The neuropsychology of sport concussion

by

Mareen Weber

A thesis submitted to
The University of Birmingham
for the degree of
DOCTOR OF PHILOSOPHY

School of Sport and Exercise Sciences

The University Of Birmingham

October 2010

Abstract

This thesis presents four empirical chapters that challenge current sport concussion research and practice. Chapter 2 measured sport concussion knowledge in the UK general public using an online survey. It showed high sport concussion awareness, but limited and erroneous understanding. Chapter 3 examined the effect of terminology (i.e., concussion; mild traumatic brain injury, mTBI; minor head injury, mHI) on familiarity, injury outcome expectations and symptom self-report in athletes using a questionnaire. The mTBI terminology was the least familiar, reliably more negative conceptualised, but knowledge was more accurate than the other two. Symptom self-report did not vary with terminology or injury history. Chapter 4 compared the late neuropsychological functioning in self-reported sport-concussed to non-concussed athletes using a comprehensive test battery. Injury self-report was associated with worse memory recall and executive function shifting. Chapter 5 piloted a computerised neuropsychological test battery in athletes using a longitudinal control group design. A single case study showed transient deficits in memory recall and executive function at one to six weeks post-concussion. The data overall suggest that (i) education is needed; (ii) the interchangeable terminology use is inappropriate; (iii) sport concussion assessment should be complemented by memory recall and executive function tests; (iv) case studies might be more appropriate than group comparisons.

This thesis comprises the following:

Empirical papers:

- Weber, M. & Edwards, M.G. (2010). The effect of brain injury terminology on university athletes' expected injury outcome, term familiarity and actual symptom report. *Brain Injury*, 24 (11), 1364-1371.

Published abstracts:

- Weber, M. & Edwards, M.G. (2010). Does terminology influence participant response to sport head injury? *Brain Injury*, 24 (3), 296.
- Weber, M., Ring, C., Jansari, A. & Edwards, M.G. (2010). Do aggression and executive function influence sport concussion? *Brain Injury*, 24 (3), 299.
- Weber, M. & Edwards, M.G. (2008). Frontal executive function following concussion: A need to modify assessment? *Brain Injury*, 22 (Supp1), 189.

Conference presentations:

- Weber, M. & Edwards, M.G. Does terminology influence participant response to sport head injury?, poster presented at the 8th World Congress on Brain Injury, 11-15 March 2010, Washington, USA.
- Weber, M., Jansari, A., Ring, C. & Edwards, M.G. Do executive function and aggression influence sport concussion?, poster presented at the 8th World Congress on Brain Injury, 11-15 March 2010, Washington, USA.
- Weber, M. & Edwards, M.G. Perception of head injuries in sport: The wording matters!, poster presented at the MTBI 2009 An International Conference on Mild Traumatic Brain Injury, 12-15 August 2009, Vancouver, BC, Canada.

- Weber, M. & Edwards, M.G. Late outcome psychological measures following concussion, poster presented at the 1st Meeting of the Federation of the European Neuropsychological Societies, 2-5 September 2008, Edinburgh, Scotland, United Kingdom.

- Weber, M. & Edwards, M.G. Frontal executive function following concussion: A need to modify assessment?, poster presented at the 7th World Congress in Brain Injury, 9-12 April 2008, Lisbon, Portugal.

Acknowledgements

I would like to thank my supervisors Martin and Chris for their guidance through the PhD labyrinth. Your support, help and commitment have made this PhD an enjoyable experience. Thank you for your optimism, your patience (not only with my occasional stubbornness), your flexibility and for letting me spend a considerable time abroad.

I thank my parents and grand parents for their huge support during this big and all previous big, medium and small endeavors. I know that not all the paths I have chosen have been easy for you to accompany, and I thank you for letting me have my own choices in life.

I thank my beloved sister Susan and my brother-in-law Helge for their unconditional love and support. Thank you for sharing the joys, listening to all my complaints and providing me with a lovely home every once in a while. I thank my nephew Konstantin, my niece Xenia and my niece-or-nephew-to-be for making me the proudest aunt on earth. Thank you all for providing the much needed relaxation during the past three years and for all the (mental and real) hugs and kisses.

My biggest thanks goes to my husband Thomas. Thank you for your boundless understanding, support, encouragement, optimism, patience, 'emergency surgeries' and love. Without you, this would not have been possible. Thank you for believing in me, for putting everything into perspective and for being my home.

Contents

List of Figures

List of Tables

Chapter 1

General Introduction

A recent consensus statement defined sport concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (McCrory, Meeuwisse, Johnston, Dvorak, Aubry, Molloy & Cantu, 2009). Support for this statement comes from animal research. This has shown that experimental head trauma disturbs the neural membrane yielding complex irregular ionic shifts that cannot be immediately regulated due to a mismatch between the energy that is available and the amount that would be necessary for the compensatory regulation (see Giza & Hovda, 2001 for a detailed account). In line with this, the sport concussion definition emphasised that any resulting symptoms reflected a cerebral-functional, and not cerebral-structural abnormality that was transient and able to recover. Animal research has found that most post-concussion neurometabolic changes resolve over ten days post-injury (Giza & Hovda, 2001). Although much research has been carried out in animal studies and biological models, it is not yet clear how the changed neurometabolism relates to the clinical injury presentations. Typically, sport concussion symptoms may involve loss of consciousness, post-traumatic amnesia, somatic symptoms (e.g., headache, dizziness, nausea), cognitive deficits (e.g., subjective and objective difficulties in concentration or memory) and emotional symptoms (e.g., feeling easily angered or frustrated) (see Johnston, McCrory, Mohtadi & Meeuwisse, 2001 for a review).

To assess the sport concussion effects in athletes, a multifaceted assessment approach has been recommended (McCrory et al., 2009). This should include neuropsychological testing. The aim is to measure whether and to what extent the sustained sport concussion impairs cognitive or behavioural functions. For example, following a sport concussion, athletes typically show impairments in tests of memory and reaction time (e.g., Iverson, Brooks, Collins & Lovell, 2006a). In order to determine the cognitive deficit, the recommended approach is a comparison of pre-injury versus post-injury test performances. That is, at the beginning of the sport season (before the injury), athletes undergo neuropsychological testing. Then, if a sport concussion is suspected to have occurred or actually sustained, athletes are tested again on the same neuropsychological tests after the injury. The neuropsychological tests are then repeated in set time periods (e.g., every four days). Recovery is assumed complete if the cognitive functions involved in the tests return to the pre-injury performance levels. For example, a typical finding would be a significantly increased mean reaction time or decreased memory performance at day one to day five following the injury (in comparison to pre-injury performance), but substantial improvements at day ten (i.e., no difference in comparison to pre-injury performance) (Iverson et al., 2006a). Using this method, neuropsychological test results should aid the decision on when it is safe for injured athletes to return to sport training and competition. The literature shows general consent by which no athlete should be returned to training and competition until all sport concussion effects have resolved (Guskiewicz, Bruce, Cantu, Ferrara, Kelly, McCrea, Putukian & Valovich McLeod, 2006; McCrory et al., 2009).

Based on US injury occurrence rates, approximately 300,000 people have been estimated to have a sport concussion every year (as cited in Guskiewicz, Weaver, Padua & Garrett, 2000). In the UK, however, there are only prevalence estimates for head trauma in general (i.e., not sport concussion in particular). Head traumas account for one million Accident and Emergency admissions each year (Kay & Teasdale, 2001). Similar to sport concussion, the vast majority of these injuries (i.e., 90%) could be classified as mild or minor, and were mainly sustained during a fall, assault or road traffic accident (Kay & Teasdale, 2001). This suggests a high prevalence of head trauma of comparatively low severity in the UK. The true prevalence however, is likely to be much higher, as the above estimate does not include injured individuals that attended a general practicioner's services or did not seek any medical advice at all. The latter might particularly apply to cases of sport concussion. For example, it has been estimated that up to 50% of sport concussion incidence goes unreported to professional staff (McCrea, Hammeke, Olson, Leo & Guskiewicz, 2004).

In addition to the yet unknown epidemiological scope of sport concussion in the UK, four related issues emerge from the literature. The first two issues relate to the definition. These are: (1) the lack of sport concussion knowledge in the general public; and (2) the heterogeneous use of terminology to relate to the injury. The last two issues relate to the neuropsychological assessment. These are: (3) the potential lingering of cognitive deficits following the injury; and (4) insufficiencies in the neuropsychological assessment tools currently used. The following review will use the relevant literature on sport concussion to introduce these issues, particularly in terms of their significance to athletic health care. It will conclude with an overview of the empirical studies that were conducted in the thesis to address the issues raised.

1.1 Lack of knowledge

It is important to know what the general public knows about brain injury. Knowledge plays an important part in informed decision-making (Woolf, Chan, Harris, Sheridan, Braddock, Kaplan, Krist, O'Connor & Tunis, 2005). Only if an individual knows about an injury, can risks that are associated with it be evaluated. For example, assume that an individual does not know that a direct head impact was sufficient, but not necessary to cause sport concussion. Then, if the individual sustained a concussion, they might be less able to identify the injury (i.e., a brain injury) and take appropriate measures (e.g., seek medical advice) despite experiencing relevant symptoms (e.g., dizziness, headaches, nausea). This point is particularly important for sport concussion, as to a significant extent, sport concussion remains unrecognised and/or unreported to professional staff (McCrea et al., 2004). Yet, little research has been conducted that has assessed sport concussion knowledge in the general public. Past research has surveyed athletes (e.g., Delaney & Frankovich, 2005; Kaut, DePompei, Kerr & Congeni, 2003; Rosenbaum & Arnett, 2009; Sye, Sullivan & McCrory, 2006a) and sport coaches (e.g., Guilmette, Malia & McQuiggan, 2007a; Sarmiento, Mitchko, Klein & Wong, 2010), but not the general public.

The literature has reported that the general public shows a substantial lack of general brain injury knowledge (Chapman & Hudson, 2010; Farmer & Johnson-Gerard, 1997; Gouvier, Prestholt & Warner, 1988; Hux, Schram & Goeken, 2006; O'Jile, Ryan, Parks-Levy, Gouvier, Betz, Haptonstahl & Coon, 1997; Willer, Johnson, Rempel & Linn, 1993). Research used surveys that asked members of the general public to rate statements (e.g., "People who have had one head injury are more likely to have another") for their truthfulness. This showed that the general public expressed erroneous knowledge concerning brain injury symptoms and recovery. For example, many individuals thought that brain injury recovery was complete when the injured person "feels back to normal". To date, the research that has assessed brain injury knowledge has mainly been conducted in North America (e.g., Farmer & Johnson-Gerard, 1997; Gouvier et al., 1988; Hux et al., 2006; O'Jile et al., 1997; Willer et al., 1993). Only one study has examined the UK general public's knowledge on brain injury (Chapman & Hudson, 2010). They found that significantly less members of the UK general public possessed accurate knowledge than the US. For example, they reported that 90% did not know that a previous brain injury may result in an increased vulnerability to further brain injuries. This suggests that the UK general public possesses insufficient knowledge on brain injury.

There are two issues with the existing literature: (i) past research has not examined knowledge on sport concussion, and; (ii) research on brain injury and sport concussion knowledge with the UK general public is scarce. Research that has assessed general brain injury knowledge cannot necessarily be extended to sport concussion knowledge, as to do so would assume that the general public equates brain injury and sport concussion as the same thing. However, it might be that a sport concussion is perceived as less severe and of less significance than a (non-sport) brain injury, as the terminology and given context (i.e., concussion; sport) convey a message themselves that may influence the expressed knowledge. This could be seen as reasonable, as brain injuries differ in their severities (i.e., low to severe), and it is not clear whether participants who took part in the surveys had comparable concepts of brain injury. It might be plausible to assume that participants who conceptualised brain injury of high severity rated a statement, such as "It is good advice to remain inactive during recovery", differently than those who conceptualised a brain injury of low severity. Therefore, we think that further understanding is needed to isolate general public knowledge on sport concussion specifically.

The second issue raised concerns the importance of knowing what the UK's general public knows about sport concussion. Contact and collision sports, such as rugby union, rugby league and football, have been associated with high concussion risk (Dvorak & Junge, 2000; Hoskins, Pollard, Hough & Tully, 2006). For example, in football, concussions have been estimated to account for up to 22% of the sustained injuries (Dvorak & Junge, 2000), and in a review of injuries in rugby league, head injuries were the second most commonly sustained injuries (Hoskins et al., 2006). It is important therefore that the injury is recognised. For example, it has been found that many athletes failed to report a sustained concussion to professional staff (McCrea et al., 2004). This highlights the role that significant others might (have to) play in the recognition of the injury. At present, the following questions remain unanswered: Are members of the UK general public familiar with sport concussion? Would they be able to recognise a sport concussion? What do they know about the injury's typical symptoms and recovery?

1.2 Heterogeneous terminology

The literature uses the heterogeneous terminology (sport) concussion, mild brain injury, mild closed head injury, mild head injury, mild head trauma, mild traumatic brain injury and minor head injury to relate to head and brain traumas that were sustained in sport (Iverson, 2005). These terminologies, in particular concussion, mild traumatic brain injury and minor head injury, have been interchangeably used as synonyms (Anderson, Heitger & Macleod, 2006). It is however, not clear whether the interchangeable use of terminology was permissible (Anderson et al., 2006), and what the consequences of using, for example, the terminology sport concussion instead of sport mild traumatic brain injury or sport minor head injury, would be on injury knowledge.

The concussion terminology originated from the Latin word 'concutere' meaning to shake violently, and so implies a link to the biomechanical impact itself that leads to the injury. The mild traumatic brain injury terminology appears to also be related to the biomechanical impact, but in contrast to the concussion terminology also involves an explicit statement on the sustained injury's severity (i.e., mild). Similar to the mild traumatic brain injury terminology, the minor head injury terminology involves an explicit statement on the sustained injury's severity (i.e., minor), but in contrast to the mild traumatic brain injury terminology, the minor head injury terminology does not restrict its scope to the brain. For example, a minor head injury might mean a minor injury to the brain or a minor superficial injury (i.e., to the head, yet not to the brain). As such, the minor head injury terminology is less specific than the concussion and mild traumatic brain injury terminology. This suggests that the sport concussion, sport mild traumatic brain injury and sport minor head injury terminologies might differ in the message they convey.

We think that it is important to examine whether the terminologies that are used (i.e., sport concussion, sport mild traumatic brain injury, sport minor head injury) to refer to one injury (i.e., a brain injury) differ in what people believe they understand about the injury. For example, Whittaker, Kemp and House (2007) assessed the injury outcome expectations in patients with mild head injury at the day of the injury and followed their recovery at three months post-injury. The data revealed that symptomatic patients who showed more negative expectations at the day of the injury fared worse at the second assessment in that they self-reported significantly more symptoms than symptomatic patients with less negative expectations. If different terminology was linked to differences in knowledge and related expectations, it could be that terminology influences injury recovery. For example, an adverse injury concept (e.g., long, possibly incomplete recovery) might yield a more adverse injury outcome in the sense of a nocebo effect: those who expect worse will actually fare worse (Benedetti, Lanotte, Lopiano & Colloca, 2007; Whittaker et al., 2007). Unequivocal terminology use is important in order to reduce unintentional adverse effects that might impede the recovery from the injury. On the other hand, whereas adverse terminology effects need to be prevented, it is of equal importance that the terminology appropriately communicates the seriousness of the injury.

The questions that need to be addressed are: Are athletes equally familiar with all terminologies that are used? Do athletes know that the sport concussion, sport mild traumatic brain injury and sport minor head injury terminologies are used to refer to one injury (i.e., an injury to the brain)? Do athletes evaluate the seriousness of a sport concussion similar to a mild traumatic brain injury or minor head injury? Could a diagnosis using one terminology (e.g., sport concussion) yield a different injury outcome than a differently termed diagnosis (e.g., sport mild traumatic brain injury)?

1.3 Long-term cognitive deficits

Though sport concussion effects on neuropsychological functioning have been defined as short-lived (i.e., they recover) (McCrory et al., 2009), the empirical evidence is currently less definite. For example, prolonged neuropsychological function decrements have been reported in sport-concussed athletes in tests of attention (Cremona-Meteyard & Geffen, 1994; Ellemberg, Leclerc, Couture & Daigle, 2007; Matser, Kessels, Lezak, Jordon & Troost, 1999), memory (De Beaumont, Théoret, Mongeon, Messier, Leclerc, Tremblay, Ellemberg & Lassonde, 2009; Matser et al., 1999) and executive functioning (Di Russo & Spinelli, 2009; Ellemberg et al., 2007; McCrea, Guskiewicz, Marshall, Barr, Randolph, Cantu, Ornate, Yang & Kelly, 2003; Register-Mihalik, Mihalik & Guskiewicz, 2009). However, other studies have failed to find any long-term neuropsychological function deficits in sport-concussed athletes suggesting a full recovery (Belanger, Spiegel & Vanderploeg, 2010; Broglio, Ferrara, Piland, Anderson & Collie, 2006; Brown, Guskiewicz & Bleiberg, 2007; Catena, van Donkelaar, Halterman & Chou, 2009; Echemendia, Putukian, Mackin, Julian & Shoss, 2001; Guskiewicz, 2002; Guskiewicz, McCrea, Marshall, Cantu, Randolph, Barr, Onate & Kelly, 2003; Iverson, Brooks, Lovell & Collins, 2006b; Macciocchi, Barth, Littlefield & Cantu, 2001; Maddocks & Saling, 1996; McCrea, Kelly, Randolph, Cisler & Berger, 2002; Shuttleworth-Edwards, Smith & Radloff, 2008; Thériault, De Beaumont, Gosselin, Filipinni & Lassonde, 2009; Thornton, Cox, Whitfield & Fouladi, 2008). In the literature, the former findings have been dismissed, and instead, it has been suggested that the findings result from artefacts that originated from the use of cross-sectional study designs and insufficient control of confound variables that may have moderated neuropsychological performance (e.g., history of learning difficulties or neurological disorders, depression, illicit substance misuse etc.) (Grindel, Lovell & Collins, 2001). However, it could also be that the latter null findings might show no effects because of the same confounds (i.e., greater variance or other effects, such as practice), as findings originated from prospective longitudinal studies that required repeat neuropsychological testing (Beglinger, Gaydos, Tangphao-Daniels, Duff, Kareken, Crawford, Fastenau & Siemers, 2005). It is possible that practice effects may have masked, at least partially, the post-injury decline in cognitive domains.

Provided sufficient control of potentially confounding variables, another factor that might influence the chances of finding long-term neuropsychological impairments are with the selected tests used in the assessment. In order to measure post-concussion function decrements beyond the acute and post-acute injury stage, a more comprehensive neuropsychological test battery with a generally higher test difficulty might be necessary. This might involve comprehensive coverage of behaviours and more difficult tests to reduce any potential ceiling effects.

It is important to reliably establish whether sport concussion yields prolonged neuropsychological function deficits. If there was consistent empirical evidence for long-term neuropsychological sport concussion effects, this would have implications for athletic educational programmes, the sport concussion management and the neuropsychological assessment of sport concussion effects. If a history of one or multiple sport concussion was reliably linked to prolonged neuropsychological function impairment, then it would be necessary to communicate this health risk to the populations at risk (i.e., contact and collision sport players) and their significant others (i.e., players' parents, family and friends). Furthermore, sport concussion recovery is currently conceptualised as the return to pre-injury baseline (Lovell & Collins, 1998). If research reliably showed prolonged neuropsychological sport concussion effects, then the conceptualisation of recovery as the return to pre-injury performance would need reconsideration (i.e., as athletes would not return to baseline). Also, if prolonged neuropsychological function decrements were established in cognitive domains that were typically not included in the assessment of neuropsychological sport concussion effects, then this would cast doubts on the appropriateness of the neuropsychological test batteries that are currently in use.

Therefore, the questions that need to be addressed are: Do sport-concussed athletes show neuropsychological function impairments compared to non-concussed athletes if tested on a comprehensive neuropsychological test battery? Do any findings on long-term neuropsychological function impairments match the typical findings on the immediate neuropsychological sport concussion effects? What would be the implications of a match or non-match?

1.4 Neuropsychological testing

Neuropsychological testing has been recommended as one element in the assessment and diagnosis of sport concussion deficits. There is general clinical consent that no athlete should be returned to training and competition until all sport concussion effects have resolved (Guskiewicz et al., 2006; McCrory et al., 2009).

Over the years, computerised neuropsychological test batteries have been developed that have substituted the more traditional paper-pencil tests (e.g., CogState Sport, CogState, Ltd., Melbourne, Australia; ImPACT test, ImPACT Applications, Inc., Pittsburgh, Pennsylvania, USA). Reasons for developing these tests included the availability of theoretically indefinite alternate test versions (to reduce practice effects), reducing the costs of running these tests on a large scale, increasing the efficiency of implementing the tests, and in providing better accuracy (Collie, Darby & Maruff, 2001). For example, computerised testing allows the parallel testing of several athletes in a comparatively short amount of time (typically less than 30 minutes). However, while computerised measurement presents some clear advantages, these test batteries typically assess a restricted range of cognitive domains (i.e., mainly attention and memory recognition; Belanger & Vanderploeg, 2005). This is in contrast to clinical neuropsychological testing that typically involves cognitive measures of attention, memory recall, memory recognition, and executive functioning (Strauss, Sherman & Spreen, 2006). By using tests that have narrower cognitive focus, it might be that incorrect clinical decisions are currently made (e.g., when to return an athlete to training and competition). For example, intact memory recognition is not necessarily paralleled by intact memory recall (Bastin, Linden, Charnallet, Denby, Montaldi, Roberts & Andrew, 2004; Yeates, Blumenstein, Patterson & Delis, 1995). Furthermore, clinical research has shown that cognitive domains may follow differential recovery courses with a slower recovery curve for more complex cognitive functions such as memory recall and executive functions (Anderson & Catroppa, 2005; Christensen, Colella, Inness, Hebert, Monette, Bayley & Green, 2008).

It is important to ensure that the neuropsychological assessment of cognitive sport concussion effects is as efficient and as comprehensive as possible. Efficiency is required, as neuropsychological testing should not be perceived as adverse (both in terms of financial costs and expenditure of time) by athletes, team staff or team management. Comprehensiveness is also vital. Post-injury neuropsychological test results should aid clinical decision-making (Guskiewicz et al., 2006; McCrory et al., 2009). However, their value is restricted by the choice of neuropsychological tests included. For example, a battery with tests on reaction time and memory recognition only allows testimonies on the recovery of reaction time and memory recognition. Taking into account that complex cognitive functions may take a longer recovery (Anderson & Catroppa, 2005; Christensen et al., 2008), a test battery without tests on memory recall and executive functions might yield different post-injury testimonies concerning an athlete's cognitive recovery than a test battery that included tests on memory recall and executive functioning. For example, an athlete that underwent neuropsychological testing on a test battery with reaction time and memory recognition tests might still be cognitively impaired by the time the neuropsychological testing indicated full recovery (e.g., on memory recall and executive function).

An appropriate choice of computerised neuropsychological tests is important to athletic health care. If the neuropsychological test battery did not cover the major cognitive domains that might be compromised by a sustained sport concussion, an athlete might be prematurely advised to return to sport practice and competition. This would oppose the rationale behind neuropsychological testing. It would also potentially put the athlete at additional risks. For example, an athlete who was (unintentionally) prematurely returned to sport practice might be at risk of further injuries (Iverson, Gaetz, Lovell & Collins, 2004a). This might include further sport concussion, but also non-brain injuries. A repeat sport concussion might require a longer recovery because it occurred to a brain that had not yet recovered from the previous sport concussion. A non-brain injury might force the athlete to refrain even longer from sport participation than the sport concussion alone. It is therefore pivotal to ensure that a computerised neuropsychological test battery contains an appropriate selection of neuropsychological tests so that a sport concussion can be efficiently managed and further sport injuries prevented.

The questions that need addressing are: Does the inclusion of memory recall and executive function tests improve the computerised neuropsychological assessment of sport concussions? Do sport-concussed athletes show function decrements in memory recall and executive functioning that resolve with time? Do the more complex cognitive measures of memory recall and executive functioning follow a different recovery process than a more simple measure of reaction time?

1.5 Thesis summary

The thesis presented here aimed to answer the questions raised by these four identified issues. Each was tackled in a separate thesis chapter (Chapters 2 to 5). At the end of the thesis, the General Discussion (Chapter 6) will provide an overview of the findings and discuss the impact of the new data on the research literature and clinical guidelines.

In Chapter 2, findings from an online survey that assessed sport concussion knowledge in the UK general public are presented. The study revealed that the UK general public showed good sport concussion awareness, yet not necessarily correct understanding. Misconceptions concerning sport concussion symptoms and recovery were evident. The data suggest that sport concussion might not be well recognised in the UK and that educational programmes are needed to fill knowledge gaps and correct misunderstandings.

Chapter 3 reports findings from a questionnaire study that investigated the effect of terminology (i.e., sport concussion, sport mild traumatic brain injury, sport minor head injury) on term-related familiarity, expected injury outcome and actual symptom reporting. The data showed that terminology significantly influenced both expected injury outcome and familiarity, but not actual symptom reporting. Outcome expectations were reliably more negative for the term sport mild traumatic brain injury than sport concussion or sport minor head injury. Sport mild traumatic brain injury was the least familiar term compared to the other two. This suggests that the interchangeable use of terminology might be inappropriate and that, depending on the terminology used, athletic educational programmes might need adaption.

Chapter 4 presents results from a cross-sectional study that compared neuropsychological test performance between self-reported sport-concussed and non-concussed contact sport players. The comprehensive neuropsychological test battery combined computerised and paper-pencil tests of higher difficulty to measure attention, verbal memory and executive function. The study also controlled for major potential moderators of neuropsychological test performance. The data showed reliable performance differences between the self-reported sport-concussed and non-concussed contact sport players on measures of immediate free verbal memory recall and executive function shifting. This suggests that a sport concussion history might be associated with long-term neuropsychological function deficits. The data also propose that the inclusion of tests of memory recall and executive function might benefit the neuropsychological assessment of cognitive sport concussion effects.

Chapter 5 piloted a new computerised neuropsychological test battery that we compiled, and measured attention, verbal memory recall and executive function cognition using a longitudinal study design in healthy participants. It first established multiple baseline measures and then tested a single case athlete using a longitudinal pre-injury versus post-injury comparison and a control group comparison design. The data showed fairly stable baseline performance following one practice session, and for the single case athlete, they showed a profile of impairment followed by recovery compared to the baselines. The post-concussion function deficits were in verbal memory recall and executive functioning at one and two weeks post-injury. The findings suggest that verbal memory recall and executive function tests would add significant informative value to the neuropsychological sport concussion assessment.

Together, these new data challenge the current field of sport concussion neuropsychology. From these data, in the General Discussion (Chapter 6), we discuss and suggest new modifications that we believe the field needs to embrace in the future.

Chapter 2

Sport concussion knowledge in the UK general public

2.1 Abstract

The present study sought to investigate sport concussion knowledge in the UK general public using an online survey. Three elements in the survey were used to measure knowledge in 266 participants: familiarity with sport concussion (yes, no), injury indicators and injury statements rated for their truthfulness. Statement response options were either definite (true, false) or non-definite (probably true, probably false). Assured knowledge was defined as the choice of a definite response, and guess knowledge as the choice of a non-definite response. Response frequencies were calculated for positive sport concussion familiarity and stated injury indicators. The main analysis used odds ratios to compare rating accuracy between assured and guess responses. An additional analysis used chi-square tests to examine rating accuracy by sport concussion history. The data revealed sport concussion awareness, yet only limited understanding. Participants mostly guessed in statement ratings and showed clear misconceptions in both assured and guess knowledge. In all, the seriousness of sport concussion was clearly underestimated, though injury indicators matched clinical science indicating some notable knowledge base. An additional analysis showed that a sport concussion self-report was accompanied by greater knowledge certainty, but not accuracy. Sport-concussed participants stated a significantly greater variety of injury indicators than non-concussed participants. Our data suggest that sport concussion knowledge in the UK general public is limited and erroneous, and that a history of sport concussion might yield a false sense of security. Study findings are discussed in terms of their significance for educational programmes.

2.2 Introduction

Sport concussion management guidelines recommend a multi-faceted approach including neuropsychological assessment under the supervision of an interdisciplinary team of physicians, neuropsychologists and trainers (McCrory et al., 2009). However, the sport pitch reality is that only a few sport teams, especially at lower play levels, use neuropsychological testing as part of their sport concussion management (Covassin, Elbin, Stiller-Ostrowski & Kontos, 2009; Ferrara, McCrea, Peterson & Guskiewicz, 2001; Notebaert & Guskiewicz, 2005). This means that athletes and their significant others (e.g., coaches, family and friends) need to be able to recognise a sport concussion and take appropriate action such as ensuring that the injured athlete refrains from sport until recovery is complete. This is particularly important as a premature return-to-play following a concussion may put an athlete at a greater risk of further injury (Iverson et al., 2004a). Thus, adequate awareness and knowledge on sport concussion are pivotal for safe sport practice.

In the literature, awareness, yet not necessarily accurate understanding of sport concussion has emerged as a general theme for both athletes and members of the general public. For example, in surveys, athletes showed poor knowledge regarding injury mechanisms and symptoms, methods to map brain damage, post-injury vulnerabilities and recovery time (Rosenbaum & Arnett, 2009; Sye et al., 2006a). Typically, athletes considered loss of consciousness as necessary for a sport concussion diagnosis and the return-to-play responsibility lay with the injured athlete solely (Sye et al., 2006a). Athletes also acknowledged that rules should be bent in an important match (Sye et al., 2006a). For example, athletes admitted that they would continue to play despite experiencing dizziness or headaches following a head trauma (Kaut et al., 2003). This is at odds with current injury definitions and management guidelines (Guskiewicz et al., 2006; McCrory et al., 2009), and the data suggest that athletes underestimated the injury's seriousness, and that sport concussion knowledge was characterised by gaps and errors in understanding.

The importance of athlete knowledge of sport concussion should not be underestimated. Lacking knowledge might contribute to the fact that a substantial proportion (up to 50%) of sport concussion have been estimated to remain unreported (Goodman, Gaetz & Meichenbaum, 2001; McCrea at al., 2004; Sye et al., 2006a; Williamson & Goodman, 2006). For example, in surveys, athletes stated that they did not think the injury was serious enough to report it or did not know it was a sport concussion at all (Delaney & Frankovich, 2005; McCrea et al., 2004). Therefore, these data suggest that athletes are not necessarily reliable for self-diagnosing a sport concussion.

Lack of athlete knowledge highlights the role of significant others, such as coaches, family and friends as members of the general public, in the recognition (and management) of sport concussion. The literature that assessed coach sport concussion knowledge showed that typically they possess good awareness of the athletes' reluctance to report suspected sport concussion (Guilmette et al., 2007a; McCrea et al., 2004; Sarmiento et al., 2010).

Coaches' symptom recognition and recall has also been found to be reasonable (Cusimano, 2009; Guilmette et al., 2007a; Valovich McLeod, Schwartz & Bay, 2007), though injury recognition was worse when coaches were given injury scenarios (Valovich McLeod et al., 2007). For example, Guilmette and colleagues (2007a) surveyed US American non-certified high-school coaches and asked them to name sport concussion indicators. The most frequently named indicators were confusion or disorientation, dilated pupils, headache and loss of memory which matches well with injury definitions (e.g., Guskiewicz et al., 2006; McCrory et al., 2009). Valovich McLeod et al. (2007) presented coaches with a description of an injury and asked them whether they thought that a sport concussion was sustained or not. Only 64.7% of the coaches correctly recognised the injury as a sport concussion. Similar to the athletes, a significant proportion of surveyed coaches endorsed loss of consciousness as necessary for a sport concussion diagnosis (Valovich McLeod et al., 2007) and, more importantly, self-reported inappropriate return-to-play practices (Valovich McLeod et al., 2007; Yard, Collins & Comstock, 2009). For example, in the survey of coaches by Valovich McLeod et al. (2007), 26.7% rejected the notion that "an athlete who displays any sign or symptom of concussion should not be allowed to return to play" (p. 141). Similarly, in a study by Yard et al. (2009), American Football coaches responded that they would return a high-school student athlete to training and competition after less than one day following a traumatic impact with loss of consciousness.

Most research with the general public, including family and friends, however, typically does not focus on sport as injury context, but head and brain injury in general (Chapman & Hudson, 2010; Farmer & Johnson-Gerard, 1997; Gouvier et al., 1988; Hux et al., 2006; O'Jile et al., 1997; Willer et al., 1993). Similar to athletes, the general public expressed awareness, yet not necessarily correct understanding (Gouvier et al., 1988; Sullivan, Bourne, Choie, Eastwood, Isbister, McCrory & Gray, 2009). Misconceptions were particularly pronounced concerning recovery and symptoms, but more accurate regarding brain damage and injury mechanisms (Gouvier et al., 1988). For example, 47% falsely agreed with the proposition that brain injury recovery is complete when the injured person feels "back to normal", but only 13% falsely stated that a little brain damage does not matter, as people do not use all of their brain anyway. Over the years, there appears to have been an increase in knowledge accuracy, particularly in general brain injury issues such as the significance of brain damage or the injured person's awareness of post-injury difficulties (Farmer & Johnson-Gerard, 1997; Hux et al., 2006; O'Jile et al., 1997; Willer et al., 1993). For example, for the statement that "recovery is complete when the injured person feels 'back to normal' ", the misconception rate decreased from 47% in Gouvier et al. (1988) to 2.5% in Hux et al. (2006). However, recovery- and symptom-related misconceptions, particularly regarding loss of consciousness, post-injury memory, recovery and outcome, remained (Chapman & Hudson, 2010). For example, the study by Chapman and Hudson (2010) found that 50% of the surveyed members of the British general public agreed with the notion that recovery depends on how hard the injured individual works at it. Other research asked members of the general public to either state or recognise symptoms that they think would be experienced by a head-injured person. In contrast to reasonable symptom recognition (Ferrari, Constantoyannis & Papadakis, 2001a; Ferrari, Obelieniene, Russell, Darlington, Gervais & Green, 2001b; Gunstad & Suhr, 2001; Gunstad & Suhr, 2002; Gunstad & Suhr, 2004), the general public produced considerably less, and not necessarily accurate symptoms in free recall (Aubrey, Dobbs & Rule, 1989; Mackenzie & McMillan, 2005; Mulhern & McMillan, 2006).

Appropriate awareness and correct knowledge on sport concussion in the general public is important. As athletes themselves have been shown not to report suspected injuries (Delaney & Frankovich, 2005; McCrea et al., 2004), and coaches have reported conflicts in their roles as first aiders (i.e., what is best for the athlete) versus coaches (i.e., what is best for the team) (Ransone & Dunn-Bennett, 1999), significant others, such as family and friends, are likely to be the next in line to recognise the injury and encourage taking appropriate measures in sport pitch reality. Therefore, improving general public knowledge is critical.

In the studies reviewed here, there are a number of limitations. To the best of our knowledge, so far, no study has specifically examined sport concussion knowledge in the UK general public. Findings from studies that asked members of the general public about head and brain injury might not necessarily expand to sport concussion (Ruff & Weyer Jamora, 2009). For example, the perception of sport concussion might differ in terms of head impact force and injury consequences in comparison to the perception of injuries sustained in road traffic accidents. Studies employing road traffic accidents scenarios to depict the injury context mostly described an injury-related loss of consciousness and brief hospitalisation (e.g., Gunstad & Suhr, 2001; Gunstad & Suhr, 2002; Gunstad & Suhr, 2004). However, only a minority of sport concussion involve loss of consciousness or require hospitalisation (McCrory et al., 2009), and so the perception of the injury might differ. Also, post-injury management may depend on the context in which the injury was sustained. For example, rest is required following a sport brain injury (Guskiewicz et al., 2006; McCrory et al., 2009), but might not be advised following a brain injury sustained in a road traffic accident. This renders statements ratings such as "It is good advice to rest and remain inactive during recovery" correct within, but incorrect outside the sport context. Another limitation of the current literature is that findings on sport concussion knowledge mainly originate from North American or Australasian population surveys, and it is unclear whether results can be generalised to the UK. For example, a recent study by Chapman and Hudson (2010) found head and brain injury beliefs to be comparable between North American and the UK in such that similar misconceptions were endorsed, but they were found to be expressed by more members of the general public than in previous surveys in North America.

The present study aimed to address these limitations by assessing sport concussion knowledge specifically and only in the UK general public by means of an online survey. The main hypothesis was that sport concussion awareness would be good, but knowledge accuracy only limited. More specifically, we wanted to differentiate knowledge certainty and accuracy. So far, only one study (Farmer & Johnson-Gerard, 1997) made full use of the original four response categories (true, probably true, probably false, false); otherwise, response options were dichotomised (i.e., true and probably true, probably false and false). This means that assured statement ratings, that is, true or false, were equated with guess ratings, that is, probably true or probably false. We question the equivalence of assured knowledge or misconceptions and lucky or unlucky guesses. For example, the subjectively assured, yet inaccurate agreement with the statement "Once a recovering sports person feels 'back to normal', the recovery process is complete" might present clear misapprehension that is well anchored in the respondent's injury construct. But the choice of the less certain response option, that is, probably true or probably false, might present rather lacking knowledge, yet not necessarily a definite misconception. We think that it is important to identify both gaps and errors in sport concussion knowledge so that educational programmes can address these.

As an additional analysis, we also wanted to examine the effect of sport concussion history on knowledge certainty and accuracy. From the literature, it is yet unclear whether and how personal experience, that is, a self-reported sport brain injury, influences knowledge. Outside the sporting context, brain injury experience was shown promotive (Hux et al., 2006), detrimental (O'Jile et al., 1997) or without any influence at all (Gouvier et al., 1988; Mulhern & McMillan, 2006). Given the nature of the injury, it might be that personal injury experience might affect knowledge rather adversely, because sport concussion effects are not easily accessible to introspection or players have been faced with inappropriate post-injury management (i.e., being allowed to continue to play) that supported an overoptimistic appraisal of the injury. Likewise, personal injury experience might be differentially advantageous; it might add content, but not necessarily accuracy. Alternatively, personal sport concussion experience might have no effect at all because the highly individualised nature of the injury impedes the deduction of definite or universally valid knowledge. For the present study, the additional hypothesis was that personal experience (i.e., a self-reported history) of sport concussion would be positively related to subjective certainty, but not accuracy of knowledge. That is, we expected more participants with a sport concussion history to respond assuredly (i.e., true, false), but we did not expect more sport-concussed participants to possess accurate knowledge than uninjured participants.

2.3 Method

2.3.1 Participants

A total of 444 members of the general public accessed the online survey. About one third (32.2%) failed to complete the survey, and a further 7.9% did not meet the inclusion criteria of UK residency. The final sample consisted of 266 participants aged 16 to 76 (see Table 2.1). A-levels presented the highest educational attainment for the majority of participants (63.9%).

TABLE 2.1: Sample demographics for the main and additional hypotheses. In the additional hypothesis, sport-concussed and non-concussed participants were comparable in age, U(266)=5536, p=.32. Females were underrepresented, $\chi^2(1)$=8.03, p<.01, and contact players were over-represented, $\chi^2(1)$=11.99, p<.01, in the self-reported sport-concussed compared to the non-concussed group.

Demographic measure		Main hypothesis	Additional hypothesis	
			Sport concussion history	
			Self-report	No self-report
N		266	84	142
Age	mean (SD)	24.6 (10.6)	25.7 (10.8)	25.1 (11.5)
Gender (female)	%	63.9	49.4	67.6
Contact sport player	%	46.1	63.3	38.1

From the participants that indicated awareness of the term sport concussion, 37.0% self-reported having sustained a sport concussion. Within the sport concussion group, 57.1% reported that they had sustained more than one sport concussion (*M*=2.43, *SD*=2.6; range 1-15); 31.0% stated the most recent sport concussion within the past 12 months;

67.9% received medical attention; and 41.7% self-reported refrained from sport post-injury. Refrainment ranged from two days to not having returned to sport yet. Cumulatively, 37.1% returned to sports within a week, 45.7% within ten days and 71.4% within two weeks.

The School of Sport and Exercise Sciences University of Birmingham ethics committee approved the study in accordance with the 1964 Declaration of Helsinki. Each participant gave informed consent before providing any data.

2.3.2 Material and procedure

We used SurveyMonkey (SurveyMonkey, Portland, OR, USA) to create the survey and collect the data. Data collection took place between the 11th June 2008 and the 29th January 2010. Invitations to take part in the online survey were posted on webpages that specialise in online research and the University of Birmingham intranet.

Figure 2.1 presents a flow diagram of the survey. The survey applied a skip logic, whereby a given response would direct participants to the appropriate next item. For example, only if the participants affirmed having previously sustained a sport concussion, would they be asked to provide further details; otherwise the non-applicable items were automatically skipped and participants presented with the next item. Participants were instructed that they were able to leave the survey at any time.

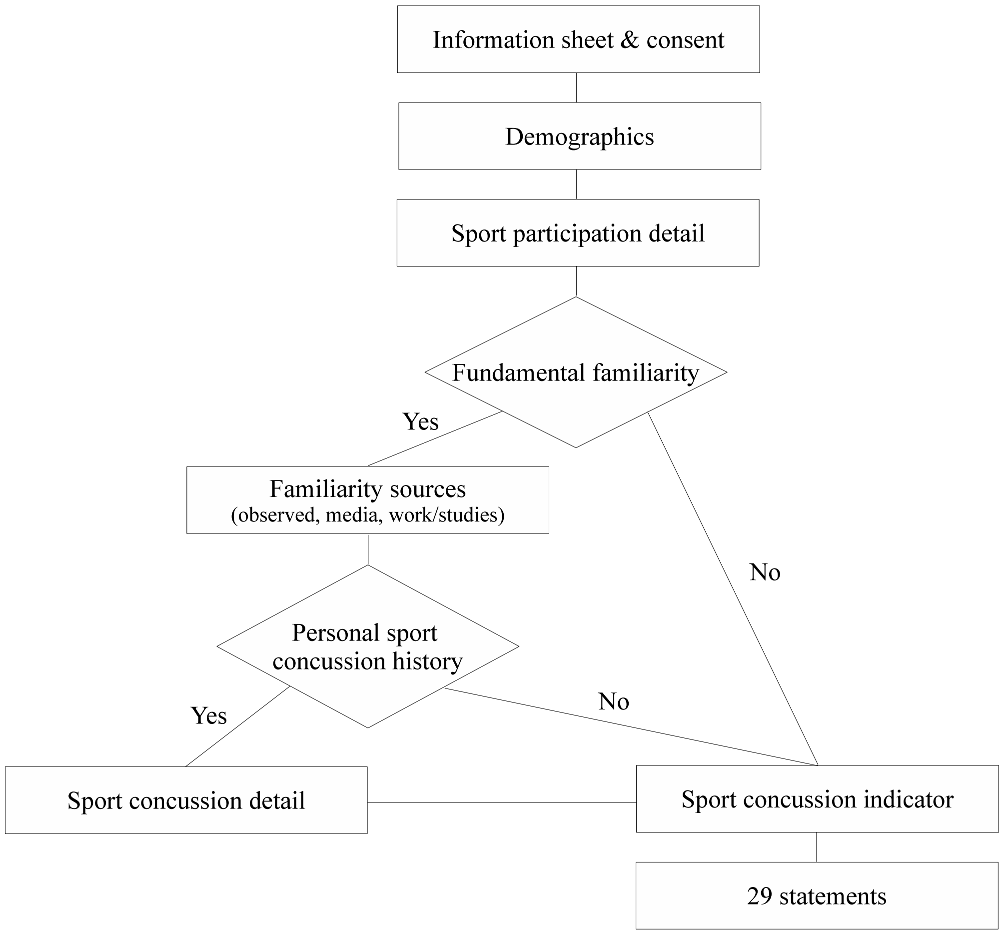


Figure 2.1: Flow chart of the questionnaire's skip logic.

The questionnaire's main section assessed fundamental sport concussion awareness and knowledge with the use of three elements. These were: (i) participants indicated their fundamental awareness with sport concussion on a dichotomised scale (yes, no); (ii) participants were asked to state 'the most important indicator that a sports person has sustained a concussion', and; (iii) participants rated 29 statements on general aspects, loss of consciousness, memory, symptoms and recovery (adapted from Gouvier et al., 1988) for truthfulness by choice of one of four response categories (true, probably true, probably false, false). We deliberately did not provide a definition of sport concussion in order not to influence participant responses.

A separate section of the questionnaire gathered detail on sport concussion history. Personal experience of sport concussion was measured by a series of items that followed if participants endorsed fundamental awareness. Participants provided information on whether they had ever sustained a sport concussion. Then, following an affirmative response, participants gave further detail on the injury (i.e., approximate time since injury, medical attention, recuperation, return to sport). In addition, the survey assessed basic demographics and sport participation detail of all participants.

2.3.3 Data analysis

The software SPSS (2009) was used for data analysis. The significance level p was preset to .05. For the main hypothesis, the dependent measures were the calculated response frequencies for the three elements fundamental awareness, statement ratings and injury indicators. To determine the fundamental sport concussion familiarity, we first calculated how many participants responded with 'yes' and 'no' to the question on whether they had encountered the term sport concussion before. We segmented statement ratings into subjectively assured (true, false) and guesses (probably true, probably false) and calculated misconception rates in assured and guess responses. To determine whether the proportion of misconceptions differed between assured and guess responses, we calculated odds ratios with 95% confidence intervals per statement. Finally, we calculated nomination frequencies of sport concussion indicators that had been named by at least five participants; all other nominations were excluded.

In the additional analysis, we included self-reported sport concussion history as an independent variable and applied chi-square tests to examine statement rating differences between self-reported sport-concussed and non-concussed participants. That is, we first examined whether groups differed in assured and guess responses independent of accuracy. Then, we tested whether sport concussion history groups differed in response accuracy by means of separate analyses for assured and guess responses. Finally, by sport concussion history, we calculated nomination frequencies of all sport concussion indicators that each had been named by at least five participants; again all other nominations were excluded. We conducted a chi-square test on the cumulative nominations by sport concussion history to determine whether self-reported sport-concussed and non-concussed participants nominated these injury indicators to an equal extent. For all comparisons, violated test assumptions were met with calculations of the coefficient of association (ϕ).

2.4 Results

The results are separated into two sections representing the two analyses for the main and additional hypotheses. In the main hypothesis section, results are separated into the three elements fundamental awareness, statement ratings and injury indicators. In the additional hypothesis section, results are separated into two elements (i.e., statement ratings and sport concussion injury indicators) only. This is due to the survey's skip logic (see Figure 2.1) by which only participants who affirmed fundamental familiarity with the term sport concussion provided detail on their personal sport concussion injury history and were included into the data analysis.

2.4.1 Main hypothesis: fundamental sport concussion awareness

The survey showed that fundamental sport concussion awareness was high (85.3%), with participants indicating that they had encountered the term sport concussion before.

2.4.2 Main hypothesis: sport concussion statement ratings

Results on sport concussion statement ratings are separated into three sections: general sport concussion aspects, loss of consciousness and memory, symptoms and recovery.

General sport concussion aspects

In four of the six statements on general sport concussion aspects, significantly less guess than assured responders provided accurate statement ratings (Table 2.2). However, in the statement on gender differences in sport concussion, significantly less assured than guess responders provided an accurate statement rating. This means that the assured expressed knowledge was that of a misconception.

TABLE 2.2: Percentage of sport concussion statement ratings. The correct answer is indicated at the end of each statement. Certainty and misconceptions (in round brackets) for assured and guess responses with odds ratios and 95% confidence intervals (in square brackets) are presented for general sport concussion statements.

Statement	Certainty (misconception)		OR [95% CI]	p
	Assured	Guess		
In sports, concussions almost never happen. (F)	62.0 (1.8)	38.0 (18.8)	0.08 [0.02−0.28]	p<.001
A concussion affects men's and women's brains differently. (T)	28.9 (81.8)	71.1 (61.4)	2.83 [1.48−5.42]	p<.01
A little brain damage does not matter since people use a small portion of their brains anyway. (F)	82.3 (0.5)	17.7 (17.5)	$\phi = -.32$	p<.001
In contact sports, such as rugby, American football and ice hockey, concussion is part of the game. (F)	42.1 (39.3)	57.9 (65.6)	0.34 [0.21−0.56]	p<.001
The only sure way to tell if someone has suffered brain damage from a concussion is by an X-ray of the brain. (F)	36.8 (38.8)	63.2 (54.8)	0.51 [0.31−0.85]	p<.05
Whiplash injuries to the neck can cause brain damage even if there is no direct blow to the head. (T)	31.2 (20.5)	68.8 (31.7)	0.56 [0.30−1.03]	p=.08

Abbreviations: T − true statement, F − false statement; OR − odds ratio, CI − confidence interval

Loss of consciousness and memory

On loss of consciousness statements, accuracy did not differ between assured and guess respondents (Table 2.3). On only one of the memory statements, significantly less guess than assured responders showed accurate statement ratings (Table 2.4). In contrast, the other memory statements ratings showed that significantly less assured than guess responders rated statements accurately. That means that most subjectively assured responses were actually misconceptions.

Table 2.3: Percentage of sport concussion statement ratings. The correct answer is indicated at the end of each statement. Certainty and misconceptions (in round brackets) for assured and guess responses with odds ratios and 95% confidence intervals (in square brackets) are presented for sport concussion loss of consciousness statements.

Statement	Certainty (misconception)		OR [95% CI]	p
	Assured	Guess		
A concussion can cause brain damage even if the sports person is not knocked out. (T)	50.0 (3.8)	50.0 (9.8)	0.36 [0.13−1.04]	p=.09
When a sports person is knocked unconscious, most wake up quickly with no lasting effects. (F)	28.6 (51.3)	71.4 (63.7)	0.60 [0.35−1.03]	p=.07

Abbreviations: T − true statement, F − false statement; OR − odds ratio, CI − confidence interval

Table 2.4: Percentage of sport concussion statement ratings. The correct answer is indicated at the end of each statement. Certainty and misconceptions (in round brackets) for assured and guess responses with odds ratios and 95% confidence intervals (in square brackets) are presented for sport concussion memory statements.

Statement	Certainty (misconception)		OR [95% CI]	p
	Assured	Guess		
Sometimes a second blow to the head can help a sports person remember things that were forgotten. (F)	58.6 (0.6)	41.4 (24.5)	0.02 [0.01−0.15]	p<.001
After a sport concussion, it is usually harder to learn than before the injury. (T)	35.3 (92.6)	64.7 (73.3)	4.54 [1.96−10.52]	p<.001
Sports persons usually have more trouble remembering things that happen after a concussion than remembering things from before. (T)	26.3 (71.4)	73.7 (54.6)	2.08 [1.15−3.75]	p<.05
A concussed sports person may have trouble remembering events before the concussion, but usually does not have trouble learning new things. (F)	20.7 (61.8)	79.3 (65.4)	0.86 [0.46−1.58]	p=.64

Abbreviations: T − true statement, F − false statement; OR − odds ratio, CI − confidence interval

Symptoms and recovery

On 11 of the 17 statements, significantly less guess than assured responders provided accurate statement ratings (Tables 2.5 and 2.6). However, misconceptions were also evident in assured responders. For example, more than three-thirds of assured responders incorrectly rejected the notion of increased likelihood of further concussion after a first injury. Assured responders also inaccurately attributed concussed athletes a good awareness for the concussion effects on performance and behaviour, and rejected the notion of post-concussion depression and its relation to sustained brain damage. Surprisingly, on the statement on the increased post-concussion likelihood of further injuries, significantly less assured than guess responders provided an accurate statement rating.

TABLE 2.5: Percentage of sport concussion statement ratings. The correct answer is indicated at the end of each statement. Certainty and misconceptions (in round brackets) for assured and guess responses with odds ratios and 95% confidence intervals (in square brackets) are presented for sport concussion symptoms and recovery statements.

Statement	Certainty (misconception)		OR [95% CI]	p
	Assured	Guess		
A concussion is harmless and never results in long-term problems or brain damage. (F)	69.9 (0.0)	30.1 (12.5)	$\phi = -.30$	p<.001
How quickly a sports person recovers from a concussion depends mainly on how hard they work on recovery. (F)	53.4 (7.7)	46.6 (36.3)	0.15 [0.07−0.30]	p<.001
It is easy to tell if a sports person has brain damage from a concussion by the way the person looks or acts. (F)	45.9 (11.5)	54.1 (40.3)	0.19 [0.10−0.37]	p<.001
Complete recovery from a concussion is not possible, no matter how badly the person wants to recover. (F)	45.5 (5.0)	54.5 (19.3)	0.22 [0.09−0.55]	p<.001
Sports people who have had one concussion are more likely to have another. (T)	43.6 (81.9)	56.4 (65.3)	2.40 [1.34−4.29]	p<.01
In sports, a concussion can have positive and negative effects on the sports person. (F)	42.1 (13.4)	57.9 (37.0)	0.26 [0.14−0.50]	p<.001
It is good advice to rest and remain inactive during recovery. (T)	39.1 (9.6)	60.9 (35.2)	0.20 [0.09−0.41]	p<.001
Once a recovering sports person feels "back to normal", the recovery process is complete. (F)	38.7 (2.9)	61.3 (17.2)	0.15 [0.04−0.49]	p<.001
Most sports persons with concussion are not fully aware of its effect on their behaviour and performance. (T)	35.0 (89.2)	65.0 (91.3)	0.79 [0.34−1.83]	p=.66
Drinking alcohol may affect a sports person differently after a concussion. (T)	33.1 (14.8)	66.9 (18.5)	0.76 [0.38−1.53]	p=.49

Abbreviations: T − true statement, F − false statement; OR − odds ratio, CI − confidence interval

Table 2.6: Percentage of sport concussion statement ratings. The correct answer is indicated at the end of each statement. Certainty and misconceptions (in round brackets) for assured and guess responses with odds ratios and 95% confidence intervals (in square brackets) are presented for sport concussion symptoms and recovery statements.

Statement	Certainty (misconception)		OR [95% CI]	p
	Assured	Guess		
A sports person who has recovered from a concussion is less able to withstand a second blow to the head. (T)	32.3 (39.5)	67.7 (49.4)	0.67 [0.40−1.13]	p=.14
Recovery from a sport concussion is usually complete in about a week. (F)	27.1 (25.0)	72.9 (46.9)	0.38 [0.21−0.69]	p<.01
Asking sports persons who were concussed about their recovery is the most accurate, informative way to find out how they have progressed. (F)	24.4 (33.8)	75.6 (52.7)	0.46 [0.26−0.82]	p<.05
A sports person who has a concussion will be "just like new" in several weeks. (F)	22.2 (22.0)	77.8 (51.2)	0.27 [0.14−0.53]	p<.001
Concussed sports persons usually show good understanding of their problems because they experience them every day. (F)	22.9 (16.4)	77.1 (33.7)	0.39 [0.19−0.81]	p<.05
A sport concussion may cause one to feel depressed, hopeless, and sad. (T)	17.7 (48.9)	82.3 (37.4)	1.60 [0.85−3.02]	p=.19
Emotional problems after sport concussion are usually not related to brain damage. (F)	18.0 (52.1)	72.0 (39.0)	1.70 [0.91−3.19]	p=.11

Abbreviations: T − true statement, F − false statement; OR − odds ratio, CI − confidence interval

2.4.3 Main hypothesis: sport concussion injury indicators

The most frequently named indicators were dizziness (16.9%), disorientation and confusion (15.0%), and loss of consciousness (14.3%) followed by head trauma (8.3%), headache (7.5%), memory loss (4.1%), altered consciousness (3.0%), nausea (3.4%) and drowsiness (1.9%).

2.4.4 Additional hypothesis: sport concussion statement ratings

Sport concussion history influenced response ratings in ten statements (Table 2.7). Independent of response accuracy, significantly more participants with sport concussion history chose an assured response option (i.e., true or false) than uninjured participants. Also, independent of having responded subjectively assured or guessing, significantly more participants with sport concussion history rated statements inaccurately.

Table 2.7: Effects of sport concussion history on participant response certainty and misconceptions

Abbreviated statement	Sport concussion history: Self-reported Assured	Self-reported Guess	Not self-reported Assured	Not self-reported Guess	$\chi^2(1)$	p
	(Misconception)					
General						
In contact sports, [...] concussion is part of the game. (F)	47.1	52.9	41.5	58.5	**6.25**	**.014**
	(**57.5**)	(75.6)	(**32.2**)	(62.7)		
In sports, concussions almost never happen. (F)	**71.8**	28.2	**55.6**	44.4	**5.85**	**.017**
	(3.3)	(8.3)	(1.3)	(22.2)		
[...] concussion can have positive and negative effects [...]. (F)	44.7	55.3	38.7	61.3	**5.19**	**.026**
	(23.7)	(**51.1**)	(9.1)	(**31.0**)		
Memory						
[...] a second blow [...] can help [...] remember [...]. (F)	64.7	35.3	55.6	44.4	**5.03**	**.034**
	(0.0)	(**36.7**)	(1.3)	(**15.9**)		
[...] more trouble remembering [...] after a concussion than [...]	**35.3**	64.7	**23.2**	76.8	**3.85**	**.036**
from before. (T)	(70.0)	(54.5)	(75.8)	(56.9)		
[...] trouble remembering [...] from before [...], but [...] not [...]	**28.2**	71.8	**16.2**	83.8	**4.69**	**.024**
new things. (F)	(66.7)	(68.9)	(60.9)	(64.7)		
Symptoms and recovery						
How quickly [...] recovers [...] depends mainly on [...] work at	**70.6**	29.4	**45.8**	54.2	**13.23**	**.000**
recovering. (F)	(6.7)	(40.0)	(7.7)	(32.5)		
Emotional problems [...] not related to brain damage. (F)	**25.9**	74.1	**13.4**	86.6	**5.62**	**.015**
	(50.0)	(36.5)	(52.6)	(38.2)		
[...] will be ”just like new” in several weeks. (F)	**29.4**	70.6	**18.3**	81.7	**3.76**	**.039**
	(32.0)	(45.0)	(11.5)	(55.2)		
Recovery is [...] complete in about a week. (F)	**36.5**	63.5	**21.8**	78.2	**5.74**	**.013**
	(25.8)	(57.4)	(29.0)	(43.2)		

Abbreviations: T − true statement, F − false statement. Significant comparisons are in bold.

2.4.5 Additional hypothesis: sport concussion indicators

Sport concussion history did not influence the type of indicators that were most frequently named (Table 2.8). In the sport concussion group, these cumulatively accounted for 64.4%, and in the non-concussed group for 79.1% of all indicators stated. This difference was statistically significant, OR=0.48, 95% CI [0.27, 0.84], $p<.05$. This means that injury indicator nomination was more varied in the sport concussion group.

TABLE 2.8: Sport concussion injury indicators by sport concussion history

Indicator	Sport concussion history		OR	95% CI	*p*
	Self-reported	Not self-reported			
Cumulative	64.4	79.1	0.48	[0.27, 0.84]	.01
Loss of consciousness	8.2	17.1	0.44	[0.19, 1.05]	.09
Confusion, disorientation	12.9	16.0	0.79	[0.38, 1.68]	.59
Dizziness	11.8	19.3	0.57	[0.27, 1.21]	.16
Headache	4.7	8.8	0.52	[0.17, 1.60]	.18
Head trauma	7.7	9.4	1.26	[0.51, 3.14]	.64
Altered consciousness	5.9	1.7	3.78	[0.88, 16.19]	.11
Nausea	3.5	3.3	1.09	[0.27, 4.45]	1.0
Memory loss	4.7	3.9	1.25	[0.36, 4.39]	.75
Drowsiness	2.4	1.7	1.46	[0.24, 8.88]	1.0

Abbreviations: OR − odds ratio, CI − confidence interval

2.5 Discussion

The purpose of this study was to examine sport concussion knowledge in the general public of the UK. As the main hypothesis, we expected to find sport concussion awareness, but only limited knowledge. As an additional hypothesis, we expected personal sport concussion history to influence knowledge in such that more participants with a sport concussion history would respond in an assured way (i.e., true, false). But we did not expect that more sport-concussed than non-concussed participants displayed accurate knowledge. Our data supported both hypotheses.

We found substantial sport concussion awareness and a notable knowledge base on sport concussion. For example, participants correctly acknowledged the potential health threat that a sport concussion can pose and consented to the significance of brain damage, the frequent occurrence of sport concussion, and the insignificance of loss of consciousness for brain damage to occur. This was also reflected in the nominated injury indicators that included subjectively accessible symptoms (e.g., dizziness, drowsiness, or headache) and objectively observable signs (e.g., loss of or altered consciousness, memory loss or amnesia).

However, despite the good sport concussion awareness and notable knowledge base, sport concussion understanding was only reasonable, and misconceptions prevailed. More specifically, in misconceptions, three themes emerged. The first theme was that participants clearly underestimated the seriousness of sport concussion. This was exemplified by the high proportion of participants that rejected the idea of increased vulnerability to and likelihood of re-injury. A considerable part of participants even considered sport concussion as a part of contact or collision sports, or attributed positive effects to a sport concussion. Participants also underestimated the prevalence of post-injury learning difficulties, post-traumatic and retrograde amnesia, which was also reflected by the very low proportion of participants who stated memory loss as a sport concussion indicator. Participants also underestimated the time and the significance of rest that are both needed for recovery. The second theme on misconceptions that was inferred from the data was that participants lacked knowledge on injury mechanisms. For example, direct head trauma was one of the most frequently named sport concussion indicators. Similarly, in the statement ratings, a substantial proportion of participants did not know that a direct head impact may be sufficient, but not necessary to cause brain damage. The third theme on misconceptions deduced from the data was that participants lacked knowledge on recovery assessment. For example, a substantial proportion considered the injured individual itself as 'the most accurate, informative' source in order to evaluate recovery progress, even though most respondents acknowledged that a sport-concussed individual does not have full awareness and understanding for the sport concussion effects and that the subjective feeling of recovery was not to be equated with objective recovery. Also, participants incorrectly attributed the ability to map brain damage to X-Ray. Taken together, this suggests that the UK general public holds significant misconceptions on sport concussion.

Response certainty which could be interpreted as one knowledge indicator typically was below 50% for the vast majority (i.e., 24 of 29) of statements. This suggests that most participants guessed when they rated the sport concussion statements. As one would expect, accurate knowledge was significantly lower in guess than assured responders. However, we noted a few exemptions. For example, significantly less assured than guess respondents (correctly) acknowledged gender differences, the possibility of post-injury learning difficulties, post-traumatic amnesia and increased re-injury likelihood. This means that the majority of assured responders showed certain of (the accuracy of) their response that was actually a misconception. This suggests true misapprehensions that might be well-established in the participants' subjective injury constructs. Furthermore, in a selection of statements, accuracy did not differ between assured and guess respondents. This was particularly evident concerning loss of consciousness, and symptoms and recovery. This suggests that statements might have been differentially difficult to answer and that the assessed knowledge areas might have been more challenging for the participants.

Our data is consistent with previous research from North America that reported significant misconceptions on head and brain injury in members of the general public (Gouvier et al., 1988; Guilmette & Malia, 2004; Hux et al., 2006; Rosenbaum & Arnett, 2009; Willer et al., 1993). However, compared to previous North American findings, we also noted differences. For example, misconceptions on injury mechanisms, post-injury emotional disturbance and memory were considerably higher than previously reported (Gouvier et al., 1988; Guilmette & Malia, 2004; Hux et al., 2006; Willer et al., 1993). In principle, this appears to be in line with a recent study on brain injury beliefs in Britain (Chapman & Hudson, 2010) that reported that in the UK, misconceptions were endorsed by significantly more members of the general public than previously found in the North American population. It is not clear what might have contributed to this difference. Most of the research on sport concussion has been conducted in North America, thus it could be that this has led to greater awareness and knowledge in the North American compared to the UK population. However, direct comparisons are difficult. For example, in contrast to past research, we used the sport concussion instead of the more general head or brain injury terminology. It is plausible to assume that the terminology we used (i.e., the term concussion instead of head injury or brain injury) and the injury context (i.e., sport only) might have influenced statements ratings and ultimately misconceptions as well. Except for Rosenbaum and Arnett (2009), all past studies employed the head injury terminology. The term head injury might be broader conceptualised in such that it may not be restricted to brain injuries, but include non-brain injuries, such as superficial cuts and bruises, as well (Anderson et al., 2006; Wills & Leathem, 2001). Furthermore, sport concussion is thought to be located at the lower end of a continuous severity scale of (traumatic) brain injury (Iverson, 2009). This might have influenced statement ratings and led to an underestimation of the injury's effects. Future research is needed to extend these findings and consider what influence terminology has on knowledge.

As anticipated in the additional hypothesis, sport concussion history influenced response behaviour. Our data revealed that significantly more self-reported sport-concussed than non-concussed participants chose assured response options (i.e., true, false). This means that the personal sport concussion experience was accompanied by a greater subjective knowledge certainty. However, as hypothesised, greater response certainty was not paralleled by superior knowledge accuracy. This means that self-reported sport-concussed participants who chose an assured response option did not possess more accurate knowledge than self-reported non-concussed responders who also chose an assured response option; a personal sport concussion history did not benefit sport concussion knowledge accuracy. In contrast, on the statement on sport concussion being part of contact sports, significantly more assured responders with a self-reported sport concussion history expressed a misconception than assured responders with no self-reported sport concussion history. This finding is particularly worrisome, as it suggests that the attitude towards sport concussion might be summarised as 'inevitable if you play a contact sport'. In addition to assured response, sport concussion history was also associated to knowledge misconceptions in guess responses. Significantly more guess responders with sport concussion history (incorrectly) consented to positive sport concussion effects and to the assistance of a second head trauma in recovering lost memories. These unexpected findings reiterate that the general public clearly underestimated the seriousness of sport concussion.

The findings from the additional analysis appear in contrast to past research (Gouvier et al., 1988; Hux et al., 2006; Mulhern & McMillan, 2006; O'Jile et al., 1997). Our data showed that personal sport concussion history influenced the certainty with which participants rated statements on sport concussion, but the influence of sport concussion history on response accuracy was less clear-cut and restricted to three statements. However, the methodological differences between the past research and the present study impede the comparison of findings. Past research had dichotomised response categories (i.e., collapsed the response categories probably true and true, and probably false and false), but the present study defined a definite statement rating (i.e., true, false) as assured knowledge and a non-definite statement rating (i.e., probably true, probably false) as a guess, and then identified accurate knowledge and misconceptions. This allowed us not only to examine knowledge accuracy, but also the certainty with which this was (or was not) expressed. We acknowledge that the new method does not allow conclusions on the participants' overall subjective knowledge certainty. Therefore, in future research, an additional item that asks members of the general public to rate their subjective overall level of sport concussion knowledge (e.g., on a analogue scale from 0 indicating no knowledge at all to 10 know all about it) might pose a beneficial extension. Furthermore, a comparison of the subjective overall knowledge ratings before and after the participant rated the statements for their truthfulness might add valuable detail.

In summary, the main analysis of our data suggests that the UK general public possessed limited sport concussion knowledge. Therefore, educational programmes are needed to increase sport concussion knowledge in the UK general public. Our data suggest a notable knowledge base that might be of particular importance to educators, as it may provide the initial point from which educational programmes could act. These programmes should specifically aim to connect the term sport concussion to brain injury, as our data showed that the UK general public possessed (some) knowledge on brain injury, and that they possess (some) knowledge on sport concussion, but that they might not be fully aware that a sport concussion *is* indeed a brain injury. Thus, these programmes should use the apparent knowledge base, fill the knowledge gaps and correct existing misconceptions. This particularly concerns the seriousness of sport concussion, its injury mechanisms, recovery, and recovery assessment. The additional analysis from our data suggests that a personal sport concussion history might give a false sense of security. Having experienced at least one sport concussion might have led to the subjective belief of (accurate) sport concussion knowledge. This might pose a significant hindrance to educational programmes. Sport-concussed members of the general public might 'feel' knowledgeable and be less accessible to (possibly contradictory) information of educational initiatives. Therefore, educational programmes should specifically approach members of the general public with a sport concussion history to correct their false sense of security that appeared to accompany the personal injury experience. For the UK, the overall aim should be to parallel the high sport concussion awareness with sufficient and accurate sport concussion knowledge yielding a greater safety in sport practice.

Chapter 3

The effect of brain injury terminology on university athletes' expected injury outcome, term familiarity and actual symptom report

3.1 Abstract

The present study sought to determine the influence of the terms concussion, mild traumatic brain injury and minor head injury on expected injury outcome, term-related familiarity and actual symptom reporting using a questionnaire that varied the terms concussion, mild traumatic brain injury and minor head injury. 224 university student athletes were allocated one questionnaire version each. Athletes rated injury outcome statements for their truthfulness, specified term familiarity and completed measures on post-concussion symptoms, anxiety, depression, pain and affectivity. Chi-square tests compared response frequencies of statement ratings and familiarity between questionnaire versions, and a rank-based multivariate method compared psychological measures between questionnaire versions by injury history. Terminology significantly influenced both expected injury outcome and familiarity. Outcome expectations were reliably more negative for the term mild traumatic brain injury than concussion or minor head injury. Mild traumatic brain injury was the least familiar term. However, terminology groups did not differ in actual symptom reporting. The data showed that the use of terminology affected athletes' injury outcome expectations and familiarity. The impact of the data and advice for the best term for future use are discussed. While it is not easy to make a clear recommendation, the data clearly indicate a strong need for education of brain injury at university level and possibly beyond.

3.2 Introduction

In Chapter 2, we surveyed members of the UK general public to measure sport concussion knowledge. We found that the general public possessed good sport concussion awareness, yet not sufficiently accurate knowledge. In all, participants underestimated the seriousness of a sport concussion. In the discussion of Chapter 2, we suggested that the terminology (i.e., concussion) might have contributed to the underestimation of the injury's seriousness. We proposed that participants showed knowledge on sport concussions and knowledge on brain injury, but appeared not to have necessarily linked sport concussion to brain injury. Therefore, Chapter 3 will examine the effect of terminology on how the injury is conceptualised.

In the literature, terminology has been shown to influence injury self-report rates in athletes (Delaney, Lacroix, Leclerc & Johnston, 2000; Delaney, Lacroix, Gagne & Antoniou, 2001; Delaney, Lacroix, Leclerc & Johnston, 2002; Kaut et al., 2003; LaBotz, Martin, Kimura, Hetzler & Nichols, 2005; Valovich McLeod, Bay, Heil & McVeigh, 2008). Here, higher sport concussion self-reports were found if colloquial terms (i.e., bell rung, dinged) or a symptom-based approach were used compared to direct injury history questions. This suggests that asking 'have you ever sustained a concussion' might yield different self-report rates than asking 'have you ever sustained an mTBI' or 'have you ever sustained a mHI'. For example, compared to the concussion terminology, self-report rates might be lower for mTBI because the terminology is less familiar or associated with a greater injury severity. In turn, self-reports for mHI might be higher compared to the concussion terminology because of the inclusion of non-brain injuries.

Terminology might also influence how an injury is conceptualised. This might be particularly relevant concerning injury-related expectations. For example, brain-injured athletes may report symptoms, such as headache or dizziness, and show temporary impairment in cognitive functions of attention, memory and executive function (see Iverson, 2005 for a review), and recovery for about 80 to 90% is quick and does not leave prolonged sequelae (McCrory et al., 2009). Why 10 to 20% show prolonged or incomplete recovery is not yet well understood (Asplund, McKeag & Olsen, 2004; Lovell, 2009; McCrory et al., 2009). It has been suggested that injury-related expectations may play a crucial role: injured individuals who expect worse recovery will actually fare worse compared to those with more positive expectations (Hoge, Goldberg & Castro, 2009; Wood, 2004).

The literature has typically shown that the athlete's expectation concerning post-injury outcome is incorrect and rather negative. For example, independent of sport head or brain injury history, athletes were reported to expect more subjective symptoms at six months after a sport head injury or concussion compared to before the injury (Ferguson, Mittenberg, Barone & Schneider, 1999; Gunstad & Suhr, 2001; Gunstad & Suhr, 2002; Gunstad & Suhr, 2004). However, in comparison to actual symptom reports from sport head- or brain-injured athletes, their expectations were greater, and there was no difference between the injured and uninjured athletes' symptom report. Analysis of the uninjured athletes showed that they overestimated the number of expected symptoms after the head or brain injury, but underestimated the quality of these symptoms (Ferguson et al., 1999; Gunstad & Suhr, 2001; Gunstad & Suhr, 2002; Gunstad & Suhr, 2004). For example, compared to uninjured non-athlete controls or depressed controls, fewer uninjured athletes expected a brain-injured individual to experience cognitive, memory-related, affective or somatic symptoms (Gunstad & Suhr, 2001).

From these findings, it is important to define what constitutes 'negative expectations', how they might be activated and what consequences they have. From a theoretical perspective, expectations do not work alone, but form with identity, that is, the name of the medical condition, the experienced symptoms, their associated cause, duration and controllability an elaborate cognitive representation that in turn may influence recovery and outcome (Leventhal, Brissette & Leventhal, 2003) With regard to the present paper, it is important to note that the identity component of the concept sport brain injury varies across the terms concussion, mild traumatic brain injury (mTBI) and minor head injury (mHI) (Iverson, 2005). This use of interchangeable terminology has been repeatedly challenged (Anderson et al., 2006; DeMatteo, Hanna, Mahoney, Hollenberg, Scott, Law, Newman, Lin & Xu, 2010; McCrory, 2001; Wills & Leathem, 2001). It has been suggested that the terms themselves convey different messages and do not form synonyms

(Anderson et al., 2006; Wills & Leathem, 2001). The terms might also vary in their familiarity and the extent to which they communicate a favourable outcome; more people might be acquaint with the term concussion (Kelly, 2000), and concussion might suggest a more favourable outcome (Iverson, 2009) or at least less seriousness (DeMatteo et al., 2010) than the term mTBI.

The importance of terminology should not be underestimated. In all, past research suggests that sport brain injury terminology differs in familiarity and understanding which in turn might not only influence injury-related expectations, but ultimately also recovery and outcome, as indicated by symptom self-reports or neuropsychological tests. For example, expectations have been found to alter neuropsychological test performance. In two studies by Suhr and Gunstad (2002a, 2002b), brain-injured, but otherwise highly functioning university students received either a neutral or a test instruction stating that neuropsychological impairment was common in individuals with a sport brain injury history. The data showed that the test instruction group performed significantly worse in neuropsychological tests than the neutral instruction group. Further evidence for the importance of terminology for recovery and outcome came from a study that found a concussion diagnosis predictive of a better outcome (i.e., earlier hospital discharge and return to school) than an mTBI diagnosis (DeMatteo et al., 2010). It was also found that in brain-injured children, a concussion in comparison to an mTBI diagnosis was more likely if CT scans were normal. The authors speculated whether physicians used the concussion term so as not to raise alarm with the parents, but nevertheless regarded concussion as a synonym of mTBI, though less severe. From this, parents might have (falsely) interpreted the concussion diagnosis or the absence of CT abnormalities as the absence of brain injury and subsequently consented to an earlier, possibly premature return to school. Therefore, concussion and mTBI appear treated as distinct injuries (McCrory et al., 2009; Wills, 2001) which leads to our notion that injury outcome expectations might vary with the terminology used; with more negative outcome expectations for the term mTBI than concussion or mHI.

In the study presented here, we wanted to examine how familiar university athletes were with the different terminology in use (i.e., concussion, mTBI, mHI) and whether associated expectations differed. In addition, we wanted to examine the association between injury history, terminology and actual injury outcome. That is, would athletes who self-reported a sport mTBI differ in their symptom self-report compared to those who self-reported a sport concussion or sport mHI and controls respectively? Therefore, the study's objectives were (i) to determine the influence of the terms concussion, mild traumatic brain injury and minor head injury on injury outcome expectations; (ii) to explore the participants' familiarity with the terms used; and (iii) to explore whether subjective symptom reports depend on terminology and a self-reported history of concussion, mild traumatic brain injury or minor head injury compared to controls. We hypothesised that terminology would influence injury outcome expectations, that familiarity with the terminology used would vary, and that brain-injured participants' symptom self-reports would vary with terminology.

3.3 Method

3.3.1 Participants

224 university athletes aged 17 to 34 (M=19.9, SD=2.34; 58% female) completed the study. More than half of the athletes (57.6%) played a contact sport, such as hockey, rugby or football, as their main sport. On average, players spent 6.2 hours per week playing their main sport (SD=3.64, range 0.5-22.0 hours). A-levels represented the highest educational attainment for 83.5% of the sample (i.e., they were mostly undergraduate degree students).

Participants were recruited from the School of Sport and Exercise Sciences and university sport teams, and the undergraduate sport science students received course credits for their study participation. The university's local ethics subcommittee approved the study in accordance with the 1964 Declaration of Helsinki. Written informed consent was obtained from all study participants.

3.3.2 Material and procedures

The questionnaire came in three versions that only differed in the key condition terminology. That is, the reference of the condition altered such that it was either concussion, mild traumatic brain injury or minor head injury. The questionnaire versions did not vary in any other aspects and were presented in the traditional paper-pencil format. They applied a skip logic, whereby a given response would direct participants to the appropriate next item. For example, only if the participants affirmed that they were familiar with the term, they would be asked to provide further details; otherwise the participants were asked to skip the non-applicable items and move to the next item. Each questionnaire was pseudo-randomly allocated to one participant (so that approximately equal numbers of participants completed each questionnaire version).

Injury outcome expectations were measured using 29 statements (see Appendix A) that participants were asked to rate for their truthfulness using four response categories (true, probably true, probably false, false) (adapted from Gouvier et al., 1988; Guilmette & Paglia, 2004). Familiarity with the term used was measured by means of three items. First, participants indicated their fundamental term familiarity on a dichotomised scale ('yes', 'no'). Then, in case of fundamental term familiarity, they specified the sources of familiarity (personal injury history, observed in significant others, media, studies/ work). Finally, an open-end question asked the participant to state the single most important indicator of a concussion, mild traumatic brain injury or minor head injury depending upon the questionnaire version allocated. The questionnaire concluded with series of established questionnaires that measured the symptoms each participant experienced at the time of the study (see Appendix B). These included the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983), the Positive and Negative Affectivity Scales (PANAS; Watson, Clark & Tellegen, 1988), the Rivermead Post Concussion Symptoms Questionnaire (RPQ; King, Crawford, Wenden, Moss & Wade, 1995) and an eleven-point analogue scale to measure pain (from zero 'no pain at all' to 10 'pain as bad as you can imagine') (adapted from McDowell & Newell, 1996).

The Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) measured anxiety and depression. The questionnaire listed seven statements each on anxiety and depression. Each statement came with four response options. Participants were asked to choose one of four response options for each of the 14 statements and relate them to their past week. We followed the standard scoring by which each statement rating yielded a score between 0 and 3 (a greater score indicated greater severity). Rating scores were summed separately for anxiety and depression yielding two composite scores. A higher composite value (maximum: 21) corresponded to a more severe clinical manifestation. Both composite scores served as the dependent variables.

The Positive and Negative Affect Scales (PANAS; Watson et al., 1988) measured positive and negative affect. The questionnaire listed 20 adjectives (ten positive, ten negative) that the participants used to describe how they felt in the past week. For each adjective (e.g., excited as a positive, guilty as a negative), the participant chose a number between 1 (very slightly or not at all) and 5 (extremely) to describe the felt intensity. A higher score represented a more intense feeling. Participant ratings were then summed separately for positive and negative adjectives (maximum: 50 each). A higher composite score represented a more positive or negative affect. Both composite scores (positive affect, negative affect) served as the dependent variables.

The Rivermead Post Concussion Symptoms Questionnaire (RPQ; King et al., 1995) measured subjective symptomatology. It listed 16 cognitive and somatic-emotional symptoms that were rated for their severity on a scale from 0-4 (0=not experienced at all, 1=no more of a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem). Participants were asked to relate the symptoms to the past 24 hours only. We followed the standard scoring instructions (i.e., the severity ratings of 0 and 1 were treated as 0), but derived a total sum score as the dependent variable (a higher sum score represented a higher severity).

Pain experienced in the past week was measured with a analogue rating scale (McDowell & Newell, 1996). The scale ranged from 0 ('no pain') to 10 ('pain as bad as you can imagine') with a higher score representing a more severe pain experience. The participant circled the number that best represented the pain experienced in the week prior to testing.

The number circled served as the dependent variable.

The questionnaire also measured demographics, detail on sports participation and sport brain injury history detail regarding the most recent incident. Note that depending on the questionnaire version allocated participants indicated whether they had or had not sustained a concussion, or mTBI, or mHI. Participants who negated a history of concussion or mTBI or mHI followed the questionnaire's skip logic to the next appropriate item.

Following allocation of a questionnaire, participants were introduced to the study purpose and the questionnaire itself. Testing took place in small groups of up to eight participants in a quiet room under exam conditions and lasted approximately 30 minutes. An experimenter supervised the questionnaire administration.

3.3.3 Data analysis

To analyse injury outcome expectations, chi-square analyses tested associations between the terminology and statement response frequencies. Due to violated test assumptions, the original four response categories were collapsed into two categories 'true' and 'false', as carried out in previous studies (Gouvier et al., 1988; Willer et al., 1993). Significant chi-square tests were followed by pairwise calculations of odds ratios and 95% confidence intervals, whereby the significance level p was Bonferroni-corrected for multiple comparisons and set to .017. To analyse familiarity, similar chi-square and post-hoc analyses were run that tested associations between terminology and participant response. Multivariate differences in participant symptom reports between questionnaire versions and by injury history were analysed using the rank-based Munzel-Brunner Method (R function: mulrank; Wilcox, 2005) in the R environment (R Development Core Team, 2009).

3.4 Results

The results for the influence of terminology on injury outcome expectations, familiarity and symptom reporting will be reported separately. The three groups as formed by the terminology used did not differ in age, gender, education, contact sport participation or sport hours played (see Table 3.1).

Table 3.1: Demographics by terminology group

Measure		Terminology used		
		Concussion	Mild TBI	Minor HI
N		79	76	69
Age	mean (SD)	20.2 (2.88)	19.8 (2.18)	19.6 (1.75)
Gender (female)	%	60.8	53.9	59.4
A−level education	%	84.4	81.6	84.1
Contact sport participation	%	58.2	56.6	58.0
Sport hours per week	mean (SD)	6.3 (4.02)	6.3 (3.78)	5.9 (2.88)

Abbreviations: TBI − traumatic brain injury, HI − head injury

3.4.1 Terminology on injury outcome expectations

Chi-square tests showed significant associations between terminology and statement response for seven statements. For the statement of whether the injury is part of a contact sport game, there was a significantly higher agreement for mHI than concussion and mTBI. For the other statements, there was a trend whereby participant responses were different for the mTBI questionnaire version compared to the concussion and mHI versions. In the mTBI terminology group, more participants expected learning difficulties, depression, increased likelihood of and vulnerability to comparable injuries post-injury, and less participants expected a short and remnant-free recovery (see Table 3.2 for details).

Table 3.2: Significant associations between terminology and statement response (%). '...' is where the term was presented.

Statement	Term	T&PT	χ^2-test	Post-hoc test	OR [95% CI], p
In contact sports, a ... is part of the game.	concussion	50.6	$\chi^2(2)=7.72$, $p<.05$	C vs. mTBI	1.08 [0.56, 2.03], p=.48
	mTBI	48.7		mHI vs. mTBI	2.41 [1.22, 4.77], p<.017
	mHI	69.6		mHI vs. C	2.23 [1.13, 4.38], p<.017
After a ..., it is usually harder to learn than before the injury.	concussion	11.4	$\chi^2(2)=10.71$, $p<.01$	mTBI vs. C	3.81 [1.64, 8.86], p<.01
	mTBI	32.9		mTBI vs. mHI	1.93 [0.90, 4.11], p=.06
	mHI	20.3		C vs. mHI	0.51 [0.20, 1.25], p=.10
A ... may cause one to feel depressed, sad and hopeless.	concussion	54.4	$\chi^2(2)=7.31$, $p<.05$	mTBI vs. C	1.71 [0.89, 3.28], p=.07
	mTBI	67.1		mTBI vs. mHI	2.50 [1.27, 4.91], p<.01
	mHI	44.9		C vs. mHI	1.46 [0.77, 2.80], p=.16
Recovery from a ... is usually complete in about a week.	concussion	34.2	$\chi^2(2)=11.19$, $p<.01$	C vs. mTBI	2.52 [1.18, 5.36], p<.017
	mTBI	17.1		mHI vs. mTBI	3.51 [1.64, 7.55], p<.017
	mHI	42.0		C vs. mHI	0.72 [0.37, 1.40], p=.21
A sports person who has a ... will be 'just like new' in several weeks.	concussion	39.2	$\chi^2(2)=13.77$, $p<.01$	C vs. mTBI	3.82 [1.75, 8.35], p<.001
	mTBI	14.5		mHI vs. mTBI	3.57 [1.60, 7.98], p<.01
	mHI	37.7		C vs. mHI	1.07 [0.55, 2.08], p=.49
Sports people who have had one ... are more likely to have another.	concussion	24.1	$\chi^2(2)=10.27$, $p<.01$	mTBI vs. C	2.70 [1.36, 5.35], p<.01
	mTBI	46.1		mTBI vs. mHI	2.41 [1.20, 4.88], p<.01
	mHI	26.1		C vs. mHI	0.89 [0.43, 1.89], p=.46
A sports person who has recovered from a ... is less able to withstand a second blow to the head.	concussion	48.1	$\chi^2(2)=15.35$, $p<.001$	mTBI vs. C	3.75 [1.87, 7.52], p<.001
	mTBI	77.6		mHI vs. mTBI	0.62 [0.29, 1.29], p=.14
	mHI	68.1		mHI vs. C	2.31 [1.18, 4.51], p<.017

Abbreviations: T – true, PT – probably true, OR – odds ratio, CI – confidence interval, C – concussion, mTBI – mild traumatic brain injury, mHI – minor head injury

3.4.2 Terminology on familiarity

Chi-square tests revealed a significant effect of terminology on fundamental term familiarity, $\chi^2(2)=63.81$, $p<.001$ (see Table 3.3). Post-hoc analyses found significant differences between the terms concussion and mTBI, OR=14.71, 95% CI [6.74−32.09], $p<.001$, and mHI and mTBI, OR=7.86, 95% CI [3.79−16.30], $p<.001$, but no difference between concussion and mHI, OR=1.87, 95% CI [0.82−4.25], $p=.14$. This showed that mTBI was the least familiar term.

TABLE 3.3: Participant agreement on familiarity and its sources by terminology (in %)

Measure	Terminology		
	Concussion	Mild TBI	Minor HI
Fundamental term familiarity	85.4	28.4	75.7
Familiarity source			
Personal experience	35.3	26.1	44.2
Observation in significant others	43.7	43.5	32.1
Media	22.5	43.5	41.5
Work/ studies	26.9	47.8	17.2

Abbreviations: TBI − traumatic brain injury, HI − head injury

Analyses of the sources of familiarity (see Table 3.3) did not reveal an association between terminology and personal experience of sport head injury, $\chi^2(2)=2.42$, $p=.29$, or observation in significant others, $\chi^2(2)=1.89$, $p=.39$. However, terminology was related to media as informational source, $\chi^2(2)=6.42$, $p<.05$. Post-hoc analyses showed that there was no difference between mTBI and concussion, OR=2.64, 95% CI [0.98−7.15], $p=.05$, or mTBI and mHI, OR=1.08, 95% CI [0.40-2.91], $p=.53$. There was a trend towards a significant difference between mHI and concussion, OR=2.44, 95% CI [1.12−5.32], p=.019. Similarly, the chi-square analysis of the factor work/ studies as familiarity source by terminology was significant, $\chi^2(2)=7.59$, p<.05. Post-hoc comparisons did not find significant differences between concussion and mHI, OR=1.75, 95% CI [0.72−4.25], p=.15, or mTBI and concussion, OR=2.51, 95% CI [0.95−6.63], p=.05, but showed a significant difference between mTBI and mHI, OR=4.38, 95% CI [1.47−13.01], p<.01. This indicated that the factor work/ studies constituted to a greater extent a familiarity source for the term mTBI than mHI. Similarly, media presented a familiarity source to more participants who were familiar with the term mHI than concussion.

The final data reported for the effects of terminology on familiarity considered the three most frequently named indicators. These were as follows: in the concussion questionnaire: dizziness (20.8%), loss of consciousness (14.3%), loss of memory (9.1%) or disorientation/ confusion (9.1%); in the mTBI questionnaire: concussion (25.0%), disorientation/ confusion (14.1%), loss of consciousness (12.5%) or dizziness (12.5%) and; in the mHI questionnaire: dizziness (28.1%), concussion (18.8%) and bleeding (7.8%) or headache (7.8%).

3.4.3 Terminology on actual symptom reporting

Analysis of the effects of terminology on actual symptom reporting used the Munzel-Brunner Method (Wilcox, 2005) in R (R Development Core Team, 2009) and did not find a significant multivariate difference in psychological measures of subjective symptoms, anxiety, depression, positive affect, negative affect and pain between the questionnaire versions and participants with or without a self-reported history of sport concussion or mTBI or mHI, $F_N[16.75]=.99$, $p=.46$ (see Table 3.4).

Table 3.4: Descriptives of psychological measures by terminology and sport head injury history (mean±SD)

Psychological measure	Sport head injury	Terminology used		
		Concussion	Mild TBI	Minor HI
RPQ	self-reported	11.21±9.23	11.33±8.26	9.00±6.70
	not self-reported	11.91±9.11	8.91±6.81	9.64±6.97
HADS anxiety	self-reported	4.71±3.24	4.50±2.81	4.57±2.33
	not self-reported	5.91±3.28	5.21±2.79	5.13±2.91
HADS depression	self-reported	1.96±1.90	1.33±1.51	1.35±1.37
	not self-reported	2.45±1.97	1.81±1.54	1.71±1.79
PANAS positive affect	self-reported	33.08±7.06	37.83±8.50	35.52±6.42
	not self-reported	32.18±7.39	32.16±7.01	33.64±7.01
PANAS negative affect	self-reported	16.88±5.37	15.67±5.05	15.00±3.06
	not self-reported	17.16±6.16	16.09±5.23	16.49±5.89
Pain scale	self-reported	3.04±2.68	2.00±2.53	2.91±2.28
	not self-reported	2.71±2.22	3.23±2.52	2.69±2.03

Abbreviations: TBI − traumatic brain injury, HI − head injury, RPQ − Rivermead Post Concussion Questionnaire, HADS − Hospital Anxiety and Depression Scale, PANAS − Positive and Negative Affect Schedule

3.5 Discussion

The purpose of this study was to investigate the impact of concussion, mild traumatic brain injury or minor head injury terminology on injury outcome expectations, familiarity and actual symptom reporting. We hypothesised that each of these dependent measures would vary with terminology, and all but the last hypotheses were supported.

The data shared a common theme. The term mTBI was conceptualised as more negative and the least familiar than the terms concussion and mHI. Participants indicated that mTBI was a longer-lasting sport injury that did not necessarily involve a complete recovery, and might leave the athlete with learning difficulties, depression-like symptoms and a higher susceptibility to further comparable injuries. While we do not assume that injury outcome expectations were affected by differences in fundamental term familiarity alone, it appears reasonable that familiarity sources may vary in their accuracy, and perhaps influence injury outcome expectations. For example, the familiarity source of work/ studies which was more often reported for mTBI might provide more accurate and universally valid knowledge than that from personal or observed experience (i.e., correctly negative). This is in agreement with prior research reporting that personal injury experience is unrelated to knowledge accuracy (Sefton, 2003; Smith-Seemiller, Fow, Kant & Franzen, 2003). Furthermore, while the data here showed that terminology exerted limited influence on injury indicator nomination, that is, nominated indicators overlapped and entailed post-injury symptoms of introspection (e.g., dizziness, headache), and observable peri- and post-injury characteristics (e.g., loss of consciousness and bleeding, disorientation respectively), one of the indicators of mTBI and mHI was concussion. This suggests that the terms mTBI and mHI over-arch the term concussion. In line with the term's Latin origins (concutere - to shake violently), concussion seems conceptualised as the biomechanical impact itself that may lead to structural damage (mTBI) or the diagnosis of a mHI as a consequence. Thus, mTBI and mHI form a bigger concept. Consistent with this, bleeding was listed solely for mHI. Taking into account that mHI was considered by significantly more participants as part of a contact sport game than both concussion and mTBI, it seems that mHI represents a much broader injury concept that expands beyond an injury to the brain and includes superficial injuries, such as cuts and bruising (Wills, 2001).

Contrary to one of the hypotheses, we failed to find any difference in symptom self-report between the questionnaire versions by injury history. A possible explanation for this might be that individuals who sustained a brain trauma had not recognised the sustained injury (i.e., as either a concussion, mTBI or mHI) (McCrea et al., 2004) and failed to report it. This means that there may have been brain-injured athletes in the control groups as group allocation was based on injury self-report. It is also possible that athletes who recognised the sustained injury as a concussion or mHI did not equate it with an mTBI, and subsequently failed to self-report the injury history when allocated a differently termed questionnaire version. In turn, those who self-reported an mTBI might have been superior in their knowledge in such that they were aware that the mTBI terminology is frequently used as synonym for concussion and mHI. Future research might benefit from symptom-based methods to improve identification of injury history and subsequently group allocation (Kaut et al., 2003; LaBotz et al., 2005; Valovich McLeod et al., 2008). For example, in addition to direct questions (e.g., have you sustained a concussion/mTBI/mHI), athletes could be asked whether they have experienced symptoms such as headaches, dizziness or nausea following a head impact.

The findings reported here discourage the interchangeable use of terminology to relate to sport brain injury. We might propose that using the term with the more favourable expected outcomes would be better. Our data showed that the term concussion held the greatest familiarity and the lesser negative expectations; so, one could argue that the use of the term concussion is desirable. McCrory (2001) reasoned that only the concussion term communicates the transient nature of impaired neurological function, but not the mTBI term. Our findings support this argument. However, looking at the quality of the responses given, it was clear that only a minority of the participants held accurate expectations for the term concussion. On the contrary, the seriousness of the injury associated with the term concussion was clearly and systematically underestimated (see also Farmer & Johnson-Gerard, 1997; Gouvier et al., 1988; Guilmette, Malia & McQuiggan, 2007b; Guilmette & Paglia, 2004; Hux et al., 2006; McGrane & Cascella, 2000; Mulhern & McMillan, 2006; Sye, Sullivan & McCrory, 2006b; Swift & Wilson, 2001; Willer et al., 1993). The term mTBI proved less familiar to participants, and the associated injury outcome expectations were more negative supporting McCrory's (2001) discouragement of the use of mTBI terminology. However, mTBI-related expectations were more accurate than those for the term concussion, thus encouraging the term's use. Lastly, the term mHI showed that participants' expectations were comparable to that with the term concussion, but the term appeared too broad and unspecific. Therefore, considering both familiarity and injury outcome expectations together, the recommended terminology choice (concussion or mTBI) hangs in balance.

What is clear is that independent of terminology, education on sport brain injuries is needed to achieve a change in health-related behaviour such as self-reporting symptoms following a head impact or refraining from sport following a suspected or diagnosed brain injury. These changes are thought to be more likely if individuals consider the injury as serious, themselves vulnerable to the potential sequelae and the associated health behaviour costs (e.g., refraining from sport) as both beneficial and acceptable (Becker & Maiman, 1975). Our data suggest that in athletes these conditions might not be met (yet).

Our findings have important implications for athletic education on sport brain injury. Our data reiterate the persisting need for education on sports brain injury at university level and possibly beyond (Chapman & Hudson, 2010). Depending upon the terminology used, educational programmes might also need adaptation in such that programmes that use the term concussion might have to correct the overoptimistic view that athletes appeared to have. However, programmes using the mTBI terminology might have to tone down the message that the term mTBI itself appears to convey. Finally, programmes that employ the mHI terminology might have to refocus their targeted audience to issues of brain injury. We suggest that educating athletes about the true nature and outcome of sport brain injuries would most likely cause a balance between the expected and actual outcome and lead to better athlete health behaviour.

Chapter 4

Prolonged neuropsychological function decrements following sport concussion

4.1 Abstract

The present study sought to determine the prolonged neuropsychological function decrements following sport concussion. Using a comprehensive neuropsychological test battery, 23 self-reported sport-concussed and 57 non-concussed university contact sport athletes participated. The battery measured attention, memory and executive function while controlling for major neuropsychological function confound moderators. Non-parametric univariate ANOVAs examined the neuropsychological test performance by sport concussion self-report. The data showed that self-reported sport-concussed athletes performed worse on measures of immediate free verbal memory recall and executive function shifting. The data are discussed in terms of their significance to recent injury definitions, applied neuropsychological test batteries and the suitability of group comparisons in sport concussion research.

4.2 Introduction

Chapters 2 and 3 of this thesis examined two definition-related issues: sport concussion knowledge in the UK general public and the heterogeneous terminology that is used to relate to the injury. The following two chapters addressed two issues that related to the neuropsychological assessment of sport concussion. In the present chapter, we examined whether a sport concussion history was associated with prolonged decrements in neuropsychological functioning.

Within the Zurich Concussion in Sport Consensus statement, sport concussion was defined as 'the rapid onset of short-lived impairment of neurologic function that resolves spontaneously' (McCrory et al., 2009). The definition indicates that sport concussion effects are thought to be transient, and injury resolution requires no assistance, and simply just time. To determine the time needed by an individual for recovery, neuropsychological testing is recommended (Guskiewicz et al., 2006; McCrory et al., 2009; Scolaro Moser, Iverson, Echemendia, Lovell, Schatz, Webbe, Ruff & Barth, 2007). The promoted approach is an individual pre- versus post-injury comparison of subjective symptoms and cognitive performance (Grindel et al., 2001). That is, the athlete should undergo pre-season testing to establish a so-called baseline of normal pre-injury performance. Then, in case of a sport concussion, the athlete is tested again on parallel versions of the same tests. The athlete's post-injury performance is compared to the pre-injury measures, and shows an impairment if the two differ significantly. Following subsequent tests, when post-injury test performance equals or exceeds the pre-injury baseline, it is concluded that the injury has resolved. Within the sport concussion management guidelines, it is recommended that no athlete should be allowed to train or compete until all sport concussion effects have resolved (McCrory et al., 2009), as there is an increased risk of sustaining (any kind of) further injuries (Iverson, Gaetz, Lovell & Collins, 2004a).

In contrast to the definition and prescribed guidelines, the literature shows some evidence of long-term cognitive effects following sport concussion (i.e., cases where the deficit has presumedly not resolved). For example, at a minimum of one month post-injury, sport-concussed athletes have been shown to report more symptoms (Shehata, Wiley, Richea, Benson, Duits & Meeuwisse, 2009) and perform worse on tests of visual and verbal memory (De Beaumont et al., 2009; Matser et al., 1999), attention (Cremona-Meteyard & Geffen, 1994; Ellemberg et al., 2007; Matser et al., 1999) and executive functions (Di Russo & Spinelli, 2009; Ellemberg et al., 2007; McCrea et al., 2003; Register-Mihalik et al., 2009) than uninjured athletes. For repeat sport concussion, a dose-response relationship (i.e., the more sport concussions an athlete sustains, the worse the neuropsychological functioning) has been proposed, as verbal memory (Iverson, Gaetz, Lovell & Collins, 2004b; Killam, Cautin & Santucci, 2005; Matser, Kessels, Lezak & Troost, 2001), attention (Bernstein, 2002; Collins, Grindel, Lovell, Dede, Moser, Phalin, Nogle, Wasik, Cordry, Daugherty, Sears, Nicolette, Indelicato & McKeag, 1999; Register-Mihalik et al., 2009), and executive functioning performance (De Beaumont et al., 2009) have all been reported to be worse following multiple than single sport concussion. Multiple sport concussions have also been linked to more severe post-concussion symptoms (Bruce & Echemendia, 2004; Gaetz, Woodman & Weinberg, 2000; Iverson et al., 2004b; Register-Mihalik et al., 2009), prolonged recovery (Bruce & Echemendia, 2004), in-season disqualification (Guskiewicz et al., 2003) and even early retirement from sport (Tegner & Lorentzon, 1996).

Further doubt on the transient nature of sport concussion has been casted by findings of increased injury and illness vulnerabilities following injury. For example, in a prospective cohort study of sport concussion incidence in American Football, sport-concussed athletes were reported to be three times more likely to sustain a further sport concussion within the play season than non-concussed athletes (Delaney et al., 2000; Guskiewicz et al., 2003) suggesting that there may be lasting remnants that increase the chances of further sport concussion (nb. the alternative argument might be that the athlete is prone to injury). In support of the former, single sport concussion has also been linked to late-life clinical depression (Guskiewicz, Marshall, Bailes, McCrea, Harding, Matthews, Register-Mihalik & Cantu, 2007). Again, a dose-response relationship (i.e., the more sport concussions an athlete sustains, the higher the risk) has been discussed as the prevalence of diagnosed depression appeared to be higher following recurrent sport concussion; retired athletes with three or more self-reported sport concussions were three times more likely to have been diagnosed with clinical depression (Guskiewicz et al., 2007). Other evidence showed that multiple sport-concussed athletes scored significantly lower on a measure of mental health and social functioning (Guskiewicz, Marshall, Bailes, McCrea, Cantu, Randolph & Jordan, 2005; Kuehl, Snyder, Erickson & Valovich McLeod, 2010). Athletes with multiple sport concussions were also reported to be three times more likely to complain of subjective memory deficits, and their subjective complaints were confirmed when significant others were included in the survey (Guskiewicz et al., 2005).

One problem with the literature on long-term cognitive sport concussion effects is that the tests used and the data found is not consistent (i.e., no particular neuropsychological function decrement in sport-concussed athletes has been reported; see Belanger et al., 2010; Broglio et al., 2006; Brown et al., 2007; Catena et al., 2009; Echemendia et al., 2001; Guskiewicz, 2002; Guskiewicz et al., 2003; Iverson et al., 2006b; Macciocchi et al., 2001; Maddocks & Saling, 1996; McCrea et al., 2002; Shuttleworth-Edwards et al., 2008; Thériault et al., 2009; Thornton et al., 2008). For example, De Beaumont et al. (2009) tested sport-concussed retired athletes and found that they performed worse on tests of visual memory and response inhibition compared to matched uninjured athletes. In contrast, McCrea et al. (2003) reported performance decrements in sport-concussed athletes on an executive function test of verbal fluency, but not verbal memory or inhibition, and Echemendia et al. (2001) did not find any prolonged neuropsychological deficits in sport-concussed athletes at all.

Several explanations are possible to explicate these inconsistencies. Many studies that did not find long-term cognitive sport concussion effects were conducted in the context of sport concussion management programmes that use the individual pre-injury versus post-injury comparison approach (e.g., Broglio et al., 2006; Brown et al., 2007; Catena et al., 2009; Echemendia et al., 2001; Guskiewicz, 2002; Guskiewicz et al., 2003; Iverson et al., 2006b; Killam et al., 2005; Macciocchi et al., 2001; Maddocks & Saling, 1996; McCrea et al., 2002; Shuttleworth-Edwards et al., 2008). It could be that athlete motivation differed between baseline and post-injury assessment. For example, within a sport concussion management programme, the athlete's post-injury performance on neuropsychological tests could have played a significant role in the return-to-play decision. The athlete might have intentionally underperformed at baseline, but increased the efforts at post-injury assessments to achieve quick post-injury clearance and facilitate faster return-to-play (Bailey, Echemendia & Arnett, 2006; Echemendia & Julian, 2001; Echemendia & Cantu, 2003). This could render baseline measures invalid reference points. It is also possible that the repeated testing yielded practice effects that masked, at least partially, any post-injury cognitive decline (Belanger et al., 2010). For example, if the performance gain from repeat assessment equaled or exceeded the cognitive decline caused by the sport concussion, there would be no change between the pre-injury and post-injury test performance. This might yield the conclusion that the suspected sport concussion did not result in any cognitive impairment, or, even worse, that no sport concussion was sustained at all.

Findings that support the notion of long-term neuropsychological sport concussion effects originate from cross-sectional study designs, but have largely been dismissed in the literature (Grindel et al., 2001). It has been argued that cross-sectional data can be confounded by extraneous variables that are considered to influence neuropsychological test performance. Known confounders that might lead to reported differences between sport-concussed and non-concussed athletes could be age (young vs. old; Heaton, Grant & Matthews, 1986; Reitan & Wolfson, 1997), gender (male vs. female; Ellemberg et al., 2007); alcohol consumption levels (low vs. high; Oscar-Berman & Marinković, 2007), education (high vs. low; Heaton et al., 1986; Reitan & Wolfson, 1997), illegal substance use (none vs. present; Gonzalez, 2007; Rogers & Robbins, 2001), learning disabilities (none vs. present; Collins et al., 1999; Pennington, 2009; Wood & Rutterford, 2006), neurologically active medication (none vs. present; e.g., Loring, Marino & Meador, 2007 for antiepileptic medication effects), psychiatric disorders (none vs. present; Castaneda, Tuulio-Henriksson, Marttunen, Suvisaari & Lönnqvist, 2008), tobacco smoking (none vs. present; Swan & Lessov-Schlaggar, 2007), and perceived task difficulty (low vs. high; Reinhard & Dickhäuser, 2009). In all of these cases, the latter would also cause reduced cognitive performance. However, these moderator influences cannot be assumed to be constant through the play season (Baron & Kenny, 1986; Meeuwisse, Tyreman, Hagel & Emery, 2007) meaning that the potential confounds would need measurement and data-analytic incorporation at each assessment throughout the season to control for confound effects.

Independent of research design, inconsistency in research findings might also be related to differences in group allocations. For example, some studies grouped athletes with no, one and two self-reported sport concussions together (Brown et al., 2007; Scolaro Moser & Schatz, 2002), while others did not include a control group (Macciocchi et al., 2001; Scolaro Moser & Schatz, 2002; Thornton et al., 2008). Furthermore, concerning the control group, some studies used non-concussed contact sport players (Rutherford, Stephens, Potter & Fernie, 2005), whereas others tested non-concussed non-contact players (Shuttleworth-Edwards & Radloff, 2008). It has been argued that provided sufficient confound moderator control, non-concussed non-contact sport players presented the more appropriate control group, as any group differences were more likely to originate from the sport played and the injury sustained (Rutherford et al., 2005). However, non-contact sport players might differ in motivation (Echemendia & Julian, 2001; Echemendia et al., 2003) and competitiveness (Maxwell, Visek & Moores, 2009) from contact sport players, and therefore might not pose an appropriate control group. For example, contact sport players have been shown to be more competitive than non-contact sport players (Maxwell et al., 2009) which might be associated with greater engagement and better performance on the neuropsychological tests.

Inconsistencies in the literature might also be due to differences in the choice of neuropsychological tests used. For example, some studies employed rather crude and easy cognitive measures such as word lists with as little as five words to quantify learning and delayed memory recall (McCrea et al., 2002; Shehata et al., 2009). Other research assessed only a limited range of cognitive functions (Broglio et al., 2006; Echemendia et al., 2003; Iverson et al., 2006b; McCrea et al., 2002; Shehata et al., 2009). For example, computerised assessment of sport concussion tends to rely mainly on measures of attention (Belanger & Vanderploeg, 2005), and not all batteries assessed memory recall (e.g., CogState Sport, CogState Ltd., Melbourne, Australia; Erlanger, Feldman, Kutner, Kaushik, Kroger, Festa, Barth, Freeman & Broshek, 2003; Iverson et al., 2006a) or executive functioning (e.g., Erlanger et al., 2003; Iverson et al., 2006a; McCrea et al., 2002; Shehata et al., 2009). This might be due to the fact that behavioural measures of attention, such as simple or complex reaction times, are more easily operationalised than memory recall or executive functioning, but it may bias or even contort the assessment. For example, memory recognition may be related to memory free recall (Haist, Shimamura & Squire, 1992), but functional dissociations are known from the literature (Bastin et al., 2004). Also, recognition may involve recollection, a familiarity-based decision or both (Vilberg & Rugg, 2007). This means that the information gained through the assessment of memory recognition cannot necessarily be generalised to the individual's memory recall ability. Similarly, the lack of tests that measure executive functioning means that no behavioural measure of complex cognition (Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000) is available. Performance on tests that measure executive function rely to a large extent on the frontal lobes (Heilman & Valenstein, 2003), and might arguably be areas particularly susceptible to the biomechanical forces of a brain trauma (Heilman &

Valenstein, 2003). Therefore, functional assessment of memory recall and executive functioning should be considered despite any relative difficulties in using these assessments.

The importance of potential long-term effects of sport concussion clearly needs further investigation. If research were to show consistent long-term effects, the way by which sport concussion recovery is currently operationalised, namely as the return to baseline, would need reconsideration. Furthermore, with contact and collision sports remaining popular (Sport England; http://www.sportengland.org, last accessed on 5 July 2010), the associated late health care costs could be significant, and appropriate prevention measures, such as the communication of the potential health risks to at-risk populations, encouraged (Chalmers, 2002).

The present study sought to assess long-term neuropsychological sport concussion effects (i.e., at least three months post-injury) in a carefully controlled post-injury only control group design. The study assessed cognitive measures of attention, memory and executive functioning. To increase the study's validity, we applied both computerised and paper-pencil tests depending on which mode would provide a more valid measure. We also increased the general test difficulty and controlled for major confounding variables (i.e., age, gender, learning difficulty, neurological and psychiatric disorders, alcohol consumption, neurologically active medication, perceived task difficulty and subjective symptomatology). We hypothesised that there would be significant group differences between the sport-concussed and non-concussed contact sport athletes in the cognitive measures of attention, memory and executive functioning.

4.3 Method

4.3.1 Participants

We recruited 70 contact sport athletes aged 18 to 27 (20% trimmed M=19.12, SE=0.15, 95% CI [18.81, 19.54]; 38.6% female) of which 23 participants (32.9%) self-reported a sport concussion. Exclusion criteria were a self-reported neurological disorder other than sport concussion, learning disability, neurologically relevant medication, illegal drug consumption within four weeks prior to testing and head trauma outside of sport.

Descriptive analysis of the sport concussion data showed that the majority of sport concussions (63.6%) were sustained more than 12 months prior to testing. Most participants however, could not recall the exact time of injury. Of the more recent sport concussions, 18.2% happened between three and six months, 4.5% between seven and nine months and 13.6% between ten to twelve months prior to testing. One participant did not provide an estimate for the time since injury. From the athletes who reported a sport concussion, 78.3% provided detail on whether or not they experienced loss of consciousness. Of those, 33.3% self-reported loss of consciousness. No reliable information could be obtained concerning post-traumatic amnesia. Following the injury, 50.0% did not seek medical attention; 40.9% attended Accident and Emergency services and the remaining 9.1% sought assistance with a general practitioner. One participant did not give any information on medical treatment. Of those providing detail on return to sport (91.3%), 28.6% did not refrain from sport, but returned to play on the day of the injury, and 42.8% returned to training and competition within one week post-injury. This means that cumulatively, 71.4% returned to sport practice and competition within one week post-concussion. The remaining 28.6% refrained from sport for more than seven days.

The control measures for potential confound moderator variables for self-reported sport-concussed and non-concussed athletes are presented in Table 4.1. This showed no significant differences between the self-reported sport-concussed and non-concussed athletes for age, gender, admitted consumption of illicit drugs (past 12 months), alcohol consumption levels and tobacco smoking, expressed cognitive and somatic-emotional symptoms, anxiety, depression, positive affect, negative affect and perceived task difficulty.

The School of Sport and Exercise Sciences University of Birmingham ethics committee approved the study in accordance with the 1964 Declaration of Helsinki. Undergraduate sport science students received course credits for their participation. Each participant provided written informed consent.

Table 4.1: Control of potential confound variables between participants with self-reported sport concussion history compared to self-reported non-concussed athletes

Measure		Sport concussion history		test statistic [df]	p
		Self-reported	Not self-reported		
n		23	47		
Age	$M_t \pm SE_t$	19.07±0.29	19.14±0.18	0.05 [1,26.56][b]	.83
Gender (female)	%	30.4	42.6	0.96 [1][a]	.44
AUDIT Drug misuse	%	17.4	17.0	0.01 [1][a]	1.0
AUDIT Risky alcohol drinking	%	78.3	74.5	0.12 [1][a]	1.0
AUDIT Tobacco smoking	%	0.0	2.1	0.50 [1][a]	1.0
RPQ Cognitive symptoms	$M_t \pm SE_t$	0.13±0.29	0.62±0.24	1.84 [1, 33.16][b]	.18
RPQ Somatic-emotional symptoms	$M_t \pm SE_t$	2.20±0.88	2.10±0.59	0.01 [1, 27.88][b]	.92
HADS Anxiety	$M_t \pm SE_t$	4.47±0.47	4.83±0.40	0.38 [1, 34.76][b]	.54
HADS Depression	$M_t \pm SE_t$	1.40±0.39	1.31±0.29	0.04 [1, 30.57][b]	.85
PANAS Positive Affect	$M_t \pm SE_t$	36.20±1.78	33.55±0.94	1.95 [1, 22.77][b]	.18
PANAS Negative affect	$M_t \pm SE_t$	14.87±0.94	14.89±0.58	0.01 [1, 26.02][b]	.98
TDI Difficulty	$M_t \pm SE_t$	3.27±0.29	3.76±0.12	2.82 [1, 19.13][b]	.11

Abbreviations: M_t– 20% trimmed mean, SE_t– standard error of the trimmed mean, df– degrees of freedom; AUDIT– Alcohol Use Disorder Identification Test, RPQ– Rivermead Post Concussion Questionnaire, HADS– Hospital Anxiety and Depression Scale, PANAS– Positive and Negative Affect Scales, TDI– Task Difficulty Inventory.

a – χ^2 test test statistic with degrees of freedom in square brackets, b – non-parametric ANOVA test statistic F_t with degrees of freedom in square brackets

4.3.2 Measures

The neuropsychological test battery comprised six questionnaires and ten neuropsychological tests (see Table 4.2 for an overview). The six questionnaires were used to control for potential confound moderators of neuropsychological functioning. These were the Injury Assessment Questionnaire (IAQ), the Rivermead Post Concussion Questionnaire (RPQ; King et al., 1995), the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983), the Alcohol Use Disorder Identification Test (AUDIT; Bohn, Babor & Kranzler, 1995), the Positive and Negative Affect Scales (PANAS; Watson et al., 1988) and the Task Difficulty Inventory (TDI; Phillips, Carroll, Burns & Drayson, 2005) (Appendix B). In the following six paragraphs each of these questionnaires is explained.

TABLE 4.2: Applied questionnaires and neuropsychological tests with derived dependent or confound moderator variables in the order they appeared in the study

Questionnaires and tests by cognitive domain			Dependent variable
(1)	Q	Injury Assessment Questionnaire	age, gender
			learning or neurological disorder (yes, no)
(2)	Q	Rivermead Post Concussion Symptom Q	subscores cognitive (/16), somatic-emotional (/48)
(3)	M	Hopkins Verbal Learning Test	
(4)	M	BUCS Story Recall and Recognition	immediate free recall (/15)
(5)	EF	Stroop Test	time to complete (in s)
(6)	EF	Wisconsin Card Sorting Test	number of cards (/128), perseverations in false (%)
(7)	A	CANTAB Reaction Time	mean reaction time (in ms)
(8)	A	CANTAB Rapid Visual Processing	mean reaction time (in ms)
(9)	EF	CANTAB Intra/Extradimensional Shift	number errors
(10)	Q	Hospital Anxiety and Depression Scale	subscores anxiety (/21), depression (/21)
(11)	EF	Trail Making Test	part B time (s)
(12)	Q	Alcohol Use Disorder Identification Test	sum score (/40)
			illicit substance abuse past year/month (yes, no)
			tobacco smoking; medication (yes, no)
(13)	EF	BUCS Rule Finding	number correct (/18)
(14)	Q	Positive and Negative Affect Scales	subscores Positive affect (/50), Negative affect (/50)
	M	Hopkins Verbal Learning Test	delayed free recall (/12)
	M	BUCS Story Recall and Recognition	delayed free recall (/15)
(15)	EF	Paced Auditory Serial Addition Test	number correct (/122)
(16)	Q	Task Difficulty Inventory	difficulty (/6)

Abbreviations: Q – Questionnaire, M – Memory, EF – Executive Function, A – Attention; CANTAB – Cambridge Neuropsychological Test Automated Battery, BUCS – Birmingham University Cognitive Screen.
Questionnaires were used to control for moderator confounds of neuropsychological test performance.

We collected background information with the Injury Assessment Questionnaire (IAQ). This was assembled for this study and assessed demographics (age, gender, sport) and history of sport concussion, non-brain sport injuries, neurological and learning disorders.

The Rivermead Post Concussion Symptoms Questionnaire (RPQ; King et al., 1995) measured subjective symptomatology. It listed 16 cognitive and somatic-emotional symptoms that were rated for their severity on a scale from 0-4 (0=not experienced at all, 1=no more of a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem). Participants were asked to relate the symptoms to the past 24 hours only. We followed the standard scoring instructions (i.e., the severity ratings of 0 and 1 were treated as 0), but derived two sum scores as the dependent variables (Potter, Leigh, Wade & Fleminger, 2006; Lannsjö, af Geijerstam, Johansson, Bring & Borg, 2009). The first sum score summed the participant ratings for cognitive symptoms (forgetfulness/ poor memory; poor concentration; taking longer to think), and the second summed the participant ratings of the remaining somatic-emotional symptoms. For each of the sum scores, a higher score represented a higher severity.

The Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) measured anxiety and depression. The questionnaire listed seven statements each on anxiety and depression. Each statement came with four response options. Participants were asked to choose one of four response options for each of the 14 statements and relate them to their past week. We followed the standard scoring by which each statement rating yielded a score between 0 and 3 (a greater score indicated greater severity). Rating scores were summed separately for anxiety and depression yielding two composite scores. A higher composite value (maximum: 21) corresponded to a more severe clinical manifestation. Both composite scores served as the dependent variables.

The Alcohol Use Disorder Identification Test (AUDIT; Bohn et al., 1995) screened for risky alcohol-consuming behaviour by means of ten items. The first eight items were scored on a 5-point scale and indicated alcohol consumption frequency and quantity. The remaining two items concerned drinking-related problems (e.g., a person was injured because of the individual's drinking) and were rated on a 3-point scale. A sum score was calculated (maximum: 40), whereby a score of equal or greater 8 classified hazardous drinking behaviour (Saunders, Aasland, Babor, de la Fuente & Grant, 1993). We used the derived sum score to group participants into self-reported versus no self-reported hazardous alcohol drinking habits. We modified the AUDIT test by adding a list of illegal substances to measure drug use in the past year and past month (adapted from Ramsey, Baker, Goulden, Sharp & Sondhi, 2001). We also presented two questions that assessed current medication and tobacco smoking behaviour. For the added questions, participants chose one of three response options (yes, no, do not want to answer) per substance. We used the questionnaire ratings to group study participants into: self-reported versus no self-reported illicit drug abuse within 12 months prior to testing; self-reported versus no self-reported illicit drug abuse within four weeks prior to testing; self-reported versus no self-reported tobacco smoking; self-reported versus not self-reported medication intake.

The Positive and Negative Affect Scales (PANAS; Watson et al., 1988) measured positive and negative affect. The questionnaire listed 20 adjectives (ten positive, ten negative) that the participants used to describe how they felt in the past week. For each adjective (e.g., excited as a positive, guilty as a negative), the participant chose a number between 1 (very slightly or not at all) and 5 (extremely) to describe the felt intensity. A higher score represented a more intense feeling. Participant ratings were then summed separately for positive and negative adjectives (maximum: 50 each). A higher composite score represented a more positive or negative affect. Both composite scores (positive affect, negative affect) served as the dependent variables.

The Task Difficulty Inventory (TDI) measured perceived test battery characteristics (Phillips et al., 2005) and was carried out at the end of the study. It listed seven questions that participants were asked to rate on a Likert scale from 0 (not at all) to 6 (extremely). The questions concerned test battery difficulty, perceived stressfulness, battery-related arousal, battery-related confusion, engagement with the test battery, battery-related embarrassment and overall personal performance. Participants were instructed not to relate to a singular test, but the test battery as a whole. Only the battery-related perceived difficulty served as the dependent variable.

The neuropsychological test battery tested cognitive measures of attention, verbal memory recall and executive function. A total of ten tests were used in the battery. These were the Hopkins Verbal Learning Test (HVLT; Brandt & Benedict, 2001), the Birmingham University Cognitive Screen (BUCS; Humphreys, Samson, Bickerton & Riddoch, 2009) subtest Story Recall and Recognition, the Stroop test (Stroop, 1935), the Wisconsin Card Sorting Test WCST (Grant & Berg, 1993), the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition Ltd., Cambridge, UK) subtests Reaction Time (RTI), Rapid Visual Information Processing (RVP) and Intradimensional/Extradimensional Shift (IED), the Trail Making Test (Reitan, 1958), the BUCS Rule Finding and Switching (RF; Humphreys et al., 2009), and the Paced Auditory Serial Addition Test (Gronwall & Sampson, 1974). The following ten paragraphs explain what was involved in each test. The tests are explained in the order they appeared in the testing.

The memory test Hopkins Verbal Learning Test (HVLT; Brandt & Benedict, 2001) presented the participant with 12 high-frequency words of three semantic categories over three learning trials. After each trial, the participant was asked to recall as many words from the list as possible. After an interval of approximately 40 minutes, free recall and (yes/no) recognition amongst semantically similar distractor words were assessed. After the learning trials, the experimenter did not inform the participant about the delayed re-assessment. We randomly used one of six parallel versions. Only delayed free recall (maximum: 12) served as the dependent variable.

The Birmingham University Cognitive Screen (BUCS; Humphreys et al., 2009) subtest Story Recall and Recognition measured memory recall. The experimenter read an 84-word story to the participant. Story details had then to be recalled immediately and approximately 40 minutes following the auditory presentation. After the immediate recall, the experimenter did not inform the participant about the delayed re-assessment. Note that we did not assess recognition in order to prevent material re-learning. In the immediate and delayed free recall, segmented retrieval was scored by the experimenter and summed separately (maximum: 15) to serve as the dependent variables.

The paper-pencil Stroop Test (Stroop, 1935) measured response inhibition and listed 90 colour words in incongruent colour ink (e.g., the word blue in green ink). The task was to name the colour of the ink as fast as possible and with as few errors as possible. The experimenter pointed out errors that needed correction and recorded completion time in seconds as dependent variable. The task was preceded by a reading task of a list of 90 colour words in black ink.

The computerised version of the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1993) measured the executive function shifting. It presented a stack of target cards and four stimulus cards on the computer screen. The participant was asked to match each card of the stack to one of the four stimulus cards. Each stimulus card was marked by a number underneath (i.e., 1 to 4). To match a target card with one of the stimulus cards, the participant pressed the number underneath the stimulus card (e.g., 1 if the participant thought the target card matched the stimulus card 1). No information on the sorting rule was given, but feedback on accuracy provided. The sorting followed a pattern, but changed without notice. A new rule was introduced when six cards had been successfully matched in a row. The aim was to sort as many cards as possible using the correct rule. The task self-terminated after nine rules were detected or 128 cards had been sorted. The automatic test output of outcome measures contained the number of cards sorted and perseverations in false responses that served as the dependent variables.

The Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition Ltd., Cambridge, UK) subtest Reaction Time (RTI) measured reaction time. It recorded participant response with the CANTAB press pad and the CANTAB touch screen. At the beginning of the CANTAB RTI task, the participant was instructed to press the press pad while observing the computer screen. In the centre of the computer screen, there was a white circle in which a yellow dot appeared. The participant was instructed to release the press pad as fast as possible, touch the target dot on the touch screen, return to the press pad and press it down again. The test consisted of two parts. In part one, the target dot appeared in one circle only, whereas in part two the target dot randomly appeared in any of the five circles possible. The automatic test output contained the mean reaction time for correct response trials (i.e., the time from the target appearance to the press pad release) that served as the dependent variable.

The CANTAB Rapid Visual Information Processing (RVP) measured sustained attention. Participant response was recorded with the CANTAB press pad. Single digits from 2 to 9 appeared in a pseudo-random order in a white box in the middle of the screen at a rate of 100 per minute. The participant was instructed to detect three different sequences of single digits (i.e., 3-5-7, 2-4-6, 4-6-8) and respond by pressing the pad. The press pad should be pushed down briefly when the last digit of a sequence appeared. For example, in the target sequence 3-5-7, the participant pressed the press pad as soon as the last digit of the series (the 7) appeared. The task lasted four minutes with the first minute used as a practice trial. Target digits appeared at a rate of 16 every two minutes. The automatic test output contained the mean reaction time for correct responses that served as the dependent variable.

In the CANTAB subtest Intradimensional/ Extradimensional Shift (IED), the participant learned rules by utilising feedback on behavioural correctness (executive function). The CANTAB touch screen was used to record participant response. The IED task would present four equally sized white rectangles on a black screen. In two of the rectangles, an abstract pattern each appeared. The participant decided for one pattern by touching the rectangle that contained the pattern on the touch screen. Immediately following the participant response, automatic feedback was provided. The rectangles changed colour (i.e., from white to green for a correct and from white to red for an incorrect response), and there was an acoustic signal (i.e., a high tone for a correct and a low tone for an incorrect response). Then, two new abstract patterns appeared, and the participant made a new choice followed again by immediate feedback. The rule changed after six correct pattern decisions whereby difficulty increased (i.e., the patterns became visually more complex). The task self-terminated after nine successful rule changes or 50 incorrect responses. The automatic test output contained the error rate that served as the dependent variable.

The Trail Making Test (TMT; Reitan, 1958) consisted of two parts. The test measured psychomotor function and information processing (part A), and the executive function shifting (part B). In part A, participants connected ascending numbers from 1 to 25. In part B, participants alternated between ascending numbers and letters (e.g., 1-A-2-B). The experimenter pointed out any errors and guided the participant back to the last correct point from which the participant continued with the test. In both parts, the time to complete the task in seconds was recorded, but only TMT part B served as the dependent variable.

The paper-pencil Birmingham University Cognitive Screen (BUCS) subtest Rule Finding and Switching (RF; Humphreys et al., 2009) measured the executive function shifting. It presented the participant with a 6-by-6 grey grid with two red and one green cells and one black dot. Within a sequence of stimuli, the black dot moved in a predictable fashion. Participants had to anticipate the dot's movement which could be within a single dimension (moving in one direction followed by a change in direction) or across dimensions (switching from direction to colour-bound rule). The experimenter asked where the participant thought the dot would move to next, and the participant pointed to the field on the grid. Then, the experimenter showed the participant where the dot had moved to, and the participant again had to point out on the grid where the dot would move next. There were three rules with increasing complexities, and 18 dot movements in total. Correct predictions were scored with a sum score (maximum: 18) that served as the dependent variable.

The Paced Auditory Serial Addition Test (PASAT; Gronwall & Sampson, 1974) was developed to quantify information processing after concussion. The participant listened to a recorded series of single-digit numbers and was required to add the most two recent numbers providing an answer before the next digit was read out. For example, if the series was 3 - 5 - 2 - 5, the participant would say 8 - 7 - 7. We used a four-minute version with inter-digit intervals of 2.4, 2.0, 1.6 and 1.2 seconds for one minute each. The experimenter scored correct answers (maximum: 122) and summed them into the dependent variable.

4.3.3 Procedures

Testing took place in a quiet room with only one experimenter present. Following written consent, participants completed the fixed battery of questionnaires and neuropsychological tests, as described in the previous section. The fixed test order allowed us to maximise the interval between immediate and delayed memory recall in the HVLT and BUCS Story tests, to balance test difficulty levels and to group the computerised tests (for time efficiency). Before each test, the experimenter provided standard test instructions, and, if applicable for the particular test, a practice run. Short intermittent breaks were given. Following the study, the experimenter debriefed the participant, but provided no feedback on actual test performance.

4.3.4 Data analysis

The independent variable was sport concussion history. We allocated participants to either the sport-concussed or non-concussed group based on their injury self-report. We used SPSS (2009) for all parametric and R-based scripts (Wilcox, 2005) for non-parametric data analyses. The significance level p was preset to .05.

Dependent variables as derived from neuropsychological tests (see Table 4.2) proved non-normally distributed in Shapiro-Wilk tests in SPSS (2009) and could not be normalised with logarithmic or square-root transformations. Therefore, we used non-parametric univariate ANOVAs (R function: t1way; Wilcox, 2005) in R (R Development Core Team, 2009) to compare the trimmed means (γ=.2) of a dependent variable between self-reported sport-concussed and non-concussed athletes.

4.4 Results

Trimmed means (γ=.2), standard errors of the trimmed means, 95% confidence intervals and test statistics for the dependent measures are presented in Table 4.3. Only two non-parametric univariate ANOVAs revealed significant differences between sport-concussed and non-concussed athletes. This was on the BUCS Story Recall and Recognition test and the WCST. In the BUCS Story Recall and Recognition test, self-reported sport-concussed athletes recalled significantly less details immediately following the auditory story presentation than the self-reported non-concussed athletes, indicating that their immediate free verbal memory recall was worse. In the WCST, self-reported sport-concussed athletes showed a higher proportion of perseverations in false responses than self-reported non-concussed athletes. This indicates that self-reported sport-concussed athletes maintained a sorting rule despite receiving feedback that this sorting rule was inaccurate.

Table 4.3: Trimmed means (γ=.2), standard errors, 95% confidence intervals and test statistics for dependent measures

Measure	Sport concussion history						non-parametric ANOVA		
	Self-reported			Not self-reported					
	M_t	SE_t	95% CI	M_t	SE_t	95% CI	F_t	[df]	p
HVLT delayed free recall	10.73	0.41	[9.85, 11.62]	10.24	0.28	[9.66, 10.82]	1.07	[1, 28.45]	.31
Story immediate free recall	9.20	0.42	[8.30, 10.10]	10.22	0.24	[9.74, 10.71]	5.05	[1, 23.96]	.03
Story delayed free recall	9.03	0.53	[7.90, 10.17]	9.19	0.38	[8.42, 9.96]	0.06	[1, 29.41]	.80
Stroop test time (s)	90.43	3.76	[82.47, 98.60]	87.55	1.83	[83.81, 91.29]	0.58	[1, 21.51]	.46
WCST number of cards	93.27	8.59	[74.84, 111.69]	99.76	5.34	[88.82, 110.69]	0.46	[1, 26.12]	.50
WCST perseverations (%)	66.34	2.27	[61.48, 71.21]	58.06	1.30	[55.40, 60.72]	11.27	[1, 24.39]	.003
RTI reaction time (ms)	295.87	7.79	[279.15, 312.58]	300.76	4.88	[290.76, 310.76]	0.05	[1, 26.56]	.83
RVP reaction time (ms)	403.96	13.59	[374.81, 433.10]	386.44	7.78	[370.32, 402.56]	1.40	[1, 24.61]	.25
IED errors	9.00	0.63	[7.64, 10.36]	9.69	0.47	[8.73, 10.65]	0.85	[1, 30.37]	.36
TMT-B time in s	31.53	2.19	[26.85, 36.22]	32.76	1.79	[29.08, 36.43]	0.21	[1, 33.37]	.65
RF correct	14.93	0.32	[14.24, 15.63]	14.72	0.29	[14.13, 15.32]	0.26	[1, 35.74]	.62
PASAT correct	95.07	3.27	[88.06, 102.07]	93.24	2.61	[87.89, 98.59]	0.21	[1, 32.62]	.65

Abbreviations: M_t – 20% trimmed mean, SE_t – standard error of the trimmed mean, CI – confidence interval, df – degrees of freedom, HVLT – Hopkins Verbal Learning Test, WCST – Wisconsin Card Sorting Test, RTI – Reaction Time, RVP – Rapid Visual Processing IED – Intra-/Extradimensional Shift, TMT-B – Trail Making Test part B, RF – Rule Finding, PASAT – Paced Auditory Serial Addition Test

4.5 Discussion

The study's objective was to assess the long-term neuropsychological functions (i.e., at least three months) following sport concussion in university athletes compared to controls while controlling for potential moderators of age, gender, sport participation, learning difficulty, neurological and psychiatric disorders, illicit drug misuse, tobacco smoking, alcohol consumption, neurologically active medication, perceived task difficulty and subjective symptomatology. We hypothesised to find reliable differences between self-reported sport-concussed and non-concussed athletes on cognitive measures of attention, memory and executive functioning. Our data partially supported the hypothesis.

The data showed selected neuropsychological performance decrements in self-reported sport-concussed athletes in measures of immediate free verbal recall (i.e., BUCS Story Recall and Recognition, immediate free recall; Humphreys et al., 2009) and the executive function shifting (i.e., WCST perseverations in false responses; Grant & Berg, 1993). On the BUCS Story Recall and Recognition, self-reported sport-concussed athletes showed significantly worse performance on the immediate free verbal recall. They recalled significantly less details immediately following the auditory story presentation than self-reported non-concussed athletes. However, in contrast, there was no performance difference on the delayed free recall between self-reported sport-concussed and non-concussed athletes. This suggests that though self-reported sport-concussed athletes retained less story details than self-reported non-concussed athletes (i.e., immediate free recall), they were able to retain the story details between the immediate and delayed free recall assessment. On the other side, self-reported non-concussed athletes retained more story details than self-reported sport-concussed athletes immediately following the auditory story presentation, but appeared not be able to retain all story details between the immediate and delayed memory recall assessment.

On the WCST, the proportion of perseverations in false response was significantly higher in self-reported sport-concussed than non-concussed athletes. Perseverations signify that the feedback given was not used in an efficient way, and that despite knowing that the previous card was falsely sorted, the sorting rule was applied to a new card again. This means that self-reported sport-concussed athletes failed to make efficient use of the provided feedback in such that they did not adapt their behavioural response strategy as efficiently as self-reported non-concussed athletes. The lack of adaptation however, appeared not to be represented in the number of cards necessary to complete the task. All athletes succeeded in the task in that they completed the task with no significant difference in the number of cards used.

Our findings are in contrast to the current sport concussion definition that emphasised the transiency of neuropsychological sport concussion effects (Guskiewicz et al., 2006, McCrory et al., 2009). Our data also contradicts past research that did not find neuropsychological decrements in (self-reported) sport-concussed athletes beyond the acute and post-acute recovery stage (i.e., at least one month post-injury; see Belanger et al., 2010; Broglio et al., 2006; Brown et al., 2007; Catena et al, 2009; Echemendia et al., 2001; Guskiewicz, 2002; Guskiewicz et al., 2003; Iverson et al., 2006b; Macciocchi et al., 2001; Maddocks & Saling, 1996; McCrea et al., 2002; Shuttleworth-Edwards et al., 2008; Thériault et al., 2009). Instead, our data suggest long-lasting effects of sport concussion on some cognitive measures.

It is interesting that the present study found cognitive deficits on tests that are not often used in neuropsychological test batteries for sport concussion. Therefore, direct comparisons of these data are difficult with few comparative empirical data on the WCST available (e.g., Ettenhofer & Abeles, 2009; Rutherford et al., 2005; Thornton et al., 2008). This might be linked to the fact that much research has employed a longitudinal study design with repeat neuropsychological testing that does not allow the application of the WCST due to the substantial practice effects (Ellemberg, Henry, Macciocchi, Guskiewicz & Broglio, 2009). The few data that is available however, actually showed no evidence that WCST performance differed between sport-concussed and non-concussed athletes (e.g., Ettenhorfer et al., 2009; Rutherford et al., 2005; Rutherford, Stephens, Fernie & Potter, 2009; Thornton et al., 2008).

Concerning memory recall, most research reported in the literature has employed word lists and not found any significant performance deficits in sport-concussed athletes compared to non-concussed controls (e.g., Collins et al., 1999; Ellemberg et al., 2007; Guskiewicz, Ross & Marshall, 2001; McCrea et al., 2003; Rutherford et al., 2005; Rutherford et al., 2009). Therefore, it seems that the use of stories may have increased task difficulty and made the test battery more sensitive to the sport concussion injury effects.

As presented in the introduction of this chapter, cross-sectional designs that compare self-reported sport-concussed and non-concussed athletes on different neuropsychological test are usually criticised for not controlling confounding moderator variables (Grindel et al., 2001). In the present study, we carefully controlled the potential confound moderator variables of age, gender, learning difficulties, neurological and psychiatric disorders, illicit drug misuse, tobacco smoking, alcohol consumption levels, neurologically active medication, perceived task difficulty and subjective symptomatology. Therefore, the data presented here could not be caused by the confound variables listed above.

A further argument against the validity of cross-sectional multiple test designs could be that the probability to find a neuropsychological deficit increases with the number of tests used (Ingraham & Aiken, 1996). For example, using a test battery with 12 measures (i.e., the number of dependent variables we derived in the present study), the probability to find one abnormal score (i.e., deviant by 2 standard deviations) was estimated to be between 20 and 30%. In the present study, two of the twelve tests showed significant effects making it unlikely that the findings were due to chance. In addition, consideration of the individual athlete scores shows interesting data consistent with the main findings of the chapter (see Tables 4.4 and 4.5). Here, 95% confidence intervals were derived from the data of self-reported non-concussed athletes and compared to the test scores of each individual with a self-reported sport concussion. This showed evidence of individual abnormal scores (i.e., outside of the 95% confidence interval). Applying the same approach by Ingraham and Aiken (1996), the probability for just two abnormal scores by any individual (i.e., deviant by 2 standard deviations) on a test battery with 12 dependent measures would already fall significantly below chance. Adopting more stringent criteria of 20% trimming and 3 standard deviations, we were able to confidently identify abnormal test scores. This analysis suggests a wide range of deficits present in individuals with a history of sport concussion that cannot be explained by chance. Furthermore, as the data showed individual differences, it suggests that deficits caused by sport concussion are perhaps not unitary, and further investigations are required to understand individual deficits caused by sport concussion.

Table 4.4: Individual test scores for self-reported sport-concussed female athletes. The 'x' indicates a score outside of the control group's 95% confidence interval that represents a deficit.

Age	Injury time	HVLT	Story		Stroop	WCST		RTI	RVP	IED	TMT B	RF	PASAT	Σ abnormal
			IFR	DFR		Cards	P							
18	>12		x					x	x	x		x		5
19	>12							x		x		x		3
19	>12		x		x			x	x			x	x	6
19	7–9		x		x		x	x	x					5
20	>12						x	x				x		3
21	>12					x			x		x		x	4
24	n/a				x	x	x	x			x			5

Abbreviations: HVLT – Hopkins Verbal Learning Test, IFR – immediate free recall, DFR – delayed free recall, WCST – Wisconsin Card Sorting Test, P – WCST perseverations, RTI – Reaction time, RVP – Rapid Visual Processing, IED – Intra-/Extradimensional Shift, TMT – Trail Making Test, RF – Rule Finding, PASAT – Paced Auditory Serial Addition Test; >12 – sustained concussion more than 12 months ago, 7-9 – sustained concussion 7 to 9 months ago, 10-12 – sustained concussion 10 to 12 months ago, 4-6 – sustained concussion 4 to 6 months ago

Table 4.5: Individual test scores for self-reported sport-concussed male athletes. The 'x' indicates a score outside of the control group's 95% confidence interval that represents a deficit.

Age	Injury time	HVLT	Story		Stroop	WCST		RTI	RVP	IED	TMT B	RF	PASAT	Σ abnormal
			IFR	DFR		Cards	P							
18	>12					x	x			x	x			4
18	10−12		x		x	x	x							4
18	10−12					x	x	x	x	x	x	x	x	8
18	>12		x	x	x	x			x		x			6
18	4−6		x				x		x					3
18	4−6	x	x	x	x		x			x		x	x	8
19	4−6	x	x	x	x		x	x	x		x	x	x	10
19	>12	x	x				x		x					4
19	4−6		x				x							2
19	>12	x	x				x							3
19	>12		x				x							2
20	>12		x				x					x		4
20	4−6	x	x	x			x					x		5
20	>12		x	x	x	x				x	x			6
20	>12		x	x	x		x						x	5
21	>12				x		x		x			x		4

Abbreviations: HVLT − Hopkins Verbal Learning Test, IFR − immediate free recall, DFR − delayed free recall, WCST − Wisconsin Card Sorting Test, P − WCST perseverations, RTI − Reaction time, RVP − Rapid Visual Processing, IED − Intra-/Extradimensional Shift, TMT − Trail Making Test, RF − Rule Finding, PASAT − Paced Auditory Serial Addition Test; >12 − sustained concussion more than 12 months ago, 7-9 − sustained concussion 7 to 9 months ago, 10-12 − sustained concussion 10 to 12 months ago, 4-6 − sustained concussion 4 to 6 months ago

In the data presented here, we suggest that sport concussion may yield prolonged neuropsychological decrements. This is in contrast to the injury definition that was published within the Consensus Statement on Sport Concussions and described sport concussion effects as transient (McCrory et al., 2009). In turn, this raises the question of whether the conceptualisation of sport concussion recovery as the return to pre-injury baseline measures still holds and whether currently used neuropsychological test batteries provide adequate test tools. Whereas the cross-sectional design of the present study does not allow analysis of return to pre-injury baseline, it is important to note that the present study found neuropsychological performance decrements on group measures of verbal memory recall and executive functioning. Both measures typically do not form part of the test batteries that measure the neuropsychological effect of sport concussion (e.g., CogState Sport, CogState, Ltd., Melbourne, Australia; ImPACT test, ImPACT Applications, Inc., Pittsburgh, Pennsylvania, USA) and suggests that these measures need to be included to gain more understanding of deficits following sport concussion. It was interesting that in self-reported sport-concussed athletes, no reduced neuropsychological performance was found on the word list test (i.e., the HVLT; Brandt & Benedict, 2001) that typically forms part of test batteries that measure neuropsychological sport concussion effects (e.g., ImPACT test, ImPACT Applications, Inc., Pittsburgh, Pennsylvania, USA). It is possible that word list tests are only of sufficient difficulty to measure performance decrements in the acute and possibly post-acute recovery stage, but not beyond. Our data propose that more complex and difficult memory tasks, such as the story recall test we used, might present an appropriate and more sensitive substitute.

Our finding of reduced executive function performance in self-reported sport-concussed athletes offers further support to the notion that the currently used neuropsychological sport concussion test batteries might need adaptation. For example, following traumatic brain injury, different recovery curves have been observed for different cognitive domains (Anderson & Catroppa, 2005; Brooks, Deelman, van Zomeren, van Dongen, van Harskamp & Aughton, 1984; Christensen et al., 2008). For example, more basic functions such as simple reaction time were shown to recover more quickly than more complex functions such as executive functions (Anderson & Cantroppa, 2005; Brooks et al., 1984; Christensen et al., 2008). Given this point that more complex cognitive functions such as memory recall and executive functioning are currently not sufficiently measured, it might be that unbeknown to the professional staff and athlete, the athlete is prematurely cleared to return to training and competition risking further injuries (e.g., Iverson et al., 2004a).

Here, we did not consider differences in performance decrements between history of a singular sport concussion and history of multiple sport concussion. Past research has suggested a dose-reponse relationship whereby an increasing number of sport concussion would be accompanied by increasingly worse neuropsychological test performance (e.g., Bernstein, 2002; Collins et al., 1999; De Beaumont et al., 2009; Iverson et al., 2004b;

Killam et al., 2005; Matser et al., 2001; Register-Mihalik et al., 2009). In the study presented here, athletes were asked whether they had sustained a sport concussion, and, if so, how many sport concussions were sustained. The data showed that the majority of athletes were not able to provide an estimate for the number of sport concussions that they had sustained, thus data analysis could not be extended to this aspect. Even if athletes were able to give an estimate, the estimate's validity could be questionable. For example, Gabbe, Finch, Bennell and Wajswelner (2003) compared athlete retrospective injury reports to their sport team injury records. They found that although athletes were able to retrospectively recall accurately whether or not they had sustained a sport injury, only 80% could accurately recall how many sport injuries were sustained within the last 12 months. Future experiments should consider this factor in order to determine whether the number of sport concussions further increased the likelihood of long-term cognitive deficits.

Related to this last point is the question of whether athletes correctly identified that they had received a sport concussion. In Chapters 2 and 3, we demonstrated that athletes had limited knowledge on sport concussion. Lacking knowledge might have adversely impacted the injury's recognition and therefore the self-report rates. In the present study, lacking knowledge was reflected in the reported return-to-play practices. Following the sport concussion, more than 25% of the athletes did not refrain from training and competition, and, cumulatively, almost 75% returned to sport within seven days of the sustained injury.

Thus, it is possible that an athlete might have sustained a sport concussion, but failed to self-report it in the study because of the athlete's limited knowledge of sport concussion. Future research should combine retrospective injury self-reports with a symptom-based approach (LaBotz et al., 2005; Valovich McLeod et al., 2008). For example, in addition to the traditional question; "have you ever sustained a sport concussion?"; the athlete might be asked whether they had ever sustained a head impact that led to a cluster of symptoms, such as dizziness, headache or disorientation and confusion. By using this approach, the athlete might better recall the symptoms of sport concussion rather than deciding upon their self-diagnosis.

The present study suggests that the neuropsychological assessment of sport concussion needs improvement. It is clear from the data that complex and more difficult tests would help understanding of what behaviours are influenced in the long-term by sport concussion injuries. In particular, we suggest the use of memory recall and executive function tests to explore these issues. A second improvement would be to regard the neuropsychological test performance differences we found between self-reported sport-concussed and non-concussed athletes at the individual level. That is, each individual will have sustained a head impact of individual force, velocity and direction that would have disturbed the brain in potentially different ways leading to different abnormalities. Current research that compares between groups might hide some of these individual differences in deficits (Iverson, 2010). For example, stroke research has shown that differently located brain lesions yield different behavioural correlates (de Haan, Nys & Van Zandvoort, 2006; Nys, Van Zandvoort, de Kort, Jansen, Van der Worp, Kappelle & de Haan, 2005). Occipital lobe lesions are typically associated with deficits in visual perception and construction (Nys et al., 2005), whereas lesions in the parietal lobe may yield deficits in attention (Bartolomeo & Chokron, 2002). That is, injury from stroke is not considered as a unitary deficit (de Haan et al., 2006). This point transferred to sport concussion suggests that different head impacts might be associated with different neuronal abnormalities and behavioural correlates, and that it might not be appropriate to summarise individual injuries under one unitary umbrella term of sport concussion. We suggest that future research should aim to differentiate sport-concussed athletes by the type of impact or individual neuronal abnormalities in order to better understand the relationship between the injury and the behavioural deficits.

The neuropsychological function decrements in memory and executive functioning that we found might have been salient due to the complexity of the behaviour. It might be that both tests required large enough neuronal-functional networks to span the majority of sport-concussed athletes. For example, the executive function shifting has been shown to involve structures in the prefrontal cortex, striatum, thalamus and posterior parietal cortex (Monchi, Petrides, Petre, Worsley & Dagher, 2001). Similarly, memory recall may entail structures in the prefrontal cortex (Blumenfeld & Ranganath, 2007), the temporal lobe (Kopelman, Bright, Buckman, Fradera, Yoshimasu, Jacobson & Colchester, 2007), the thalamus (Stewart, Griffith, Okonkwo, Martin, Knowlton, Richardson, Hermann & Seidenberg, 2009) and the brain stem (Sepulcre, Masdeu, Sastre-Garriga, Goñi, Vélez-de-Mendizábal, Duque, Pastor, Bejarano & Villislada, 2008). Considering this, it might be that particular profiles of sport-concussed athletes show individual differences in specific deficits, but that complex functions (e.g., executive function) might show general deficits in many of the athletes due to the complexities involved in the behaviour. Examining individual athletes rather than use of a group design would allow for both complex and simple deficits to be detected.

Chapter 5

Mapping the neuropsychological recovery of sport concussion

5.1 Abstract

This longitudinal study piloted a newly compiled computerised neuropsychological test battery comprising of attention, verbal memory recall and executive function tests. The pre-injury versus post-injury comparison design comprised six assessments: two (pre-injury) baselines and four (post-injury) follow-ups. There were two aims to the study: (i) to establish multiple control group baselines and examine practice effects across assessments and; (ii) to diagnose and map athlete sport concussion recovery using a longitudinal single case design. We hypothesised that (i) performance gains would be concentrated in the double baseline and; (ii) there would be post-injury cognitive deficits that resolved with time. Data from 16 healthy student athletes that completed all neuropsychological assessments revealed some practice between the first and second baseline, but fairly stable performance afterwards. A further 11 university contact sport athletes completed the two baselines, and of these one athlete returned for follow-up assessment following a suspected sport concussion. The single case data showed memory recall deficits at one week and executive function deficits at one to six weeks post-injury compared to the athlete's own second pre-injury baseline and the control group. The data suggest that (i) the second of two baselines might provide a better reference for longitudinal comparisons and; (ii) the new computerised neuropsychological test battery was sensitive to the acute and post-acute sport concussion effects and the tracking of recovery. The data are discussed in terms of their significance to the neuropsychological sport concussion assessment and the current conceptualisation of recovery.

5.2 Introduction

Chapter 4 of this thesis contrasted the neuropsychological test performance of self-reported sport-concussed and non-concussed contact sport players using a comprehensive neuropsychological test battery that we had compiled. We proposed that the addition of verbal memory recall and executive function tests would improve the neuropsychological assessment of late (i.e., at least three months post-injury) sport concussion effects. Our data supported our proposition in that self-reported sport-concussed athletes performed significantly worse on measures of memory recall and executive function shifting compared to the non-concussed athletes. We suggested that these behaviours might take longer to recover following a sport concussion. However, as these tests are rarely used in current clinical test batteries for sport concussion diagnosis, it remains to be shown whether these tests would also provide more sensitivity to the acute and post-acute neuropsychological assessment of sport concussion, and furthermore show the increased time for recovery. In Chapter 5, we present data from a longitudinal study that piloted a newly compiled computerised neuropsychological test battery that included memory recall and executive function tests in addition to the typical attention tests commonly used in the current computerised neuropsychological test batteries cited in the literature.

The general aim of sport concussion programmes is to safeguard athlete health. The common approach used in the current sport concussion management programmes has been already described in Chapter 4. This typically involves a longitudinal pre-injury (baseline) versus post-injury comparison approach and was first introduced by Barth, Alves, Ryan, Macciochi, Rimel, Jane and Nelson (1989). The approach has been promoted as the 'gold standard' ever since (Collins et al., 1999). Theoretically, the approach can be applied to all behaviours that might be influenced by sport concussion: subjective symptoms, cognitive function and postural control (McCrory et al., 2009), but practically, the literature has mainly described the application to the assessment of cognitive function.

The assessment of pre-injury compared to post-injury measures has methodological advantages. For example, it can provide better control over factors that may confound an athlete's test score, such as previous sport concussion (irrespective of whether diagnosed or recognised), learning difficulties, or any other factors (see Chapter 4 for a discussion). The assessment not only allows an estimate of whether and how the sustained or suspected sport concussion has affected cognitive function, but also the time frame taken for the athlete to return (or recover) back to baseline performance (Collins et al., 1999).

The assessment approach created by Barth et al. (1989) led to the development of computerised neuropsychological test batteries. Compared to paper-pencil neuropsychological tests, these computerised test batteries are typically self-administered and offer potentially indefinite parallel test versions with standardised instructions (i.e., as the trial selection within the tests is randomised). Because of these factors and automated test scoring, the associated financial costs and the time taken to carry out the tests are reduced (Collie et al., 2001). The most common tests used in the literature are the ImPACT (ImPACT Applications, Inc., Pittsburgh, PA, USA) and the CogState Sport (CogState, Ltd., Melbourne, Australia) test batteries. The ImPACT test is composed of six separate modules that measure different underlying neuropsychological functions (1: attentional processes and verbal memory recognition; 2: design memory, visual memory recognition and visual working memory; 3: visual working memory and visual processing speed; 4: visual processing speed, learning and memory; 5: choice-reaction time, impulse control and response inhibition; 6: working memory and visual-motor response speed; http://www.impacttest.com, last accessed on 5 July 2010). In the test, the individual's performance on all six modules is summarised into four composite scores (verbal memory composite, visual memory composite, reaction time composite, processing speed composite) that represent either response accuracy (verbal and visual memory composite) or response speed (reaction time composite, processing speed composite). The CogState Sport contains only four tests that measure different underlying neuropsychological functions (1: psychomotor function and speed of processing; 2: visual attention and vigilance; 3 and 4: visual learning and memory; http://www.cogstate.com, last accessed 5 July 2010). The performance indicators include one response speed and one response accuracy measure per test.

From the description of the main test batteries currently used in the literature, it is evident that the existing computerised neuropsychological test batteries vary notably in the number and type of tests they include and the neuropsychological functions that are measured. The common areas tested include different aspects of attention and memory recognition (Belanger & Vanderploeg, 2005). However, they do not provide a measure of memory recall. This might be due to the fact that memory recognition is easier to operationalise than memory recall (Michael W. Collins, PhD, ImPACT Applications, Inc., personal communication, April 2008). That is, the emphasis of the assessment is currently one of efficiency over that of finding effective diagnosis measures. It is important to note that the information that is gained through the assessment of memory recognition cannot be necessarily generalised to memory recall. Memory recognition may be related to memory free recall (Haist et al., 1992), but functional dissociations are known from the literature (Bastin et al., 2004; Yeates et al., 1995). Also, recognition may involve recollection, a familiarity-based decision or both (Vilberg & Rugg, 2007), and therefore suggest that recognition is easier than recall.

The current computerised test batteries also omit executive function tests. While the ImPACT test assessment contains the module 'Colour Match' that applies the test principle of the Stroop test (Stroop, 1935), measuring response inhibition and impulse control (Schatz, Pardini, Lovell, Collins & Podell, 2006), the derived composite score is not reported as an outcome measure (e.g., Iverson, Lovell & Collins, 2003). Instead, the composite score has been used to *exclude* athletes from statistical data analysis. High values on this composite score have been interpreted as indicative of poor effort and lacking engagement with the test (Iverson et al., 2003) (nb. an alternative interpretation would be that the score indicates performance deficits in executive function inhibition). The omission of executive function tests might be due to the fact that some tests show strong practice effects (e.g., the Wisconsin Card Sorting Test WCST; Grant & Berg, 1993) (Beglinger et al., 2005). The omission however is still surprising as executive function cognition relies to a large extent on the frontal lobes and interconnections between cortical networks that, in turn, might be considered particularly susceptible to the biomechanical forces of a brain trauma (Heilman & Valenstein, 2003). Intact executive functions have also been shown to be important for other cognitive domains, such as visual and verbal memory (Busch, Booth, McBride, Vanderploeg, Curtiss & Duchnick, 2005; Tremont, Halpert, Javorsky & Stern, 2000). Therefore, without executive function tests, no behavioural measure of complex cognition (Miyake et al., 2000) is currently assessed.

Another limitation of the current test batteries concerns the comparison between the pre-injury (baseline) versus post-injury comparison approach (Barth et al., 1989). The method necessitates a valid pre-injury (baseline) measure than can serve as the reference point against which post-injury measures are contrasted. Baseline measures may be derived from a singular or double assessment at the beginning of the play season (Faletti, Maruff, Collie & Darby, 2006; Hinton-Bayre, Geffen, Geffen, McFarland & Frijs, 1999).

The literature has described mainly singular pre-injury assessments (Belanger & Vanderploeg, 2005), but it might be argued that this is not sufficient. For example, it has been found that most practice occurs between the first and second assessment of cognitive tests (Faletti et al., 2006; Hinton-Bayre et al., 1999). Therefore, following a sport concussion, performance gains due to practice may mask (at least partially) post-injury performance decline (i.e., appearing to show recovery, but in fact showing improved performance through practice). From this, it appears that a double baseline assessment would be more appropriate, and that the second of the two baseline assessments might act as the better valid measure to use than that of a singular baseline.

Related to the last point, pre-injury (baseline) measures can also be distorted by differences in motivation (Bailey et al., 2006; Echemendia & Julian, 2001; Echemendia & Cantu, 2003). For example, athletes who participate in sport concussion programmes would be aware that their post-injury performance would aid the return-to-play decision-making process. That is, the athlete would know that the post-injury performance needs to reach or better exceed pre-injury (baseline) measures to yield medical clearance. Therefore, an athlete might decide to intentionally perform at a suboptimal level at the pre-injury assessment in order to allow for any small reduced cognitive performance following injury. From our experience, athletes seem to place more emphasis on competing in sport than their long-term health. By intentionally reducing cognitive performance in the pre-injury baseline, the contrast between pre-injury and post-injury performance would become invalid.

An alternative approach might be to compare a sport-concussed athlete's (post-injury) measures to those derived from uninjured athletes who underwent a comparable repeat assessment scheme. This approach might reduce the confound moderator variable of motivation and provide a more detailed picture on how sport concussion influences cognitive function independent of practice.

The present study piloted a new computerised neuropsychological test battery that comprised tests of attention, verbal memory recall and executive function. There were two parts to the study. The first involved the creation and testing of appropriate control group measures (i.e., multiple baselines). The second part of the study tested a single case participant in a pre-injury compared to post-injury design and in comparison to the control group. In Part 1, the aim was to examine whether there were performance gains between a first and second baseline (i.e., a practice effect) and whether control group performance was stable from Baseline 2 in three further assessments that would normally constitute post-concussion tests 2, 3 and 4. In Part 2, the aim was to determine whether any impairment could be detected in a single case recently sport-concussed athlete, and whether the deficits would recover. Critically, post-injury performance was compared to the athlete's own second pre-injury baseline and also to the control group baselines.

The Method, Results and Discussion sections for Part 1 and 2 are presented separately. The final section of this chapter will discuss the findings from both parts of the study.

5.3 Part 1: Control group multiple baseline measures

5.3.1 Method

5.3.1.1 Participants

The study tested 16 university athletes aged 18 to 20 (M=19.13, SD=0.62, 95% CI [18.80, 19.45]; 62.5% female) that responded to study announcements (i.e., posters and postcards) placed with university sport teams (netball, English football, American football, ice hockey, lacrosse, rugby union, rugby league) and across the university campus. Exclusion criteria were a history of brain injury, neurological disorder and learning difficulty. No participant admitted to smoke tobacco, take neuroactive medication or have consumed any illicit substance in the four weeks prior to testing.

The local university ethics committee approved the study in accordance with the 1964 Declaration of Helsinki. All participants provided informed written consent.

5.3.1.2 Material and procedure

The study contained three elements: (i) a semi-structured interview; (ii) a set of established questionnaires and; (iii) the computerised neuropsychological test battery. The semi-structured interview assessed basic demographics and sport participation. We screened each participant for brain injury history, diagnosed learning difficulties, neurological disorders, tobacco smoking as well as current medication, alcohol and illicit drug consumption four weeks prior to testing (Appendix C).

In the questionnaire assessment, three established questionnaires were used. These were the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983), the Post Concussion Symptom Scale (PCSS; adapted from McCrory, Johnston, Aubry, Cantu, Dvorak, Graf-Baumann, Kelly, Lovell & Schamasch, 2005) and a pain analogue rating scale (McDowell & Newell, 1996) (Appendix B). Table 5.1 presents an overview over the questionnaires and derived dependent variables. The following three paragraphs describe each questionnaire in the order that they were completed by the participant.

Table 5.1: Derived dependent variables for each questionnaire

Psychological questionnaire		Derived DV
Post Concussion Symptom Scale	subscale symptom frequency	sum score (/96)
	subscale symptom intensity	sum score (/96)
	subscale symptom duration	sum score (/96)
Hospital Anxiety and Depression Scale	subscale anxiety	sum score (/21)
	subscale depression	sum score (/21)
pain rating scale		score (/10)

Abbreviations: DV − dependent variable

The Post Concussion Symptom Scale PCSS (adapted from McCrory et al., 2005) measured symptom self-report within the past 24 hours. It listed 24 symptoms. Each symptom was rated for frequency, intensity and duration on a five-point scale (frequency: not at all, seldom, often, very often, all the time; intensity: not at all, vaguely present, clearly present, interfering, disabling; duration: not at all, a few seconds, a few minutes, a few hours, constant). Each symptom rating was numerically scored (0 to 4), whereby a higher number represented a higher frequency, intensity or duration. Composite scores were calculated by summing all symptom scores for frequency, intensity and duration separately (maximum: 96 each; a higher score corresponded to a more severe clinical manifestation). The three composite scores served as the dependent variables.

The Hospital Anxiety and Depression Scale HADS (Zigmond & Snaith, 1983) is a widely used self-report measure of anxiety and depression and consists of 14 statements (seven statements each measure anxiety and depression). Each statement comes with four response options, and participants were asked to choose one response from four. We followed the standard scoring instructions. Each statement rating was transformed into a score between 0 and 3. A higher composite score represented a greater severity. All anxiety statement scores were summed into an anxiety composite score (maximum: 21), and all seven depression statement scores were summed into a depression composite (maximum: 21). A higher composite corresponded to a more severe clinical manifestation. Both composite scores served as the dependent variables.

Pain experienced in the past week was measured with a analogue rating scale (McDowell

& Newell, 1996). The scale ranged from 0 ('no pain') to 10 ('pain as bad as you can imagine') with a higher score representing a more severe pain experience. The participant circled the number that best represented the pain experienced in the week prior to testing. The number served as the dependent variable.

The computerised neuropsychological test battery consisted of five cognitive tasks that assessed verbal memory recall, attention and executive functioning. The battery is described in the following five paragraphs (see Table 5.2 for an overview of the tests and derived dependent variables).

Table 5.2: Dependent variables for each neuropsychological test

Neuropsychological test		Derived dependent variable
Verbal memory	Story	immediate free recall (/20) delayed free recall (/20)
Attention	Simple Reaction Time	mean reaction time (ms)
Executive function		
Updating	2-back Task	mean reaction time (ms) correct response (/12) false positive response
Inhibition	Stop-Signal Task	mean reaction time (ms) correct response (/29) false response
Shifting	Number-Letter Task	shift trials mean reaction time (ms) shift costs (ms) shift trials correct response (/71) shift trials false response

Verbal memory was assessed using a series of short stories consisting of approximately 250 words (adapted from Jansari, Davis & Kapur, 2004). There were ten possible stories, and only one was used in each assessment. These were selected in a random order for each participant. The stories were presented over headphones. The task involved remembering the story's details, and was measured using immediate and delayed recall. Immediately after the story was presented, the participant was asked to recall as much detailed information as possible about the story. Delayed recall was tested approximately 20 minutes after the initial presentation. The participant was not informed that a delayed assessment would occur later in the assessment. The experimenter used story-specific scoring sheets to record the participant's recall performance. The dependent measures were the number of details correctly recalled (maximum: 20 each).

For the assessment of attention, we used a Simple Reaction Time task (adapted from Sosnoff, Broglio, Hillman & Ferrara, 2007). Participants were asked to fixate on a black dot that was presented in the centre of the screen. At a random interval, the dot was replaced by a target cross (i.e., "+") that appeared at the same position. The participant was required to make a response to the target as fast as possible by pressing a button on the button box. The task started with a short practice and was followed by the recorded test. The target was displayed for a maximum duration of 5000ms, though once a response was recorded, the target was removed. The dependent measure was the mean reaction time (ms) for correct response trials.

To measure executive function, three tasks were used. These were the 2-back Task (adapted from Harvey, Le Bastard, Levy, Allilaire, Duboi & Fossati, 2004), the Stop-Signal Task (adapted from Miyake et al., 2000; Verbruggen, Logan & Stevens, 2008) and the Number-Letter Task (adapted from Rogers & Monsell, 1995; Miyake et al., 2000). The 2-back Task (adapted from Harvey et al., 2004) measured executive function updating. A series of 12 different, yet phonetically similar stimuli (b, B, d, D, g, G, p, P, t, T, v, V) was presented in a pseudo-random order in the centre of the screen. Each stimuli was presented for 500ms following by a blank screen interval for 500ms. Participants were required to decide by button press whether a letter at a given moment was the same as the letter presented two items before. Participants were instructed to ignore the case of the letter. The task consisted of a short practice followed by the sequential presentation of 96 visual items, of which 12 were 2-back matched. The dependent measures were the mean reaction time for correct response trials (ms), the number of correct (maximum: 12) and false positive (error) responses.

To assess the executive function inhibition, we used a simplified Stop-Signal Task (adapted from Miyake et al., 2000; Verbruggen et al., 2008). It consisted of two parts. In the first part, participants performed a visual discrimination task. A fixation cross (200ms) was replaced by one of two types of stimuli and required an item-specific button press by the participant. Each stimulus was presented for 1250ms, or until the participant's response was recorded. In the second part, the same visual discrimination task was run. However, this time if a 'stop signal' (a computer-emitted tone; 750 Hz, for 75ms) sounded, the participant had to inhibit the response for the particular target and continue with the next item on the screen. A short practice preceded 72 trials, whereby one-third of the trials had a 'stop signal'. The test measured the ability to inhibit a planned response. Therefore, the interval between visual target and stop-signal was computed by subtracting 225ms from the mean reaction time of the first part of the task. The dependent measures were the number of correct responses to non-stop trials (maximum: 29), the number of false responses and the mean reaction time for correct response trials (ms).

The executive function shifting was measured using the Number-Letter Task (adapted from Rogers & Monsell, 1995; Miyake et al., 2000) A number-letter pair (e.g., 1F) was presented in one of the four quadrants of the computer screen. If the pair appeared in one of the top quadrants, the participant was asked to indicate by button press whether the number was odd or even. If the pair was presented in one of the bottom quadrants, the participants indicated by button press whether the letter was a vowel or consonant (matched in number of stimuli items). The test consisted of three practice and recorded trial blocks. In the first trial block, paired stimuli only appeared at the top of the screen, and in the second trial block, paired stimuli only appeared at the bottom of the screen. In each of these two trial blocks, 5 practice and 18 recorded paired stimuli trials were presented. In the third trial block, practice trials were followed by 72 trials whereby the presentation started in the top left quadrant and rotated clockwise around all four quadrants. Each stimuli was presented for a maximum of 5000ms, or until the participant responded. A blank screen interval of 150 ms followed each stimulus. Dependent measures were derived from the third trial block. These were the reaction time for correct response trials (ms), the number of correct responses (maximum: 71; the first participant response was excluded), the number of false (error) responses, and the switch costs (ms) (calculated by subtracting non-shift trial reaction times: top left to top right or bottom right to bottom left; from shift-trial reaction times: top right to bottom right, bottom left to top left).

The tests were presented on a Apple MacBook computer using PsyScope software (Cohen, MacWhinney, Flatt & Provost, 1993). Participant response was recorded with an iolab Systems button box (Figure 5.1).

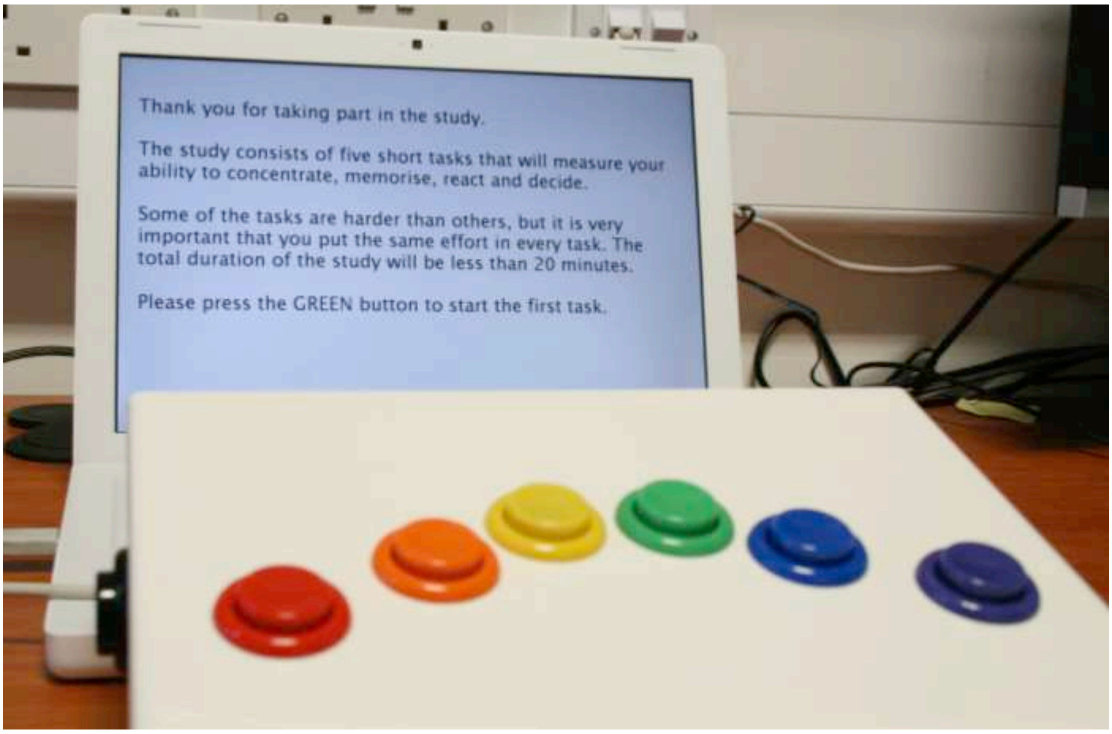


FIGURE 5.1: Experimental set-up.

There were two baseline measures, and all participants completed them. Baseline 2 took place one day after the Baseline 1 assessment. Participants returned for four additional baseline assessments (i.e., post-baseline measures Post 1 to Post 4). The interval between Baseline 2 and the Post 1 assessment was standardised to one week. The remaining three follow-ups were scheduled for one week, two weeks and six weeks following the Post 1 assessment (see Table 5.3). The semi-structured interview at Baseline 1 covered basic demographics, sport participation, history of head and brain injury, learning disabilities, tobacco smoking, alcohol and illicit drug consumption plus current medication (the latter four variables were assessed using a modified Alcohol Use Disorder Identification Test AUDIT; Saunders et al., 1993). At all follow-up assessments, demographics and sport-related detail were skipped, and the experimenter only inquired details of illicit drug use, medication and changes in tobacco smoking or alcohol consumption habits. As already presented, these data details were used for exclusion criteria and confound moderator control only.

TABLE 5.3: Testing scheme for the control group athletes

Assessment	Day 0	Day 1	1 week	2 weeks	3 weeks	7 weeks
	Baseline 1	Baseline 2	Post 1	Post 2	Post 3	Post 4
Measures	HADS PCSS pain CNTB	PCSS CNTB	HADS PCSS pain	HADS PCSS pain CNTB	HADS PCSS pain CNTB	HADS PCSS pain CNTB

Abbreviations: HADS – Hospital Anxiety and Depression Scale, PCSS – Post Concussion Symptoms Scale, CNTB – computerised neuropsychological test battery

In the next part of the assessment session, the participant was asked to complete the questionnaires. These were the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983), Post Concussion Symptom Scale (PCSS; adapted from McCrory et al., 2005) and the pain rating scale (McDowell & Newell, 1996). At the Baseline 2, each participant only completed the Post Concussion Symptom Scale. Both the Hospital Anxiety and Depression Scale and the pain rating scale were not repeated, as these questionnaires asked the participant to relate to the past week prior to testing.

After the interview and the questionnaire pack, the participant was introduced to the computerised neuropsychological test battery and the response button box. The experimenter informed the participant that task instructions would appear on the screen and that it was very important to read them carefully. Then, the participant was familiarised with the button box. The experimenter explained which buttons would be used throughout the battery assessment and that irrelevant buttons were deactivated. The participant was instructed to take breaks as needed. Each cognitive assessment started and ended with the verbal memory task. This allowed a maximised time interval between the immediate and delayed recall. The remaining three tasks were randomised between individuals and assessments. Each task began with the task instruction that was presented on the screen. The task was introduced, and the participant was instructed with which buttons to respond. Except for the verbal memory task, a practice run preceded the test run. Note that participants did not perform any cognitive tasks at the Post 1 assessment (one week following Baseline 2; see Table 5.3). At the end of the cognitive assessments, the participant was thanked and, if applicable, the next assessment was scheduled. Each assessment (i.e., interview, questionnaire pack and computerised neuropsychological test battery) took less than 30 minutes to complete.

5.3.1.3 Data analysis

The independent variable was assessment (i.e., consisting of Baseline 1, Baseline 2, Post 1, Post 2, Post 3, Post 4) depending upon the dependent measure tested (see Table 5.3). SPSS (SPSS, 2009) was used for data analysis. The significance level p was set to .05. To test performance differences across assessments, we used repeated-measures ANOVAs. Given a normal distribution of the dependent variables, one parametric test was used for each task or questionnaire. If the test assumption of sphericity was violated, we applied the Greenhouse-Geisser correction. Planned contrasts compared Baseline 1 and Baseline 2 (i.e., immediate practice), Baseline 2 and Post 1, Post 1 and Post 2, Post 2 and Post 3, and Post 3 and Post 4 (i.e., further practice). Given a non-normal distribution of the dependent variables, one non-parametric Friedman ANOVA was used per dependent variable. A significant Friedman ANOVA was followed-up using Bonferroni-corrected pairwise Wilcoxon signed rank tests (i.e., the planned contrasts). The effect size r[1] was calculated for any significant pairwise comparisons.

[1] $r = \frac{z}{\sqrt{N}}$

5.3.1.4 Results

Results are first presented for the questionnaires followed by the neuropsychological tests (ordered by the cognitive domains verbal memory, attention and executive function). Descriptives for all dependent variables are presented in Table 5.4.

Table 5.4: Means and standard deviations for all dependent variables

Test	Assessment					
	Baseline 1	Baseline 2	Post 1	Post 2	Post 3	Post 4
Post Concussion Symptom Scale						
frequency	9.19 (5.41)	4.94 (3.62)	6.19 (7.31)	6.06 (5.34)	4.69 (2.83)	4.81 (4.78)
intensity	10.50 (7.40)	5.94 (4.64)	7.06 (8.13)	7.56 (6.67)	5.50 (4.31)	5.69 (5.52)
duration	13.69 (9.24)	7.69 (6.05)	8.13 (8.26)	9.75 (9.48)	6.81 (5.61)	7.12 (6.82)
Hospital Anxiety and Depression Scale						
anxiety	3.06 (2.21)		3.63 (3.69)	2.75 (2.15)	2.13 (2.17)	2.31 (2.44)
depression	2.69 (2.15)		3.56 (2.76)	3.19 (2.79)	3.06 (2.74)	2.63 (2.28)
Pain rating scale						
pain rating	2.50 (1.90)		2.63 (2.16)	2.19 (2.23)	2.00 (1.63)	1.94 (1.69)
Story						
immediate recall	10.53 (3.84)	12.13 (2.73)		13.41 (2.32)	14.40 (2.32)	13.03 (3.50)
delayed recall	9.97 (3.75)	11.91 (3.26)		12.72 (2.31)	13.37 (2.66)	12.63 (4.19)
Simple Reaction time						
mean RT	247.24 (25.43)	241.25 (38.68)		249.73 (34.75)	259.94 (40.43)	264.79 (31.99)
2-back Task						
mean RT	464.85 (78.71)	482.80 (75.84)		466.60 (84.16)	447.47 (89.69)	484.19 (104.39)
correct response	6.81 (2.64)	6.75 (2.49)		6.79 (2.99)	7.31 (3.63)	6.88 (3.32)
false response	10.13 (6.94)	6.56 (5.02)		4.43 (5.87)	4.13 (4.80)	3.25 (4.19)
Stop-Signal Task						
mean RT	445.83 (51.02)	427.39 (86.26)		421.42 (78.60)	420.24 (75.89)	414.42 (75.03)
correct response	28.38 (0.81)	28.56 (0.63)		28.69 (0.48)	28.27 (0.80)	27.75 (1.13)
false response	2.00 (0.73)	1.63 (0.96)		1.15 (0.80)	1.60 (1.24)	2.25 (1.34)
Number-Letter Task						
mean RT	1332.14 (230.64)	1106.07 (210.76)		1011.57 (184.69)	917.69 (199.40)	884.23 (178.73)
shift cost	421.21 (204.91)	326.83 (185.17)		284.14 (199.40)	264.38 (139.91)	217.54 (177.12)
correct response	31.81 (3.62)	32.50 (2.03)		33.00 (1.80)	33.75 (1.13)	33.75 (0.86)
false response	3.13 (3.61)	2.50 (2.03)		2.50 (1.80)	1.25 (1.13)	1.25 (0.56)

Abbreviations: RT − reaction time

Questionnaires

Analysis of the Post Concussion Symptom Scale, Hospital Anxiety and Depression Scale and pain rating scale was carried out using repeated-measures Friedman ANOVA and post-hoc Bonferroni-corrected Wilcoxon tests. Analysis of the Post Concussion Symptom Scale showed significant differences across assessments for all dependent variables (frequency: $\chi^2(5)=24.18$, $p<.001$; intensity: $\chi^2(5)=21.58$, $p<.01$ and; duration: $\chi^2(5)=23.62$, $p<.001$). Planned post-hoc analyses only revealed a significant contrast for Baseline 1 and 2 for all dependent variables (frequency: T=2.00, r=-.81; intensity: T=21.00, r=-.61; and duration: T=5.00, r=-.81) indicating decreased symptom reports. Analysis of the Hospital Anxiety Depression Scale showed a significant effect across assessment for anxiety, $\chi^2(4)=11.22$, $p<.05$, but not for depression, $\chi^2(4)=3.15$, p=.53. The planned contrast analyses however revealed no differences for anxiety. Analysis of the pain analogue scale rating showed no difference across assessments, $\chi^2(4)=4.24$, p=.37.

Verbal memory

A repeated-measures ANOVA showed that both memory recall measures differed significantly across assessments (immediate recall: F[5, 56]=4.69, $p<.001$; delayed recall: F[4, 56]=2.69, $p<.05$). The planned contrasts revealed a significant performance difference for the immediate free recall between Baseline 2 and Post 2 only, F[1, 14]=4.68, r=.50, indicating improved immediate memory recall.

Attention

The repeated-measures ANOVA for the dependent variable mean Simple Reaction Time showed no performance differences across assessments, F[4, 52]=1.22, p=.31.

Executive function

Analysis of updating and inhibition executive function tasks used repeated-measures Friedman ANOVA and Bonferroni-corrected Wilcoxon tests for the planned contrasts. Analysis of executive function updating (i.e., the 2-back Task) mean reaction time and correct response showed no performance differences across assessments (mean reaction time: $\chi^2(4)$=2.13, p=.71; correct response: $\chi^2(4)$=2.97, p=.56). However, analysis of false positive (error) responses revealed significant differences, $\chi^2(4)$=24.08, p<.001, whereby there was a significant performance gain between Baseline 1 and Baseline 2 only, T=15.00, r=-.60, indicating that the false positive (error) response significantly decreased.

Analysis of executive function inhibition (i.e., the Stop-Signal Task) mean reaction time and correct response also showed no performance difference across assessments (mean reaction time: $\chi^2(4)$=3.73, p=.44; correct response: $\chi^2(4)$=5.96, p=.20). However, analysis of mean false errors revealed performance differences across assessments, $\chi^2(4)$=9.74, p<.05, though in the post-hoc analyses, there were no significant performance differences for the planned contrasts.

Analysis of executive function shifting (i.e., the Number-Letter Task) used both repeated-measures ANOVA and repeated-measures Friedman ANOVA. The repeated-measures ANOVA for correct response mean reaction time and shift cost showed significant differences across assessments (correct response mean reaction time: $F[4, 52]=29.16$, $p<.001$; shift cost: $F[4, 52]=3.88$, $p<.01$). For mean reaction time, planned contrasts revealed significant performance gains between Baseline 1 and Baseline 2, $F[1, 13]=14.61$, $r=-.73$, and Baseline 2 and Post 2, $F[1, 13]=5.65$, $r=-.55$. For shift cost, planned contrasts did not show significant differences. The repeated-measures Friedman ANOVA for correct response and false (errors) response revealed significant differences across assessments (correct response: $\chi^2(4)=12.87$, $p<.05$; false (error) response: $\chi^2(4)=12.87$, $p<.05$), though in Bonferroni-corrected post-hoc Wilcoxon tests, there were no significant performance differences for the planned contrasts.

5.3.1.5 Discussion

In the longitudinal study presented here, we piloted a newly compiled neuropsychological computerised test battery in a sample of healthy (i.e., self-reported non-concussed) university athletes. We hypothesised to find symptom self-report decrease in questionnaires and performance gains in neuropsychological measures between the Baseline 1 and 2, but not consecutive assessments. Our data provided partial support for this.

In the analysis of the Post Concussion Symptom Scale, participant response behaviour showed the expected hypothesis. Symptom frequency, intensity and duration self-reports significantly reduced between the first and the second baseline, but showed stable response behaviour afterwards. However, on the Hospital Anxiety and Depression Scale and the pain rating scale, there were no differences across assessments, suggesting that athletes showed no changes in response for these latter measures.

Previous research has reported that the more often the questionnaires are administered, the less symptoms are self-reported (Broglio & Pütz, 2008; Guskiewicz et al., 2003). Our data do not support this relationship. The symptom self-report in all of the measures here stabilised after the second questionnaire administration. Only analysis of the Post Concussion Symptom Scale showed reduced symptom report between Baseline 1 and 2, somewhat supporting Broglio and Pütz (2008) and Guskiewicz et al. (2003). One possible explanation for the apparent differential effect of assessment frequency might involve the difficulty with which the questionnaire can be completed. For example, the Post Concussion Symptom Scale lists single- or double-word symptoms that need to be rated for their frequency, intensity and duration, but the Hospital Anxiety and Depression Scale lists more comprehensive statements that need to be rated for their validness. Therefore, it is possible that it might be easier for participants to rate symptoms than statements. Furthermore, the Hospital Anxiety and Depression Scale may constitute a questionnaire that measures both states (i.e., constructs that may vary considerably) and traits (that are comparatively stable) (Dobson, 1985), whereas the Post Concussion Symptom Scale might measure just states. Therefore, flexibility in responses may vary more in the Post Concussion Symptom Scale than the Hospital Anxiety and Depression Scale. From these findings, the questionnaire data suggest that symptom baseline measures that are derived from a singular baseline might overestimate the pre-injury (baseline) symptom rate, and instead suggest that the second of two baselines might constitute a more valid reference for the post-injury assessment comparison.

The data from the computerised neuropsychological tests mostly showed stable performance across the assessments (i.e., there was no evidence of practice). The only measures that showed an immediate practice effect between Baseline 1 and 2 were the dependent variables of executive function updating (i.e., the 2-back Task) false positive (error) response and executive function shifting (i.e., the Number-Letter Task) mean reaction time. In addition, practice effects were also found between Baseline 2 and Post 2 for verbal memory immediate free recall and executive function shifting mean reaction time. This suggests that measures considering a sport-concussed athlete in a longitudinal pre-injury (baseline) versus post-injury comparison would benefit from additional comparison to a control group in order to control for any practice effects on the tasks. Here, the dependent measures of executive updating (i.e., the 2-back Task) false positive error, verbal memory immediate free recall and executive function shifting (i.e., the Number-Letter Task) mean reaction time might falsely be attributed with incorrectly assuming a non-concussion diagnosis or falsely believing that the athlete recovered.

5.4 Part 2: Single case study

Part 1 of this chapter presented data from a longitudinal study that piloted a newly compiled computerised neuropsychological test battery involving tests of memory, attention and executive function in healthy (self-reported non-concussed) athletes. In Part 2, we present data from a single case athlete with a suspected sport concussion. The same assessment as that in Part 1 was used in order to diagnose the suspected sport concussion and also to map recovery.

5.4.1 Method

5.4.1.1 Participants

For the second part of the study, we recruited eleven active university contact and collision sport athletes aged 18 to 25 (M=22.00, SD=2.15, 95% CI [20.56, 23.44]; 36.4% female). The exclusion criterion was a history of learning difficulties. No participant admitted to smoke tobacco, take neurologically active medication, or have consumed illicit substances in the four weeks prior to testing. From the sample, we present data from the case of a 23-year old female lacrosse and field hockey player. The athlete has competitively participated in her main sport lacrosse for about eight years with an average of four hours sport participation a week. The abbreviated Alcohol Use Disorder Identification Test (AUDIT; Saunders et al., 1993) did not suggest hazardous levels of alcohol consumption.

She disclosed the occasional use of asthma inhalers. The athlete self-reported one previous head/brain injury that was sustained in sport more than 12 months prior to testing. The participant's highest educational attainment was a B.Sc. At the time of the study, she attended a postgraduate training program at university.

The local university ethics committee approved the study in accordance with the 1964 Declaration of Helsinki. All participants provided informed written consent.

5.4.1.2 Material and procedures

The material used and the assessment schedule were the same as those used in Part 1 (see Table 5.3). As in Part 1, there were two baseline measures (Baseline 1, Baseline 2). All eleven athletes completed them, but only athletes who sustained a sport concussion participated in the four follow-up assessments (i.e., Post 1 to Post 4). Therefore, at Baseline 2, all 11 participants were instructed on what may constitute a sport concussion (Pocket SCAT 2; McCrory et al., 2009) and that they would need to contact the experimenter in the case of a suspected or diagnosed sport concussion. Participants were also provided with the questionnaire pack and instructed that in the event of a sport concussion, they would need to complete it on the day of the injury. In the event of a sport concussion, the experimenter would schedule three more follow-up assessments of recovery at one, two and six weeks post-concussion (Post 2 to 4). The rest of the procedure for Part 2 was the same as that for Part 1 (see 5.3.1.2).

In the single case study, the athlete suspected having sustained a sport concussion 45 days after completion of both baselines. The injury happened while attending a field hockey evening training session. At the athlete's account, a hockey ball bounced off the stick and hit her face just above the left brow. The injury did not result in any loss of consciousness. The athlete described a brief episode of post-traumatic amnesia, though the length could not be estimated in retrospect. The impact itself led to a superficial wound with bleeding for which the athlete was admitted to Accident and Emergency services for medical treatment. At her account, the medical staff attended exclusively to the bleeding wound, but did not assess her for a sustained brain injury. She was discharged following wound treatment. The injured athlete contacted the experimenter the day after the injury. She rejected the idea of having sustained a sport concussion, but was unsure of her self non-diagnosis. No subjective symptoms other than bleeding and bruising were stated on the day of the injury (Post 1) or at any later assessments. During the cognitive testing at one and two weeks post-injury (Post 2 and 3), the athlete admitted having problems performing the tests to her usual standards. She described watching herself making errors despite knowing how to succeed in the task. No follow-up medical treatments were sought, and the athlete returned to sport practice and competition three days post-concussion.

5.4.1.3 Data analysis

The independent variable was assessment (i.e., consisting of Baseline 2, Post 1, Post 2, Post 3, Post 4) depending upon the dependent measure tested (see Table 5.3). There were two separate analyses of the data. Based on the findings from Part 1 of this chapter, the first analysis compared the injured individual's post-injury scores to her own second pre-injury Baseline 2 using Reliable Change Indices (RCI). The RCI[2] calculation was carried out using a spreadsheet and followed the same method as that used by Chelune, Naugle, Lüders, Sedlak and Awad (1993) and Iverson et al. (2003). The RCI analyses provided a benchmark of significant change between a retest and a baseline score while accommodating for practice effects. A RCI of ±1.03 is considered borderline (p<.30; Erlanger, Saliba, Barth, Almquist, Webright & Freeman, 2001), and a RCI of greater than ±1.28, ±1.65 and ±1.96 indicates a significant change with p<.20, p<.10 and p<.05 respectively. Considering the health risks that have been suggested for repeat sport concussion in close proximity (i.e., the athlete's brain is re-injured before the first injury has resolved; McCrory, 1998), a conservative approach is recommended by which a RCI of ±1.28 (which equals p<.20) serves as the minimum criterion for diagnosing the injury (Collie, 2004; Erlanger et al., 2001).

The second analysis compared the individual's score to the control group using a modified Silverstein method for multiple neuropsychological tests (Crawford & Garthwaite, 2002). Data analysis was carried out by means of the freely available software 'PROFLIMS.EXE'

[2] $RCI = \frac{(X_2 - X_1) - (\mu_2 - \mu_1)}{SE_{diff}}$

with $SE_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$ and $SEM_1 = SD_1(1 - \sqrt{r_{12}})$, $SEM_2 = SD_2(1 - \sqrt{r_{12}})$

whereby $X_1 -$ baseline score, $X_2 -$ retest score, $\mu_1 -$ control group baseline mean; $\mu_2 -$ control group retest mean, $SE_{diff} -$ standard error of the difference, SEM − standard error of measurement, $SD_1 -$ standard deviation of control group baseline mean, $SD_2 -$ standard deviation of control group retest mean by Crawford and Garthwaite (2002). The method first standardised individual test scores into z scores. Then, the mean of all z scores was calculated, and each individual z score contrasted to the z score mean. The derived t score for the discrepancy was used to test the significance. The one-tailed significance was multiplied by 100 providing a point estimate (in %) and a 95% confidence limit of discrepancy compared to the control group. For example, a point estimate of 5% indicated that less than 5% of the population were estimated to have a lower discrepancy between individual and mean z score. Contrasts were run between each assessment (Baseline 2, Post 1, Post 2, Post 3, Post 4 dependent on the variable tested).

5.4.1.4 Results

Results are first presented for the questionnaires followed by the neuropsychological tests (ordered by the cognitive domains verbal memory, attention and executive function). For each, we will present results on the pre-injury baseline versus post-injury comparison followed by the individual versus control group comparison.

Questionnaires

Analysis of the Post Concussion Symptom Scale PCSS showed that compared to Baseline 2, symptom frequency, intensity and duration were significantly greater on the day of the injury (Post 1), and then appeared to follow separate recovery curves. The symptom frequency remained elevated at one week post-injury (Post 2), but then returned to the

Baseline 2 level for the post-injury assessments 3 and 4. The symptom intensity remained significantly greater at one and two weeks post-concussion (Post 2 and 3) than at Baseline 2, but returned to Baseline 2 at six weeks post-injury (Post 4). Finally, the symptom duration returned to Baseline 2 at two weeks post-injury (Post 2) (Table 5.5).

Table 5.5: Reliable Change Indices for the questionnaires

Dependent measure		Baseline 2 versus			
		Post 1	Post 2	Post 3	Post 4
Post Concussion Symptom Scale	Frequency	6.49∗	1.32‡	-0.46	-2.09∗
	Intensity	4.24∗	2.27∗	2.63∗	0.11
	Duration	4.67∗	-1.39‡	-1.90†	-4.44∗
Hospital Anxiety and Depression Scale	Anxiety	-1.35‡	1.40‡	-0.68	-2.42∗
	Depression	1.60‡	4.40∗	2.59∗	0.05
Pain rating scale	Pain rating	-0.67	-0.45	-1.65†	-1.63‡

∗ $p<.05$, † $p<.10$, ‡ $p<.20$

Comparison between the individual and control group for all questionnaire baseline measures did not reveal any significant differences (nb. the critical t value for df=15 and one-tailed p=.05 was 1.75). However, post-concussion comparisons with the control group showed significant t score discrepancies. For the Post Concussion Symptom Scale PCSS, symptom frequency and duration were significantly greater than that of the control group on the day of the injury (Post 1), but returned to the control group baseline for the other post-concussion assessments (Post 2 to 4) (Table 5.6).

Table 5.6: Z scores, point estimates and confidence limits for the questionnaire ratings of the individual compared to healthy controls

Assessment	Measure								
	PCSS frequency			PCSS intensity			PCSS duration		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	1.95	1.12	85.96 [69.27, 96.25]	0.66	-1.63	6.21 [0.74, 18.50]	2.03	1.24	88.23 [72.45, 97.31]
Post 1	4.51	3.40	99.98 [99.83, 100.00]	1.92	0.07	52.68 [33.68, 71.23]	3.25	4.10	99.95 [99.59, 100.00]
Post 2	1.86	0.23	58.82 [39.47, 76.64]	1.26	-1.04	15.70 [4.62, 32.92]	0.87	1.70	5.45 [0.56, 17.02]
Post 3	1.65	0.71	75.63 [56.73, 89.96]	1.74	1.08	85.21 [68.27, 95.86]	1.46	0.23	58.75 [39.41, 76.58]
Post 4	0.67	0.47	67.67 [48.25, 83.99]	0.60	0.37	64.23 [44.77, 81.20]	0.28	-0.44	33.30 [16.78, 52.74]

Assessment	Measure								
	HADS anxiety			HADS depression			pain scale		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	2.24	0.63	73.23 [54.10, 88.24]	1.07	-0.60	27.72 [12.46, 46.92]	0.79	-1.35	9.79 [1.88, 24.59]
Post 1	0.64	-1.14	13.57 [3.52, 30.08]	1.97	0.25	59.56 [40.19, 77.28]	0.17	-4.10	0.05 [0.00, 0.41]
Post 2	3.38	1.46	91.74 [77.89, 98.67]	2.80	1.55	92.86 [79.80, 99.01]	0.36	-1.84	4.28 [0.33, 14.59]
Post 3	1.79	0.32	62.42 [42.98, 79.71]	2.16	1.79	95.34 [84.59, 99.60]	-0.61	-4.63	0.02 [0.00, 0.13]
Post 4	0.69	0.20	57.90 [38.60, 75.85]	1.04	0.90	80.89 [62.82, 93.42]	-0.56	-1.41	8.92 [1.56, 23.20]

Abbreviations: PCSS – Post Concussion Symptom Scale, HADS – Hospital Anxiety and Depression Scale, CL – confidence limit

Analysis of the Hospital Anxiety and Depression Scale HADS showed that compared to Baseline 2, anxiety symptoms were reduced on the injury day (Post 1), elevated at one week post-injury (Post 2), and then returned to Baseline 2 at two and six weeks post-injury (Post 3 and 4). In contrast, depression symptoms were elevated on the injury day (Post 1) and at one and two weeks post-injury (Post 2 and 3) compared to Baseline 2, but returned to Baseline 2 at six weeks post-injury (Post 4) (Table 5.5).

For the Hospital Anxiety and Depression Scale HADS, the only significant difference between the individual and the control group was for depression symptoms which were greater for the individual than the control group at two weeks post-concussion (Post 3). For the remaining assessments, there were no significant differences (Table 5.5).

Analysis of the pain rating scale in the individual compared to Baseline 2 showed that there were no differences on the injury day (Post 1) and after one week (Post 2), but that pain ratings reduced at two and six weeks post-injury (Post 3 and 4) (Table 5.6).

Finally, there were significantly reduced pain ratings for the individual compared to the control group on the injury day and at one and two weeks post-concussion (Post 1 to 3). However, there were no differences at six weeks post-injury (Post 4) (Table 5.6). Figures 5.2 to 5.4 plot the questionnaire data for the single case and the control group.

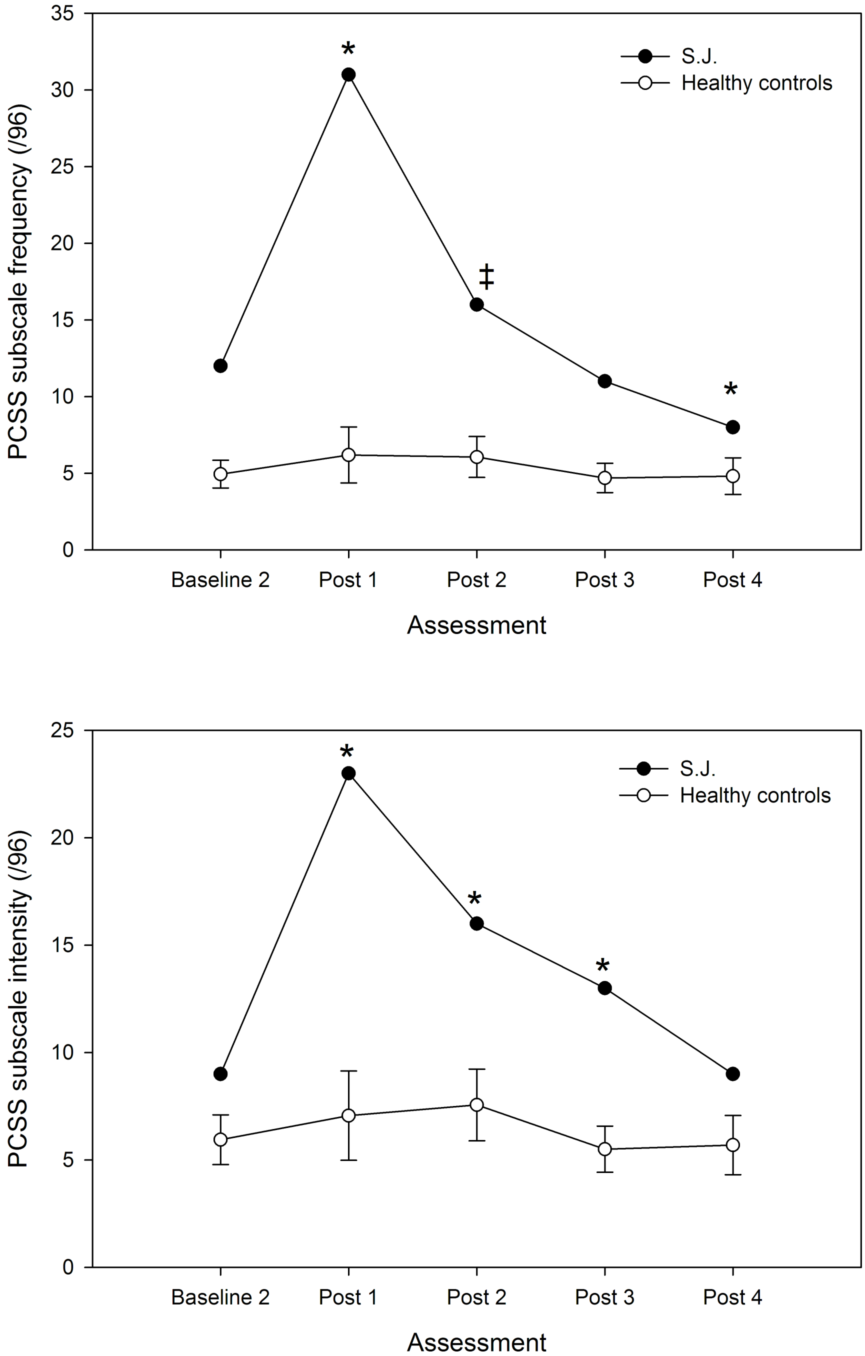


FIGURE 5.2: PCSS frequency (upper graph) and intensity (lower graph) for healthy controls (means, standard errors) and the single case study S.J. (* $p<.05$ ‡ $p<.20$)

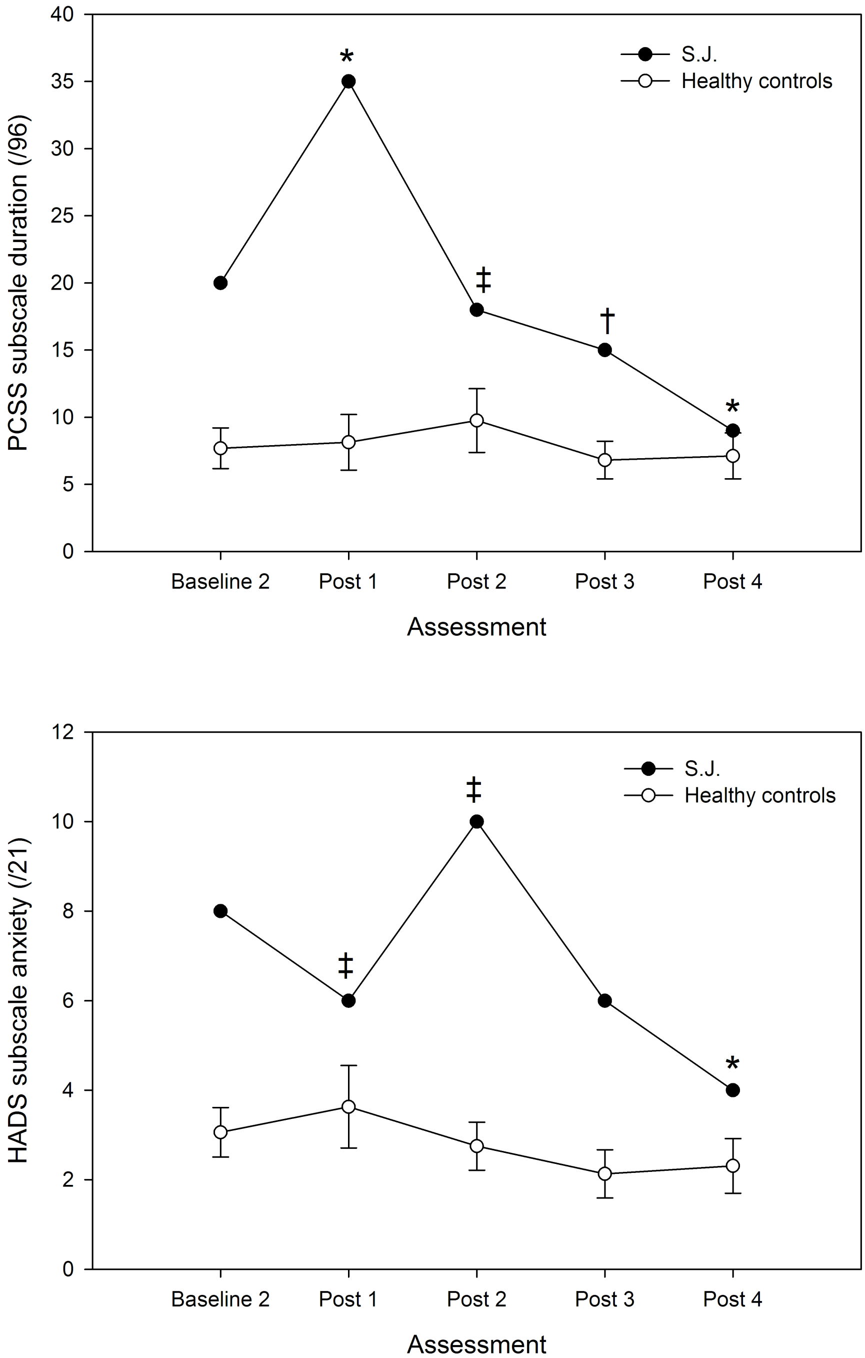


FIGURE 5.3: PCSS duration (upper graph) and HADS anxiety (lower graph) for healthy controls (means, standard errors) and the single case study S.J. ($*$ p<.05 † p<.10 ‡ p<.20)

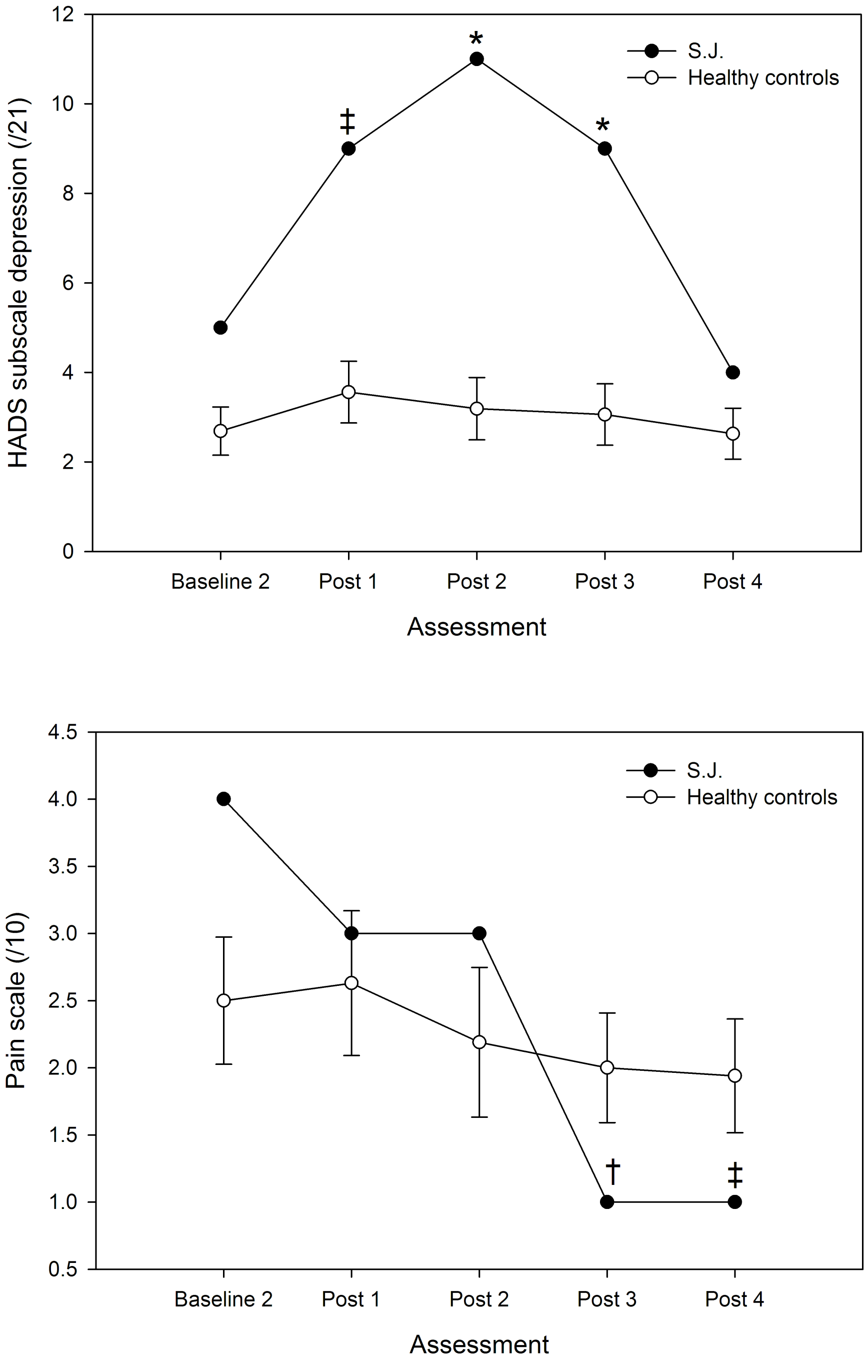


FIGURE 5.4: HADS depression (upper graph) and pain scale ratings (lower graph) for healthy controls (means, standard errors) and the single case study S.J. (∗ $p<.05$ † $p<.10$ ‡ $p<.20$)

Verbal memory

Analysis of the pre-injury baseline versus post-injury comparison for the immediate and delayed recall showed reduced scores at one week post-injury (Post 2). There were no further differences (Table 5.7). The individual versus control group comparison was not significant for any of the assessments (Table 5.8).

Table 5.7: Reliable Change Indices for the memory recall

Dependent measure		Baseline 2 versus		
		Post 2	Post 3	Post 4
Verbal memory	Immediate free recall	-1.58‡	-0.35	0.04
	Delayed free recall	-2.08∗	-0.38	0.32

∗ p<.05, † p<.10, ‡ p<.20

Table 5.8: Z scores, t scores for the discrepancy, point estimates and confidence limits for memory recall of the individual compared to healthy controls

Assessment	Memory immediate recall			Memory delayed recall		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	0.87	0.57	28.69 [13.19, 47.96]	1.10	0.10	46.01 [27.60, 65.11]
Post 2	-0.18	0.70	24.77 [9.56, 45.11]	-0.10	0.62	27.14 [11.21, 47.69]
Post 3	0.69	0.05	48.00 [28.83, 67.53]	0.99	0.65	73.03 [53.22, 88.49]
Post 4	0.71	0.57	71.00 [51.71, 86.58]	1.04	1.21	87.77 [71.79, 97.11]

Abbreviations: CL − confidence limit

Figure 5.5 plots the memory recall for the single case and the control group across assessments.

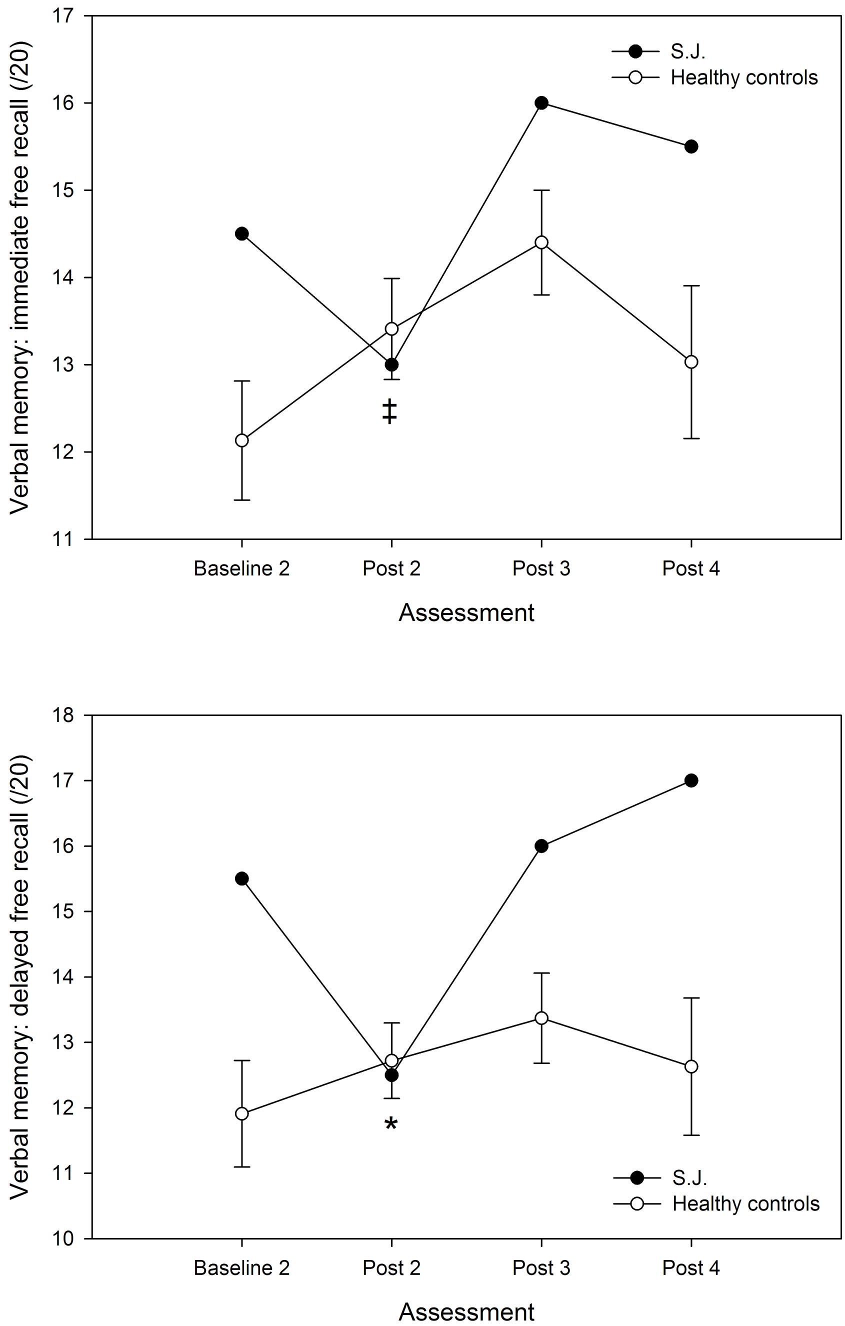


FIGURE 5.5: Verbal memory immediate recall (upper graph) and delayed recall (lower graph) for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

Attention

Analysis of the pre-injury baseline versus post-injury comparison on Simple Reaction Time showed significantly reduced at all post-injury assessments (Post 2 to 4) compared to Baseline 2 indicating that the athlete improved with each test (Table 5.9).

However, analysis of the individual versus control group comparison did not yield a significant difference at any of the assessments (see Table 5.10 and Figure 5.6).

TABLE 5.9: Reliable Change Indices for Simple Reaction Time

Dependent measure		Baseline 2 versus		
		Post 2	Post 3	Post 4
Simple Reaction Time	Mean RT	-2.67∗	-4.49∗	-10.42∗

Abbreviations: RT − reaction time; ∗ p<.05, † p<.10, ‡ p<.20

TABLE 5.10: Z scores, t scores for the discrepancy, point estimates and confidence limits for Simple Reaction Time of the individual compared to healthy controls

Assessment	Simple Reaction Time		
	z score	t score	point estimate [95% CL]
Baseline 2	1.51	0.35	63.40 [43.95, 80.52]
Post 2	1.20	0.71	75.48 [55.17, 90.62]
Post 3	0.45	-0.36	36.08 [18.57, 56.17]
Post 4	-0.72	-0.95	17.75 [5.77, 35.52]

Abbreviations: CL − confidence limit

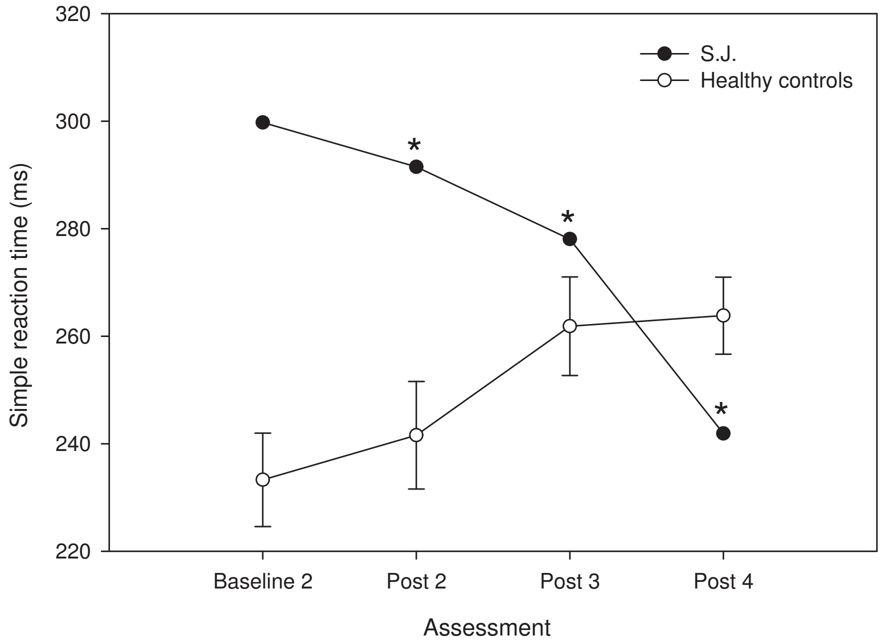


FIGURE 5.6: Simple Reaction Time for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

Executive function

Analysis of the pre-injury versus post-injury comparison on the executive function updating (i.e., the 2-back Task) showed increased mean reaction time, correct and false positive response at one and two weeks post-injury (Post 2 and 3). Mean reaction time was also increased at six weeks post-injury (Post 4). However, for the other measures, assessment at week 6 (Post 4) revealed return to Baseline 2 (Table 5.11).

Analysis of the individual score versus control group comparison did not yield significant differences for any of the measures across the assessments (Table 5.12, Figures 5.7 and 5.8).

TABLE 5.11: Reliable Change Indices for the executive function updating

Dependent measure		Baseline 2 versus		
		Post 2	Post 3	Post 4
2-back Task	Mean reaction time	15.91∗	10.34∗	9.03∗
	Correct response	2.42∗	2.48∗	0.39
	False positive response	3.47∗	2.28∗	0.14

∗ p<.05, † p<.10, ‡ p<.20

TABLE 5.12: Z scores, t scores for the discrepancy, point estimates and confidence limits for the executive function updating of the individual compared to healthy controls

Assessment	2-back reaction time		
	z score	t score	point estimate [95% CL]
Baseline 2	-0.52	-0.73	23.76 [9.26, 42.59]
Post 2	1.41	0.90	80.71 [61.21, 93.93]
Post 3	0.98	0.19	57.34 [37.46, 75.88]
Post 4	0.70	0.11	54.23 [34.59, 73.21]
Assessment	2-back correct response		
	z score	t score	point estimate [95% CL]
Baseline 2	-1.10	-1.14	13.56 [3.52, 30.07]
Post 2	0.74	0.17	56.64 [36.14, 75.85]
Post 3	0.74	-0.01	49.72 [30.38, 69.19]
Post 4	-0.57	-1.08	14.86 [3.94, 32.46]
Assessment	2-back false positive		
	z score	t score	point estimate [95% CL]
Baseline 2	-0.51	-0.74	23.60 [9.51, 42.41]
Post 2	1.12	0.58	71.40 [50.76, 87.74]
Post 3	0.39	-0.43	33.77 [16.70, 53.85]
Post 4	-0.54	-1.18	12.96 [3.03, 29.86]

Abbreviations: RT − reaction time, CL − confidence limit

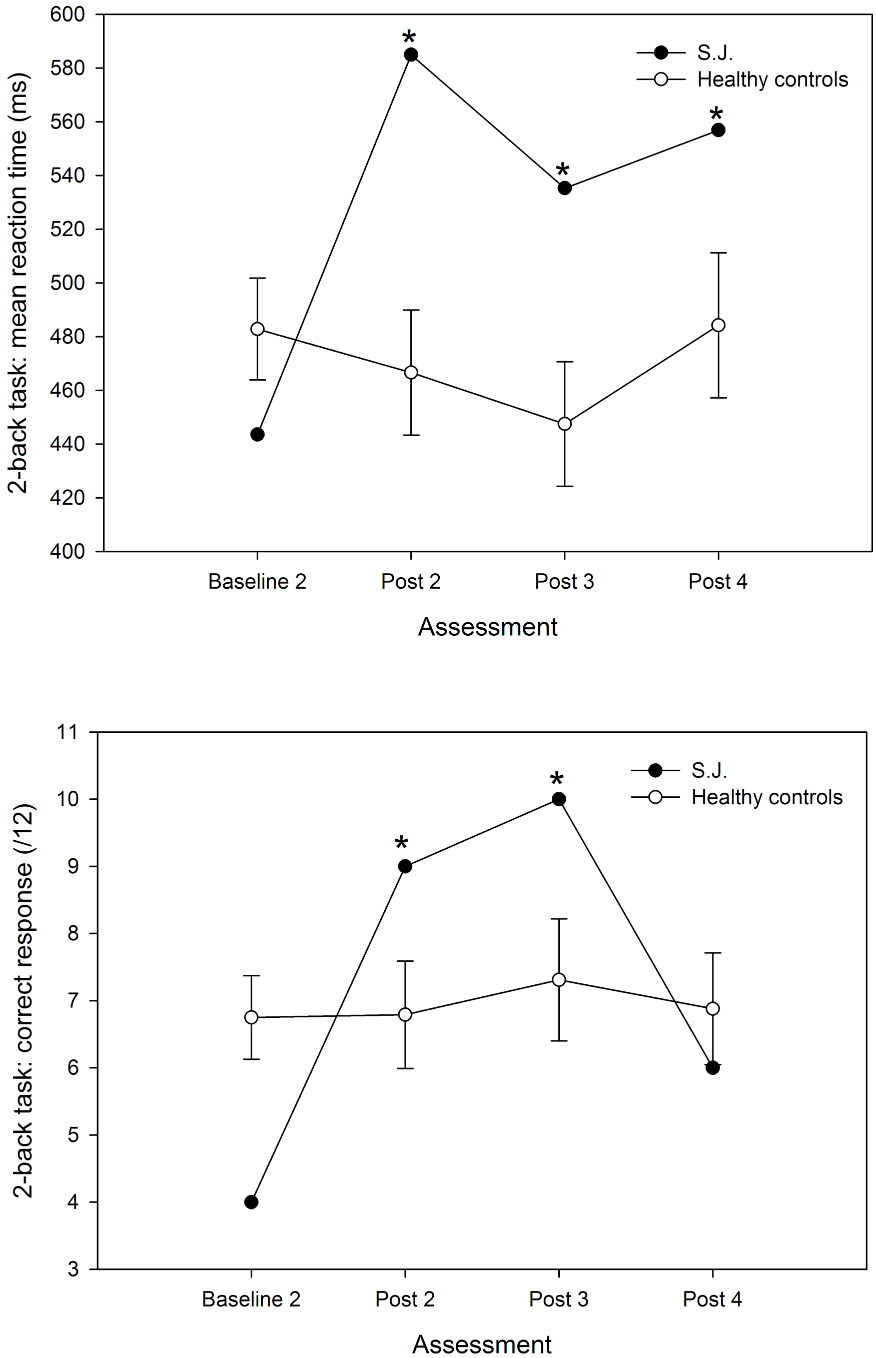


FIGURE 5.7: Executive function updating mean reaction time and correct response for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

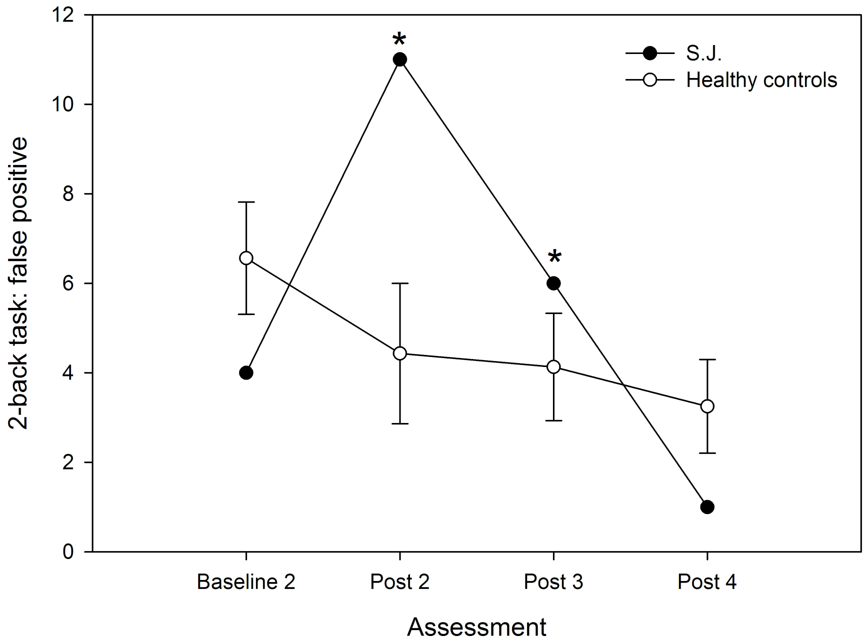


FIGURE 5.8: Executive function updating false positive response for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

Analysis of the pre-injury versus post-injury comparison on the executive function inhibition (i.e., the Stop-Signal Task) showed mean reaction time for correct response trials and correct response significantly lower, but false positive (error) response higher at one week post-injury (Post 2) compared to Baseline 2. At two weeks post-injury (Post 3), the mean reaction time and the correct response returned to Baseline 2, but the elevated false (error) response indicated a prolonged deficit. At six weeks post-injury (Post 4), the false (error) response returned to Baseline 2. The significantly higher mean reaction time and correct response at six weeks post-injury (Post 4) compared to Baseline 2 indicated better than Baseline 2 performance (Table 5.13, Figures 5.9 and 5.10).

TABLE 5.13: Reliable Change Indices for the executive function inhibition

Dependent measure		Baseline 2 versus		
		Post 2	Post 3	Post 4
Stop-signal task	Mean reaction time	-5.80∗	-0.45	6.60∗
	Correct response	-2.73∗	0.26	1.37‡
	False (error) response	5.51∗	1.68†	-0.44

∗ $p<.05$, † $p<.10$, ‡ $p<.20$

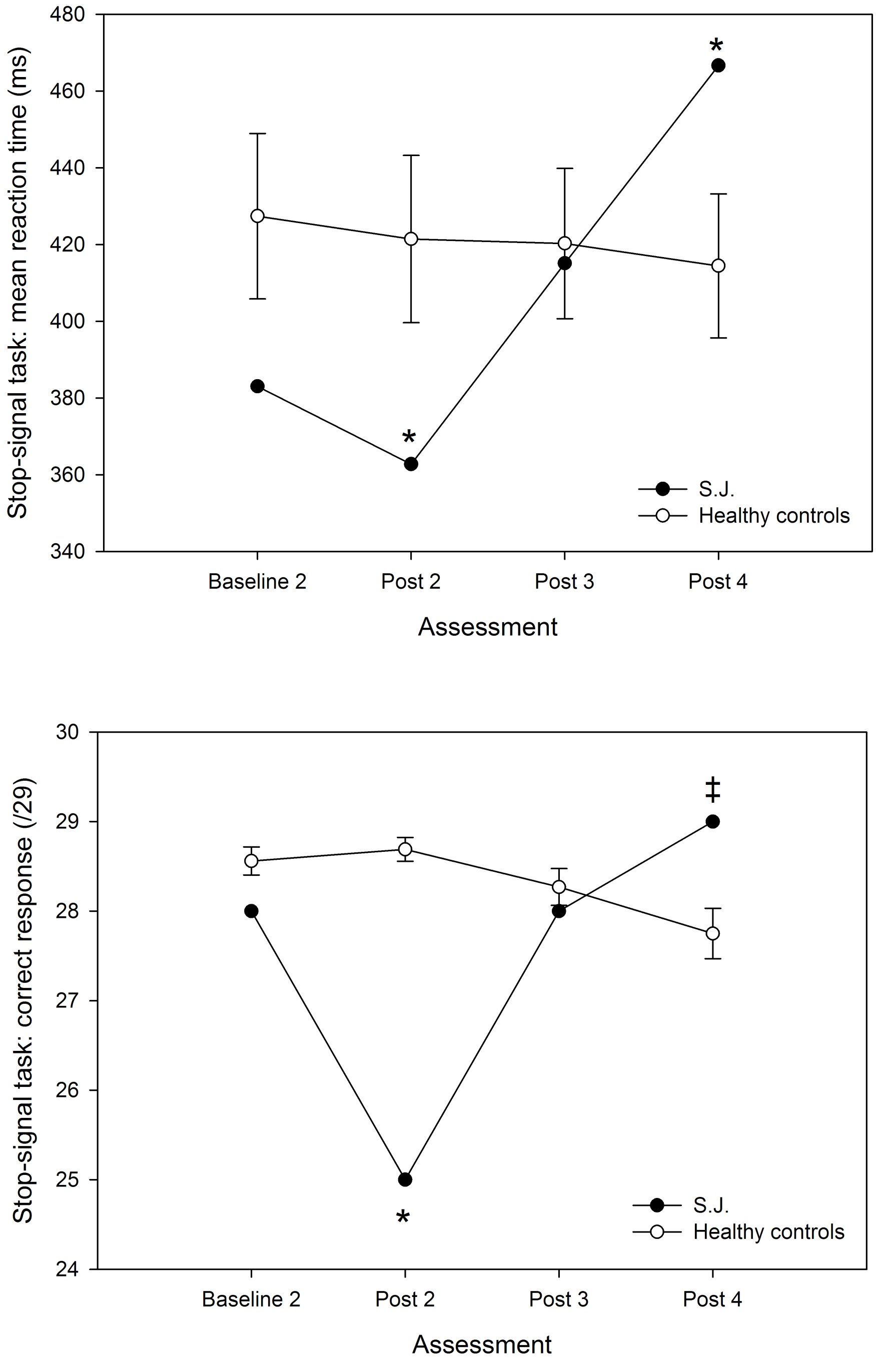


FIGURE 5.9: Executive function inhibition mean reaction time (upper graph) and correct response (lower graph) for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

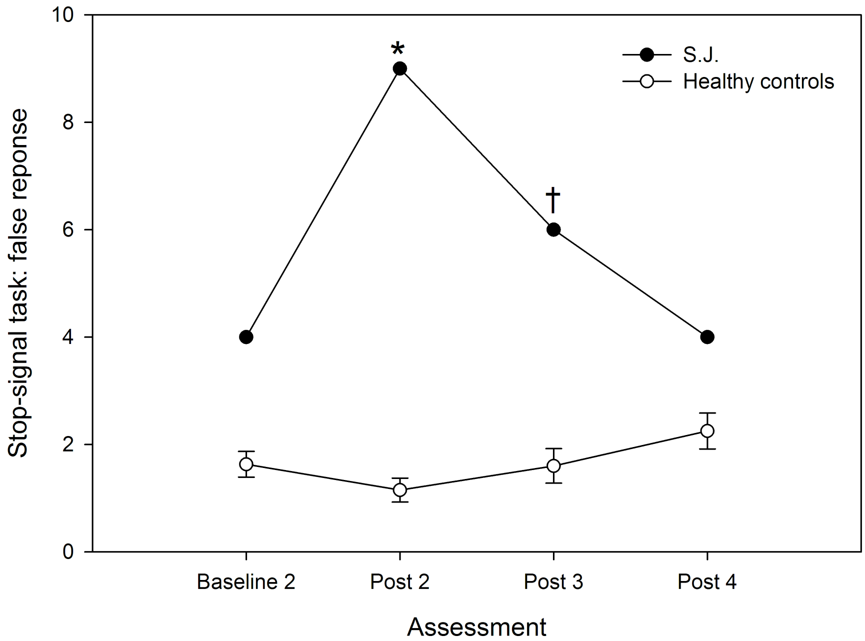


FIGURE 5.10: Executive function inhibition false (error) response for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10 ‡ p<.20)

Analysis of the individual versus control group comparison showed a significant difference on the inhibition false response at Baseline 2, one week (Post 2) and two weeks post-injury (Post 3). The t scores for the discrepancy indicated that the individual made significantly more false (error) responses than the control group. In addition, at one week post-injury (Post 2), the t scores for the discrepancy indicated that the individual also presented significantly less correct response than the control group (Tables 5.14).

Table 5.14: Z scores, t scores for the discrepancy, point estimates and confidence limits for the executive function inhibition of the individual compared to healthy controls

Assessment	SST mean reaction time			SST correct response			SST false response		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	-0.01	-0.25	40.15 [22.48, 59.53]	-0.89	-1.15	13.36 [3.42, 29.80]	2.48	2.37	98.42 [92.48, 99.97]
Post 2	-0.75	-1.28	11.06 [2.04, 27.80]	-7.69	-8.21	0.00 [0.00, 0.00]	9.80	8.65	100.00 [100.00, 100.00]
Post 3	-0.07	-0.94	18.04 [5.66, 36.53]	-0.34	-1.20	12.43 [2.79, 29.12]	3.54	2.62	99.00 [94.36, 99.99]
Post 4	0.70	0.12	54.82 [35.08, 73.67]	1.11	0.62	72.59 [52.75, 88.17]	1.30	0.63	73.19 [53.40, 88.61]

Abbreviations: SST − Stop-Signal Task, CL − confidence limit

Analysis of the pre-injury baseline versus post-injury comparison on the executive function shifting test (i.e., the Number-Letter Task) revealed significantly lower mean reaction time in correct response shift trials, shift cost and correct response, and higher false (error) response at one and two weeks post-injury (Post 2 and 3) compared to Baseline 2. At six weeks post-injury (Post 4), the mean reaction time, shift cost and false (error) response showed greater than at Baseline 2, but the correct response remained significantly lower compared to Baseline 2 (Table 5.15).

Table 5.15: Reliable Change Indices for the executive function shifting

Dependent measure		Baseline 2 versus		
		Post 2	Post 3	Post 4
Number-letter task	Mean reaction time	-9.52∗	-5.03∗	1.42 ‡
	Correct response	-3.31∗	-1.43‡	-2.13∗
	False response	3.60∗	1.43‡	1.47‡
	Shift cost	-13.82∗	-6.92∗	1.28 ‡

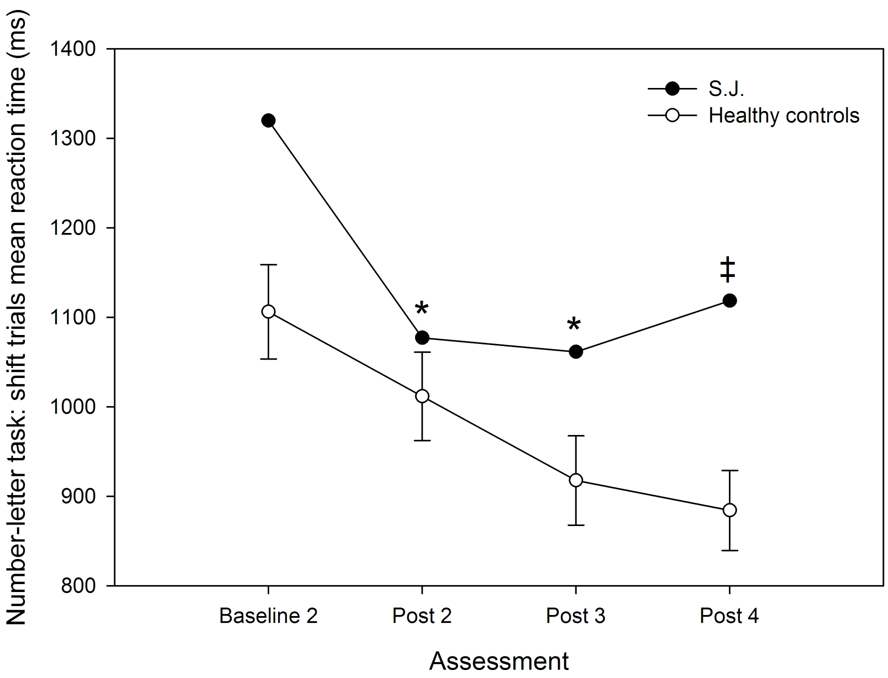
∗ p<.05, † p<.10, ‡ p<.20

Analysis of the individual versus control group comparison revealed a significant shift cost difference at Baseline 2. The t score for the discrepancy indicated that the individual's shift cost was significantly greater than that of the control group. A second difference presented for correct response at one week post-concussion (Post 2). The t scores for the discrepancy indicated that the individual's correct response was significantly lower than that of the control group. There were no further differences at two and six weeks post-injury (Post 3 and 4) (Table 5.16, Figures 5.11 and 5.12).

TABLE 5.16: Z scores, t scores for the discrepancy, point estimates and confidence limits for executive function shifting of the individual compared to healthy controls

Assessment	NLT shift trials RT			NLT shift cost		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	1.01	1.00	83.29 [65.78, 94.83]	1.69	2.37	98.42 [92.48, 99.97]
Post 2	0.35	-0.22	41.54 [22.59, 62.73]	0.59	0.04	51.57 [31.44, 71.39]
Post 3	0.72	-0.04	48.62 [29.39, 68.10]	1.52	0.97	82.57 [64.23, 94.69]
Post 4	1.31	0.90	80.86 [62.12, 93.69]	1.88	1.54	92.69 [78.97, 99.06]
Assessment	**NLT shift trials correct**			**NLT shift trials false (error)**		
	z	t	estimate [95% CL]	z	t	estimate [95% CL]
Baseline 2	1.23	0.84	79.37 [61.02, 92.47]	-1.23	-1.54	7.19 [1.00, 20.27]
Post 2	1.67	-2.11	2.76 [0.08, 11.73]	-1.67	1.03	84.01 [65.33, 95.74]
Post 3	0.22	-0.47	32.26 [15.51, 52.32]	-0.22	-0.95	17.88 [5.57, 36.33]
Post 4	-0.88	-1.16	13.26 [3.17, 30.29]	0.88	0.32	62.46 [42.40, 80.23]

Abbreviations: NLT − Number-Letter Task, RT − reaction time, CL − confidence limit



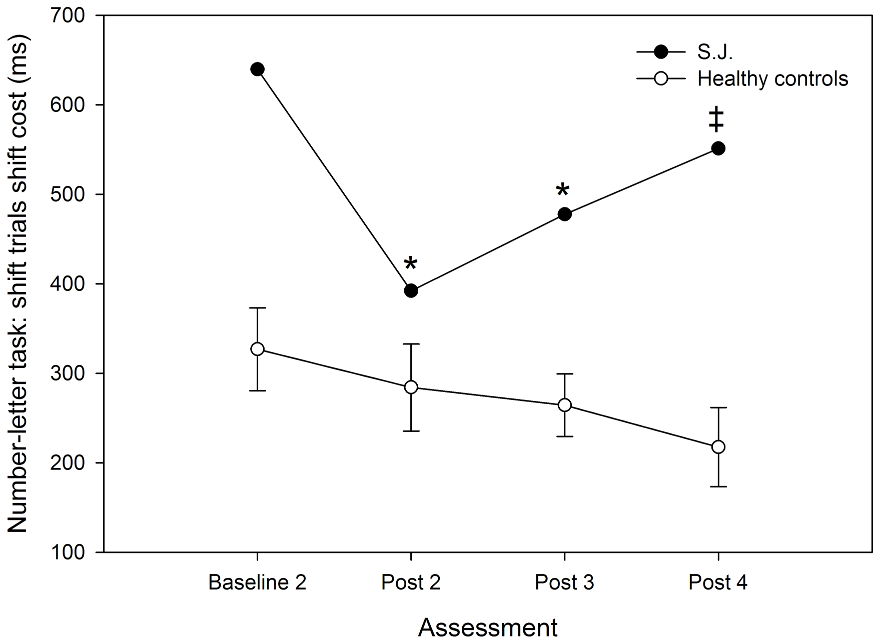
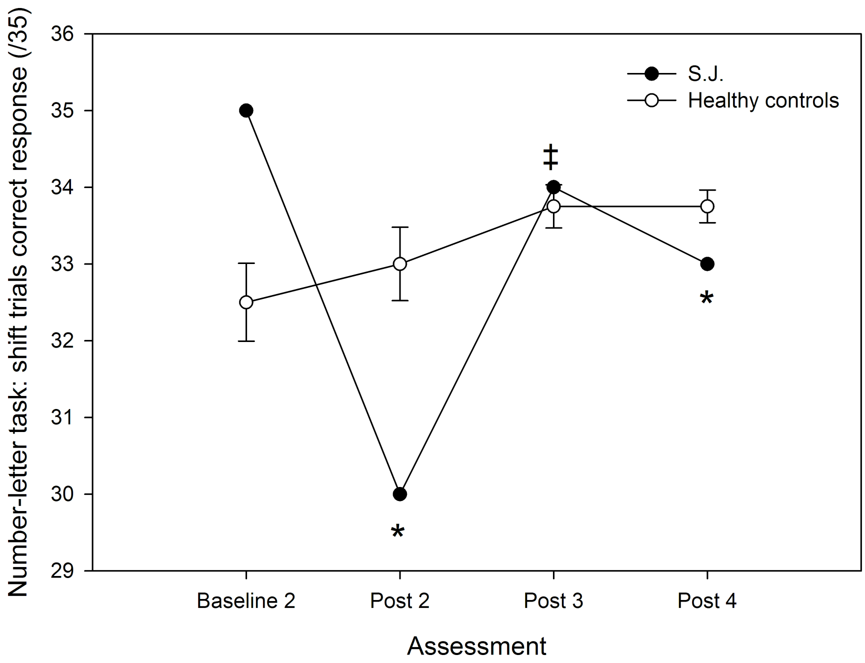


FIGURE 5.11: Executive function shifting mean reaction time (upper graph) and shift cost (lower graph) for healthy controls (means, standard errors) and the single case study S.J. (∗ p<.05 † p<.10‡ p<.20)



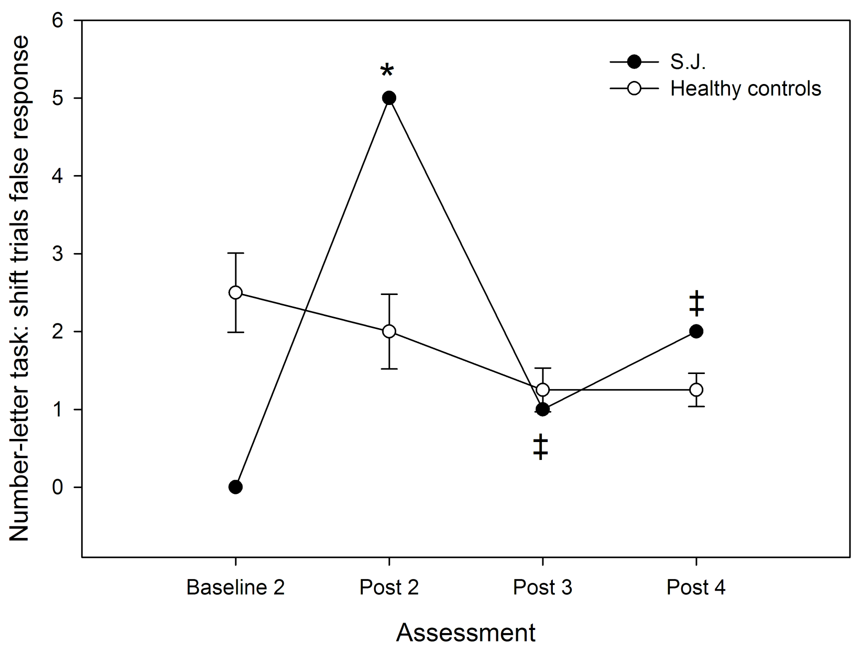


FIGURE 5.12: Executive function shifting correct (upper graph) and false (error) response (lower graph) for healthy controls (means, standard errors) and the single case study S.J. ($*$ p<.05 † p<.10‡ p<.20)

5.4.2 Discussion

The longitudinal single case study presented here examined questionnaire data and the neuropsychological functions following sport concussion in a female athlete using established questionnaires and a newly compiled computerised neuropsychological test battery, as introduced in Part 1 of this chapter. The athlete's post-injury test performance was contrasted to both her own pre-injury Baseline 2 and the multiple control group baseline measures as described in Part 1 of this chapter. We hypothesised that the athlete would show post-concussion impairment (i.e., increased symptom self-report, decreased neuropsychological function) that would resolve with time. Our data supported this hypothesis.

Using the pre-injury versus post-injury comparison approach (Barth et al., 1989), the athlete showed a marked increase in the questionnaire measures of subjective symptom frequency, intensity and duration, as well as symptoms of anxiety and depression. The subjective symptoms measured with the Post Concussion Symptom Scale PCSS (McCrory et al., 2005) showed most augmented on the day of the injury. Symptom frequency, intensity and duration followed differential recovery courses. Symptom duration returned to baseline at one week post-injury followed by symptom frequency at two weeks and symptom intensity at six weeks post-injury. In contrast to the PCSS symptom self-report, symptoms of anxiety showed mixed moderation, lower on the day of the injury, higher one week after injury and then returning to baseline. Depression was clearer peaking at one week post-injury and remaining greater until after two weeks post-concussion. At six weeks following the sport concussion, all of the symptom self-report measures showed baseline or below-baseline return suggesting recovery.

These findings are in line with the literature that showed a significant increase in subjective symptoms following a sport concussion using questionnaires (e.g., Guskiewicz et al., 2001, Iverson et al., 2006a; McClincy, Lovell, Pardini, Collins & Spore, 2006, McCrea et al., 2003). However, the athlete's post-injury questionnaire symptom self-report was in contrast to her symptom "free nomination". That is, to the questions of whether she experienced any symptoms or problems following the injury, she did not report any symptoms at all. This highlights both the advantage and disadvantage of self-report questionnaires. They may provide additional information that cannot be obtained from the athlete, but also may yield an overestimation of the experienced symptoms. The finding that the symptoms reported in the questionnaires increased immediately after the sport concussion, but then returned to baseline suggests that the questionnaire provided a framework for reporting symptoms without the athlete having to explicitly acknowledge that they had a problem. In our experience, athletes tend to deny the injury in order to facilitate faster return to play.

Although our data support existing literature, they are also contra past research, as we did not show subjective symptoms resolved within seven days (e.g., as in Guskiewicz et al., 2001, Iverson et al., 2006a, McClincy et al., 2006, McCrea et al., 2003). This might be associated to the difference in questionnaire use. For example, past research asked sport-concussed athletes to rate a comparable comprehensive list of symptoms for severity only (Lovell et al., 1998), whereas the present study asked the athlete to rate frequency, intensity and duration of experienced symptoms. It is plausible that the concept of symptom severity might involve different aspects. For example, an athlete might consider the experienced headache as severe because the headache occurred very often (i.e., symptom frequency), or because it felt strong (i.e., symptom intensity), or because it lasted long (i.e., symptom duration). Depending on the athlete's conceptualisation of symptom severity, the questionnaire response behaviour might differ. Our data suggest the differential assessment of symptom frequency, intensity and duration might add valuable information to the assessment of sport concussion effects.

The finding of increased symptoms for anxiety and especially depression is difficult to explain. So far, the literature has treated both as confound moderator variables (Iverson, 2005) and a potential risk factor that might prolong recovery (McCrory et al., 2009). For example, the recent consensus statement on sport concussion (McCrory et al., 2009) recommended athletes with prolonged recovery to be screened for anxiety and depression (as if these factors were the reason for the prolonged recovery). Depression is usually associated with prolonged out-of-play following a sport injury (Broshek & Freeman, 2005). However, in the present study, the sport-concussed athlete returned to sport practice shortly after the sport concussion, therefore refraining from sport cannot be considered a decisive factor for the increased depression symptoms reported here. Instead, it appears plausible that the delayed augmentation in anxiety and depression might present a genuine sport concussion post-injury outcome. Another factor that might explain the finding is the literature that has reported a positive association between depression and subjective symptom self-report (Trahan, Ross & Trahan, 2001). That is, with increased anxiety and depression, athletes report more subjective symptoms. However, in the present single case study, the PCSS symptom report, anxiety and depression appeared dissociated. Anxiety and depression symptoms peaked later than the PCSS subjective symptoms (i.e., at one week post-injury compared to on the day of injury). Therefore, at present, it remains unclear whether the present study's finding on protracted augmented anxiety and depression symptoms post-concussion represents a feature of the case study's individual recovery course or whether this finding could be replicated in further longitudinal single case studies.

From the analyses carried out in Part 1 of this chapter, we reported that questionnaire symptom report was stable from Baseline 2 for subsequent assessments. Here, in Part 2, we only measured differences from Baseline 2 assessment. Therefore, any differences in the pre-injury versus post-injury comparison are unlikely due to practice effects and are more likely linked to the sustained sport concussion. Analysing the data using the individual score versus control group comparison therefore provides unnecessary, but nevertheless supportive evidence. These analyses first of all showed that the case study's Baseline 2 questionnaire rating was comparable to that of the control group. This suggests that her previous sport concussion was not associated with any baseline increased symptom self-report. Following the sport concussion, the significant symptom increase compared to her own Baseline 2 showed also significant compared to the control group. For example, on the day of the injury (Post 1), the case study's symptom frequency and duration were significantly greater than in the control group. However, at one week post-injury (Post 2), the symptom duration remained elevated compared to the control group, though the pre-injury versus post-injury comparison indicated a baseline return. This suggests that single case versus control group comparisons may add supportive meaningful detail on a sport-concussed athlete's recovery from injury.

On the neuropsychological tests, the athlete exhibited marked function decrements on measures of memory recall and executive function following the sport concussion. In Part 1, practice effects on the neuropsychological tests were found between Baseline 1 and 2, and between Baseline 2 and Post 2. In the data presented here, we only compared the post-injury tests to Baseline 2. Therefore, for the majority of the dependent variables, we should expect stable performance over repeated tests. The only two dependent measures to show some evidence of practice in Part 1 between Baseline 2 and Post 2 was for immediate free recall and executive function shifting mean reaction time. For these two measures, comparison with the control group should provide additional support to the analyses that consider the comparison of the athlete's post-injury and own pre-injury assessments.

The data for verbal memory recall showed that the athlete had reduced immediate and delayed recall at one week post-injury (Post 2) compared to their own Baseline 2. While there were no differences between the athlete and the control group at any of the assessments, the fact that the athlete got worse at the Post 2 assessment rather than better as indicated by a practice effect suggests that there was an impairment in verbal memory recall. However, the athlete's verbal recall scores returned to the individual's baseline level at the Post 3 and Post 4 assessments, and these scores were no different to that of the controls (that show a practice effect; at least for the immediate free verbal memory recall). Therefore, the apparent return to baseline could also be explained by practice suggesting that caution is needed in interpreting this data.

The data for executive function shifting mean reaction time showed significant differences between the post-injury tests 2 and 3 in comparison to Baseline 2. However, these data revealed that reaction time reduced (i.e., the athlete responded faster). Comparison with the control group revealed no difference between the athlete and the control group across assessments. Therefore, the data in the individual can entirely be explained by the practice effect for this particular variable.

As the analyses carried out in Part 1 found that all other dependent variables were stable between Baseline 2 and post-injury assessments 2, 3 and 4, any other dependent measures showing significant differences between the athlete's post-injury performance compared to the pre-injury Baseline 2, or to the control group cannot be explained by practice effects. That is to say, any apparent deficits that subsequently improve likely reflect true recovery rather than practice. For the other dependent variables, there were a mix of deficits that lasted for different time periods. From these, the deficits associated with executive functions showed the greater effects. On the executive function updating (i.e., the 2-back Task), the mean reaction time remained significantly increased until six weeks post-injury (Post 4) compared to baseline. Similarly, on the executive function inhibition (i.e., the Stop-Signal Task), the sustained sport concussion was reflected in greater false response until two weeks post-injury (Post 3). In contrast to the executive function updating, the athlete's post-injury executive function inhibition performance was more varied. For example, at one week post-injury (Post 2), the increased false response was accompanied by more correct response, but a faster mean reaction time indicating that the increased cognitive workload that might have come with the speeded reaction could not be paralleled with a similar response efficiency. At two weeks post-injury (Post 3), recovery was apparent, as mean reaction time and correct response showed baseline return, but recovery was not complete because the false response remained increased. At six weeks post-injury (Post 4), mean reaction time, correct and false response recovered. These relationships between variables are important as it might suggest that the athlete might have protracted her response in order to succeed in this test (i.e., to increase the correct and decrease the false response). As already discussed, the executive function shifting (i.e., the Number-Letter Task) mean reaction time and shift cost decreased until two weeks post-injury (Post 3) indicating practice-related performance gains. However, following the sport concussion, the correct response showed a marked decrease, while the false response increased significantly that both remained until six weeks post-concussion (Post 4; dependent variables not showing practice effects in Part 1). This suggests that similar to the executive function inhibition, speeded response could not be paralleled with response accuracy, and that the sport concussion appeared to influence a balance of components involved in executive functions. In all, the data suggest that following a sport concussion the executive functioning might take a longer recovery course than other cognitive domains (i.e., attention, memory recall) because of the complexity of components involved.

Our finding of the memory (recall) decrement post-injury is consistent with the literature that showed performance deficits following a sport concussion (e.g., Colvin, Mullen, Lovell, West, Collins & Groh, 2009, Field, Collins, Lovell & Maroon, 2003, Iverson et al., 2006a, McClincy et al., 2006). However, the present data does not allow to conclude whether memory recall tests are superior to the more widely used memory recognition tests. Future research should include memory recognition tests to contrast recall and recognition recovery and examine whether these might follow differential courses.

In the data here, analysis of attention tests (i.e., the Simple Reaction Time task) showed practice effects for the comparison between post-injury measures (Post 2, 3 and 4) and Baseline 2 in the athlete and no differences compared to the control group data. This finding appears to contradict past research on acute sport concussion effects (e.g., McClincy et al., 2006; see Belanger & Vanderploeg, 2005 for a recent meta-analysis). In this literature, effects on attention are reported. It might be that there were no effects in our data as the test used was too easy or that the impairment (i.e., the area of the brain affected) was not that involved in attention.

There is only limited literature on executive function following sport concussion. Concerning the executive function updating, data using a similar, yet solely visual (and therefore less cognitive demanding) 2-back task appeared to support the test's sensitivity to acute sport concussion effects (Collie, Maruff, Makdissi, McStephen, Darby & McCrory, 2004). Similar findings to these have been reported using non-computerised tests (i.e., the Paced Auditory Serial Addition Test PASAT, Gronwall & Sampson, 1974), where marked reductions in the acute and post-acute recovery stage following sport concussion have been found (e.g., Barth, 1989). However, empirical evidence is not consistent (e.g., Macciocchi et al., 2001, Maddocks & Saling, 1996). In contrast, the literature so far has not shown any consistent evidence for post-concussion function impairments in the executive function inhibition. For example, using the Stroop test (Stroop, 1935), worse test performance was found in self-reported sport-concussed athletes within one week (Bruce & Echemendia, 2003, Echemendia et al., 2001), but not beyond (e.g., McCrea et al., 2003, also see Randolph, McCrea & Barr, 2005). No comparative data on the computerised executive function inhibition assessment following sport concussion is currently available. The findings of executive function shifting decrements following sport concussion is consistent with the literature that used paper-pencil shifting tests (e.g., the Trail Making Test B; Reitan, 1958). On the TMT-B, sport-concussed athletes performed worse in the acute phase (i.e., up to seven days post-injury) following the injury (e.g., Collins et al., 1999, Guskiewicz et al., 2001, Lovell & Collins, 1998, Macciocchi et al., 2001), though empirical consistency is lacking (Makdissi, 2001). Again, no data on the computerised assessment of the executive function shifting is currently available for comparison.

One final aspect of interest was that the control group comparison with the athlete showed that executive function inhibition and shifting Baseline 2 was worse for the athlete. The inhibition false response and shifting shift cost were already greater at the baseline suggesting that perhaps the previously sustained sport concussion might have compromised the cognitive domains of inhibition and shifting. Compared to the control group, the case study's post-injury performance on the executive functions inhibition and shifting showed increasing performance at one and two weeks post-concussion (Post 2 and 3). Also, at one week post-injury (Post 2), the athlete's inhibition correct response was worse than in the control group. These findings suggest that additional control group comparisons may add informational value concerning the neuropsychological effects with athletes that have sustained multiple concussions (and long-term deficits).

5.5 Conclusions

The present longitudinal study piloted a newly compiled computerised neuropsychological test battery involving tests of attention, memory recall and executive function. There were two aims. The first aim was to establish multiple control group baseline measures using a longitudinal double baseline and multiple follow-ups assessment scheme that would also be applied to map sport concussion recovery. The second aim was to contrast a sport-concussed athlete's post-injury performance against the own pre-injury baseline and the multiple control group baseline measures.

In the first part of the study, the data showed that the newly compiled test battery was of sufficient comprehensiveness and test difficulty to be used to map sport concussion recovery. Practice-related performance gains showed, but were, as hypothesised, mainly restricted to the first and second assessment (i.e., the double baseline). This suggests that the second of two baselines might provide a more valid reference measure against which post-injury performance to contrast. In the second part of the study, the data of a single case athlete showed that a sport concussion resulted in function deficits of memory recall and executive function. This suggests that the inclusion of memory recall and executive function tests might improve the neuropsychological sport concussion assessment. Furthermore, the data showed that executive function recovery followed a prolonged course. This indicated that return-to-play protocols that involve data from computerised test batteries without executive function tests might prematurely conclude that sport concussion recovery was complete and the athlete allowed to return to sport practice and competition. The two data analysis methods, the pre-injury versus post-injury comparison using Reliable Change Indices (RCI) and the individual score versus control group comparison, complemented each other. Whereas the RCI provided information on the injury-related change, the control group comparison allowed conclusions on whether the pre-injury measures were abnormal and whether the return to the own baseline also signified return to the control group baseline and not only simply a practice effect. In all, our data suggest that currently used computerised neuropsychological test batteries might need to be complemented by tests of memory recall and executive functions and that the pre-injury versus post-injury comparison should be supplemented with a control group comparison to yield a more comprehensive picture of athlete neuropsychological test performance.

Future research should replicate the findings of Part 1 in a larger participant sample to better understand whether any other practice effects were missed due to a lack of power. Also, it might be interesting to have two control groups. As in the present study, one group would consist of athletes that never had sustained a sport concussion before, whereas the other group would have had a sport concussion history. It would also be interesting to test multiple case studies to assess consistencies in the data and also to understand differences between particular profiles of single case sport-concussed athletes.

Chapter 6

General Discussion

In this chapter, we summarise and discuss the empirical findings from this thesis (Chapters 2 to 5). As presented in the General Introduction (Chapter 1), four themes were addressed: knowledge, terminology, long-term cognitive sport concussion effects and longitudinal neuropsychological testing. We will first provide a brief overview of the main findings and discuss them with regard to the relevant literature. Following this, we will present the limitations in the thesis and then conclude with the description of interesting research avenues that could be pursued on the basis of the findings from this thesis.

6.1 Empirical thesis findings

Sport concussion programmes typically aim to safeguard athlete health through their expertise on recognition (or diagnosis), management and prevention. If no expert advice is available (e.g., at lower play levels), the responsibility passes over to the athlete and their significant others (i.e., coaches, family and friends as members of the general public). As athletes have been reported to conceal or ignore sport concussion symptoms (see McCrea et al., 2004 for discussion of this matter), significant others might have to play an important role in the injury's recognition. However, no data is currently available on whether the UK general public possesses sufficient knowledge to recognise sport concussion and encourage appropriate post-injury behavioural adaptation (e.g., seek medical attention and rest, refrain from sport; Guskiewicz et al., 2006; McCrory et al., 2009). Therefore, in Chapter 2, we assessed the sport concussion knowledge in the UK general public by means of an online survey. The study measured the fundamental familiarity with the term sport concussion (i.e., familiar versus not familiar), the certainty with which sport concussion knowledge was expressed (i.e., assured versus guess) and how accurate the expressed knowledge actually was (i.e., accurate versus misconception). Based on the literature that reported variegated and widespread misconceptions on brain injury in the North American general public (e.g., Gouvier et al., 1988; Willer et al., 1993), we anticipated the fundamental familiarity with sport concussion to be high, but actual understanding, as reflected in the response certainty and accuracy, to be low.

The data revealed that the majority of the UK general public assessed showed fundamental sport concussion familiarity and a notable knowledge base, as for example indicated by the accurate nomination of sport concussion indicators. Overall, the certainty with which knowledge was expressed was low, and misconceptions prevailed. These were particularly pronounced concerning injury mechanisms, symptoms and recovery. In all, the injury's seriousness was clearly underestimated. Unsurprisingly, more guess than assured respondents expressed misconceptions. Interestingly, more assured than guess responders showed misconceptions concerning the post-injury likelihood of further injury, gender differences, post-injury learning difficulties and the presence of post-traumatic amnesia. This means that participants were certain of knowledge that was actually a misconception. The findings were consistent with our hypotheses and suggest that in the UK general public, sport concussion knowledge is limited and erroneous. We advise that educational programmes are needed to increase sport concussion knowledge and correct misconceptions, and expect that this measure would in turn lead to improvements in athlete health.

The second theme that the thesis addressed concerned that of the terminology used for sport concussion. The literature has employed the terminologies concussion, mild traumatic brain injury and minor head injury as synonyms (Iverson, 2005). This interchangeable terminology use has been contested, and it has been suggested that what individuals believe they understand about the injury may differ under each terminology (Anderson et al., 2006; McCrory, 2001). Therefore, in Chapter 3, we measured the effect of terminology (i.e., concussion, mild traumatic brain injury, minor head injury) on term-related familiarity, injury outcome expectations and actual symptom reporting in a student athlete population using a questionnaire. We anticipated that familiarity and injury outcome expectations would vary with the terminology used. Furthermore, we anticipated that the symptom self-report in self-reported injured compared to uninjured athletes would vary with the terminology used.

The data supported these hypotheses and showed that terminology affected both familiarity and injury outcome expectations, but not actual symptom report. The term mild traumatic brain injury was the least familiar compared to the other two. Injury outcome expectations were reliably more negative for the mild traumatic brain injury than the concussion and minor head injury terminology. However, terminology groups by injury history did not differ in their actual symptom self-report. On the basis of this data, we suggest that the different terminologies should not be used interchangeably. Existing athlete educational programmes should adapt their teaching content to compensate for what athletes believe they understand about the injury.

In the third part of the thesis, we were interested in whether we could detect any long-term cognitive deficits following sport concussion. The literature has defined sport concussion as the result of biomechanical forces that affect the brain and elicit a pathophysiological process (McCrory et al., 2009) that influences underlying cognition. These changes in the brain's neurometabolism and neurotransmission (Giza & Hovda, 2001) are thought to be transient and to typically resolve within seven to ten days (McCrory et al., 2009). In the literature, some studies have reported evidence of neuropsychological long-term function deficits in sport-concussed compared to uninjured athletes (e.g., Cremona-Meteyard & Geffen, 1994; De Beaumont et al., 2009; Di Russo & Spinelli, 2009). Yet, other papers suggest that there are no long-term cognitive deficits (e.g., Echemendia et al., 2001; Guskiewicz, 2002; Guskiewicz et al., 2003; Iverson et al., 2006b). This inconsistency might be at least partially due to the neuropsychological test batteries used and that these did not have sufficient test difficulty and comprehensiveness to fully map long-term neuropsychological deficits following sport concussion. On this basis, we proposed that making the tests harder and including tests of memory recall and executive function would improve the neuropsychological assessment of sport concussion. Therefore, in Chapter 4, we assessed the neuropsychological functioning of self-reported sport-concussed compared to non-concussed student contact sport athletes by means of a comprehensive neuropsychological test battery of higher test difficulty and more varied tests. Controlling for potential confound moderators, we anticipated reliable test performance differences between self-reported sport-concussed and non-concussed athletes in measures of attention, memory and executive function.

The data presented showed some support for this hypothesis. Sport-concussed athletes performed significantly worse on tests of free verbal memory recall and executive function shifting. The findings suggest that the inclusion of verbal recall and executive function tests would improve the neuropsychological sport concussion assessment. In a post-hoc single case comparison, each sport-concussed athlete showed at least two abnormal test scores compared to the uninjured athletes mean test performance. However, the single case comparisons varied in the type of deficit. Therefore, we argued that within sport concussion, the variability of the sustained injuries was too great to summarise participants under one umbrella of sport concussion. Subsequently, we suggested that until better injury-related within-group homogeneity was achieved, single case studies might present a better approach for assessing the long-term effects of sport concussion on athlete health.

The final part of the thesis developed methods for single case longitudinal neuropsychological testing. Within the sport concussion research field, computerised neuropsychological testing (Collie et al., 2001) using a pre-injury versus post-injury comparison approach has been promoted as the 'gold standard' of sport concussion assessment (McCrory et al., 2009). Most of the experiments reported in the literature used a single baseline pre-injury comparison to the post-injury measures. However, the literature has also suggested that the largest performance gains occur between the first and second assessment (Faletti et al., 2006, Hinton-Bayre et al., 1999). This suggests that a double instead of singular pre-injury (baseline) assessment was required. The findings of long-term neuropsychological deficits in sport-concussed athletes in Chapter 4 suggested that the inclusion of memory recall and executive function tests might improve the assessment of acute and post-acute sport concussion effects. Therefore, in Chapter 5, using a longitudinal double baseline control group design, we piloted a newly compiled computerised neuropsychological test battery consisting of memory recall, attention and executive function tests in a university student athlete population. There were two study aims. The first aim was to establish multiple control group baseline measures and examine practice-related performance gains that may come with repeat administration of the tests. The second aim was to use the multiple control group baselines in the context of a single case study and contrast a recently sport-concussed athlete performance against their own baseline and the multiple control group baselines. We hypothesised that performance gains were restricted to the first and second assessments (i.e., the double baseline) and that following a sport concussion, the athlete would show performance deficits compared to the own baseline and the control group, but that the identified performance decrements would resolve with time.

As predicted, the data showed that the majority of performance gains occurred between the first and second assessment indicating that the second of two baselines would provide a more valid reference measure. Neuropsychological test performance was fairly stable across the remaining assessments. The single case study revealed performance decrements in memory recall and executive function. Whereas memory recall deficits were only identified at one week post-injury, executive function decrements remained at two and six weeks post-injury. The data suggest that memory recall and executive function should be used to complement the neuropsychological sport concussion assessment and that these tests might detect neurocognitive impairment beyond the typically assumed recovery period of seven to ten days (McCrory et al., 2009).

6.2 Thesis limitations

While the data presented in this thesis have important implications for both future sport concussion research and clinics, several limitations need to be raised when interpreting the data and deriving future directions. These are presented in the following three paragraphs.

All of the sport concussion injury data was derived from participant self-report. Injuries can only be self-reported if the injury was originally recognised. Past research (e.g., McCrea et al., 2004; Valovich McLeod et al., 2008) and the data presented in Chapter 2 suggest that the UK general public has very limited knowledge of sport concussion and so likely misdiagnose whether or not they have ever sustained a sport concussion. This limitation might have been particularly relevant in Chapters 2 and 3, as test performance was compared between sport-concussed and non-concussed participants, and group allocation was based on the participant sport concussion injury self-report. Therefore, it cannot be excluded that individuals who had sustained the injury, but did not recognise it as such, failed to report it. Therefore, group allocation cannot be assumed as error-free in the thesis. A better approach would be to match injury self-reports with medical records. However, considering the ethical hurdles, the involved temporal and personal costs, this approach proved not feasible within this thesis. Furthermore, Kay and Teasdale (2001) reported that only very few individuals with sport concussion appeared to seek any medical attention, so making confirmation with medical records impossible. Another approach would have been to improve the direct assessment of injury history (i.e., asking "have you ever sustained this injury") by providing an injury definition to the participant. In addition, if a symptom-based injury history assessment was included (i.e., asking participants whether they recall having experienced any of a list of symptoms, such as headache, dizziness, or sensitivity to light, following an impact to the head or neck; see LaBotz et al., 2005) might have helped identify individuals who had sustained a sport concussion, but failed to recognise it themselves.

Another limitation of the thesis is that all of the data collected here originated from university student study volunteers, mainly from the University of Birmingham. Participation required that athletes volunteered their time. This self-selection might have been an issue that caused bias in the participants that took part in the thesis studies. It would be better to have had a larger sample of participants that better reflected the general population. For example, access to a wider range of members of the general public, including older adults, and a mix of background (e.g., work, education, socio-economic status etc.) would better represent the general population. This could be achieved by for example recruiting participants through snowball sampling (as done by Chapman & Hudson, 2010) or local sport clubs. The sample limitation restricts the generalisability of the data presented in Chapters 3, 4 and 5, though if wider samples were obtained, the groups would need balancing for factors that may influence health-related knowledge, neuropsychological functioning and sport concussion recovery. For example, age and education are known moderators of health knowledge (Kenkel, 1991), neuropsychological test performance (Grindel et al., 2001) and sport concussion recovery (McCrory et al., 2009). In the present thesis, the sampling focus had group homogeneity and so it provided reasonable control over known confound moderators. Therefore, future studies should consider testing a wider range of participants, making sure of group homogeneity.

The final limitation concerns the number of dependent variables used from the applied statistical tests. In the thesis, the stated hypotheses concerned comparatively comprehensive constructs (e.g., sport concussion knowledge, post-concussion neuropsychological functioning) that were operationalised using multiple dependent variables (e.g., 29 statements in Chapters 2 and 3, 12 measures derived from the applied neuropsychological tests in Chapter 4). This means that multiple statistical comparisons were conducted to test the hypotheses. For example, in the main hypothesis of Chapter 2, we calculated one odds ratio per statement, but additional analyses required three chi-square tests per statement (i.e., one to address response certainty by sport concussion history, one to address misconceptions in assured responders by sport concussion history, and one to address misconceptions in guess responders by sport concussion history). In Chapters

4 and 5, we operationalised neuropsychological functioning using multiple neuropsychological test measures (e.g., mean reaction time, errors) in comparatively small samples. Using multiple tests could have increased the chances of a type one error (i.e., reporting a significant finding than was caused by chance). To improve statistical robustness, it would be better to increasing the sample size and perhaps introduce composite scores into the data analysis. For example, in Chapter 5, composite scores could be calculated for each neuropsychological function area (e.g., memory, executive function shifting) to reduce the number of dependent variables and statistical comparisons. However, while reducing the number of conducted statistical tests may appear desirable, it is important to maintain a comparable level of informational detail. Therefore, one composite score each to reflect reaction time and response efficiency (i.e., error responses, response omissions) respectively might yield a balance between improving statistical robustness and maintaining behavioural test detail.

6.3 Future directions

The following paragraphs will present future avenues based on the data from the thesis that we suggest would have important research and clinical implications.

On the basis of findings from Chapter 2, one interesting avenue of research would be to develop an educational programme on sport concussion for athletes, implement it and test whether it improves sport concussion knowledge *and* yields changes in the injury's appraisal and post-injury sport playing behaviour (e.g., acceptance of and compliance with the advised rest). This could be started at the university team level and, if successful, extended to a larger audience (e.g., coaches, the general public etc.). Related to this, it would be interesting to assess whether the terminology effect from Chapter 3 disappears with better injury knowledge. For example, if participants better understand the seriousness of concussion, do they regard it with similar understanding as that currently shown for mild traumatic brain injury? It would also be interesting to measure long-term effects of the educational programme and re-assess the UK general public's sport concussion knowledge in perhaps five years to test whether an improvement in knowledge accuracy could be found (similar to that reported for the North American population by Hux et al., 2006).

An interesting avenue of research that could be pursued from the data presented in Chapter 4 could be the incorporation of biological markers. Chapter 4 showed evidence of late neuropsychological performance differences between self-reported sport-concussed and non-concussed university contact sport athletes in measures of memory recall and executive functioning. In the discussion of Chapter 4, we argued that within sport concussion, the heterogeneity in the sustained head impact and resulting clinical manifestation might be too great to dichotomise any given sample and that a biological marker might be necessary to improve comparability of the groups via the sustained injury. Whereas conventional brain imaging methods, such as computer tomography and structural magnetic resonance imaging (MRI), have not been able to prove structural abnormalities (Bigler, 2001), this does not imply the absence of brain abnormalities, but that the current clinical methods might not be sensitive enough. A better method might be to use Diffusion Tensor Imaging (DTI; Bigler & Bazarian, 2010; Zhang, Johnson, Pennell, Ray, Sebastianelli & Slobounov, 2010). The DTI method utilises the movement of water molecules parallel to fiber tracts in order to map the brain's white matter tracts. In intact white matter tracts, the myelin sheath around the axons restricts the movement of water molecules, so that movement is limited parallel to the fiber tract. However, if white matter tracts are damaged, the myelin sheath allows water molecules to move more freely and so, water molecules may move perpendicular to the fiber tracts. The DTI method can detect this difference in normal versus damaged tracts (e.g., Zhang et al., 2010). It would be interesting to combine DTI and neuropsychological testing. For example, findings from DTI could be used to identify athletes with white matter abnormalities. Based on DTI findings, individuals might be grouped together. Their neuropsychological test performance could be compared to uninjured athletes with no structural white matter abnormalities. This might increase the within-group homogeneity and yield greater consistency in the literature.

The combined approach of brain imaging and neuropsychological testing could also be extended to the assessment of sport concussion recovery. Chapter 5 presented data from a single case study using a pre-injury (baseline) versus post-injury control group comparison design. Here, the neuropsychological testing could be complemented by brain imaging. Athletes could undergo not only pre-season neuropsychological testing, but also pre-season brain imaging, and DTI could be combined with functional MRI and the neuropsychological test battery. In the pre-injury versus post-injury comparison, the DTI could provide data on any changes in the individual's white matter integrity. Functional MRI data could be used to determine whether the Blood-Oxygen-Level Dependence BOLD signal for a particular cognitive test in the neuropsychological test battery shows reduced signal intensity (indicative of impairment) or whether cortical and subcortical networks that an individual recruits during tests change following the injury. This might provide valuable insight into how the injury affects the brain and how these changes correlate with behaviour (i.e., the neuropsychological test performance and the symptoms reported). One advantage of this combined approach could be that it might serve as an additional educational tool in order to improve the athlete's awareness of the seriousness of sport concussion and compliance with advised return-to-play guidelines. Data from this thesis suggest that athletes tend to underestimate the injury's seriousness and that a sport concussion is not necessarily paralleled with brain injury. Brain imaging data that explicitly showed changes between the pre-injury (baseline) and post-injury assessments might help to convey this message to the sport-concussed athlete.

6.4 Conclusion

This thesis set out to address four issues that emerged from the sport concussion literature. The first part of this thesis focused on two injury-knowledge related issues: the assessment of the UK general public's sport concussion knowledge and the examination of whether the heterogeneous terminologies that are synonymously used to relate to the injury are homogeneous or heterogeneous in their overall injury constructs. The second part of this thesis focused on improving the neuropsychological assessment of sport concussion at two different post-injury recovery stages: the late recovery phase (i.e., at least three months post-injury) and the acute and post-acute recovery phase (i.e., up to six weeks post-injury). The data from this thesis revealed that sport concussion knowledge in the UK general public was insufficient and characterised by misconceptions (Chapter 2). The homogeneously used terminologies sport concussion, sport mild traumatic brain injury and sport minor head injury were actually heterogeneously conceptualised (Chapter 3). Self-reported sport concussion was associated with worse verbal memory recall and executive function in the late post-injury stage (Chapter 4), and memory recall and executive function deficits could be detected in the acute and post-acute recovery stage following a sport concussion (Chapter 5).

In the future, we recommend that educational programmes should be established that aim at improving the UK general public's sport concussion knowledge. To counteract the heterogeneous injury understanding that individuals appeared to have, education programmes should correct the overoptimistic view that appears to be associated with the term sport concussion and tone down the negative injury outcome expectations associated with the term mild traumatic brain injury. Programmes that use the minor head injury terminology should refocus their target audience to brain injury. With better education programmes and increased knowledge, we suggest re-assessment the UK's sport concussion knowledge, both immediately following the programme and some time later to establish whether knowledge has increased and also whether terminology has become homogeneous.

We also advise that the neuropsychological assessment of sport concussion should be expanded to include tests of memory recall and executive function in order to yield a more comprehensive and difficult testing tool that is used to assess both long-term and immediate short-term injury effects. We also recommend that new brain imaging methods are introduced into the clinical management of sport concussion and used for the injury diagnosis and the mapping of the injury recovery. Furthermore, we propose that brain imaging might provide a method of grouping injured athletes on the basis of brain injury and that doing so might lead to better understanding of the types of behaviour deficits associated with brain abnormalities.

Appendix A

Supplementary Tables

TABLE A.1: The injury outcome statements used in the questionnaires - Part A1. The underlined part of the statement indicates the terminology manipulation. For each of the three questionnaires, only one term was presented, and one participant was allocated one version.

A sports person who has recovered from a concussion/mild traumatic brain injury/minor head injury is less able to withstand a second blow to the head.
It is easy to tell if a sports person has brain damage from a concussion/mild traumatic brain injury/minor head injury by the way the person looks or acts.
Sports people who have had one concussion/mild traumatic brain injury/minor head injury are more likely to have another.
A concussion/mild traumatic brain injury minor head injury can cause brain damage even if the sports person is not knocked out.
A concussion/mild traumatic brain injury/minor head injury is harmless and never results in long-term problems or brain damage.
Sometimes a second blow to the head can help a sports person remember things that were forgotten.
A little brain damage does not matter since people only use a small portion of their brains anyway.
How quickly a sports person recovers from concussion/mild traumatic brain injury/minor head injury depends mainly on how hard they work at recovering.
Complete recovery from concussion/mild traumatic brain injury/minor head injury is not possible, no matter how badly the sports person wants to recover.
After a concussion/mild traumatic brain injury/minor head injury, it is usually harder to learn than before the injury.
Whiplash injuries to the neck can cause brain damage even if there is no direct blow to the head.
The only sure way to tell of someone has suffered brain damage from a concussion/mild traumatic brain injury/minor head injury is by an X-ray of the brain.
Drinking alcohol may affect a sports person differently after a concussion/mild traumatic brain injury/minor head injury.
A concussion/mild traumatic brain injury/minor head injury affects men's and women's brains differently.
When a sports person is knocked unconscious, most wake up quickly with no lasting effects.

Table A.2: The injury outcome statements used in the questionnaire - Part A2. The underlined part of the statement indicates the terminology manipulation. For each of the three questionnaires, only one term was presented, and one participant was allocated one version.

Sports persons usually have more trouble remembering things that happen after a concussion/mild traumatic brain injury/minor head injury than remembering things from before.
Emotional problems after concussion/mild traumatic brain injury/minor head injury are usually not related to brain damage.
Once a recovering sports person feels back to normal, the recovery process is complete.
It is good advice to rest and remain inactive during recovery.
Asking sports persons with a concussion/mild traumatic brain injury/minor head injury about their recovery is the most accurate, informative way to find out how they have progressed.
A sports person who has a concussion/mild traumatic brain injury/minor head injury will be just like new in several weeks.
Recovery from a concussion/mild traumatic brain injury/minor head injury is usually complete in about a week.
A sports person with a concussion/mild traumatic brain injury/minor head injury may have trouble remembering events before the concussion/mild traumatic brain injury/minor head injury, but usually does not have trouble learning new things.
A concussion/mild traumatic brain injury/minor head injury may cause one to feel depressed, sad, and hopeless.
Sports persons with a concussion/mild traumatic brain injury/minor head injury usually show a good understanding of their problems because they experience them every day.
Most sports persons with concussion/mild traumatic brain injury/minor head injury are not fully aware of its effect on their behaviour and performance.
In contact sports, such as rugby, American football, or ice hockey, concussion/mild traumatic brain injury/minor head injury is part of the game.
In sports, concussions/mild traumatic brain injuries/minor head injuries almost never happen.

Appendix B

Questionnaires

Alcohol Use Disorder Identification Test (AUDIT)

Please answer some questions about your use of alcohol beverages during the last year.	
How often do you have a drink containing alcohol? ( ) never ( ) monthly or less ( ) 2-4 times a month ( ) 2-3 times a week ( ) 4 or more times a week	*How often during the last year have you needed a first drink in the morning to get yourself going after a heavy drinking session?* ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily
How many drinks do you have on a typical day when you are drinking? ( ) 1 or 2 ( ) 3 or 4 ( ) 5 or 6 ( ) 7 to 9 ( ) 10 or more	*How often during the last year have you had a feeling of guilt or remorse after drinking?* ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily
How often do you have six or more drinks on one occasion? ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily	*How often during the last year have you been unable to remember what happened the night before because you had been drinking?* ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily
How often during the last year have you found that you were not able to stop drinking once you had started? ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily	*Have you or someone else been injured because of your drinking?* ( ) no ( ) yes, but not in the last year ( ) yes, during the last year

How often during the last year have you failed to do what was expected of you because of drinking? ( ) never ( ) less than monthly ( ) monthly ( ) weekly ( ) daily or almost daily	*Has a relative, friend, doctor, or other health care worker been concerned about your drinking or suggested to cut down?* ( ) no ( ) yes, but not in the last year ( ) yes, during the last year

Please answer some questions about your use of drugs during the last 12 months!

Have you IN THE LAST 12 MONTHS taken	**yes**	**no**	**Don't want to answer**
AMPHETAMINES (SPEED, WHIZ, UPPERS)?			
CANNABIS (MARIJUANA, GRASS, HASH, GANJA, BLOW, DRAW, SKUNK)?			
COCAINE/ COKE?			
CRACK/ ROCK/ STONES?			
ECSTASY ('E')?			
HEROIN (SMACK, SKAG, 'H')?			
LSD or ACID?			
MAGIC MUSHROOMS?			
METHADONE or PHYSEPTONE?			
SEMERON?			
TRANQUILLISERS (TEMAZAPAM, VALIUM)?			
AMYL NITRITE (POPPERS)?			
ANABOLIC STERIODS (STEROIDS)?			
GLUES, GAS or AEROSOLS (to sniff or inhale)?			
	yes	**no**	**Don't want to answer**
Apart from anything you have already mentioned, have you ever taken PILLS or POWDERS (not prescribed by a doctor) when you didn't know what they were?			
Apart from anything you have already mentioned, have you EVER SMOKED SOMETHING (excluding tobacco) when you didn't know what it was?			
Apart from anything you have already mentioned, have you EVER taken ANYTHING ELSE THAT YOU THOUGHT WAS A DRUG (not prescribed by a doctor) when you didn't know what it was?			

Have you IN THE LAST MONTH taken	**yes**	**no**	**Don't want to answer**
AMPHETAMINES (SPEED, WHIZ, UPPERS)?			
CANNABIS (MARIJUANA, GRASS, HASH, GANJA, BLOW, DRAW, SKUNK)?			
COCAINE/ COKE?			
CRACK/ ROCK/ STONES?			
ECSTASY ('E')?			
HEROIN (SMACK, SKAG, 'H')?			
LSD or ACID?			
MAGIC MUSHROOMS?			
METHADONE or PHYSEPTONE?			
SEMERON?			
TRANQUILLISERS (TEMAZAPAM, VALIUM)?			
AMYL NITRITE (POPPERS)?			
ANABOLIC STERIODS (STEROIDS)?			
GLUES, GAS or AEROSOLS (to sniff or inhale)?			

	yes	**no**	**Don't want to answer**
Apart from anything you have already mentioned, have you ever taken PILLS or POWDERS (not prescribed by a doctor) when you didn't know what they were?			
Apart from anything you have already mentioned, have you EVER SMOKED SOMETHING (excluding tobacco) when you didn't know what it was?			
Apart from anything you have already mentioned, have you EVER taken ANYTHING ELSE THAT YOU THOUGHT WAS A DRUG (not prescribed by a doctor) when you didn't know what it was?			

Please answer some questions on your current medication usage!

	yes	no
Do you take any medication at the moment?		
Please specify.		
Was the medication prescribed by a doctor?		
Have you bought the medication without a prescription (“over the counter”)?		
Do you smoke?		

Hospital Anxiety and Depression Scale HADS

Please choose one out of the four given responses per question and indicate how you felt during last week.

I feel tense or 'wound up':
( ) most of the time
( ) a lot of the time
( ) from time to time, occasionally
( ) not at all

I still enjoy the things I used to enjoy:
( ) definitely as much
( ) not quite so much
( ) only a little
( ) hardly at all

I get a sort of frightened feeling as if something awful is about to happen:
( ) very definitely and quite badly
( ) yes, but not too badly
( ) a little, but it doesn't worry me
( ) not at all

I can laugh and see the funny side of things:
( ) as much as I always could
( ) not quite so much now
( ) definitely not so much now
( ) not at all

Worrying thoughts go through my mind:
( ) a great deal of the time
( ) a lot of the time
( ) from time to time, but not too often
( ) only occasionally

I feel cheerful:
( ) not at all
( ) not often
( ) sometimes
( ) most of the time

I feel as if I am slowed down:
( ) nearly all the time
( ) very often
( ) sometimes
( ) not at all

I get a sort of frightened feeling like "butterflies" in the stomach:
( ) not at all
( ) occasionally
( ) quite often
( ) very often

I have lost interest in my appearance:
( ) definitely
( ) I don't take as much care as I should
( ) I may not take quite as much care
( ) I take just as much care as ever

I feel restless as if I have to be on the move:
( ) very much indeed
( ) quite a lot
( ) not very much
( ) not at all

I look forward with enjoyment to things:
( ) as much as I ever did
( ) rather less than I used to
( ) definitely less than I used to
( ) hardly at all

I get sudden feelings of panic:
( ) very often indeed
( ) quite often
( ) not very often
( ) not at all

I can sit at ease and feel relaxed:
( ) definitely
( ) usually
( ) not often
( ) not at all

I can still enjoy a good book or radio or TV programme:
( ) often
( ) sometimes
( ) not often
( ) very seldom

Injury Assessment Questionnaire IAQ

Age	
Height (in centimetre)	
Gender	Female / Male
Weight (in kilogram)	
Years in education	

1. What kind of sport do you participate in? Please provide details below.

____

____

____

2. Have you ever had a concussion?

yes		no	

If your answer is no, please got to question 11.

3. How many concussions have you experienced within the last 12 months?

1		2		3		More than 3	
						How many?	

4. When did the most recent concussion incident happen? Please specify.

____

All the following questions relate to the most recent concussion you experienced.

5. How did the most recent concussion occur? Please specify.

assault		
fall		
sport		Please specify: ____________________
traffic accident		
other		Please specify: ____________________

6. Did you lose consciousness?

yes		no		don't remember	

If so, how you long (in minutes) did you lose consciousness? ____________

7. Were you examined by a doctor or at hospital?

yes		no		
Please specify	GP		A&E	

8. Following concussion which symptoms did you experience? Please specify.

____

____

9. For how long was it before you returned to sport and/or physical activity and/or work/ school/ university following concussion?

same day	
next day	
after 2 days	
after 3 days	
after 4 days	
after 5 days	
after 6 days	

after more than 7 days		Please specify:

10. Why did you refrain from returning to sport and/or physical activity and/or work/ school/ university following concussion?

own decision	
doctor's advise	

other		Please Specify:

11. Have you ever had any other sports-related injury within the last 12 months?

yes		no	

If your answer is no, please got to question 19.

12. If so, how many injuries occurred within the last 12 months? Please specify.

1		2		3		More than 3	
						How many?	

13. If so, when did the most recent injury happen? Please specify.

____

14. Which part of your body did you injure? Please provide details below.

____

____

15. Were you examined by a doctor or at hospital?

yes		no		
Please specify	GP		A&E	

16. Following the injury which symptoms did you experience? Please specify.

____

____

17. For how long was it before you returned to sport and/or physical activity and/or work/ school/ university following injury?

same day	
next day	
after 2 days	
after 3 days	
after 4 days	
after 5 days	
after 6 days	

after more than 7 days		Please specify: ______________________

18. Why did you refrain from returning to sport and/or physical activity and/or work/ school/ university following injury?

own decision	
doctor's advise	

other		Please Specify: ________

19. Have you been diagnosed with any neurological condition, such as epilepsy or migraine?

yes		no	

Please specify: ________

20. Have you been diagnosed with any learning difficulty, such as dyslexia?

yes		no	

Please specify: ________

Pain analogue scale

How much pain did you experience in the <u>last week</u>? Please circle the number that best describes your pain at its worst in the past week.

0	1	2	3	4	5	6	7	8	9	10

no pain — pain as bad as you can imagine

Positive and Negative Affect Scales PANAS

This list consists of a number of words that describe different feelings and emotions. Read each item and then circle the appropriate answer next to that word. Indicate to what extent you have felt this way during the past week.

Use the following scale to record your answers.

(1) Very slightly or not at all (2) A little (3) Moderately

(2) Quite a bit (5) Extremely

	very slightly or not at all	a little	moderately	quite a bit	extremely
interested	1	2	3	4	5
distressed	1	2	3	4	5
excited	1	2	3	4	5
upset	1	2	3	4	5
strong	1	2	3	4	5
guilty	1	2	3	4	5
scared	1	2	3	4	5
hostile	1	2	3	4	5
enthusiastic	1	2	3	4	5
proud	1	2	3	4	5
irritable	1	2	3	4	5
alert	1	2	3	4	5
ashamed	1	2	3	4	5
inspired	1	2	3	4	5
nervous	1	2	3	4	5
determined	1	2	3	4	5
attentive	1	2	3	4	5
jittery	1	2	3	4	5
active	1	2	3	4	5
afraid	1	2	3	4	5

Post Concussion Symptom Scale PCSS

Sometimes people experience symptoms which can cause worry or nuisance. We would like to know if you **now** (i.e. over the last **24 hours**) suffer any of the symptoms given below. Please rate the *frequency*, *intensity* and *duration* of the following symptoms:

headache	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
'pressure in the head'	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
neck pain	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
balance problems or dizzy	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
nausea or vomiting	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
vision problems	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant

hearing problems/ 'ringing'	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
'don't feel right'	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
feeling 'dinged' or dazed	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
confusion	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
feeling slowed down	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
feeling 'like in a fog'	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
drowsiness	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
	frequency	not at all	seldom	often	very often	all the time

fatigue or low energy	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
more emotional than usual	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
irritability	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
difficulty concentrating	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
difficulty remembering	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
sadness	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
nervous or anxious	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
	frequency	not at all	seldom	often	very often	all the time

trouble falling asleep	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
sleeping more than usual	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
sensitivity to light	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant
sensitivity to noise	*frequency*	not at all	seldom	often	very often	all the time
	intensity	not at all	vaguely present	clearly present	interfering	disabling
	duration	not at all	a few seconds	a few minutes	a few hours	constant

Rivermead Post Concussion Questionnaire RPQ

Sometimes people experience symptoms which can cause worry or nuisance. We would like to know if you now suffer any of the symptoms given below. For each one please circle the number closest to our answer

0	=	not experienced at all
1	=	no more of a problem
2	=	a mild problem
3	=	a moderate problem
4	=	a severe problem

Do you now (i.e. over the last 24 hours) suffer from:

headaches	0	1	2	3	4
feelings of dizziness	0	1	2	3	4
nausea and/or vomiting	0	1	2	3	4
noise sensitivity, easily upset by loud noise	0	1	2	3	4
sleep disturbance	0	1	2	3	4
fatigue, tiring more easily	0	1	2	3	4
being irritable, easily angered	0	1	2	3	4
feeling depressed or tearful	0	1	2	3	4
feeling frustrated or impatient	0	1	2	3	4
forgetfulness, poor memory	0	1	2	3	4
poor concentration	0	1	2	3	4
taking longer to think	0	1	2	3	4
blurred vision	0	1	2	3	4
light sensitivity, easily upset by bright light	0	1	2	3	4
double vision	0	1	2	3	4
restlessness	0	1	2	3	4

Task Difficulty Inventory TDI

Please circle what applies.

How difficult did you find the tasks?

Not at all difficult	0	1	2	3	4	5	6	Extremely difficult

How stressful did you find the tasks?

Not at all stressful	0	1	2	3	4	5	6	Extremely stressful

How arousing (exciting) did you find the tasks?

Not at all Arousing	0	1	2	3	4	5	6	Extremely arousing

How well do you think you performed?

Not very Well	0	1	2	3	4	5	6	Very well

How confusing did you find the tasks?

Not at all confusing	0	1	2	3	4	5	6	Extremely confusing

How engaging did you find the tasks?

Not at all engaging	0	1	2	3	4	5	6	Extremely engaging

How embarrassing did you find the tasks?

Not at all embarrassing	0	1	2	3	4	5	6	Extremely embarrassing

Please specify if you experienced one of the tasks as particularly difficult?

Appendix C

Semi-structured Interview

Semi-structured Interview

Testing Session			Planned testing	Date of Testing
1	baseline 1			
2	baseline 2			
3	date of injury (post 1)			
4	post 2	1 week after injury		
5	post 3	2 weeks after injury		
6	post 4	6 weeks after injury		
7	post 5 (optional)	12 weeks after injury		

BASELINE 1

Demographics & Sports

Age ____________ Main Team Sport ____________ Average hours per week ______

Number of years participating competitively in main team sport ____________

Highest level ever played in main team sport

- international ☐
- national ☐
- regional ☐
- county ☐
- club ☐

Gender

- Female ☐
- Male ☐

What is your highest educational attainment?

- GCSE ☐
- A-level, International Baccalaureate, AS-level ☐
- Diploma ☐
- BA, BEng, BSc ☐
- MA, MPhil, MRes, MSc ☐
- MD, PhD, Doctorate ☐

History of head injuries

Have you ever had a head injury?	no	☐		
	yes, in sports	☐	within the past 2 weeks	☐
			within the past month	☐
			1-3 months ago	☐
			3-6 months ago	☐
			6-9 months ago	☐
			9-12 months ago	☐
			longer than 12 months ago	☐
	yes, but not in sports	☐	within the past 2 weeks	☐
			within the past month	☐
			1-3 months ago	☐
			3-6 months ago	☐
			6-9 months ago	☐
			9-12 months ago	☐
			longer than 12 months ago	☐
Did you sustain more than one head injury?	no	☐		

yes ☐ How many? ___________

Have you been diagnosed with any neurological condition? no ☐
yes ☐ Which one? ___________

Have you been diagnosed with any learning difficulty? no ☐
yes ☐ Which one? ___________

Smoking, alcohol & drug consumption

Do you smoke? no ☐
yes ☐

Have you taken any illegal drugs during the last 4 weeks? no ☐
yes ☐ Which? ___________

Are you currently taking any medication? no ☐
yes, prescribed ☐ Which? ___________
yes, bought over counter ☐ Which? ___________

Do you drink alcohol? yes ☐ no ☐

For *males*: how often do you have 8 or more drinks on one occasion?

For *females*: how often do you have 6 or more drinks on one occasion?

never ☐
less than monthly ☐
monthly ☐
weekly ☐
daily or almost daily ☐

never ☐
less than monthly ☐
monthly ☐
weekly ☐
daily or almost daily ☐

How often during the last year have you been unable to remember what happened the night before because you had been drinking?

never ☐
less than monthly ☐
monthly ☐
weekly ☐
daily or almost daily ☐

In the last year has a relative or friend, or a doctor or health worker been concerned about your drinking or suggested to cut down?

no ☐
yes, on one occasion ☐
yes, on more than one occasion ☐

INTERVIEW DAY OF INJURY – POST 1

How did the injury happen? ______________________________

match/ competition ☐ practice/ training ☐

Have you lost consciousness? no ☐ yes ☐ For roughly how long? ______________________

Have you experienced a memory loss? no ☐ yes ☐ For roughly how long? ______________________

Following the injury, did you experience any symptoms? no ☐ yes ☐

Which symptoms? ______________________

Were you examined by a doctor or at hospital? no ☐ yes ☐

Following the injury, have you returned to match/ competition, practice/ training? no ☐ yes ☐

Have your smoking or drinking habits changed? no ☐

yes ☐ How? ________________

Have you taken any illegal drugs during the last 4 weeks? no ☐

yes ☐ Which? ________________

Are you currently taking any medication? no ☐

yes, prescribed ☐ Which? ____________________
yes, bought over counter ☐ Which? ____________________

POST 2 – 1 WEEK POST-INJURY

Have all injury-related symptoms resolved? no ☐ yes ☐

Were you examined by a doctor or at hospital? no ☐ yes ☐

Have you returned to match/ competition, practice/ training yet? no ☐ yes ☐ When? ________________

Have your smoking or drinking habits changed?
no ☐
yes ☐ How? ____________________

Have you taken any illegal drugs during the last 4 weeks?
no ☐
yes ☐ Which? ____________________

Are you currently taking any medication?
no ☐
yes, prescribed ☐ Which? ____________________
yes, bought over counter ☐ Which? ____________________

POST 3 – 2 WEEKS POST-INJURY

Have all injury-related symptoms resolved? no ☐ yes ☐

Were you examined by a doctor or at hospital? no ☐ yes ☐

Have you returned to match/ competition, practice/ training yet? no ☐ yes ☐

Have your smoking or drinking habits changed?
no ☐
yes ☐ How? ____________________

Have you taken any illegal drugs during the last 4 weeks?
no ☐
yes ☐ Which? ___________________

Are you currently taking any medication?
no ☐
yes, prescribed ☐ Which? __________________
yes, bought over counter ☐ Which? __________________

POST 4 – 6 WEEKS POST-INJURY

Have all injury-related symptoms resolved? no ☐ yes ☐

Were you examined by a doctor or at hospital? no ☐ yes ☐

Have you returned to match/ competition, practice/ training yet? no ☐ yes ☐

Have your smoking or drinking habits changed?	no	☐	
	yes	☐	How? ____________________
Have you taken any illegal drugs during the last 4 weeks?	no	☐	
	yes	☐	Which? __________________
Are you currently taking any medication?	no	☐	
	yes, prescribed	☐	Which? __________________
	yes, bought over counter	☐	Which? __________________

Bibliography

Anderson, T., Heitger, M., and Macleod, A. D. (2006). Concussion and mild head injury. *Practical Neurology*, 6(6):342.

Anderson, V. and Catroppa, C. (2005). Recovery of executive skills following paediatric traumatic brain injury (tbi): a 2 year follow-up. *Brain Injury*, 19(6):459–70.

Asplund, C. A., McKeag, D. B., and Olsen, C. H. (2004). Sport-related concussion: factors associated with prolonged return to play. *Clinical Journal of Sport Medicine*, 14(6):339–43.

Aubrey, J. B., Dobbs, A. R., and Rule, B. G. (1989). Laypersons' knowledge about the sequelae of minor head injury and whiplash. *Journal of Neurology, Neurosurgery and Psychiatry*, 52(7):842–846.

Bailey, C. M., Echemendia, R. J., and Arnett, P. A. (2006). The impact of motivation on neuropsychological performance in sports-related mild traumatic brain injury. *Journal of the International Neuropsychological Society*, 12(4):475–84.

Baron, R. M. and Kenny, D. a. (1986). The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, 51(6):1173–82.

Barth, J., Alves, W., Ryan, T., Macciocchi, S., Rimel, R., Jane, J., and Nelson, W. (1989). Mild head injury in sports: neuropsychological sequelae and recovery of function. *Mild head injury*, pages 257–275.

Bartolomeo, P. and Chokron, S. (2002). Orienting of attention in left unilateral neglect. *Neuroscience & Biobehavioral Reviews*, 26(2):217–234.

Bastin, C., Linden, M., Charnallet, A., Denby, C., Montaldi, D., Roberts, N., and Andrew, M. (2004). Dissociation between recall and recognition memory performance in an amnesic patient with hippocampal damage following carbon monoxide poisoning. *Neurocase*, 10(4):330–44.

Becker, M. and Maiman, L. (1975). Sociobehavioral determinants of compliance with health and medical care recommendations. *Medical Care*, 13(1):10–24.

Beglinger, L. J., Gaydos, B., Tangphao-Daniels, O., Duff, K., Kareken, D. a., Crawford, J., Fastenau, P. S., and Siemers, E. R. (2005). Practice effects and the use of alternate forms in serial neuropsychological testing. *Archives of Clinical Neuropsychology*, 20(4):517–29.

Belanger, H. G., Spiegel, E., and Vanderploeg, R. D. (2010). Neuropsychological performance following a history of multiple self-reported concussions: a meta-analysis. *Journal of the International Neuropsychological Society*, 16(2):262–7.

Belanger, H. G. and Vanderploeg, R. D. (2005). The neuropsychological impact of sports-related concussion: a meta-analysis. *Journal of the International Neuropsychological Society : JINS*, 11(4):345–57.

Benedetti, F., Lanotte, M., Lopiano, L., and Colloca, L. (2007). When words are painful: unraveling the mechanisms of the nocebo effect. *Neuroscience*, 147(2):260–71.

Bernstein, D. M. (2002). Information processing difficulty long after self-reported concussion. *Journal of the International Neuropsychological Society*, 8(5):673–82.

Bigler, E. D. (2001). Distinguished Neuropsychologist Award Lecture 1999. The lesion(s) in traumatic brain injury: implications for clinical neuropsychology. *Archives of Clinical Neuropsychology*, 16(2):95–131.

Bigler, E. D. and Bazarian, J. J. (2010). Diffusion tensor imaging: a biomarker for mild traumatic brain injury? *Neurology*, 74(8):626–7.

Blumenfeld, R. S. and Ranganath, C. (2007). Prefrontal cortex and long-term memory encoding: an integrative review of findings from neuropsychology and neuroimaging. *Neuroscientist*, 13(3):280–91.

Bohn, M. J., Babor, T. F., and Kranzler, H. R. (1995). The alcohol use disorders identification test (audit): validation of a screening instrument for use in medical settings. *Journal of Studies on Alcohol*, 56(4):423–32.

Brandt, J. and Benedict, R. H. B. (2001). *Hopkins verbal learning test– revised: professional manual*. Psychological Assessment Resources, Lutz, FL.

Broglio, S. P., Ferrara, M. S., Piland, S. G., Anderson, R. B., and Collie, a. (2006). Concussion history is not a predictor of computerised neurocognitive performance. *British Journal of Sports Medicine*, 40(9):802–5; discussion 802–5.

Broglio, S. P. and Puetz, T. W. (2008). The effect of sport concussion on neurocognitive function, self-report symptoms and postural control : a meta-analysis. *Sports medicine (Auckland, N.Z.)*, 38(1):53–67.

Brooks, D. N., Deelman, B. G., van Zomeren, A. H., van Dongen, H., van Harskamp, F., and Aughton, M. E. (1984). Problems in measuring cognitive recovery after acute brain injury. *Journal of Clinical Neuropsychology*, 6(1):71–85.

Broshek, D. K. and Freeman, J. R. (2005). Psychiatric and neuropsychological issues in sport medicine. *Clinical Journal of Sport Medicine*, 24(3):663–79.

Brown, C. N., Guskiewicz, K. M., and Bleiberg, J. (2007). Athlete characteristics and outcome scores for computerized neuropsychological assessment: a preliminary analysis. *Journal of Athletic Training*, 42(4):515–23.

Bruce, J. M. and Echemendia, R. J. (2003). Delayed-onset deficits in verbal encoding strategies among patients with mild traumatic brain injury. *Neuropsychology*, 17(4):622–9.

Bruce, J. M. and Echemendia, R. J. (2004). Concussion history predicts self-reported symptoms before and following a concussive event. *Neurology*, 63(8):1516–8.

Busch, R. M., Booth, J. E., McBride, A., Vanderploeg, R. D., Curtiss, G., and Duchnick, J. J. (2005). Role of executive functioning in verbal and visual memory. *Neuropsychology*, 19(2):171–80.

Castaneda, A. E., Tuulio-Henriksson, A., Marttunen, M., Suvisaari, J., and Lönnqvist, J. (2008). A review on cognitive impairments in depressive and anxiety disorders with a focus on young adults. *Journal of Affective Disorders*, 106(1-2):1–27.

Catena, R. D., van Donkelaar, P., Halterman, C. I., and Chou, L.-S. (2009). Spatial orientation of attention and obstacle avoidance following concussion. *Experimental brain research*, 194(1):67–77.

Chalmers, D. J. (2002). Injury prevention in sport: not yet part of the game? *Injury Prevention*, 8 Suppl 4:IV22–5.

Chapman, R. C. G. and Hudson, J. M. (2010). Beliefs about brain injury in britain. *Brain Injury*, 24(6):797–801.

Chelune, G., Naugle, R., Lüders, H., Sedlak, J., and Awad, I. (1993). Individual change after epilepsy surgery: Practice effects and base-rate information. *Neuropsychology*, 7(1):41–52.

Christensen, B. K., Colella, B., Inness, E., Hebert, D., Monette, G., Bayley, M., and Green, R. E. (2008). Recovery of cognitive function after traumatic brain injury: a multilevel modeling analysis of canadian outcomes. *Archives of Physical Medicine and Rehabilitation*, 89(12 Suppl):S3–15.

CogState Ltd. (). CogState Sport. Melbourne, Australia.

Cohen, J., MacWhinney, B., Flatt, M., and Provost, J. (1993). PsyScope: An interactive graphical system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods Instruments and Computers*, 25:257–257.

Collie, A. (2004). Statistical procedures for determining the extent of cognitive change following concussion. *British Journal of Sports Medicine*, 38(3):273–278.

Collie, A., Darby, D., and Maruff, P. (2001). Computerised cognitive assessment of athletes with sports related head injury. *British Journal of Sports Medicine*, 35(5):297–302.

Collie, A., Maruff, P., Makdissi, M., McStephen, M., Darby, D. G., and McCrory, P. (2004). Statistical procedures for determining the extent of cognitive change following concussion. *British Journal of Sports Medicine*, 38(3):273–8.

Collins, M. W. (2008). Discussion on impact test modules. Personal communication.

Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., Nogle, S., Wasik, M., Cordry, D., Daugherty, K. M., Sears, S. F., Nicolette, G., Indelicato, P., and McKeag, D. B. (1999). Relationship between concussion and neuropsychological performance in college football players. *JAMA*, 282(10):964–70.

Colvin, A. C., Mullen, J., Lovell, M. R., West, R. V., Collins, M. W., and Groh, M. (2009). The role of concussion history and gender in recovery from soccer-related concussion. *The American Journal of Sports Medicine*, 37(9):1699–704.

Covassin, T., Elbin, R. J., Stiller-Ostrowski, J. L., and Kontos, A. P. (2009). Immediate post-concussion assessment and cognitive testing (ImPACT) practices of sports medicine professionals. *Journal of athletic training*, 44(6):639–44.

Crawford, J. R. and Garthwaite, P. H. (2002). Investigation of the single case in neuropsychology: confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*, 40(8):1196–208.

Cremona-Meteyard, S. L. and Geffen, G. M. (1994). Persistent visuospatial attention deficits following mild head injury in australian rules football players. *Neuropsychologia*, 32(6):649–62.

Cusimano, M. D. (2009). Canadian minor hockey participants' knowledge about concussion. *Canadian Journal of Neurological Sciences*, 36(3):315–20.

De Beaumont, L., Théoret, H., Mongeon, D., Messier, J., Leclerc, S., Tremblay, S., Ellemberg, D., and Lassonde, M. (2009). Brain function decline in healthy retired athletes who sustained their last sports concussion in early adulthood. *Brain*, 132(Pt 3):695–708.

de Haan, E. H., Nys, G. M., and Van Zandvoort, M. J. (2006). Cognitive function following stroke and vascular cognitive impairment. *Current Opinion in Neurology*, 19(6):559–64.

Delaney, J. S. and Frankovich, R. (2005). Head injuries and concussions in soccer. *Clinical Journal of Sport Medicine*, 15(4):216–9; discussion 212–3.

Delaney, J. S., Lacroix, V. J., Gagne, C., and Antoniou, J. (2001). Concussions among university football and soccer players: a pilot study. *Clinical Journal of Sport Medicine*, 11(4):234–40.

Delaney, J. S., Lacroix, V. J., Leclerc, S., and Johnston, K. M. (2000). Concussions during the 1997 canadian football league season. *Clinical Journal of Sport Medicine*, 10(1):9–14.

Delaney, J. S., Lacroix, V. J., Leclerc, S., and Johnston, K. M. (2002). Concussions among university football and soccer players. *Clinical Journal of Sport Medicine*, 12(6):331–8.

DeMatteo, C. A., Hanna, S. E., Mahoney, W. J., Hollenberg, R. D., Scott, L. a., Law, M. C., Newman, A., Lin, C.-Y. a., and Xu, L. (2010). "My child doesn't have a brain injury, he only has a concussion". *Pediatrics*, 125(2):327–34.

Di Russo, F. and Spinelli, D. (2009). Sport is not always healthy: Executive brain dysfunction in professional boxers. *Psychophysiology*, pages 1–10.

Dobson, K. (1985). The relationship between anxiety and depression. *Clinical Psychology Review*, 5(4):307–324.

Dvorak, J. and Junge, A. (2000). Football injuries and physical symptoms. a review of the literature. *American Journal of Sports Medicine*, 28(5 Suppl):S3–9.

Echemendia, R. J. and Cantu, R. C. (2003). Return to play following sports-related mild traumatic brain injury: the role for neuropsychology. *Applied Neuropsychology*, 10(1):48–55.

Echemendia, R. J. and Julian, L. J. (2001). Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. *Neuropsychology Review*, 11(2):69–88.

Echemendia, R. J., Putukian, M., Mackin, R. S., Julian, L., and Shoss, N. (2001). Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sport Medicine*, 11(1):23–31.

Ellemberg, D., Henry, L. C., Macciocchi, S. N., Guskiewicz, K. M., and Broglio, S. P. (2009). Advances in sport concussion assessment: from behavioral to brain imaging measures. *Journal of Neurotrauma*, 26(12):2365–82.

Ellemberg, D., Leclerc, S., Couture, S., and Daigle, C. (2007). Prolonged neuropsychological impairments following a first concussion in female university soccer athletes. *Clinical Journal of Sport Medicine*, 17(5):369–74.

Erlanger, D., Feldman, D., Kutner, K., Kaushik, T., Kroger, H., Festa, J., Barth, J., Freeman, J., and Broshek, D. (2003). Development and validation of a web-based neuropsychological test protocol for sports-related return-to-play decision-making. *Archives of Clinical Neuropsychology*, 18(3):293–316.

Erlanger, D., Saliba, E., Barth, J., Almquist, J., Webright, W., and Freeman, J. (2001). Monitoring resolution of postconcussion symptoms in athletes: Preliminary results of a web-based neuropsychological test protocol. *Journal of Athletic Training*, 36(3):280–287.

Ettenhofer, M. L. and Abeles, N. (2009). The significance of mild traumatic brain injury to cognition and self-reported symptoms in long-term recovery from injury. *Journal of Clinical and Experimental Neuropsychology*, 31(3):363–72.

Falleti, M. G., Maruff, P., Collie, A., and Darby, D. G. (2006). Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. *Journal of clinical and experimental neuropsychology*, 28(7):1095–112.

Farmer, J. and Johnson-Gerard, M. (1997). Misconceptions about traumatic brain injury among educators and rehabilitation staff: A comparative study. *Rehabilitation Psychology*, 42(4):273–286.

Ferguson, R. J., Mittenberg, W., Barone, D. F., and Schneider, B. (1999). Postconcussion syndrome following sports-related head injury: expectation as etiology. *Neuropsychology*, 13(4):582–589.

Ferrara, M. S., McCrea, M., Peterson, C. L., and Guskiewicz, K. M. (2001). A Survey of Practice Patterns in Concussion Assessment and Management. *Journal of Athletic Training*, 36(2):145–149.

Ferrari, R., Constantoyannis, C., and Papadakis, N. (2001a). Cross-cultural study of symptom expectation following minor head injury in Canada and Greece. *Clinical Neurology and Neurosurgery*, 103(4):254–9.

Ferrari, R., Obelieniene, D., Russell, A. S., Darlington, P., Gervais, R., and Green, P. (2001b). Symptom expectation after minor head injury. A comparative study between Canada and Lithuania. *Clinical Neurology and Neurosurgery*, 103(3):184–190.

Field, M., Collins, M. W., Lovell, M. R., and Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? a comparison of high school and collegiate athletes. *Journal of Pediatrics*, 142(5):546–53.

Gabbe, B. J., Finch, C. F., Bennell, K. L., and Wajswelner, H. (2003). How valid is a self reported 12 month sports injury history? *British journal of sports medicine*, 37(6):545–547.

Gaetz, M., Goodman, D., and Weinberg, H. (2000). Electrophysiological evidence for the cumulative effects of concussion. *Brain Injury*, 14(12):1077–88.

Giza, C. C. and Hovda, D. A. (2001). The neurometabolic cascade of concussion. *Journal of Athletic Training*, 36(3):228–235.

Gonzalez, R. (2007). Acute and non-acute effects of cannabis on brain functioning and neuropsychological performance. *Neuropsychology Review*, 17(3):347–61.

Goodman, D., Gaetz, M., and Meichenbaum, D. (2001). Concussions in hockey: there is cause for concern. *Medicine and Science in Sports and Exercise*, 33(12):2004–9.

Gouvier, W. D., Prestholdt, P. H., and Warner, M. S. (1988). A survey of common misconceptions about head injury and recovery. *Archives of Clinical Neuropsychology*, 3(4):331–343.

Grant, D. A. and Berg, E. A. (1993). *Wisconsin card sorting test*. Western Psycological Services.

Grindel, S. H., Lovell, M. R., and Collins, M. W. (2001). The assessment of sport-related concussion: the evidence behind neuropsychological testing and management. *Clinical Journal of Sport Medicine*, 11(3):134–43.

Gronwall, D. M. A. and Sampson, H. D. (1974). *The psychological effects of concussion*. Auckland University Press.

Guilmette, T. J., Malia, L. A., and McQuiggan, M. D. (2007a). Concussion understanding and management among New England high school football coaches. *Brain Injury*, 21(10):1039–1047.

Guilmette, T. J., Malia, L. a., and McQuiggan, M. D. (2007b). Concussion understanding and management among New England high school football coaches. *Brain injury*, 21(10):1039–47.

Guilmette, T. J. and Paglia, M. F. (2004). The public's misconception about traumatic brain injury: a follow up survey. *Archives of Clinical Neuropsychology*, 19(2):183–189.

Gunstad, J. and Suhr, J. A. (2001). "Expectation as etiology" versus "the good old days": postconcussion syndrome symptom reporting in athletes, headache sufferers, and depressed individuals. *Journal of the International Neuropsychological Society*, 7(3):323–333.

Gunstad, J. and Suhr, J. A. (2002). Perception of illness: nonspecificity of postconcussion syndrome symptom expectation. *Journal of the International Neuropsychological Society*, 8(1):37–47.

Gunstad, J. and Suhr, J. A. (2004). Cognitive factors in Postconcussion Syndrome symptom report. *Archives of Clinical Neuropsychology*, 19(3):391–405.

Guskiewicz, K. M. (2002). No evidence of impaired neurocognitive performance in collegiate soccer players. *American Journal of Sports Medicine*, 30(4):630.

Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., Putukian, M., and McLeod, T. C. V. (2006). Research based recommendations on management of sport related concussion: summary of the National Athletic Trainers' Association position statement. *British Journal of Sports Medicine*, 40(1):6–10.

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Cantu, R. C., Randolph, C., and Jordan, B. D. (2005). Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery*, 57(4):719–26; discussion 719–26.

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Harding, H. P., Matthews, A., Mihalik, J. R., and Cantu, R. C. (2007). Recurrent concussion and risk of depression in retired professional football players. *Medicine and Science in Sports and Exercise*, 39(6):903–9.

Guskiewicz, K. M., McCrea, M., Marshall, S. W., Cantu, R. C., Randolph, C., Barr, W., Onate, J. A., and Kelly, J. P. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the ncaa concussion study. *JAMA*, 290(19):2549–55.

Guskiewicz, K. M., Ross, S. E., and Marshall, S. W. (2001). Postural stability and neuropsychological deficits after concussion in collegiate athletes. *Journal of Athletic Training*, 36(3):263–273.

Guskiewicz, K. M., Weaver, N. L., Padua, D. A., and Garrett, Jr, W. E. (2000). Epidemiology of concussion in collegiate and high school football players. *American Journal of Sports Medicine*, 28(5):643–50.

Haist, F., Shimamura, A. P., and Squire, L. R. (1992). On the relationship between recall and recognition memory. *Journal of Expermental Psychololology*, 18(4):691–702.

Harvey, P. O., Le Bastard, G., Pochon, J. B., Levy, R., Allilaire, J. F., Dubois, B., and Fossati, P. (2004). Executive functions and updating of the contents of working memory in unipolar depression. *Journal of Psychiatric Research*, 38(6):567–76.

Heaton, R., Grant, I., and Matthews, C. (1986). Differences in neuropsychological test performance associated with age, education, and sex. *Neuropsychological assessment of neuropsychiatric disorders*, pages 100–120.

Heilman, K. M. and Valenstein, E. (2003). *Clinical neuropsychology.* Oxford University Press, Oxford, 4th ed edition.

Hinton-Bayre, A. D., Geffen, G. M., Geffen, L. B., McFarland, K. A., and Frijs, P. (1999). Concussion in Contact Sports: Reliable Change Indices of Impairment and Recovery. *Journal of Clinical and Experimental Neuropsychology*, 21(1):70–86.

Hoge, C. W., Goldberg, H. M., and Castro, C. A. (2009). Care of war veterans with mild traumatic brain injury–flawed perspectives. *New England Journal of Medicine*, 360(16):1588–1591.

Hoskins, W., Pollard, H., Hough, K., and Tully, C. (2006). Injury in rugby league. *Journal of Science and Medicine in Sport / Sports Medicine Australia*, 9(1-2):46–56.

Humphreys, G. W., Samson, D., Bickerton, W. L., and Riddoch, M. J. (2009). The Birmingham University Cognitive Screen (BUCS).

Hux, K., Schram, C. D., and Goeken, T. (2006). Misconceptions about brain injury: a survey replication study. *Brain Injury*, 20(5):547–553.

ImPACT Applications, Inc. (). Impact test. Pittsburgh, Pennsylvania, USA.

Ingraham, L. and Aiken, C. (1996). An empirical approach to determining criteria for abnormality in test batteries with multiple measures. *Neuropsychology*, 10(1):120–124.

Iverson, G. (2010). Mild traumatic brain injury meta-analyses can obscure individual differences. *Brain Injury*, (0):1–10.

Iverson, G. L. (2005). Outcome from mild traumatic brain injury. *Current Opinion in Psychiatry*, 18(3):301–317.

Iverson, G. L. (2009). Clinical and Methodological Challenges Associated with Identifying Residual Cognitive Deficits. MTBI 2009: An International Conference on Mild Traumatic Brain Injury.

Iverson, G. L., Brooks, B. L., Collins, M. W., and Lovell, M. R. (2006a). Tracking neuropsychological recovery following concussion in sport. *Brain injury*, 20(3):245–52.

Iverson, G. L., Brooks, B. L., Lovell, M. R., and Collins, M. W. (2006b). No cumulative effects for one or two previous concussions. *British Journal of Sports Medicine*, 40(1):72–5.

Iverson, G. L., Gaetz, M., Lovell, M. R., and Collins, M. W. (2004a). Cumulative effects of concussion in amateur athletes. *Brain injury*, 18(5):433–43.

Iverson, G. L., Gaetz, M., Lovell, M. R., and Collins, M. W. (2004b). Relation between subjective fogginess and neuropsychological testing following concussion. *Journal of the International Neuropsychological Society*, 10(6):904–6.

Iverson, G. L., Lovell, M. R., and Collins, M. W. (2003). Interpreting change on impact following sport concussion. *Clinical Neuropsychologist*, 17(4):460–7.

Jansari, A., Davis, K., and Kapur, N. (2004). Faking it! using accuracy and reaction times to develop a battery for detecting malingered amnesia. Paper presented at the First joint Conference of the European Neuropsychological Societies, Modena, Italy.

Johnston, K. M., McCrory, P., Mohtadi, N. G., and Meeuwisse, W. (2001). Evidence-based review of sport-related concussion: clinical science. *Clinical Journal of Sport Medicine*, 11(3):150–9.

Kaut, K. P., DePompei, R., Kerr, J., and Congeni, J. (2003). Reports of head injury and symptom knowledge among college athletes: implications for assessment and educational intervention. *Clin J Sport Med*, 13(4):213–21.

Kay, A. and Teasdale, G. (2001). Head injury in the United Kingdom. *World Journal of Surgery*, 25(9):1210–1220.

Kelly, J. P. (2000). Concussion in sports and recreation. *Seminars in Neurology*, 20(2):165–71.

Kenkel, D. (1991). Health behavior, health knowledge, and schooling. *Journal of Political Economy*, 99(2):287–305.

Killam, C., Cautin, R. L., and Santucci, A. C. (2005). Assessing the enduring residual neuropsychological effects of head trauma in college athletes who participate in contact sports. *Archives of Clinical Neuropsychology*, 20(5):599–611.

King, N. S., Crawford, S., Wenden, F. J., Moss, N. E., and Wade, D. T. (1995). The Rivermead Post Concussion Symptoms Questionnaire: a measure of symptoms commonly experienced after head injury and its reliability. *Journal of Neurology*, 242(9):587–592.

Kopelman, M. D., Bright, P., Buckman, J., Fradera, A., Yoshimasu, H., Jacobson, C., and Colchester, A. C. F. (2007). Recall and recognition memory in amnesia: patients with hippocampal, medial temporal, temporal lobe or frontal pathology. *Neuropsychologia*, 45(6):1232–46.

Kuehl, M. D., Snyder, A. R., Erickson, S. E., and McLeod, T. C. V. (2010). Impact of prior concussions on health-related quality of life in collegiate athletes. *Clinical Journal of Sport Medicine*, 20(2):86–91.

LaBotz, M., Martin, M. R., Kimura, I. F., Hetzler, R. K., and Nichols, A. W. (2005). A comparison of a preparticipation evaluation history form and a symptom-based concussion survey in the identification of previous head injury in collegiate athletes. *Clinical Journal of Sport Medicine*, 15(2):73–78.

Lannsjö, M., af Geijerstam, J.-L., Johansson, U., Bring, J., and Borg, J. (2009). Prevalence and structure of symptoms at 3 months after mild traumatic brain injury in a national cohort. *Brain injury*, 23(3):213–9.

Leventhal, H., Brissette, I., and Leventhal, E. (2003). *The self-regulation of health and illness behaviour*. Routledge.

Loring, D. W., Marino, S., and Meador, K. J. (2007). Neuropsychological and behavioral effects of antiepilepsy drugs. *Neuropsychology Review*, 17(4):413–25.

Lovell, M. (2009). The management of sports-related concussion: current status and future trends. *Clinical Journal of Sport Medicine*, 28(1):95–111.

Lovell, M. R. and Collins, M. W. (1998). Neuropsychological assessment of the college football player. *Journal of Head Trauma Rehabilitation*, 13(2):9–26.

Macciocchi, S. N., Barth, J. T., Littlefield, L., and Cantu, R. C. (2001). Multiple concussions and neuropsychological functioning in collegiate football players. *Journal of Athletic Training*, 36(3):303–306.

Mackenzie, J. A. and McMillan, T. M. (2005). Knowledge of post-concussional syndrome in naive lay-people, general practitioners and people with minor traumatic brain injury. *British Journal of Clinical Psychology*, 44(Pt 3):417–424.

Maddocks, D. and Saling, M. (1996). Neuropsychological deficits following concussion. *Brain Injury*, 10(2):99–104.

Makdissi, M. (2001). Computerised cognitive assessment of concussed Australian Rules footballers. *British Journal of Sports Medicine*, 35(5):354–360.

Matser, E. J., Kessels, A. G., Lezak, M. D., Jordan, B. D., and Troost, J. (1999). Neuropsychological impairment in amateur soccer players. *JAMA*, 282(10):971–3.

Matser, J., Kessels, A., Lezak, M., and Troost, J. (2001). A Dose-Response Relation of Headers and Concussions With Cognitive Impairment in Professional Soccer Players. *Journal of Clinical and Experimental Neuropsychology*, 23(6):770–774.

Maxwell, J., Visek, a., and Moores, E. (2009). Anger and perceived legitimacy of aggression in male Hong Kong Chinese athletes: Effects of type of sport and level of competition. *Psychology of Sport and Exercise*, 10(2):289–296.

McClincy, M. P., Lovell, M. R., Pardini, J., Collins, M. W., and Spore, M. K. (2006). Recovery from sports concussion in high school and collegiate athletes. *Brain Injury*, 20(1):33–9.

McCrea, M., Guskiewicz, K. M., Marshall, S. W., Barr, W., Randolph, C., Cantu, R. C., Onate, J. A., Yang, J., and Kelly, J. P. (2003). Acute effects and recovery time following concussion in collegiate football players: the ncaa concussion study. *JAMA*, 290(19):2556–63.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., and Guskiewicz, K. (2004). Unreported concussion in high school football players: implications for prevention. *Clinical Journal of Sport Medicine*, 14(1):13–17.

McCrea, M., Kelly, J. P., Randolph, C., Cisler, R., and Berger, L. (2002). Immediate neurocognitive effects of concussion. *Neurosurgery*, 50(5):1032–40; discussion 1040–2.

McCrory, P. (2001). What's in a name? *British Journal of Sports Medicine*, 35(5):285–a–286.

McCrory, P. and Berkovic, S. (1998). Second impact syndrome. *Neurology*, 50(3):677.

McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Kelly, J., Lovell, M., and Schamasch, P. (2005). Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *British Journal of Sports Medicine*, 39(4):196–204.

McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., and Cantu, R. (2009). Consensus Statement on Concussion in Sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *British Journal of Sports Medicine*, 43 Suppl 1:i76–90.

McDowell, I. and Newell, C. (1996). *Measuring health: A guide to rating scales and questionnaires*. Oxford Press, New York, 2nd editio edition.

Mcgrane, S. A., Cascella, P. W., and A, S. (2000). TBI knowledge and pragmatic assessment among Connecticut school speech?language pathologists. *Brain Injury*, 14(11):975–986.

McLeod, T. C. V., Bay, R. C., Heil, J., and McVeigh, S. D. (2008). Identification of sport and recreational activity concussion history through the preparticipation screening and a symptom survey in young athletes. *Clinical Journal of Sport Medicine*, 18(3):235–240.

Meeuwisse, W. H., Tyreman, H., Hagel, B., and Emery, C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine*, 17(3):215–9.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., and Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cognitive Psychology*, 41(1):49–100.

Monchi, O., Petrides, M., Petre, V., Worsley, K., and Dagher, A. (2001). Wisconsin Card Sorting revisited: distinct neural circuits participating in different stages of the task identified by event-related functional magnetic resonance imaging. *The Journal of Neuroscience*, 21(19):7733–41.

Mulhern, S. and McMillan, T. M. (2006). Knowledge and expectation of postconcussion symptoms in the general population. *Journal of Psychosomatic Research*, 61(4):439–445.

Notebaert, A. J. and Guskiewicz, K. M. (2005). Current trends in athletic training practice for concussion assessment and management. *Journal of Athletic Training*, 40(4):320–5.

Nys, G. M. S., Van Zandvoort, M. J. E., De Kort, P. L. M., Jansen, B. P. W., Van der Worp, H. B., Kappelle, L. J., and De Haan, E. H. F. (2005). Domain-specific cognitive recovery after first-ever stroke: a follow-up study of 111 cases. *Journal of the International Neuropsychological Society*, 11(7):795–806.

O'Jile, J., Ryan, L., Parks-Levy, J., Gouvier, W., Betz, B., Haptonstahl, D., and Coon, R. (1997). Effects of head injury experience on head injury misconceptions. *International Journal of Rehabilitation and Health*, 3(1):61–67.

Oscar-Berman, M. and Marinković, K. (2007). Alcohol: effects on neurobehavioral functions and the brain. *Neuropsychology Review*, 17(3):239–57.

Pennington, B. F. (2009). *Diagnosing learning disorders: a neuropsychological framework*. Guilford Press, New York, 2nd ed edition.

Phillips, A. C., Carroll, D., Burns, V. E., and Drayson, M. (2005). Neuroticism, cortisol reactivity, and antibody response to vaccination. *Psychophysiology*, 42(2):232–238.

Potter, S., Leigh, E., Wade, D., and Fleminger, S. (2006). The Rivermead Post Concussion Symptoms Questionnaire: a confirmatory factor analysis. *Journal of Neurology*, 253(12):1603–14.

Ramsay, M., Baker, P., Goulden, C., Sharp, C., and Sondhi, A. (2001). Drug misuse declared in 2000: results from the British Crime Survey. *Home Office Research, Development and Statistics Directorate.*

Randolph, C., McCrea, M., and Barr, W. B. (2005). Is neuropsychological testing useful in the management of sport-related concussion? *Journal of Athletic Training*, 40(3):139–52.

Ransone, J. and Dunn-Bennett, L. R. (1999). Assessment of first-aid knowledge and decision making of high school athletic coaches. *Journal of Athletic Training*, 34(3):267–271.

Register-Mihalik, J., Mihalik, J., and Guskiewicz, K. (2009). Association Between Previous Concussion History and Symptom Endorsement During Preseason Baseline Testing in High School and Collegiate Athletes. *Sports Health: A Multidisciplinary Approach*, 1(1):61.

Reinhard, M.-A. and Dickhäuser, O. (2009). Need for cognition, task difficulty, and the formation of performance expectancies. *Journal of Personality and Social Psychology*, 96(5):1062–76.

Reitan, R. M. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills*, 8:271–276.

Reitan, R. M. and Wolfson, D. (1997). The influence of age and education on neuropsychological performances of persons with mild head injuries. *Applied Neuropsychology*, 4(1):16–33.

Rogers, R. and Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology*, 124(2):207–231.

Rogers, R. D. and Robbins, T. W. (2001). Investigating the neurocognitive deficits associated with chronic drug misuse. *Current Opinion in Neurobiology*, 11(2):250–7.

Rosenbaum, A. M. and Arnett, P. A. (2009). The development of a survey to examine knowledge about and attitudes toward concussion in high-school students. *Journal of Clinical and Experimental Neuropsychology*, pages 1–13.

Ruff, R. and Weyer Jamora, C. (2009). Myths and Mild Traumatic Brain Injury. *Psychological Injury and Law*, 2(1):34–42.

Rutherford, A., Stephens, R., Fernie, G., and Potter, D. (2009). Do uk university football club players suffer neuropsychological impairment as a consequence of their football (soccer) play? *Journal of Clinical and Experimental Neuropsychology*, 31(6):664–81.

Rutherford, A., Stephens, R., Potter, D., and Fernie, G. (2005). Neuropsychological impairment as a consequence of football (soccer) play and football heading: preliminary analyses and report on university footballers. *Journal of Clinical and Experimental Neuropsychology*, 27(3):299–319.

Sarmiento, K., Mitchko, J., Klein, C., and Wong, S. (2010). Evaluation of the centers for disease control and prevention's concussion initiative for high school coaches: "heads up: concussion in high school sports". *The Journal of School Health*, 80(3):112–8.

Saunders, J. B., Aasland, O. G., Babor, T. F., de la Fuente, J. R., and Grant, M. (1993). Development of the Alcohol Use Disorders Identification Test (AUDIT): WHO Collaborative Project on Early Detection of Persons with Harmful Alcohol Consumption–II. *Addiction*, 88(6):791–804.

Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., and Podell, K. (2006). Sensitivity and specificity of the impact test battery for concussion in athletes. *Archives of Clinical Neuropsychology*, 21(1):91–9.

Scolaro Moser, R., Iverson, G. L., Echemendia, R. J., Lovell, M. R., Schatz, P., Webbe, F. M., Ruff, R. M., and Barth, J. T. (2007). Neuropsychological evaluation in the diagnosis and management of sports-related concussion. *Archives of Clinical Neuropsychology*, 22(8):909–16.

Scolaro Moser, R. and Schatz, P. (2002). Enduring effects of concussion in youth athletes. *Archives of Clinical Neuropsychology*, 17(1):91–100.

Sefton, J. E. (2003). An Examination of Factors that Influence Knowledge of and Reporting of Head Injuries in College Football. Master's thesis, New Britain (CT): Central Connecticut State University.

Sepulcre, J., Masdeu, J. C., Sastre-Garriga, J., Goñi, J., Vélez-de Mendizábal, N., Duque, B., Pastor, M. A., Bejarano, B., and Villoslada, P. (2008). Mapping the brain pathways of declarative verbal memory: Evidence from white matter lesions in the living human brain. *Neuroimage*, 42(3):1237–43.

Shehata, N., Wiley, J. P., Richea, S., Benson, B. W., Duits, L., and Meeuwisse, W. H. (2009). Sport concussion assessment tool: baseline values for varsity collision sport athletes. *British Journal of Sports Medicine*, 43(10):730–4.

Shuttleworth-Edwards, A. B. and Radloff, S. E. (2008). Compromised visuomotor processing speed in players of Rugby Union from school through to the national adult level. *Archives of Clinical Neuropsychology*, 23(5):511–20.

Shuttleworth-Edwards, A. B., Smith, I., and Radloff, S. E. (2008). Neurocognitive vulnerability amongst university rugby players versus noncontact sport controls. *Journal of Clinical and Experimental Neuropsychology*, 30(8):870–84.

Smith-Seemiller, L., Fow, N. R., Kant, R., and Franzen, M. D. (2003). Presence of post-concussion syndrome symptoms in patients with chronic pain vs mild traumatic brain injury. *Brain Injury*, 17(3):199–206.

Sosnoff, J. J., Broglio, S. P., Hillman, C. H., and Ferrara, M. S. (2007). Concussion does not impact intraindividual response time variability. *Neuropsychology*, 21(6):796–802.

SPSS Inc. (2009). PASW Statistics 17.0.

Stewart, C. C., Griffith, H. R., Okonkwo, O. C., Martin, R. C., Knowlton, R. K., Richardson, E. J., Hermann, B. P., and Seidenberg, M. (2009). Contributions of volumetrics of the hippocampus and thalamus to verbal memory in temporal lobe epilepsy patients. *Brain and Cognition*, 69(1):65–72.

Strauss, E., Sherman, E. M. S., and Spreen, O. (2006). *A compendium of neuropsychological tests: administration, norms, and commentary*. Oxford University Press, Oxford, 3rd ed edition.

Stroop, J. R. (1935). *Studies of interference in serial verbal reactions*. George Peabody College for Teachers, Nashville, Tenn.

Suhr, J. A. and Gunstad, J. (2002a). Diagnosis threat the effect of negative expectations on cognitive performance in head injury. *Journal of Clinical and Experimental Neuropsychology*, 24(4):448–457.

Suhr, J. A. and Gunstad, J. (2002b). "Diagnosis Threat": the effect of negative expectations on cognitive performance in head injury. *Journal of Clinical and Experimental Neuropsychology*, 24(4):448–457.

Sullivan, S. J., Bourne, L., Choie, S., Eastwood, B., Isbister, S., McCrory, P., and Gray, A. (2009). Understanding of sport concussion by the parents of young rugby players: a pilot study. *Clinical Journal of Sport Medicine*, 19(3):228–30.

Swan, G. E. and Lessov-Schlaggar, C. N. (2007). The effects of tobacco smoke and nicotine on cognition and the brain. *Neuropsychology Review*, 17(3):259–73.

Swift, T. L. and Wilson, S. L. (2001). Misconceptions about brain injury among the general public and non-expert health professionals: an exploratory study. *Brain Injury*, 15(2):149–165.

Sye, G., Sullivan, S. J., and McCrory, P. (2006a). High school rugby players' understanding of concussion and return to play guidelines. *British Journal of Sports Medicine*, 40(12):1003–1005.

Sye, G., Sullivan, S. J., and McCrory, P. (2006b). High school rugby players' understanding of concussion and return to play guidelines. *British Journal of Sports Medicine*, 40(12):1003–5.

Team, R. D. C. (2009). R: A Language and Environment for Statistical Computing.

Tegner, Y. and Lorentzon, R. (1996). Concussion among swedish elite ice hockey players. *Br J Sports Med*, 30(3):251–5.

Thériault, M., De Beaumont, L., Gosselin, N., Filipinni, M., and Lassonde, M. (2009). Electrophysiological abnormalities in well functioning multiple concussed athletes. *Brain Injury*, 23(11):899–906.

Thornton, A. E., Cox, D. N., Whitfield, K., and Fouladi, R. T. (2008). Cumulative concussion exposure in rugby players: neurocognitive and symptomatic outcomes. *Journal of Clinical and Experimental Neuropsychology*, 30(4):398–409.

Trahan, D., Ross, C., and Trahan, S. (2001). Relationships among postconcussional-type symptoms, depression, and anxiety in neurologically normal young adults and victims of mild brain injury* 1. *Archives of Clinical Neuropsychology*, 16(5):435–445.

Tremont, G., Halpert, S., Javorsky, D. J., and Stern, R. A. (2000). Differential impact of executive dysfunction on verbal list learning and story recall. *The Clinical Neuropsychologist*, 14(3):295–302.

Valovich McLeod, T. C., Schwartz, C., and Bay, R. C. (2007). Sport-related concussion misunderstandings among youth coaches. *Clinical Journal of Sport Medicine*, 17(2):140–2.

Verbruggen, F., Logan, G. D., and Stevens, M. A. (2008). Stop-it: Windows executable software for the stop-signal paradigm. *Behavior Research Methods*, 40(2):479–83.

Vilberg, K. L. and Rugg, M. D. (2007). Dissociation of the neural correlates of recognition memory according to familiarity, recollection, and amount of recollected information. *Neuropsychologia*, 45(10):2216–25.

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, 54(6):1063–1070.

Whittaker, R., Kemp, S., and House, A. (2007). Illness perceptions and outcome in mild head injury: a longitudinal study. *J Neurol Neurosurg Psychiatry*, 78(6):644–646.

Wilcox, R. R. (2005). *Introduction to robust estimation and hypothesis testing*. Elsevier/Academic Press, Amsterdam, 2nd ed edition.

Willer, B., Johnson, W. E., Rempel, R. G., and Linn, R. (1993). A note concerning misconceptions of the general public about brain injury. *Archives of Clinical Neuropsychology*, 8(5):461–465.

Williamson, I. J. S. and Goodman, D. (2006). Converging evidence for the under-reporting of concussions in youth ice hockey. *British Journal of Sports Medicine*, 40(2):128–32; discussion 128–32.

Wills, S. M. and Leathem, J. M. (2001). Sports-related brain injury research: methodological difficulties associated with ambiguous terminology. *Brain Injury*, 15(7):645–8.

Wood, R. L. (2004). Understanding the 'miserable minority': a diasthesis-stress paradigm for post-concussional syndrome. *Brain injury*, 18(11):1135–53.

Wood, R. L. L. and Rutterford, N. a. (2006). The impact of mild developmental learning difficulties on neuropsychological recovery from head trauma. *Brain injury*, 20(5):477–84.

Woolf, S. H., Chan, E. C. Y., Harris, R., Sheridan, S. L., Braddock, 3rd, C. H., Kaplan, R. M., Krist, A., O'Connor, A. M., and Tunis, S. (2005). Promoting informed choice: transforming health care to dispense knowledge for decision making. *Annals of Internal Medicine*, 143(4):293–300.

Yard, E. E., Collins, C. L., and Comstock, R. D. (2009). A comparison of high school sports injury surveillance data reporting by certified athletic trainers and coaches. *Journal of athletic training*, 44(6):645–52.

Yeates, K. O., Blumenstein, E., Patterson, C. M., and Delis, D. C. (1995). Verbal learning and memory following pediatric closed-head injury. *Journal of the International Neuropsychological Society*, 1(1):78–87.

Zhang, K., Johnson, B., Pennell, D., Ray, W., Sebastianelli, W., and Slobounov, S. (2010). Are functional deficits in concussed individuals consistent with white matter structural alterations: combined fmri & dti study. *Experimental Brain Research*, 204(1):57–70.

Zigmond, A. S. and Snaith, R. P. (1983). The hospital anxiety and depression scale. *Acta Psychiatrica Scandinavica*, 67(6):361–370.