measure of severity. However, up to 89% of SRCs can occur without LOC and risk being undetected or unreported, making accurate diagnosis difficult (Daneshvar, Nowinski, McKee, & Cantu, 2010; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004).

Cognitive Effects of MTBI

The most commonly reported MTBI symptoms are headaches, dizziness, and memory or other cognitive difficulties (McCrea, 2008; Schretlen & Shapiro, 2003). Cognitive effects resulting from MTBI/SRC can often be observed immediately post-injury, though as time progresses (e.g. days, weeks or months), any ongoing effects can become difficult to detect (Echemendia, Putukian,

Mackin, Julian, & Shoss, 2001; Iverson, 2005). Long-term cognitive effects, (if present) can be subtle, leading to some suggestions that there are minimal effects on cognitive performance six-months to a year post-injury (Echemendia et al., 2001; Losoi et al., 2016; Schretlen & Shapiro, 2003). Impaired performance on response inhibition and divided attention tasks has been documented three months post- MTBI (Wall et al., 2006). Long-term impairment has been observed one-year post-MTBI (Dean & Sterr, 2013) and further study is generally recommended.

Acute neurological effects of MTBI

Neuroimaging techniques are increasingly used to analyse neurological changes post-MTBI. The development of more sensitive methods (e.g. diffusion tensor imaging) allows clearer identification of neurological damage such as diffuse axonal injuries in white matter tracts (Shenton et al., 2012). During a TBI or MTBI incident, the brain rapidly shifts within the skull in a shearing motion (Zhang, Yang, & King, 2004). Accelerative or decelerative brain movement in TBI may occur in any direction, resulting in significant linear and rotational forces (Moore, Jaffee, & Ling, 2012). A subsequent neurometabolic cascade[1] can cause delayed effects (e.g. haemorrhaging lesions, haematoma and swelling) for days or weeks following MTBI (Giza & Hovda, 2001; Le, Stiver, & Gean, 2012). Further impacts during this time cause progressive axonal injuries and white matter tract damage due to a post-concussive vulnerability (Harmon et al., 2013; Schatz, Moser, Covassin, & Karpf, 2011).

The brain can be thought of as a mass of interconnecting and intercommunicating networks. Efficient organisation and coordinated

[1] Neurometabolic cascade: Neurological events following traumatic injury characterised by events such as nonspecific depolarization/initiation of action potentials, release of neurotransmitters, efflux of potassium, increased ionic pump activity and initiation of apoptosis/cell death (Giza & Hovda, 2001).

communication within and between these networks is thought to facilitate efficient decision making and behavioural responses, though how the networks interact is not fully understood (Bonnelle et al., 2012). Persisting difficulties with high-level cognitive functions have been shown following MTBI (Fakhran, Yaeger, Collins, & Alhilali, 2014) and TBI (Kinnunen et al., 2011), suggesting neurological disruption to pathways linking brain regions within networks.

One key network (the salience network [SN][2]) is activated by attention-demanding cognitive tasks, and separates relevant internal and external stimuli to guide appropriate behavioural responses (Menon & Uddin, 2010). The SN is thought to regulate changes in other networks, particularly the default mode network (DMN). The DMN is often active whilst a person rests, processing internal states, memories and thoughts. It is less active in response to SN activation. The DMN can be sensitive even to sub-concussive head trauma, with neurological and cognitive symptoms suggesting observable DMN disruption in athletes regardless of SRC history (Bazarian, Zhu, Blyth, Borrino, & Zhong, 2012; Broglio, Eckner, Paulson, & Kutcher, 2012; Johnson, Neuberger, Gay, Hallett, & Slobounov, 2014). This raises further questions regarding the reliability of SRC identification and diagnostic methods.

Neurological damage from MTBI is thought to interfere with coupling between brain areas, causing imbalances between networks (Sours et al., 2013). This results in inefficient cognitive control/regulation of brain activity and subsequent motor control or decision making. Efficient inhibitory control is associated with rapid DMN deactivation (Bonnelle et al., 2012). This deactivation can be impaired following MTBI, suggesting disconnection between the SN and

[2] Salience network: A large-scale paralimbic–limbic network anchored in the anterior insula and dorsal anterior cingulate cortex with prominent subcortical nodes in affect and reward processing systems (Menon, 2015).

DMN and increased resources required (e.g. increased frontal lobe activation) to direct attention (Mayer et al., 2012). Abnormalities in DMN functioning can be specifically predicted by the amount of white matter damage observed across the SN (Bonnelle et al., 2012). SN structural integrity is therefore assumed necessary for efficient DMN activity regulation. Poor regulation results in inefficient cognitive and inhibitory control, which can be observed through difficulties on tasks of executive functions, such as stop-signal paradigms.

Stop-signal paradigms measure automatic response inhibition (Band, van der Molen, & Logan, 2003). Participants generate or inhibit responses to stimuli depending on the presence or absence of “stop-signals”. Response inhibition is a sensitive indicator of efficient executive functioning, as multiple cognitive systems need to work together efficiently to withhold responses (Verbruggen & Logan, 2008a, 2008b, 2009). Despite growing use in clinical and research settings, there is limited application of stop-signal paradigms in identification of SRC.

Long-term neurological and neuropsychological effects of MTBI

Progressive white matter changes can be observed for at least four years post-TBI, suggesting a chronic disease-state with potentially lifelong impairments of cognitive and neurological functioning (Bigler, 2013b; Farbota et al., 2012). However, reviews of the literature indicate that the long-term effects of MTBI are still not clearly understood (Williams et al., 2010). Delayed memory, new learning, and areas of executive function appear to be acutely affected, though memory and learning can recover within days or weeks (Belanger & Vanderploeg, 2005; Schretlen & Shapiro, 2003). Areas of executive function can be adversely affected longer-term (Wall et al., 2006). Though there can be many biological, social and psychological contributors to ongoing executive dysfunction, one

theory is that following MTBI, ongoing executive dysfunction could be an indicator of enduring neurological damage. Repeat MTBIs can result in long-term deficits to executive functions of inhibitory control or divided attention long after other cognitive abilities have recovered (Karr, Areshenkoff, & Garcia-Barrera, 2014). Changes to brain activity levels during tasks can continue to be observed post-MTBI even when cognitive abilities appear to have recovered (Chen et al., 2012).

Post-concussion syndrome (PCS). Some individuals develop a post-concussion syndrome (PCS) following MTBI, where symptoms persist for months or years (Alves, Macciocchi, & Barth, 1993; Ruff, Camenzuli, & Mueller, 1996; Williams et al., 2010). PCS is a collection of persistent symptoms, including physical (e.g. headaches, fatigue), psychological (e.g. anxiety, emotional difficulties), and cognitive (e.g. short term memory difficulties, attention or concentration difficulties). The most commonly reported persisting symptoms are depression and cognitive impairment (Silver, McAllister, & Arciniegas, 2009). PCS incidence is unclear, with approximately 15-47% of people experiencing PCS for months or years post-injury (Ruff et al., 1996; Williams et al., 2010). PCS is associated with psychological factors such as depression, trauma or expectation biases (Broshek, De Marco, & Freeman, 2015; Ferguson, Mittenberg, Barone, & Schneider, 1999; Gunstad & Suhr, 2001; Losoi et al., 2016). Persisting symptoms can indicate enduring neurological damage, though the associations between PCS symptoms, and persisting neurological and neuropsychological damage are not always clear (Broughton, 2016).

Gender and MTBI/SRC

Gender effects on cognitive functioning after MTBI are not well understood, with limited research examining gender and SRC (Covassin & Bay, 2012; Covassin & Elbin, 2011). Female athletes are at higher risk of SRC

compared to males in many sports (Covassin, Swanik, & Sachs, 2003; Gessel, Fields, Collins, Dick, & Comstock, 2007; Harmon et al., 2013; Laker, 2011). There also appears to be a greater propensity for poorer outcome for females than males: Female gender is associated with increased risk of PCS (Bazarian, Blyth, Mookerjee, He, & McDermott, 2010; Broshek et al., 2005; Covassin, Elbin, Larson, & Kontos, 2012) and could be a significant vulnerability factor in developing permanent PCS (King, 2014). Female athletes also endorse more symptoms at baselines and follow-up (Covassin et al., 2006; Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009). However, the increased PCS risk cannot always be explained by gender-biases in symptom reporting, or sport-characteristics (Preiss-Farzanegan et al., 2009). Furthermore, the effects of gender are mixed when considering specific symptoms (Covassin, Schatz, & Swanik, 2007).

There is mixed evidence for gender effects on cognitive performance following SRC. Female athletes can have greater verbal memory difficulties following SRC (Covassin & Bay, 2012; Covassin et al., 2007) and a greater performance decrease on reaction time tasks following SRC than matched males (Broshek et al., 2005). However, other research has found no significant overall effect of gender on cognitive performance following SRC (Covassin et al., 2007).

There is limited and mixed evidence for the role of gender-specific hormones such as estrogen and progesterone acting as neuro-protective factors following TBI (Bazarian et al., 2010; Davis et al., 2006; Roof, Duvdevani, & Stein, 1993). Injuries that disrupt the production of estrogen or progesterone in females of child-bearing ages can also reduce the neuroprotective effect of these hormones and even result in “withdrawal” effects (Bazarian et al., 2010; Davis et al., 2006).

Gender differences in hemispheric structure/organisation of the brain may account for some differences in outcomes. Females show reduced damage to white matter integrity in the ucinate faciculus (UF) compared to males following TBI (Fakhran et al., 2014), which can also be associated with variations in memory performance in healthy individuals and also post-MTBI. The UF is a bidirectional white matter tract that connects the lateral orbitofrontal cortex and anterior temporal lobe. Fakhran et al. (2014) note that the UF also connects hippocampus and the frontal cortex – two extrahypothalamic brain regions where the classic progesterone receptor is expressed. They explain that progesterone in the brain can result in neuroprotective signalling, enabling neurones to better withstand damage. If these areas are more intact in females than males following MTBI, Fakhran et al. suggest that this may be evidence of the protective effects of progesterone, but that further research is warranted to determine what the relationship is between progesterone and hippocampal status. Indeed, a very recent World Health Organization review also concluded that gender has not been well-studied as a prognostic indicator for MTBI outcomes (Cancelliere et al., 2016). More research reporting outcomes according to gender was recommended.

Objectives of Current Research

To further understand the longer-term effects of SRC and the influence of gender, this research aims to investigate aspects of cognitive performance and self-reported symptoms of PCS in rugby players. Specifically, we aim to identify whether a stop-signal paradigm could be an effective way to identify possible long-term cognitive changes resulting from SRC, in the absence of measurable performance deficits on more simple cognitive screening tasks. This neuropsychological evidence may indicate axonal injury or white matter tract

damage. The research also aims to provide further evidence that patients with higher historical SRC dosage are more susceptible to presenting more enduring symptoms as the beginnings of PCS.

Hypotheses

1. Higher historical SRC dosage, as measured by (a) frequency (number of SRC events) and (b) severity (the longest reported LOC duration following SRC), will be associated with impairment (i.e. slowed responses) on a stop-signal response inhibition task. This association will be moderated by gender, with female players displaying poorer performance relative to male players.
2. Higher historical SRC dosage will be associated with higher levels of self-reported post-concussive symptoms. This association will be moderated by gender, with female players reporting higher levels of post-concussive symptoms than male players.
3. Higher current levels of self-reported post-concussive symptoms will be associated with impairment (slowed responses) on a stop-signal response inhibition task. This association will be present in the absence of any associations between CogState task performance and self-reported post-concussive symptoms.

Methods

Design

This research was a cross-sectional study, utilising a single testing session. This enabled controlled testing conditions standardised across all participants. For hypothesis 1, the independent variables were SRC history (frequency and severity). The five dependent variables were five cognitive test scores. For hypothesis 2, the independent variables were SRC history (frequency

and severity) and the dependent variable was a self-reported PCS score. For hypothesis 3, the self-reported PCS score and cognitive test scores were used as correlation variables.

Participants

Participants were recruited from the male and female University of Exeter rugby clubs. In total, *N* = 86 players participated in the research, (*n* = 53 male and *n* = 33 female), representing 16.88% of the male club and 55.93% of the female club. Participants were aged between 18 and 30 years old (*M* = 20.14, *SD* = 1.98). Eighty valid profiles were retained for the main analysis (full demographics in Results section). Participants recruited to this study would have had to meet the university's academic criteria in order to gain access to courses and sports teams. This indicates average or above average intellectual ability (Barona, Reynolds, & Chastain, 1984; Crawford et al., 1989; Matarazzo & Herman, 1984).

Recruitment Procedure

All players received a verbal briefing during pre-season training sessions and were approached individually via email during the next four months. Entry into a prize draw for Amazon.co.uk gift-vouchers was offered in exchange for participation. Players were excluded if they met exclusion criteria (Table 1). The recruitment process is detailed in Figure 1.

Table 1

Exclusion Criteria for Eligibility for Participation

Participant exclusion criteria.
Not fluent in English.
Sustained MTBI within six weeks of participation.
Not studying at the university.

Diagnosis of learning disability or intellectual disability, with the exception of dyslexia.
Past TBI classified as moderate or severe in severity.
“Complex” MTBI with LOC 10 minutes or more.
Current mental health difficulties warranting current treatment (therapy or medication).
Involvement in litigation procedures following MTBI.
History of acquired non-traumatic brain injury (e.g. stroke, hypoxic or anoxic brain injury, infection, poisoning, encephalopathy, substance abuse).
Non-sporting head injuries.
Damage to brain through neurodegenerative disorder (e.g. Parkinson’s disease, dementia, Huntington’s disease, motor neurone disease).

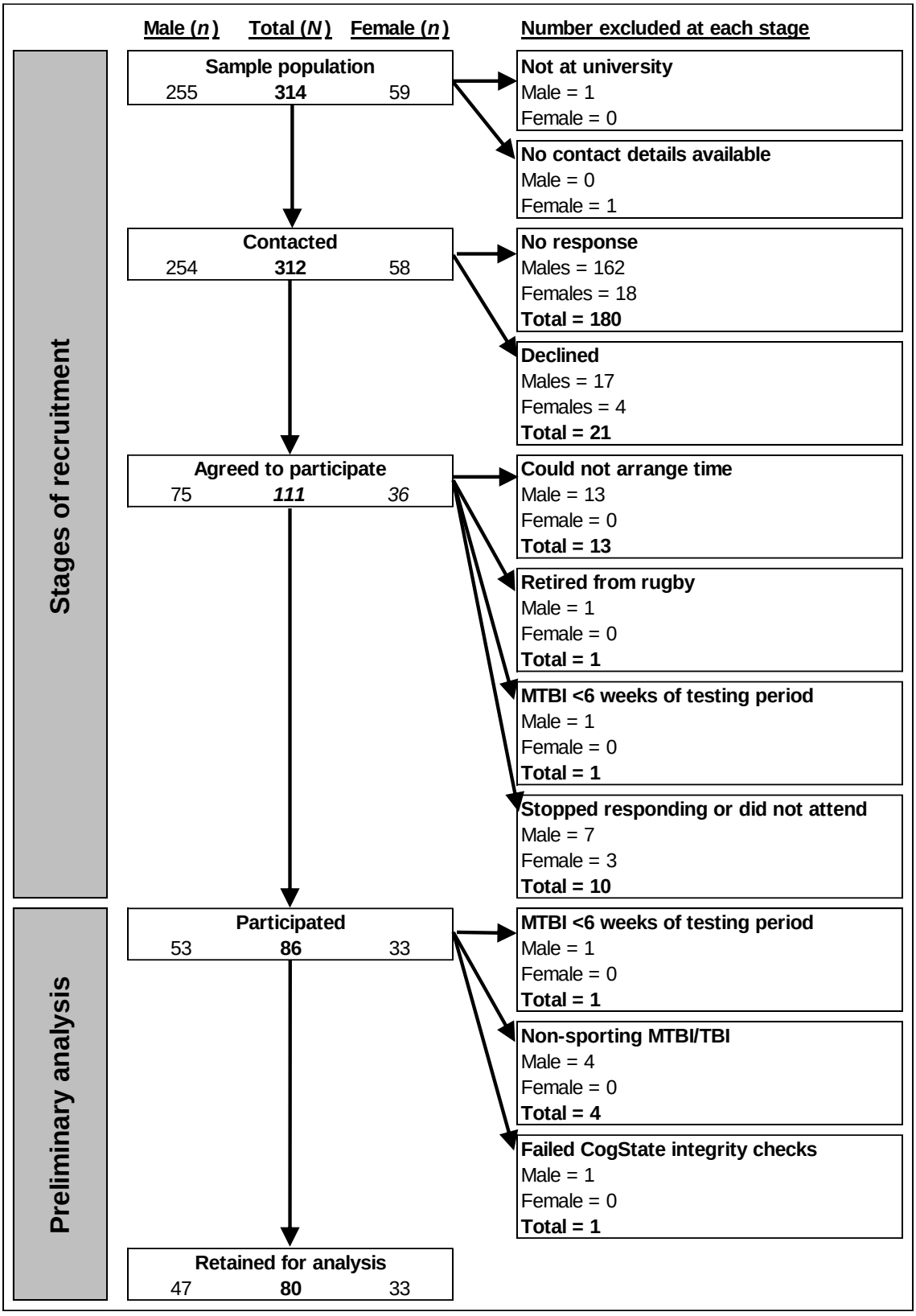

Figure 1. Flow chart depicting participant recruitment and exclusion process.

Ethical approval and considerations

This project was approved by the University of Exeter ethics committee (Appendix A). Participants received verbal and written briefings (Appendix B)

before giving written consent (Appendix C). Participants were reminded that participation was voluntary and of their right to withdraw at any time. Details of University of Exeter Student Wellbeing Services were provided within a written debrief (Appendix D).

It was planned that any participants expressing concern at their performance or symptoms, or reporting possible recent SRCs would be advised to seek further advice from club physiotherapists or coaches. Local medical consultants specialising in MTBI/SRC agreed to provide medical consultation around player safety issues and management (Appendix E). No participant concerns or issues requiring medical consultation were encountered.

Potential risks were assessed and controlled for using a risk matrix (Appendix F), adapted from a university-provided example (University of Exeter, n.d.).

Data Protection

No identifiable information was shared beyond the researcher and supervisors. Collected data were stored on a secure, password-protected University of Exeter laptop, to which only the researcher and lead supervisor had access. Paper data were secured in separate locked filing cabinets in a locked university office, to which only the lead supervisor had access. During analysis, non-identifiable raw data was stored on a secure, password-protected cloud-based storage system utilising 256-bit Advanced Encryption Standard (AES), to which only the researcher had access.

Measures

Demographic and historical SRC questionnaire. A paper-based questionnaire adapted from Hills, Cosgrave, Williams, and Lavric (2013), collected demographic and historical SRC injury data (Appendix G). SRC history

was recorded by frequency and severity:

- *Frequency:* The total number of reported SRC injuries, categorised as zero (“none”), one (“low”), two (“medium”), three or more (“high”).
- *Severity:* Categorised according to the maximum reported LOC duration from an SRC-event: “None” (dazed/confused), “LOC less than 1 minute”, “LOC 1-5 minutes”, “LOC 5-10 minutes”.

Sport Concussion Assessment Tool – 3rd edition (SCAT3). The SCAT3 is widely used in the acute period following suspected SRC. (Concussion in Sport Group, 2013; Guskiewicz et al., 2013; McCrory et al., 2013). It contains the Glasgow Coma Scale (Teasdale & Jennett, 1974), the Standardized Assessment of Concussion (McCrea et al., 1998), modified Maddocks’s questions (Maddocks, Dicker, & Saling, 1995) a balance assessment, and a symptom checklist. The SCAT3 is not a diagnostic tool, but is used to inform further assessment-needs. SCAT3 precursors have adequate psychometric properties for identifying SRC within seven days of injury (Barr & McCrea, 2001; McLeod & Leach, 2012). As a relatively new tool, there are no current validity statistics for the SCAT3.

The SCAT3 “symptom evaluation” section is a checklist of 22 common SRC symptoms. Athletes self-report symptom presence and severity on a scale of 0 (not at all), 1-2 (mild), 3-4 (moderate) or 5-6 (severe). The more symptoms endorsed (maximum = 22) and the greater the summed severity ratings (maximum = 22 x 6 = 132), then the more likely the athlete has sustained an SRC. The SCAT3 was found to have high internal validity when used with our sample (22 items; total sample α =.88; males α = .90; females α = .85).

In standard administration, athletes rate themselves based on “how you are today”. For our research, participants were instructed to ignore the “today” sentence and to instead rate how they felt over the previous two weeks, ignoring

symptoms of alcohol use. The total summed values formed the SCAT3 score for each participant. The remaining SCAT3 sections were not required as participants were not in the acute phase of SRC.

CogState Brief Battery. The CogState Brief Battery is an industry-standard concussion screening tool in SRC. It is reliable in identifying a range of cognitive difficulties, including those associated with MTBI, with acceptable construct and criterion validity (Maruff et al., 2013; Maruff et al., 2009; Appendix H). CogState batteries are a customisable selection of novel tasks, assessing a broad range of cognitive functions (CogState Ltd., n.d.-c)[3]. Data can be used to track changes in specific cognitive functions, or be compared against normative data.

The standard minimum protocol was employed (the CogState Brief Battery), as recommended by CogState for MTBI assessment (Cogstate Ltd., n.d.-a; Louey et al., 2014). Though no significant differences were expected in CogState scores between our "healthy" participants with different SRC histories/post-concussive symptom reports, the battery was used as a basic screen of cognitive functions, to facilitate greater understanding of the participants' overall cognitive functioning.

The battery contains four separate tests, taking 12-15 minutes to complete in total. For each task, individual playing cards were presented on-screen and participants had to respond according to a task-specific question. All participants were administered the tests in the same order:

1. ***Detection:*** A reaction time paradigm, measuring psychomotor function and processing speed. Participants were instructed to press

[3] CogState tasks assess cognitive functions including visual motor function; inhibitory control; spatial problem solving; processing speed; visual attention; visual learning/memory; verbal learning/memory; attention/working memory; and social-emotional cognition (CogState Ltd., n.d.-c).

a keyboard key as quickly as possible when a playing card on the screen turned over.

2. ***Identification:*** A choice reaction time paradigm, measuring visual attention and decision making. The test-question was “Is the card red?”.
3. ***One card learning:*** A pattern separation paradigm, measuring visual learning and visual memory. The test-question was “Have you seen this card before in this task?”. This test required recall of up to five minutes.
4. ***One back test:*** An n-back paradigm, measuring verbal learning and verbal working memory. The test-question was “Is this card the same as the previous card?”.For the detection test, participants pressed the “d” key as soon as a card turned over. For all other tests, participants pressed “d” to answer “yes”, or “k” to answer “no”. Instructions were presented on-screen prior to each test and verbally explained. Participants were given a brief practice before each test. A written prompt was placed within sight, reminding participants of the response keys.

CogState recommend a primary outcome measure (POM) for each test (CogState Ltd., n.d.-b). On detection and identification, the POM was reaction speed (in milliseconds). On one card learning and one back test the POM was response accuracy (in percent).

STOP-IT electronic test. The program “STOP-IT” tests response inhibition using a stop-signal paradigm to measure reaction times and error rates as an indicator of inhibitory control (Verbruggen, Logan, & Stevens, 2008). Participants were instructed to provide a motor response (pressing a keyboard

key) in response to squares or circles appearing on-screen or withhold their response if an auditory stop-signal sounded after a shape was presented. A practice block (32 trials) was followed by three experimental blocks (64 trials each). Default settings were used, though response keys were adjusted to “d” and “k” to maintain consistency with the CogState tests. A written prompt reminded participants of the response keys.

At the start of each experimental block, the stop-signal was presented on random trials after a brief delay of 250ms following the visual stimulus. This delay is known as the stop-signal delay (SSD). The SSD was increased by 50ms each time a participant was unable to inhibit their response, and decreased by 50ms when a response was successfully inhibited. Continual adjustment of the SSD functioned to establish the point at which inhibition was successful >50% of the time, allowing for calculations of the participant’s stop-signal reaction time (SSRT). Figure 2 presents a flow chart of the SSD adjustment process for each trial.

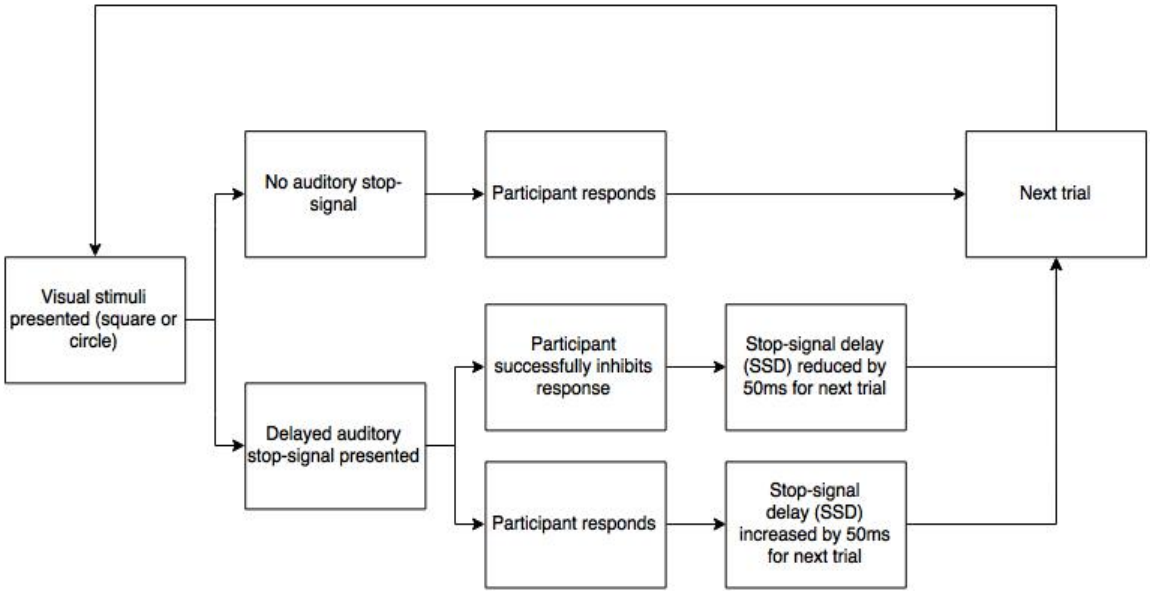

Figure 2. STOP-IT trial process and SSD adjustment procedure.

Effort testing/compliance. Effort testing is an important issue in MTBI research. Participants can misreport symptoms or underperform on assessments

if they stand to gain something, e.g. through litigation (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005; Silver, 2012). Athletes can under-report SRC, sometimes due to misunderstanding symptoms, or to avoid being removed from play (Daneshvar et al., 2010; McCrea et al., 2004; Weber & Edwards, 2010). To minimise under-reporting or under-performance, participants were reminded about confidentiality before and during testing; that data would not be passed to their club and would not affect their playing status. Participants therefore would not gain or lose anything through inaccurate responses.

Internal CogState integrity controls measured participant effort. Where participants performed poorly at a test requiring less effort/cognitive resources than on a "harder" test, this suggested either suboptimal effort, or that they had not understood the test. CogState also provided minimum recommended accuracy levels. Where accuracy fell below given cut-offs, a participant's score was deemed invalid and excluded from further analysis.

Procedure

Testing was conducted individually in controlled conditions on University of Exeter premises. Participants were tested on weekdays between 8.30am – 5.30pm. Participants were briefed, eligibility criteria were reviewed, and written consent given. Participants then completed the questionnaire, followed by the test battery[4]. All participants received a verbal debrief and a written debriefing form.

Data Analysis Strategy

Data analysis was performed in line with guidelines by Tabachnick and Fidell (2013) and Field (2013), using SPSS (version 23), Microsoft Excel, R

[4] Electronic test battery (CogState tests followed by STOP-IT test) administered using a Dell Precision M4700 laptop.

(version 3.2.4), and G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) programs. The data were screened for invalid results as part of initial data cleansing, then descriptive statistics were calculated and examined. For the main analysis, hypotheses 1 and 2 were examined through a series of regression analyses. Hypothesis 3 was examined through a series of correlations.

Results

When comparing our sample size to a-priori power calculations conducted before data collection (Appendix I), there may not be adequate power to detect effects and avoid type II errors when conducting analysis of hypotheses 1 and 3.

Preliminary Analysis and Data Cleansing

Questionnaire screening. Preliminary analysis revealed that n = 40 male participants and *n* = 12 female participants reported SRC history, totalling *n* = 52 (60.5%). Four participants were excluded after reporting non-sporting head injuries in the questionnaire. One participant was excluded after reporting recent SRC (within six weeks of testing) in the questionnaire. No participants reported SRC with LOC greater than 10 minutes, so all remaining profiles were deemed valid for further analysis.

Two participants reported partial colour-blindness (red-green). The tests used are designed to be accessible to colour-blind participants, and no difficulties were observed or reported during subsequent testing. These cases were retained.

CogState integrity checks. CogState automatically prepares test data for analysis. Detection and identification data were log10 transformed and one card learning and one back test data were arcsine transformed. CogState recommend this process as it provides optimal metric properties for assessing cognitive changes (Maruff, Snyder, McStephen, Collie, & Darby, 2006; Maruff, Werth, et

al., 2006).

No inconsistent data were identified using CogState response-time integrity checks. Three participants had potentially invalid scores on detection (<90% accuracy). Further investigation revealed accuracy scores of 89.74% for all three participants, (90% when rounded). These data were therefore retained.

One participant had an invalid score on the one back test (<50% accuracy) with accuracy of 47.2%. This indicates performance below “chance” level, suggesting either a misunderstanding of the task, suboptimal effort, or deliberately providing inaccurate responses. All data for this participant were excluded from further analysis.

Stop-signal reaction time (SSRT) calculation. An integration method was used to calculate the covert latency of the stop process, termed the stop-signal reaction time (SSRT). The integration method is a more reliable method for measuring response inhibition than means calculation (Verbruggen, Chambers, & Logan, 2013). An R script was used to calculate SSRT from the generated data: Each participant’s reaction time distribution was integrated to find the point where the integral equalled the probability responding for a specific stop-signal delay (SSD). The participant’s SSRT was subsequently calculated by subtracting the SSD from the participant’s overall response time.

Tests of normality and outliers. No unexpected missing data were identified across the dataset. Parametric assumptions were checked through examination of histograms, box-plots, Levene’s, Shapiro-Wilk, and Kolmogorov-Smirnov values. SCAT3 and SSRT were transformed using square-root transformations to correct observed skewness. Box plot examination identified two univariate outliers, one in the detection data and one in the transformed SSRT data. Each outlier was reduced using the winsorizing method (Field, 2013,

p. 198). Linear multiple regressions were calculated to test independent variable residuals for assumption of independence and homoscedascity. Visual exploration of scatterplots indicated that these assumptions would be met.

Potential confounding variables. Age, current pain levels, alcohol use, historical drug use and hours of sleep (the night prior to testing) were considered as potential confounding variables. A series of two-tailed correlations were run for age, pain, alcohol use, historical drug use and hours of sleep, against SRC dosage measures, SCAT3, SSRT, and CogState test outcomes. Age, pain, alcohol use, historical drug use and hours of sleep were not observed to be significantly correlated with any of the other variables.

CogState normative data comparisons. The CogState data were compared against normative values provided by CogState through a series of one-sample t-tests (Appendix J). The mean value for identification significantly differed from the normative mean, $t(79) = -1.22$, $p < .001$, with participants performing faster than the normative sample. No other significant differences were observed.

"Time since SRC" data. Participants had been asked to indicate the date of each SRC and the length of time since their most recent SRC. Estimates ranged between two months and ten years. However, many participants were only able to give vague estimates of dates or said they were unsure how long ago their SRC occurred. Further discussion often led to inconsistent reports, so the "time since SRC" data were therefore deemed invalid and not analysed further.

Main Analysis

Descriptive statistics. Eighty valid profiles were retained following screening (Table 2). Overall, a greater proportion of male participants reported

SRC incidents (72.3%) than female participants (36.4%).

Table 2

Age and SRC History for Valid Male and Female Profiles

		Total	Male	Female
Valid profiles		80	47	33
Mean age (*SD*)		20.18 (2.02)	20.23 (2.07)	20.09 (1.97)
History of SRC	Yes	46 (57.5)	34 (72.3*)	12 (36.4*)
n (%)	No	34 (42.5)	13 (27.7*)	21 (63.6*)
	None	34 (42.5)	13 (27.7*)	21 (63.6*)
Number of SRC	One	13 (16.3)	8 (17.0*)	5 (15.1*)
n (%)	Two	19 (23.8)	14 (29.8*)	5 (15.1*)
	Three or more	14 (17.5)	12 (25.6*)	2 (6.1*)

Note: * = Percentage of gender

SRC history variables and gender were compared to examine any relationships between them. Bonferroni's correction was employed to control for multiple testing, with an adjusted alpha level of $\alpha = .05/5 = .01$. Pearson's chi-square test of independence revealed that history of SRC (when dichotomised as "yes" or "no") significantly differed by gender with a medium effect, $\chi^2(1, N = 80) = 10.27$, $p = .001$, $\phi = 0.36$, odds ratio = 0.22. SRC frequency was observed to significantly differ by gender with a medium effect, $\chi^2(3, N = 80) = 11.90$, $p = .008$, $\phi = 0.39$. This suggests that a significantly greater proportion of males than females reported history of SRC and that males experienced a greater frequency of SRCs than females.

Fisher-Freeman-Halton Exact Test was conducted to examine the relationship between gender and SRC severity. This method was chosen over chi-square analysis, as many expected cell counts (40% of cells) were <5. SRC

severity was not observed to significantly differ by gender, $p = .022$.

Kendall's tau-b test suggested an association between SRC frequency and SRC severity, $\tau_b = .78$, $p < .001$. However, 42.5% of the sample did not report SRC history which would likely have distorted the observed relationship. The test was re-run, isolating only participants who had reported history of SRC. SRC severity was subsequently not observed to significantly differ by SRC frequency, $\tau_b = .27$, $p = .049$.

Hypothesis 1: SRC dosage predicting cognitive performance, moderated by gender. Ten two-stage hierarchical linear regressions were conducted to see if SRC frequency, SRC severity and gender significantly predicted each of the cognitive scores, and whether the predictive values of SRC frequency and SRC severity were moderated by gender. Bonferroni's correction was employed to control for multiple testing, with an adjusted alpha level of $\alpha = .05/10 = .005$. Visual inspection of scatter matrixes did not identify any correlations between predictor variables. Possible collinearity was observed through interpretation of variation inflation factor values in the second hierarchical stage when the interaction term was entered in each model. When using multiplicative interaction terms within the same model as their component variables, the values near zero stay near zero, and the high numbers get much higher, so a degree of multicollinearity is expected. This does not affect the overall fit of the model. Centring of the predictor variables was used to minimise collinearity to acceptable limits (Aiken & West, 1991; Field, 2013). For example, the variable "SRC Frequency" was initially coded as "0 = none", "1 = low", "2 = medium", and "3 = high", and unacceptable levels of collinearity were observed. These variables were subsequently recoded as "-1.5 = none", "-0.5 = low", "0.5 = medium", and "1.5 = high". Regression summary tables are available in Appendix

K.

Regression 1 (Table K1). Detection was the dependent variable. SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the regression equation explained <0.1% of the variation in detection scores. This was not significant ($F(2, 77) = 0.33$, $p = .723$), $R^2 = .01$. Introducing the interaction variable in stage two explained an additional 2.2% of the variation in detection scores. This was not a significant change in R^2, ($F(2, 76) = 0.80$, $p = .495$), $R^2 = .03$.

Regression 2 (Table K2). Identification was the dependent variable. SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the regression equation explained 1.0% of the variation in identification scores. This was not significant ($F(2, 77) = 0.41$, $p = .668$), $R^2 = .01$. Introducing the interaction variable in stage two explained less than 0.1% additional variation in identification scores. This was not a significant change in R^2, ($F(2, 76) = 0.34$, $p = .797$), $R^2 = .01$.

Regression 3 (Table K3). One card learning was the dependent variable. SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the regression equation explained 0.1% of the variation in one card learning scores. This was not significant ($F(2, 77) = 0.05$, $p = .954$), $R^2 < .01$. Introducing the interaction variable in stage two explained less than 0.1% additional variation in one card learning scores. This was not a significant change in R^2, ($F(2, 76) = 0.06$, $p = .617$), $R^2 = .02$.

Regression 4 (Table K4). One back test was the dependent variable. SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the

regression equation explained 0.5% of the variation in one back test scores. This was not significant ($F(2, 77) = 0.20$, $p = .819$), $R^2 < .01$. Introducing the interaction variable in stage two explained 2.8% additional variation in one back test scores. This was not a significant change in R^2, ($F(2, 76) = 0.86$, $p = .467$), $R^2 = .03$.

Regression 5 (Table K5). SSRT was the dependent variable. SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the regression equation explained 5.4% of the variation in SSRT. This was not significant ($F(2, 77) = 2.21$, $p = .117$), $R^2 = .05$. Introducing the interaction variable in stage two explained 0.1% additional variation in SSRT. This was not a significant change in R^2, ($F(2, 76) = 1.48$, $p = .227$), $R^2 = .06$.

Regression 6 (Table K6). Detection was the dependent variable. SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained <1.8% of the variation in detection scores. This was not significant ($F(2, 77) = 0.73$, $p = .487$), $R^2 = .02$. Introducing the interaction variable in stage two explained an additional 2.0% of the variation in detection scores. This was not a significant change in R^2, ($F(2, 76) = 1.01$, $p = .392$), $R^2 = .04$.

Regression 7 (Table K7). Identification was the dependent variable. SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained 1.0% of the variation in identification scores. This was not significant ($F(2, 77) = 0.40$, $p = .674$), $R^2 = .01$. Introducing the interaction variable in stage two explained an additional 0.3% of the variation in identification scores. This was not a significant change in R^2, ($F(2, 76) = 0.35$, $p = .791$), $R^2 = .01$.

Regression 8 (Table K8). One card learning was the dependent variable.

SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained 2.0% of the variation in one card learning scores. This was not significant ($F(2, 77) = 0.78$, $p = .463$), $R^2 < .02$. Introducing the interaction variable in stage two explained an additional 3.3% of the variation in one card learning scores. This was not a significant change in R^2, ($F(2, 76) = 1.41$, $p = .247$), $R^2 = .05$.

Regression 9 (Table K9). One back test was the dependent variable. SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained 0.4% of the variation in one back test scores. This was not significant ($F(2, 77) = 0.16$, $p = .852$), $R^2 < .01$. Introducing the interaction variable in stage two explained 2.6% additional variation in one back test scores. This was not a significant change in R^2, ($F(2, 76) = 0.79$, $p = .501$), $R^2 = .03$.

Regression 10 (Table K10). SSRT was the dependent variable. SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained 4.3% of the variation in SSRT. This was not significant ($F(2, 77) = 1.74$, $p = .1.82$), $R^2 = .04$. Introducing the interaction variable in stage two explained 0.1% additional variation in SSRT. This was not a significant change in R^2, ($F(2, 76) = 1.17$, $p = .327$, $R^2 = .04$.

The hierarchical regressions indicated that SRC frequency and SRC severity were not significantly predictive of outcomes on CogState tests or SSRT. The influence of these predictors was not moderated by gender.

Hypothesis 2: SRC dosage predicting SRC symptoms, moderated by gender. Visual inspection of scatter matrixes did not identify any correlations

between predictor variables. Inspection of a correlation matrix suggested that gender and SRC frequency were not significantly correlated with SCAT3 score. SRC severity and gender were initially observed to be significantly correlated, but after controlling for multiple tests this correlation was not significant. Two two-stage hierarchical linear regressions were conducted to see if SRC frequency, SRC severity and gender significantly predicted SCAT3 scores, and whether the predictive values of SRC frequency and SRC severity were moderated by gender. SCAT3 score was entered as the dependent variable in both regressions. Regression summary tables are available in Appendix L.

Regression 1 (Table L1). SRC frequency and gender were entered at stage one. The interaction between SRC frequency and gender was entered at stage two. At stage one, the regression equation explained 2.3% of the variation in SCAT3 scores. This was not significant ($F(2, 77) = 0.92$, $p = .404$), $R^2 = .02$. Introducing the interaction variable in stage two explained an additional 0.1% of the variation in SCAT3 scores. This was not a significant change in R^2, ($F(2, 76) = 0.64$, $p = .594$), $R^2 = .03$.

Regression 2 (Table L2). SRC severity and gender were entered at stage one. The interaction between SRC severity and gender was entered at stage two. At stage one, the regression equation explained 4.7% of the variation in SCAT3 scores. This was not significant ($F(2, 77) = 1.13$, $p = .333$), $R^2 = .05$. Introducing the interaction variable in stage two explained an additional 1.4% of the variation in SCAT3 scores. This was not a significant change in R^2 ($F(2, 76) = 0.96$, $p = .419$), $R^2 = .06$.

The hierarchical regressions indicated that SRC frequency and SRC severity were not significant predictive of SCAT3 scores, and that the influence of these predictors on SCAT3 scores was not moderated by gender.

Hypothesis 3: Association between PCS symptoms and cognitive performance. Self-reported SCAT3 scores were compared against results from each CogState task and the STOP-IT task in a series of one-tailed bivariate correlations. Pearson's product-moment correlation coefficient was used to compare associations between SCAT3 score and performance on each cognitive test. Bonferroni's correction controlled for multiple testing, with an adjusted alpha level of $\alpha = .05/5 = .01$. No significant correlations were identified between SCAT3 score and any CogState measures (SCAT3 vs detection, $r(78) = .05$, $p = .323$; SCAT3 vs identification, $r(78) = -.01$, $p = .465$; SCAT3 vs one card learning, $r(78) = -.11$, $p = .172$; SCAT3 vs one back test, $r(78) = -.06$, $p = .289$). No significant correlation was identified between SCAT3 score and SSRT, $r(78) = -.17$, $p = .069$.

Discussion

We did not find any significant relationships between SRC dosage (frequency or severity), self-reported PCS symptoms, and cognitive test performance. A greater proportion of males reported SRC compared to females, but no effect of gender was found on any of the cognitive outcome measures or self-reports of PCS symptoms.

Overall, none of our experimental hypotheses were supported by the results. We therefore accept the null hypotheses; that SRC has no observable long-term effects on cognitive test performance or self-reports of PCS symptoms following the acute-phase of the injury (longer than six weeks post- injury). This conclusion risks type II error due to our lack of statistical power when testing hypotheses 1 and 3. The results are consistent with previous studies showing that persisting SRC effects cannot be reliably measured through cognitive testing (Echemendia et al., 2001; Losoi et al., 2016; Schretlen & Shapiro, 2003). The results are inconsistent with studies that have shown cognitive difficulties and

elevated PCS symptoms in athletes over a year post-injury after single (Dean & Sterr, 2013) or multiple injuries (Wall et al., 2006).

Though we did not show any persisting “long-term” effects of SRC (symptoms from a SRC that occurred more than six weeks prior to testing) on cognitive performance or PCS symptoms, other research has concluded that SRC has significant implications on later-life neurodegenerative conditions such as dementia or CTE (McKee et al., 2010; Omalu et al., 2005). It is possible that in our university-aged participants, any longer-term effects of uncomplicated SRC may be too subtle to detect on the cognitive tests used, or too subtle to be noticed or understood as problematic by participants (Echemendia et al., 2001). In-line with the null hypothesis, there may have been no long-term effects of SRC present to be experienced by our sample.

Overall, a significantly greater proportion of male participants reported history of SRC than female participants. Males also experienced a greater frequency of SRCs than females. However, gender was not associated with SRC severity and did not significantly moderate the relationship between SRC dosage and PCS symptoms or cognitive performance. These findings are in contrast to evidence that females are often at greater risk of SRC and PCS symptoms (Covassin et al., 2003; Covassin et al., 2006; Gessel et al., 2007; Harmon et al., 2013; Laker, 2011; Preiss-Farzanegan et al., 2009).

We had anticipated that participants with higher SRC dosage would have greater difficulty on “higher level” cognitive tests, specifically showing slower responses on a stop-signal response-inhibition task. This would have provided further evidence for enduring neurological damage and ongoing disruption of communication efficiency or regulation between brain networks (Sours et al., 2013). (Fakhran et al., 2014; Kinnunen et al., 2011). However, persisting

difficulties with high-level cognitive functions were not evident in our sample as performance on all cognitive tests (including the stop-signal task) was not associated with SRC history. This suggests that neurological disruption to pathways linking brain regions/networks (i.e. SN and DMN regulation) is not necessarily an enduring symptom of SRC in university-level athletes. However, our results are not conclusive proof that there are no long-term neurological symptoms as factors related to pre- or post-injury neuropsychological functioning could be masking enduring neurological damage or vulnerabilities to future injuries or complications (Bigler, 2013a). Recent neuroimaging would suggest that even when an individual appears to have cognitively recovered, they may be recruiting more areas of the brain in order to generate appropriate responses (Chen et al., 2012). In line with recommendations from reviews such as Shenton et al. (2012), further integrated research linking cognitive performance, PCS symptoms and neuroimaging is recommended.

Limitations and Directions for Future Research

Firstly, it is important to note that sufficient statistical power was not achieved for hypotheses 1 and 3. Effects may therefore not have been detected, and we may have incorrectly accepted a false null hypothesis. Repetition with a larger sample would minimise the risk of type II errors and provide more confident conclusions regarding the presence of any effects between the variables.

Recruitment bias/sample characteristics. Due to the opportunistic recruitment, our sample may not be representative of the target population. 55.93% of the female target population were recruited compared to only 16.88% of the males. It is possible that our male participants differed from the 83.12% who declined or did not respond (e.g. SRC history, symptoms, or knowledge/awareness of SRC/MTBI). Our sample was university-educated,

which may represent higher socio-economic statuses and educational-levels than general population athletes. Furthermore, our study population did not include players who sustained SRC and subsequently stopped playing rugby. Ex-players can report more PCS symptoms than current players (Thornton, Cox, Whitfield, & Fouladi, 2008) meaning generalisability may be limited to players who continue to play following recovery. This highlights the potential importance of monitoring players who stop playing following SRC. Sporting organisations may need to consider whether they have a "duty-of-care" for long-range follow-up and support of head-injured ex-players.

In England, rugby is a popular male academic sport, though less popular for females. It is likely that our male participants had played for significantly longer than our female participants, who may have only started playing at university-level. Our male participants could therefore have been exposed to higher risks of SRC for a longer period of time. This may explain their higher incidences of SRC.

Assessment methods. The CogState battery is sensitive to SRC in the acute phase (Louey et al., 2014; Maruff et al., 2009; Straume-Naesheim et al., 2009). However, it may not be sensitive enough to detect the presence of longer-term effects. Similarly, this is the first time the STOP-IT program has been applied in the context of SRC, so sensitivity/reliability in detecting these changes are unknown. Further validation of these measures for longer-term SRC assessment, and studies using pre/post longitudinal designs would enable more accurate assessment of individual abilities and changes following SRC. The SCAT3 is also primarily administered in the acute phase. There are no statistics available regarding the SCAT3 symptom evaluation measure's sensitivity/validity for detecting long-term PCS, as it is primarily regarded as an indicator to prompt more formal assessment, so its sensitivity and reliability at detecting symptoms

in our sample cannot be verified.

Functional neuroimaging methods are increasingly used to detect short-term and long-term functional changes in the brain following MTBI/SRC (Chen et al., 2012). Replication of this research with the addition of neuroimaging and measures of performance under pressure could be more applicable to real-world performance, allowing more accurate detection of post-SRC neurological changes and whether cognitive resources are being used efficiently.

SRC history. Participants were excluded if they had sustained SRC within six weeks of testing and we attempted to record the length of time since each participant's most recent SRC. However, the majority of participants were unable to give accurate injury dates, meaning this measure was deemed invalid for analysis purposes.

Future research should take more in-depth measures of history, injury events, and pre- and post-injury symptoms. Utilising non-impact control groups with matched physical and cognitive characteristics (e.g. university-level rowers) could also help establish whether head-injured rugby players are misreporting current or premorbid symptoms (Ferguson et al., 1999; Gunstad & Suhr, 2001). Longitudinal designs following participants across multiple seasons or years would enable greater accuracy in recording baselines, historical SRCs and identifying causality.

Confounding variables. No associations were found between current alcohol use or historical drug use on test performance or PCS symptoms. However, participants were not screened for influence of alcohol at the time of testing. Current drug use was also not reported, so the effects of any performance-enhancing, depressant, stimulant or steroidal drugs cannot be

determined.

Certain psychological illnesses, such as depression are also associated with increased endorsement of PCS symptoms (Iverson, 2006). Players were not eligible to participate if they reported current treatment for mental health difficulties. However, participant mood states, attitudes and expectations towards MTBI or SRC were not measured further. It is unclear whether these variables may have affected the accuracy of self-reports of SRC history or ongoing symptoms.

Clinical Implications

The potential limitations of self-report always need consideration when assessing athletes pitch-side or clinically. Our findings do not provide much insight into whether cognitive assessment is a reliable approach for detecting cognitive difficulties at six weeks or longer following SRC in an otherwise healthy sample. Linking cognitive assessments to neuroimaging may be an important step to improving player safety. This study indicates that tracking performance over time may be valuable in identifying individual changes that are not identifiable through cross-sectional designs. Ongoing monitoring would allow more accurate identification of whether a player is experiencing patterns of increasing cognitive deficits after repeated injuries, or is at elevated risk of further neurological damage should they return to play.

Many participants reported poor understanding of symptoms or potential implications of MTBI/SRC. Poor understanding of the condition could result in an underestimation (or overestimation) of the severity of their injury and symptom reporting, unrealistic expectations regarding recovery rates, and performance/effort on assessments (Ferguson et al., 1999; Weber & Edwards, 2010). Players may under-report symptoms in order to influence the assessment

outcome and return to competitive play quicker (McCrea et al., 2004). It is also possible that any ongoing PCS symptoms, if present at all, may not be noticed or regarded as problematic by the player and therefore go unreported. Many athletes may therefore benefit from further education/awareness of MTBI/SRC through educational programmes within academic or sporting arenas (Delahunty, Delahunt, Condon, Toomey, & Blake, 2015).

Conclusions

This research found no relationships between long-term (greater than six-weeks post-SRC) cognitive performance and self-reported PCS symptoms of athletes related to SRC. Males appeared to have experienced a greater number of SRCs than females, but no effect of gender was found on any of the cognitive outcome measures or self-reported symptoms.

It is possible that structural changes may still be present despite apparent cognitive recovery, with participants still at heightened risk of complications later in life or after future SRCs (Chen et al., 2012). However, in this study we did not find evidence of observable enduring effects of SRC in this population. Caution is advised around the risk of overestimating symptoms and unnecessarily raising expectations of ongoing difficulties, as this could adversely impact a player's recovery (Broughton, 2016).

It is important to look at individual neurological changes over time, which may be undetected using broader group comparisons (Covassin et al., 2007). Holistic analysis of an individual athlete's recovery pattern in relation to individual baseline psychological or PCS scores may be much more relevant for accurate diagnosis than relying on group comparisons or normative test scores alone.

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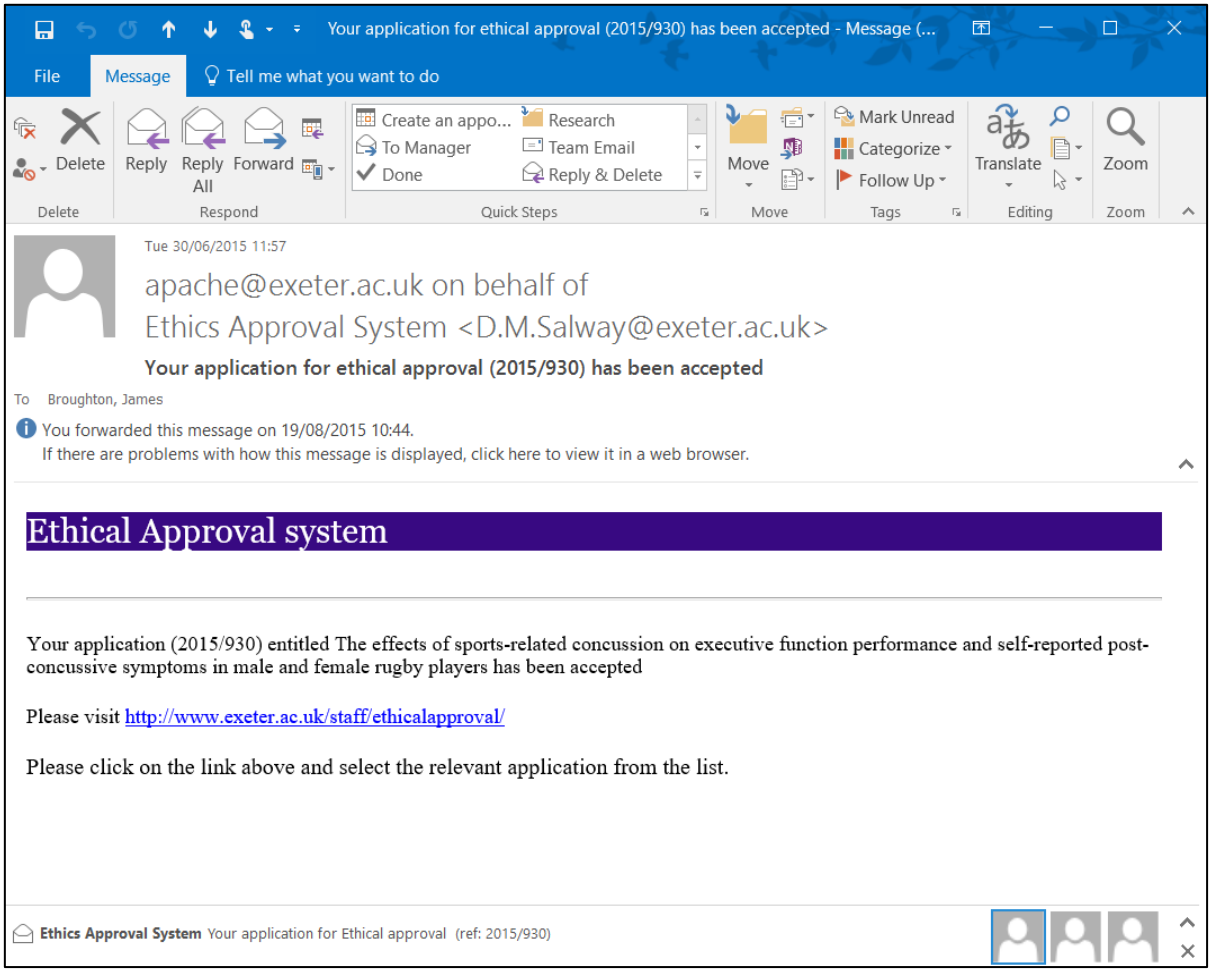
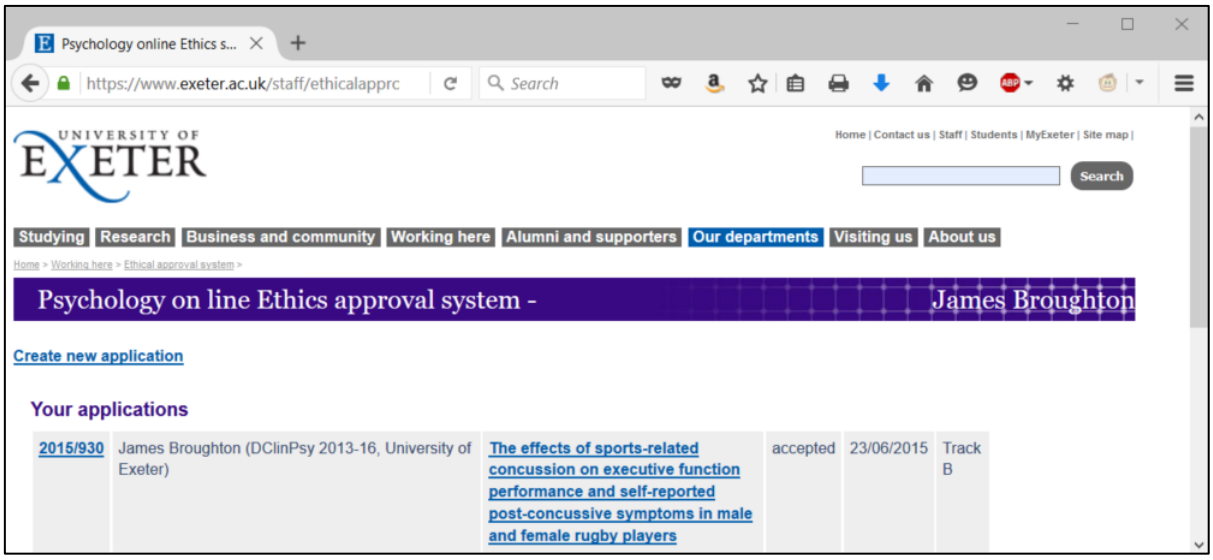
Appendix A: University of Exeter Ethical Approval





Appendix B: Participant Consent Form

P REF: _____

Participant consent form

Once you have read the information sheet, please read and complete the consent form below by circling the appropriate response:

I have read and understand the information sheet and have had the opportunity to ask any questions.	Yes No
I understand that all personally identifiable information (such as my name) will be removed from the reports.	Yes No
I understand that all material will be anonymised, that identifying information will be removed, that all material will be stored securely on University servers.	Yes No
I understand that I can say no, or change my mind at any time, and that this will not affect my role within the rugby club.	Yes No
I agree to provide my University of Exeter email address, so I may be contacted in the event of follow-up research during the 2015/16 rugby season, as detailed in the information sheet.	Yes No
I would like to be emailed information on the overall research findings	Yes No
I am willing to participate in this research into sports related concussion.	Yes No

Participant name: _____

Signature: _____ **Date:** _____

University of Exeter email address: _____

Thank you for your participation.

Appendix C: Participant Information Sheet

UNIVERSITY OF EXETER

Information Form for Participants

Purpose of the study

This study is to look at how concussion affects male and female rugby players, to further develop our understanding of what systems we should be looking at to identify damage to concussed brains. There is some evidence that the more concussions a person experiences, the harder they may find some tasks, and the longer they may take to recover. Some people also find that they have long-term symptoms after their concussion like irritability or headaches. We are interested in providing further evidence that people with historical concussions report persisting symptoms over time, and whether there are differences in concussion rates, symptoms, and test performance between male and female players. You will be asked to complete some neurocognitive tests (computerised tests on a computer). You may also be contacted at the end of the season too for some follow up testing.

What types of participants are needed?

All active players of the University Rugby Football Clubs (male and female) who do not meet our exclusory criteria. We cannot accept those with any known neurological disorder (other than concussive injury). Participants should be free from any severe and enduring mental health conditions, and should be able to speak English fluently.

What will I receive for taking part in the study?

All players who take part in the study will be entered into a prize draw for £100 of high street vouchers (1x prize of £50, 2x prizes of £25).

What will I have to do during the study?

You will be asked to attend an appointment at the rugby training grounds or on Streatham Campus, Exeter University. You will also be asked to complete some neurocognitive tests (e.g. attention and memory), and the Sports Concussion Assessment Scale 3rd Edition (SCAT3). The appointment will last around 45 minutes, to 1 hour maximum. There may be follow up research during the 2015/16 season, which you will be given the option of participating in.

What will happen if I want to drop out of the study?

Before you start the study, you will be asked to sign a consent form, in which you will agree to participate. However, you will be free to end your participation at any time, without giving a reason. You will need to complete the testing in order to be eligible for the prize draw.

What data or information will be collected and what use will be made of it?

Your data will be anonymised and analysed for our study. The findings will be written up by the researcher to be submitted as part of their Doctorate in Clinical Psychology. The findings will also be disseminated via academic journals and conference presentations, etc, but your individual results will not be published in any way that could identify you.

If any concerning data is identified by the researchers, we will contact you to inform you and suggest that you contact your GP.

All electronic data collected will be securely stored on University servers, to which only the researchers have access.

Who do I contact if I have any questions?

You will be provided with written feedback about the overall results of the study. If you have any questions about this research, either now or in the future, please feel free to contact the research team on the details below. You will be provided with a debriefing sheet after participating, with a copy of these contact details.

Primary researcher: James Broughton, jwb212@exeter.ac.uk
Research supervisor: Prof Huw Williams, w.h.williams@exeter.ac.uk
Research supervisor: Dr Phil Yates, p.j.yates@exeter.ac.uk

This study has received ethical approval from the University of Exeter Psychology Research Ethics Committee. If you have any queries or comments regarding ethics, please contact the committee chair, Dr Tim Kurz, on t.r.kurz@exeter.ac.uk.

Appendix D: Participant Debriefing Form

UNIVERSITY OF EXETER

Debriefing Form

Thank you for participating in this research into sports-related concussion.

Purpose of study

This study was looking at how concussion affects male and female rugby players, to further develop our understanding of what systems we should be looking at to identify damage in concussed brains. There is some evidence that the more concussions a person experiences, the harder they may find some tasks, and the longer they may take to recover. Some of the tests you completed look at inhibition (your ability to stop/withhold a response), which is thought to be an ability that is sensitive to concussions.

Some people also find that they have long-term symptoms after their concussion like irritability or headaches. This study was looking at the symptoms people report after experiencing sports-related concussions, whether these symptoms persist over time, and whether your history of concussion affected your performance on the computerised tests you did. The study is also looking at whether there are any differences in concussion rates, symptoms and/or test performance between male and female players.

Your data will be anonymised and analysed for the study. The findings will be written up by the researcher to be submitted as part of their Doctorate in Clinical Psychology. The findings will also be disseminated via academic journals and conference presentations, etc. but your individual results will not be published in any way that could identify you.

What will I receive for taking part in the study?

All players who have taken part in the study will be entered into a prize draw for £100 of high street vouchers (1x prize of £50, 2x prizes of £25). This draw will be held once data collection for the study has been completed and the winners will be notified by email.

What if I want to withdraw my results?

If you decide that you no longer wish for your data to be included in the study, please contact the researcher on the contact details below and it will be excluded from analysis. You do not have to give a reason for this.

What do I do if I am concerned about any symptoms of past concussions that I am experiencing?

If you have any concerns about your previous concussions and/or think you may still be experiencing symptoms of concussion, you may find it helpful to discuss this further with one or more of the following:

- The medical staff or coaches at the rugby club
- The University of Exeter Student Wellbeing Services: (01392) 724381 www.exeter.ac.uk/wellbeing
- Your GP.

Who do I contact if I have any questions?

You will be provided with written feedback about the overall results of the study via the email address you provided earlier. If you have any questions about this research, either now or in the future, please feel free to contact the research team on the details below.

Primary researcher: James Broughton, jwb212@exeter.ac.uk
Research supervisor: Prof Huw Williams, w.h.williams@exeter.ac.uk
Research supervisor: Dr Phil Yates, p.j.yates@exeter.ac.uk

England Rugby Football Union also provide information and support regarding concussion on their webpage. This can be accessed at: http://www.englandrugby.com/my-rugby/players/player-health/concussion-headcase.

This study has received ethical approval from the University of Exeter Psychology Research Ethics Committee. If you have any queries or comments regarding ethics, please contact the committee chair, Dr Tim Kurz, on t.r.kurz@exeter.ac.uk.

Thank you once again for participating in this research.

Appendix E: Medical Consultants for Research Project

Mr Adrian Harris

- Sports Physician and Head of Sports Medicine at “Exeter Chiefs” Rugby Football Club
- Executive Medical Director, Royal Devon and Exeter Hospital
- Consultant Emergency Physician and ex-lead for Royal Devon and Exeter Hospital’s Accident and Emergency Department

Dr Adam Ruben

- Club Doctor at “Exeter Chiefs” Rugby Football Club
- Consultant in Emergency Medicine at Royal Devon and Exeter Hospital’s Accident and Emergency Department

Appendix F: Risk Assessment Matrix

Table F1

Risk Assessment Matrix for Research

Identified Risk	Management of risk	Level of risk, in light of management
Maintaining confidentiality and anonymity	All subjects will be assigned numbers. No names or identifiable information will be used.	Low
	Names and codes will be stored separately to data.	
	If necessary, pseudonyms will be used in any write-up.	
	Data will be stored on password protected computers.	
	Any physical copies of data (i.e. paper copies) will be stored in a locked filing cabinet in a secure office in the University of Exeter.	
Researcher safety	Any identified issues or concerns will be raised immediately with research supervisors. The researcher will maintain clear and consistent communication channels with supervisors regarding research progress and researcher wellbeing.	Medium
	No risks are identified to the researcher from the sample population.	
Loss of data	Data will be stored on secured backed-up university systems.	Low
	All data from paper tests will be scanned and stored electronically as soon as possible.	
Emotional distress to participants in the course of research	There is a low chance of participants becoming distressed as a result of participating in the research. However, if a participant is observed to become distressed, they will be reminded of their right to withdraw. All participants will be provided	Low

Identified Risk	Management of risk	Level of risk, in light of management
	with University of Exeter Wellbeing Services contact details following participation.	
	Medical consultants from the Exeter Chiefs rugby club and Royal Devon and Exeter hospital have agreed to provide medical consultation for the research, to identify and manage any potential issues relating to player safety, prior to participation.	
Suitability and general management of research project	The trainee will be supported by their allocated research supervisors.	Low
	The thesis proposal will be evaluated for scientific quality and feasibility. Any potential problems or risks identified need to be addressed before the project is passed.	
	The trainee has access to research consultancy to obtain independent feedback should they raise concerns in this area.	
Feasibility of project	Considered by trainee and supervisors during development of project.	Medium
	Evaluated in the assessment process through independent scientific review.	
	Financial costs will be covered by the agreed research budget for DClinPsy projects (£200.00). The trainee will apply for additional funding sources as appropriate to supplement any transportation and/or accommodation expenses that exceed the DClinPsy budget.	
Participant lack of effort	There is a risk of participants not putting in effort during the testing or lying on follow-up in order to minimise any symptoms. This is a low risk however,	Low

Identified Risk	Management of risk	Level of risk, in light of management
	as participants are not playing in a professional arena, and it will be made clear to them that all data will be anonymised and not reported directly to the rugby clubs.	
Loss of access to sample	The researcher will work alongside representatives of each rugby club to ensure continued access. Both clubs have expressed an interest in participating in research in this area, with verbal and written consent provided.	Low
Sufficient resources to conduct research	Material resources have been identified as part of the research proposal and evaluated for feasibility.	Low-medium
	Appropriate consideration has been given to the number of subjects required for the research (e.g., power calculation, saturation), though this is limited by the number of subjects availabile in the sample population.	
	Research time has been allocated in the DClinPsy programme and the trainee has planned a timeline for the research, agreed by the research supervisors.	
Health and Safety	As an NHS employee, the trainee has received instruction about health and safety procedures.	Low
	Any incidents will be managed by University health and safety procedures, as appropriate.	

Appendix G: Demographic and Historical SRC Questionnaire

Participant No:

Participants Demographics Questionnaire

We are conducting a study of the experiences and symptoms people may have after a head injury or concussion. Please answer the following questions in the space provided or marking/ticking your answers as indicated by the question.

Thank you for your cooperation.

1. Gender

2. Age

3. Handedness?
   Left Right Mixed

4. Level of education studying towards (BSc, BA, MSc, MA, etc)
   Year of study

5. Position of play?
   Forward Back Specific

6. How many hours did you sleep last night?

7. Do you wear any protective headgear when playing rugby?
   Yes No Specific

8. Have you had any alcohol in the past 24 hours?
   Yes No Notes:

9. Have you eaten today?
   Yes No Notes:

10. Do you need glasses?
    Yes No Notes:

11. Are you colour blind?

Yes No Notes:

12. Do you have any hearing difficulties?

Yes No Notes:

13. Do you have any problems reading or writing?

Yes No Notes:

14. Is English your first language?

Yes No Notes:

If No, do you speak English fluently?

Yes No

15. Have you used support services for any mental health issues?

Yes ☐ No ☐

16. Have you any neurological illness or condition? E.g. stroke, encephalitis

Yes ☐ No ☐

If Yes please specify

17. Have you ever had an injury to the head that caused you to be knocked out and/or dazed and confused, for a period of time? E.g. from a sports injury, fall, blow to the head, road traffic accident?

Yes ☐ No ☐

If you answered 'Yes' to 17, continue completing the questions as listed, if 'No' skip to question 22.

18. How many times have you been knocked out and/or dazed and confused? E.g. from a sports injury, fall, blow to the head, road traffic accident?

Once ☐ Twice ☐ Three times ☐ Four times ☐ More than four times ☐

19. On the following pages, please tick the boxes that describe the times you have been knocked out and/or dazed and confused – and when, and if under influence of drug/alcohol.

Type of Injury & Date (m/year)	Dazed or Confused	Unconscious for up to 1 minute	Unconscious for 1-5 minutes	Unconscious for 5-10 minutes	Unconscious for 10-30 minutes	Unconscious for over 30 minutes
1._____ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ Any other comments:_____ _____						
2. _____ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ Any other comments:_____ _____						
3. _____ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ Any other comments:_____ _____ _____						

Type of Injury & Date (m/year)	Dazed or Confused	Unconscious for up to 1 minute	Unconscious for 1-5 minutes	Unconscious for 5-10 minutes	Unconscious for 10-30 minutes	Unconscious for over 30 minutes
4._____ _ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ Any other comments:_____ _____						
5. _____ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ Any other comments:_____ _____						
6. _____ (_____/_____)						
Notes if rugby: Taken off pitch: Yes No Return to play: Yes No If no, when: _____ Good memory of match? Yes No If no, describe: _____ ny other comments:_____ _____						

20. If you answered “Unconscious for over 30 minutes” on the previous pages, please specify the type of activity and how long for?

21. If you have sustained a head injury through any other activity or accident (e.g. car accident) please give details below.

22. Sports Concussion Assessment Tool 3rd Edition – (3) Symptom Evaluation

After a concussion, head injury or accident, some people can experience ongoing symptoms which cause worry or nuisance. We would like to know if you are currently suffering from any of the symptoms listed below. As many of these symptoms occur normally, we would like you to compare how you are **TODAY,** compared with before your concussion(s)/accident(s). For each one please circle the number closest to your answer.

0 Not experienced at all
1-2 Mild problem
3-4 Moderate problem
5-6 Severe problem

"You should score yourself on the following symptoms, based on how you feel now".

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling "slowed down"	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or anxious	0	1	2	3	4	5	6

Do your symptoms get worse with physical activity? Yes ☐ No ☐

Do your symptoms get worse with mental activity? Yes ☐ No ☐

23. Have you had any other major injuries from sports or otherwise?

Yes ☐ No ☐

If 'Yes' please specify

24. Do you have any pain from any injury or accident other than concussion or head injury?

Yes ☐ No ☐ No

If you answered 'Yes' to question 24, please answer question 25. If 'No', please skip to question 26.

25. Please rate from 1 (no pain) to 7 (very much pain) how much pain that injury causes you:

No pain Very much pain

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

26. If you have ever used illegal drugs, please indicate how frequently you used them during your most intense period of use

Never ☐ Once per year ☐ Once per month ☐ Most days ☐ Everyday ☐

27. If you drink alcohol please indicate how frequently on average

Never ☐ Once per year ☐ Once per month ☐ Most days ☐ Everyday ☐

Thank you for taking part in the study. Any information you have provided is confidential and will be used anonymously.

Appendix H: CogState Validity Tables

Table H1

Pearson's Product–moment Correlations Between CogState Performance Measures and Other Well-used Neuropsychological Measures (Extracted From Maruff et al., 2009, Table 2)

	GPB-D	GPB-ND	TMT-A	TMT-B	SDMT	Span	BVMT	RCFT-R
Detect	**.81****	**.71****	.70**	.52*	.31	.11	.17	.12
Identify	.53*	.49*	**.76****	**.78****	.74*	.10	.04	.05
One-back	.13	.21	.69*	.71*	**.81***	**.80***	.54*	.39
Learn	.17	.15	.19	.59*	.57*	.69*	**.83***	**.79***

Note: GPB = grooved pegboard; -D = dominant hand; -ND = non-dominant hand.

TMT-A/B = Trail Making Test parts A and B

SDMT = Symbol Digit Modalities Test

Span = WMS III spatial span task

BVMT = Brief Visual Memory Test

RCFT-R = Rey Complex Figure Test-Delayed Recall.

*$p < .01$; **$p < .001$.

Table H2

Group Means and Statistical Significance for Comparison of TBI Patient Group with Control Group on CogState Tasks (Extracted From Maruff et al., 2009, Table 3)

Task	Transformed data							Back-transformed data					
	Mean control group	(*SD*)	Mean clinical group	(*SD*)	*t*	*p*	%N-OL	Mean control group	Low 95% CI	Up 95% CI	Mean clinical group	Low 95% CI	Up 95% CI
Detect	2.46	0.06	2.59	0.16	5.9	<.0001	62	288.4	251.2	331.1	389.0	269.2	562.3
Identify	2.69	0.09	2.78	0.10	4.8	<.0001	53	489.8	398.1	602.6	602.6	478.6	758.6
One-back	1.22	0.12	0.93	0.39	5.7	<.0001	60	0.94	0.89	0.97	0.80	0.51	0.97
Learn	1.06	0.15	0.69	0.25	9.3	<.0001	78	0.87	0.79	0.94	0.64	0.43	0.81

Note: Cont = control; group means and standard deviation (SD) computed on transformed data described in methods.

back-transformed data = group mean of transformed data converted back to original units and 95% CIs

for Detect and Ident tasks units are milliseconds and for One-Back and Learn tasks units are percent correct responses.

%N-OL = percentage of data distributions that do not overlap.

Appendix I: A-priori Power Analysis Calculations

Table I1

Hypothesis 1 A-priori Power Analysis: Ten Regressions with Three Predictors (Including Interactions), Bonferroni-adjusted Alpha from .05 to .005.

t tests - Linear multiple regression: Fixed model, single regression coefficient			
Analysis:	A priori: Compute required sample size		
Input:	Tail(s)	=	Two
	Effect size f^2	=	0.15
	α err prob	=	0.005
	Power (1-β err prob)	=	0.80
	Number of predictors	=	3
Output:	Noncentrality parameter δ	=	3.73
	Critical t	=	2.88
	Df	=	89
	Total sample size	=	93
	Actual power	=	0.81

Table I2

Hypothesis 2 A-priori Power Analysis: Two Regressions with Three Predictors (Including Interactions), Bonferroni-adjusted Alpha from .05 to .025.

t tests - Linear multiple regression: Fixed model, single regression coefficient			
Analysis:	A priori: Compute required sample size		
Input:	Tail(s)	=	Two
	Effect size f^2	=	0.15
	α err prob	=	0.025
	Power (1-β err prob)	=	0.80
	Number of predictors	=	3
Output:	Noncentrality parameter δ	=	3.17
	Critical t	=	2.30
	Df	=	63
	Total sample size	=	67
	Actual power	=	0.81

Table I3

Hypothesis 3 A-priori Power Analysis: Five Correlations – One-way Bivariate, Bonferroni-adjusted Alpha from .05 to .01

Exact - Correlation: Bivariate normal model			
Options:	exact distribution		
Analysis:	A priori: Compute required sample size		
Input:	Tail(s)	=	One
	Correlation ρ H1	=	0.30
	α err prob	=	0.01
	Power (1-β err prob)	=	0.80
	Correlation ρ H0	=	0
Output:	Lower critical r	=	0.22
	Upper critical r	=	0.22
	Total sample size	=	107
	Actual power	=	0.80

Appendix J: Comparisons Between Collected and Normative CogState Data

Table J1

Means, Standard Deviations, and One-sample t-test Results for Collected and Normative CogState Data

Test	Data source	*M*	*SD*	*t*	*df*	*p* (2-tailed)
Detection	Collected	2.45	0.04			
	Normative	2.46	0.09			
				-1.22	79	.226
Identification	Collected	2.63	0.05			
	Normative	2.66	0.14			
				-5.19	79	<.001
One card learning	Collected	1.05	0.10			
	Normative	1.05	0.13			
				-.43	79	.667
One back test	Collected	1.38	0.11			
	Normative	1.37	0.14			
				1.07	79	.290

Appendix K: Hypothesis 1 Regression Summary Tables

Table K1

Regression Summary for SRC Frequency and Gender Predicting CogState Detection Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.09	.01	-.02
SRC frequency	<.01	.01	<.01			
Gender	-.01	.01	-.09			
Step 2				.18	.03	-.01
SRC frequency	<-.01	.01	-.06			
Gender	-.02	.01	-.18			
Gender X SRC frequency	0.01	.01	-.17			

Table K2

Regression Summary for SRC Frequency and Gender Predicting CogState Identification Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.10	.01	-.02
SRC frequency	<-.01	.01	-.02			
Gender	-.01	.01	-.11			
Step 2				.12	.01	-.03
SRC frequency	<-.01	.01	-.04			
Gender	-.01	.01	-.14			
Gender X SRC frequency	<-.01	.01	-.06			

Table K3

Regression Summary for SRC Frequency and Gender Predicting CogState One Card Learning Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.04	<.01	-.03
SRC frequency	<.01	.01	.04			
Gender	<.01	.02	.01			
Step 2				.15	.02	-.02
SRC frequency	<-.01	.01	.02			
Gender	-.01	.03	.07			
Gender X SRC frequency	-.03	.02	.17			

Table K4

Regression Summary for SRC Frequency and Gender Predicting CogState One Back Test Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.07	<.01	-.02
SRC frequency	<-.01	.01	-.04			
Gender	.01	.03	.05			
Step 2				.19	.03	<-.01
SRC frequency	-.01	.01	-.10			
Gender	-.01	.03	-.04			
Gender X SRC frequency	-.04	.03	-.19			

Table K5

Regression Summary for SRC Frequency and Gender Predicting SSRT

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.23	.05	.03
SRC frequency	.20	.11	.21			
Gender	-.09	.27	-.04			
Step 2				.24	.06	.02
SRC frequency	.19	.12	.20			
Gender	-.13	.30	-.06			
Gender X SRC frequency	-.07	.24	-.04			

Table K6

Regression Summary for SRC Severity and Gender Predicting CogState Detection Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.14	.02	-.01
SRC severity	.01	.01	.11			
Gender	-.01	.01	-.06			
Step 2				.20	.04	<.01
SRC severity	<.01	.01	.05			
Gender	-.02	.02	-.24			
Gender X SRC severity	-.01	.01	-.23			

Table K7

Regression Summary for SRC Severity and Gender Predicting CogState Identification Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.10	.01	-.02
SRC severity	<.01	<.01	<.01			
Gender	-.01	.01	-.10			
Step 2				.12	.01	-.03
SRC severity	<-.01	.01	.01			
Gender	-.02	.02	.02			
Gender X SRC severity	-.01	.01	.01			

Table K8

Regression Summary for SRC Severity and Gender Predicting CogState One Card Learning Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.14	.02	-.01
SRC severity	.01	.01	.15			
Gender	.01	.02	.05			
Step 2				.23	.05	.02
SRC severity	.01	.01	.08			
Gender	-.04	.04	-.19			
Gender X SRC severity	-.04	.02	-.29			

Table K9

Regression Summary for SRC Severity and Gender Predicting CogState One Back Test Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.06	<.01	-.02
SRC severity	<-.01	.01	<.01			
Gender	.02	.03	.06			
Step 2				.17	.03	-.01
SRC severity	-.01	.01	-.06			
Gender	-.03	.04	-.15			
Gender X SRC severity	-.04	.03	-.26			

Table K10

Regression Summary for SRC Severity and Gender Predicting SSRT

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.21	.04	.02
SRC severity	.19	.13	.18			
Gender	-.15	.26	-.07			
Step 2				.21	.04	.01
SRC severity	.20	.14	.19			
Gender	-.06	.42	-.03			
Gender X SRC severity	.07	.27	.05			

Appendix L: Hypothesis 2 Regression Summary Tables

Table L1

Regression Summary for SRC Frequency and Gender Predicting SCAT3 Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.15	.02	-.01
SRC frequency	-.23	0.18	-.16			
Gender	-.10	0.41	-.03			
Step 2				.16	.03	-.01
SRC frequency	-.21	.19	-.15			
Gender	-.03	.47	-.01			
Gender X SRC frequency	.12	.38	.04			

Table L2

Regression Summary for SRC Severity and Gender Predicting SCAT3 Score

	B	*S.E.*	*β*	*R*	R^2	Adjusted R^2
Step 1				.22	.05	.01
SRC severity	.05	.19	-.27			
Gender	-.64	.39	-.05			
Step 2				.25	.06	<-.01
SRC severity	-.02	.25	-.01			
Gender	-1.13	.78	-.36			
Gender X SRC severity	-.41	.50	-.19			

Appendix M: Instructions for Contributors: Journal of the International Neuropsychological Society

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