Social Cognition in Sports-Related Mild Traumatic Brain Injury

Marianna York-Smith

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ABSTRACT

Introduction: There is increasing interest in the potential long-term consequences of sports-related concussion (SRC). Research indicates that SRC is associated with cognitive, behavioural and emotional outcomes. Additionally, studies show SRC is associated with increased risk for neurodegeneration such as Chronic Traumatic Encephalopathy (Manley et al., 2017). Although behavioural and personality changes such as emotional lability, apathy and increased aggression in mild traumatic brain injury (mTBI) such as SRC and neurodegenerative conditions are well documented, understanding of these changes is poorly understood. It is proposed that the changes observed may be indicative of underlying impairments in social cognition.

Aims: This preliminary study aimed to assess the relationship between social cognition and SRC and their association with general cognitive abilities.

Method: Twenty-one rugby players with a history of SRC were administered a neuropsychological test battery and social cognition tests (Theory of Mind (ToM), Emotional Recognition and Empathy). Data obtained using standardised measures were quantitatively and descriptively analysed.

Results: Analysis revealed relative weaknesses in ToM and emotional recognition in the context of 'average or above average' scores on domains of general cognition when compared to normative data. Group level analyses indicated poorer performance on all measures of social cognition compared with overall performance on general cognition.

Implications: Preliminary findings suggest that social cognition should be routinely tested in the management of SRC. The findings indicate that future research should explore the relationship between social cognition and SRC.

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LIST OF ACROYNMNS

AMCC	Anterior Midline Cingulate Cortex
ANT	Affect Naming Task
ASC	Autism Spectrum Conditions
bvFTFD	Behavioural-Variant Frontotemporal Dementia
CHI	Cumulative Head Impact Scale
CTE	Chronic Traumatic Encephalopathy
dmPFC	Dorsomedial Prefrontal Cortex
FTD	Frontotemporal Dementia
IMPACT	Immediate Post-Concussion Assessment and Cognitive Testing
GCS	Glasgow Coma Scale
GLM	General Linear Model
LOC	Loss of Consciousness
mTBI	Mild Traumatic Brain Injury
MFC	Medial Frontal Cortex
PFC	Prefrontal Cortex
PTA	Post Traumatic Amnesia
SCAT	Sideline Concussion Assessment Tool
SRC	Sports-Related Concussion
SSQ	Social Stories Questionnaire
ToM	Theory of Mind
TBI	Traumatic Brain Injury
UK	United Kingdom
QCAE	Questionnaire of Cognitive and Affective Empath

1 INTRODUCTION

Social, emotional and behavioural impairments are well documented in traumatic brain injury (TBI), however surprisingly few studies have investigated the effects of mild traumatic brain injury (mTBI) on social cognition. Concussive and subconcussive considered at the mildest end of TBI are regularly sustained in contacts sports such as rugby. Research has revealed that concussive and subconcussive impacts are associated with alterations in functional activity in the prefrontal cortex (PFC). Thus, the regions shown to be vulnerable to concussive impacts are those involved with social cognition.

A narrative review using the following online databases; Science Direct, Psych Info, PubMed and Ovid Medline was conducted to provide a comprehensive background of the literature in the field of sports-related (mTBI) and concussion, the associated neuropsychological effects, and to summarise the current research in the area of social cognition. Additionally, reference lists were searched to identify further related publications.

1.1 Traumatic Brain Injury

A TBI is defined as “an alteration in brain function or brain pathology caused by an external force” (Menon, Schwab, Wright, & Maas, 2010). Despite reducing mortality rates due to improvement in treatments, TBI remains a leading cause of death and disability globally. TBI can cause significant long-term suffering predominately as a result of cognitive, behavioural and personality changes (Langlois, Rutland-Brown, & Wald, 2006). TBI is dynamic, with changes occurring over several hours, weeks and days after the injury, the consequences of which can be persistent and altering over months and years. Although mortality rates of TBI are reducing, incidence and reporting rates are on the increase, with ten times more UK hospital admissions between 2016-2017 compared with 2005-2006 (Headway, 2017).

It is estimated that nearly one million people in the United Kingdom (UK) attend an Accident and Emergency (A&E) department following a TBI of which 350,000 are admitted to hospital (Headway, 2017). However, accurate prevalence rates are difficult to attain due to differences in diagnostic criteria across different primary trusts in the UK. In addition, TBIs are often recorded as a secondary diagnosis, and therefore not included in some statistics; moreover, those with milder injuries may never present to health-care services. Young adult males (aged 15-25 years), young infants and the elderly are at highest risk of receiving a TBI (Headway, 2017). Men are 1.5 times more likely to be admitted for a head injury; however, female head injuries have increased by 23% since 2005-2006 (Headway, 2017).

1.1.1 Causes of head injury

The leading causes of TBI are road traffic accidents, falls, assault and sports-related trauma. Brain injuries can be classified into two subgroups, closed and penetrating head injuries.

1.1.2 The Nature of Traumatic Brain Injury

1.1.2.1 Closed Head Injuries

Closed injuries are the most common type of head injury, in which an external force causes a nonpenetrating injury to the brain with no fracture to the skull. Closed head injuries are routinely caused by road traffic accidents or sporting related incidents. They often involve rotational injuries, which occur when a force causes sudden changes in velocity (e.g. acceleration/deceleration), such as in car accidents when the impact may cause a person’s head to come in to contact with the windscreen. When the torso is either decelerated or accelerated rapidly, the head sustains a combination of linear and rotational accelerations. Direct impacts with the head (linear acceleration-deceleration) and inertial loading of the head (rotational acceleration-deceleration) are reported as the two major mechanisms of head-related injuries such as concussion.

1.1.2.2. Penetrating Head Injuries

A penetrating head injury occurs when the skull and protective linings are damaged, and the brain is no longer protected, such as injuries received from foreign objects such as bullets. Penetrating head injuries involve the mechanisms involved in a closed head injury in addition to damage caused by penetration and are therefore more likely to be fatal. The penetrating damage is often localised, with impairments occurring in the corresponding region of the brain. Penetrating head injuries are less common in the UK but frequently occur in armed conflict areas.

1.1.3 Primary or Secondary Damage

The damage which occurs in head injuries can be primary (i.e. happened at the time of the injury), or secondary (i.e. due to further complications as a result of the injury). Primary brain damage occurs via one of two mechanisms, haemorrhagic contusions or diffuse axonal injuries. Contusions commonly occur following direct blows, and axonal injuries are frequent after acceleration/deceleration injuries such as road traffic accidents.

Haemorrhagic contusions arise when the blood vessels supplying oxygen are ruptured, either at the point of impact (coup injury), directly opposite it (contra-coup injury), or most frequently on the frontal and temporal lobes, where the brain impacts with the sharpest, most prominent points of the skull.

Diffuse axonal injuries occur when a force causes the brain to move violently, and the differential movement results in widespread shearing or tearing of axons. Diffuse axonal injuries are often considered the most significant primary brain damage.

1.1.4 Secondary Injuries

Secondary head injuries occur over time following the primary injury, which can be either extracranial (i.e. outside of the skull) and intracranial (i.e. inside the skull). Extracranial secondary injuries include respiratory failure and associated hypotension, hypoxia or ischaemia. Maintaining breathing and protecting the airway is, therefore, a priority for dealing with a head injury. Intracranial causes of secondary head injury include haemorrhage, haematomas, cerebral oedemas, hydrocephalus and infection.

The severity of the head injury is defined as ranging from mild to moderate (in which about 50 per cent of patients will experience ‘postconcussional' symptoms) to severe TBI. These symptoms are associated with a range of disabilities, including at the most severe end of the spectrum prolonged coma. Three measures are commonly used to determine the severity of brain injury:

- The Glasgow Coma Scale (Sternbach, 2000), rates the depth and duration of altered consciousness, measured as soon as possible after the injury, combining scores across three functions, i) eye-opening ii) verbal response iiI) motor response. Scores range from 3 (most severe) to 15 (least severe).

- Loss of Consciousness (LOC) denotes the duration of unconsciousness. The length of time taken for an individual to regain consciousness is used as a proxy for the severity of the injury. Information is gathered from the patient in addition to information gained from any witnesses. Duration of LOC is commonly understood to indicate the following injury severity:
    - Mild: LOC of 30 minutes or less
    - Moderate: LOC greater than 30 minutes, and less than 24 hours
    - Severe: LOC greater than 24 hours

- Post-Traumatic Amnesia (PTA) refers to the severity of memory alteration for events after the injury. The longer the period of PTA, the more significant the injury severity. Typically, PTA scores are inferred as follows:
    - Mild injury: PTA less than 1 hour
    - Moderate injury: PTA of between 1 hour and 24 hours
    - Severe injury: PTA for longer than 24 hours

There is no universally accepted definition of severity of brain injury, and discrepancies exist within the literature, with different inclusion and exclusion criteria across the research. However, three grades of classifying injuries dominate the literature, with injuries classified as mild, moderate or severe according to the following criteria:

1.1.4.1 Mild Head Injury

An injury is considered mild if the GCS scores are between 13-15 and LOC is less than 30 minutes, with PTA of less than one hour. The impact of mild injuries is often underestimated, although symptoms often resolve spontaneously, recent research has highlighted the potential longer-term impacts of even mild head injuries. In some cases, problems resulting from mTBI may persist for months (postconcussional syndrome) and in a few cases may become persistent (Broglio et al., 2009; Ingebrigtsen, Waterloo, Marup-Jensen, Attner, & Romner, 1998; Rees & Bellon, 2007). In the acute stages following a mTBI, a triad of neuropsychological dysfunctions can occur; including impaired verbal retrieval, attention deficits and forgetfulness. Headaches, dizziness, irritability, fatigue, disrupted sleep and drowsiness are common early sequelae (Ponsford et al., 2000).

1.1.4.2 Moderate Head Injury

A moderate brain injury is defined as one with a GCS of 9-12 points, a LOC of between 30 minutes and 24 hours and PTA between 1 and 24 hours. Headaches, memory problems and difficulties with daily living activities are the most commonly reported physical sequelae, but the nature and duration of symptoms within the group vary widely. Cognitive symptoms usually include alterations in memory, planning, thinking, organising attention and concentration.

1.1.4.3 Severe Head Injury

A severe head injury is defined by a GCS score of between 3 and 8, a LOC greater than 24 hours, and PTA of more than 24 hours. Patients with a severe head injury can experience a full range of impairments across all cognitive domains. A severe head injury can result in substantial physical disabilities, emotional and behavioural changes, and long-term cognitive difficulties. Severe head injuries are rare, with patients who survive often remaining in a vegetative state for several months (Teasdale, 1995).

1.1.5 Second Impact Syndrome

The controversial term first described by Saunders and Harbaugh (1984), Second Impact Syndrome refers to a very rare fatal condition. Typically, it involves an athlete experiencing postconcucsional symptoms following a head impact. If the athlete returns to play following the injury and sustains a second head injury, diffuse cerebral swelling and brain herniation and can result in death (Bey & Ostick, 2009). Incidence is so rare that existence has been disputed (McCrory, 2001). However, given the potentially fatal consequences, the reports of cases in children and adolescents have fuelled research in the area of sports-related head injuries.

1.2 Sports-Related Mild Traumatic Brain Injury

Physiologically sport-related mTBI happens as the torso is either accelerated or decelerate rapidly, causing a combination of linear and rotational accelerations. The frontal lobe and temporal lobes areas of the brain most implicated in SRC, due to the torque effect which occurs following a head impact. Symptoms vary between individuals including changes in mood, mental health difficulties such as depression and anxiety (Manley et al., 2017), behavioural and personality changes, poor executive functioning, slurred speech, memory loss and gait impairment (Helen Ling, Hardy, & Zetterberg, 2015).

Mild traumatic brain injury or concussion in sports is an emerging public health issue due to the frequency of injuries and the potential long-term consequences. In recent years TBI and chronic traumatic encephalopathy (CTE) in contact-sport athletes have gained intense media and scientific attention. For decades it has been known that repetitive neurotrauma sustained in boxing is linked with chronic brain damage, previously defined to as ‘punch drunk syndrome’ or ‘dementia pugilistica’. However, it was thought that these problems were confined to boxers and did not apply to other contact sports. More recently there has been a growing interest in the consequences of mTBI or concussion in contact sport such as American football and rugby.

In the majority of cases concussion symptoms resolve spontaneously within seven to ten days, however, the cumulative effects and long-term consequences are now commonly documented (De Beaumont, Beauchemin, Beaulieu, & Jolicoeur, 2013; Gessel, Fields, Collins, Dick, & Comstock, 2007; Marar, McIlvain, Fields, & Comstock, 2012). Studies have indicated that long-term cognitive and motor function alterations are associated with a history of concussions (De Beaumont et al., 2013; De Beaumont, Brisson, Lassonde, & Jolicoeur, 2007; Gaetz, Goodman, & Weinberg, 2000; Theriault, De Beaumont, Tremblay, Lassonde, & Jolicoeur, 2011).

1.2.1 Defining Sports-Related Mild Traumatic Brain Injury

The terms mTBI, concussion and head-impacts are often used interchangeably, and as yet no agreed standardised definition has been proposed. Within the past 30 years, there has been a move towards distinguishing sports-related concussion (SRC) from concussions and mTBI resulting from other causes, e.g. road-traffic accidents; however, the distinction is arbitrary. Therefore, when reviewing the literature both SRC and non-sporting mTBI have been included, since they represent the same type of injury. A review of evidence conducted by Belanger and Vanderloeg (2005) concluded that the neuropsychological impacts of SRC were comparable to those found in non-sports-related mTBI, and the repetitive nature of mTBIs within contact sports is likely to be associated with more pronounced effects (Carroll et al., 2004). To remain consistent with the literature relating to mTBI sustained during sport, the term SRC will be used. However, it is acknowledged that understanding the consequences of a head injury would be better understood in relation to the severity of the symptoms, rather than attempts to classify concussion and mTBI as different entities.

In response to the ambiguity in the definition, a recent systematic review examined the current literature (Paul McCrory et al., 2017). Based on the review and in conjunction with discussions with an expert panel the following features were proposed to aid defining SRC:

- "S*RC may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head."*

- *"SRC typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over several minutes to hours."*

- *"SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies."*

- *"SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases, symptoms may be prolonged."*

- "*The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction) or other comorbidities (e.g., psychological factors or coexisting medical conditions)."*

The difficulty in agreement on the definition of SRC and therefore the clinical diagnosis represents the complexity of diagnosing injuries, with the majority of SRC occurring without loss of consciousness or apparent neurological signs. Thus, any transient neurological symptoms may represent SRC.

1.2.2 Sports-Related Subconcussive Injuries

A subconcussive injury involves impacts which result in the transfer of mechanical energy with enough force to cause damage to axons or alter neuronal integrity, but where the intensity does not reach the threshold to produce clinical symptoms. It is argued that the cumulative effects of subconcussive injuries, common in contact-sports, could lead to alterations in the cerebral structure and functioning in later life, and contribute to the development of neurodegenerative conditions such as chronic traumatic encephalopathy (CTE) and dementia (Slobounov et al., 2017). Findings from neuroimaging studies of high-school NFL players demonstrate changes in brain functional imaging following a season of cumulative asymptomatic impacts without concussion (Talavage et al., 2014). A potential dose-response relationship between estimated cumulative head impacts and later-life risk for cognitive and neurobehavioural impairments has been identified (Montenigro et al., 2017). The results are indicative of a subtle additive nature of subconcussive impacts, with estimates of subconcussive exposure predicating cognitive deficits including executive dysfunction, depression and apathy (Montenigro et al., 2017). The study developed a cumulative head impacts index (CHI) to estimate the numbers of subconcussive injuries athletes received during their career. The CHI evaluates head impacts using weighted frequencies based on the number of seasons and positions played. The study indicated that the risk of developing executive dysfunction, depression, apathy and behavioural difficulties nearly doubled once the CHI exceeded a threshold of 2800. However, studies using helmet accelerometers such as used in the study have been criticised due to inaccuracy, and have been abandoned in other studies due to weak quality reports.

Research in rugby players suggests that risks of sustaining injuries are significantly increased during match play compared with training (Williams et al., 2017). Therefore, the higher number of years playing rugby would correspond to increased match exposure, with approximately 12-16 matches played in each English rugby union season. Those participants who played rugby for a higher number of years, therefore, increasing exposure to match play, and potentially subconcussive head impacts. However, this interpretation is speculative given the difficulties in accurately determining subconcussive injury frequency, and the lack of exact data on the number of matches played.

1.2.3 Concussive Injuries in Rugby

High incidence of concussion and subconcussive impacts is well documented in contact sports. A concussion is the most commonly reported injury in Professional Rugby Union in England, constituting 12.5% of all injuries (England Professional Rugby Injury Surveillance Project Steering Group, 2018). Evidence suggests that Rugby has one of the highest rates of concussion compared with other sports such as American football, football (soccer) and hockey. In part, this is due to the speed of play and the number of head and body collisions associated with tackling (A. J. Gardner, Iverson, Williams, Baker, & Stanwell, 2014). Comparisons of the estimated rate of concussions among sport suggest the risk for amateur rugby players to be six times greater than those of American football players, with the rates increasing to over 19 times for professional Rugby Union (hereafter Rugby) players, with rates suggested to be higher for rugby league (Kirkwood, Parekh, Ofori-Asenso, & Pollock, 2015). In Amateur Rugby concussion represents between 4-8% of all injuries sustained (Roberts, Trewartha, England, Shaddick, & Stokes, 2013), with rates rising during recent years (Harmon et al., 2013).

As previously discussed, the incidence of SRC in rugby is not reliably determined given the lack of a universally accepted criterion of SRC. Rafferty et al. (2018) recently conducted a study following professional rugby players over four seasons. They concluded that after exposure to 25 matches, players were more likely to have sustained a concussion than not (Rafferty et al., 2018). A meta-analysis of concussion incidence rates in rugby analysed data from 37 studies and revealed the incidence of match-play concussion of 4.73 per 1,000 player match hours, with rates increasing for sub-elite athletes (A. J. Gardner et al., 2014). Six studies within the review considered the playing position of athletes (forwards versus backs), with incidence shown to be greater for backs compared to forwards (4.85 versus 4.02 concussions per 1,000 player match hours (A. J. Gardner et al., 2014). Players who have received a recent concussion were 20%

more likely to sustain an mTBI after 20 hours of game time compared with those with no history of concussion.

In addition to concussive incidents, the frequency of subconcussive impacts is a cause for concern within rugby. Recent biophysics studies using helmet accelerometers to take measurements of head kinematics provide a more accurate measure of subconcussive impacts sustained during contact sports. However, the application of accelerometers in rugby has been unsuccessful due to the accelerometers being displaced during play. A recent project using patches to monitor impacts in professional rugby players at Saracens rugby club was abandoned when it was found that the patches provided unreliable data as they moved too much during play. In American football, across a 14-week season on average each player sustained 652 subconcussive injuries, with rates varying depending on player positions (Broglio et al., 2009). It could be assumed that rates of subconcussive impacts are likely to be higher in rugby given that reported concussion rates are higher.

1.2.4 Neurocognitive and Psychological Outcomes of Sports-Related Concussive events

The types of cognitive impairments that are most consistently reported after a concussion include deficits in memory, cognitive processing speed, and certain types of executive functions (typically, measures of verbal fluency or response inhibition).

A growing number of studies have sought to investigate the cumulative neurocognitive effects of SRC and subconcussive events (Bailes, Petraglia, Omalu, Nauman, & Talavage, 2013; Jennings et al., 2015; Tsushima, Geling, Arnold, & Oshiro, 2016). Much of the research thus far has been conducted in America, predominately focusing on American football, with comparatively far fewer focused on rugby. One study compared rugby players with a self-reported history of three or more concussions with a control group (A. Gardner, Shores, & Batchelor, 2010). The results indicated that rugby players processing speed were significantly slower compared with controls. Similarly Hume et al compared former elite rugby players with non-contact sport players, the results indicated that a history of concussion was associated with small to moderate neurocognitive deficits (Hume et al., 2017). Another study has shown that those who have received more than three concussions during their sporting career are at fivefold risk of mild cognitive impairment after the age of 50 when compared to those who had no history of concussions (Randolph, Karantzoulis, & Guskiewicz, 2013). Shuttleworth-Edwards et al (2008), tested the residual effects of concussion in rugby players across one season, compared with controls. Before the season no differences were found between the two groups, however postseason, rugby players performed poorer on attentional tasks with a speeded visuomotor component. In contrast, a longitudinal study of Australian Rules football (ARF) players were followed over a 25-year period did not support these findings with the results not displaying evidence of objective cognitive change over the same period in which it is thought that CTE evolves (Maddocks, Blaine, Inge, McCrory, & Saling, 2017). Some studies suggest that it is the age at which athletes are first exposed to concussive events which predict later cognitive vulnerability, rather than the incidence of concussions especially those which occur between the ages of 10 and 12 years, during a critical stage of brain development (Stamm et al., 2015),m indicating the importance of considering the age of first concussion when conducting research in the area.

Manley et al. (2017) conducted a systematic review of recent studies investigating the possible long-term mental health and cognitive problems relating to exposure to impact sports and concussions. The authors conclude that there is evidence that some former athletes have neurocognitive and mental health difficulties. However, the review was unable to conclude how much of these difficulties might be attributed to subconcussive impact as opposed to concussive injuries. Additionally, currently, there seems to be little consensus on determining which individuals who may be at risk of developing long-term neurocognitive and mental health difficulties.

Depression is the most frequently mental health outcome studied. Several studies report a frequency-response of concussive events and depression reporting symptoms (Didehbani, Munro Cullum, Mansinghani, Conover, & Hart, 2013; Kerr, DeFreese, & Marshall, 2014; P.H. Montenigro et al., 2017; Yang, Peek-Asa, Covassin, & Torner, 2015).

1.2.5 Neuropsychological approaches to assessing and managing SRC

The type and cause of the head injury inform the neuropsychological impact and therefore, assessment approach. Any neuropsychological evaluation should take into consideration the time since injury, the nature, location and severity of the trauma and subsequent effects. The use of neuropsychological testing provides a way to quantify the recovery following concussion. Lessons learnt from assessing more severe head injuries, have been applied to managing SRC, with tests now established which are sensitive to detect impairments even in mild head injuries.

Historically, measuring recovery and diagnosis of SRC relied on subjective reports from athletes, who have been shown to minimise their symptoms to reduce injury time (Gronwall, 1976; Kerr, Register-Mihalik, et al., 2014). Increased research and level of interest in the area of SRC have led to the recognition of neuropsychological testing as a fundamental part of clinical management following SRC. Many sporting organisations now advocate for their use as part of concussion management and diagnosis. The use of a combination of paper and computerised testing is currently advocated, with many organisations now using the *ImPact* (Immediate Postconcussion Assessment and Cognitive Testing) a computerised concussion assessment tool (Gaudet & Weyandt, 2017).

Neuropsychological assessment is useful in assessing the functional impact of an injury, informing and managing treatment and detecting changes across time. Recommendations from neuropsychological assessments are commonly contributing to return-to-play decisions (Walker & Tesco, 2013). Assessments can assist athletes to make decisions about continuing their career following SRC, by considering the potential impact on day-to-day functioning if they keep playing, and risk further potential for a head injury.

The selection of tests used within a neuropsychological assessment is based upon the referral and the clients. Predominately neuropsychologists will use a core battery of tests designed to assess the main cognitive domains (attention, memory and learning, verbal ability, executive functioning and emotional functioning)

The use of basic neuropsychological testing is now considered a crucial element of concussion management. Different approaches to assessment are used depending on the situation; those administered on-field differ from those used to determine recovery to baseline performance. These differences reflect the time since injury and the nature of the deficits, in addition to the practicalities of conducting the assessments.

However, it is common for non-psychologists to administer and interpret tests and many of the reviews published within the area recommend that interpretations should be conducted by trained psychologists, in order to provide contextualised interpretations and reduce misdiagnosis.

1.2.5.1 On Field of Play Assessments

Research conducted by Maddocks et al (2017) found that questions relating to recent and remote memory were most sensitive in distinguishing between concussed and non-concussed athletes at the time of injury. Experts in the field collaborated to develop a valid tool to assess sports concussion, the Sport Concussion Assessment Tool 5th Addition (SCAT) (Echemendia et al., 2017)which was designed following an iterative review. The tool, however, is not a substitute for a formal medical assessment, as it is not sufficiently detailed to exclude a more significant injury which may present initially as an mTBI (McCrory, Makdissi, Davis, & Collie, 2005).

1.2.5.2 Return to Play Assessments

To determine the suitability of an athlete in returning to play assessments should include clinical symptoms of concussion (Paul McCrory et al., 2005), balance testing and a range of neurocognitive tests including domains associated with the recovery phase such as:

- Memory and learning
- Planning and ability to switch mental set
- Attention and ability to process information
- Reaction times

Some studies recommend the addition of visuospatial construction, language and sensorimotor abilities in; however, these findings are not yet well replicated (Barth, Freeman, Broshek, & Varney, 2001; Leininger, Gramling, Farrell, Kreutzer, & Peck, 1990).

1.2.5.3 Recovery to Baseline Assessment

In assessing if an athlete has recovered following SRC the most effective model would be to compare functioning following to a baseline assessment, considering confounding factors such as practice effects. It is, however, often not possible due to a lack of baseline assessment. In the absence of baseline measures, comparison with group norms with the addition of a test of premorbid functioning provides the most accurate way to assess if an athlete has returned to baseline testing, however, may not be sensitive enough to detect subtle deficits following SRC (Paul McCrory et al., 2005).

1.2.6 Neuroimaging and Sports-Related Concussive Injuries

Advancements in functional neuroimaging techniques with increased sensitivity have allowed for research to detect the cerebral changes as a result of head impact. Studies have mostly been conducted on former elite level American football players, with some on former soccer players and boxers (Ford, Giovanello, & Guskiewicz, 2013; Hart et al., 2013; Koerte et al., 2015; Strain et al., 2015).

Studies using Diffusion Tensor Imaging, have suggested a difference between American football players and non-contact athletes (Koerte et al., 2015), using structural imaging techniques, differences were observed in American football players *cavum septum pellucidum* compared to non-athlete controls. The cavum septum is a double membrane separating the right and left ventricle of the brain, important for cognitive, emotional and behavioural functioning (Das & Dossani, 2019). The differences found were associated with decreased performance on memory and word pronunciation tests. Consistent with this research in retired American footballers have demonstrated structural changes such as cortical thinning (Koerte et al., 2016) and functional changes in brain metabolism (Hampshire, MacDonald, & Owen, 2013). Studies have shown neuroanatomical changes in the anterior cingulate cortex and orbital frontal cortex following SRC, mTBI and subconcussive head impacts (Meier, Bellgowan, Bergamino, Ling, & Mayer, 2016). However, neuroimaging studies have limitations due to sampling bias in many of the studies and lack of replicability.

1.2.7 The Link Between Sports-Related Head Impacts and Neurodegenerative Conditions

Case reports have documented that several high-profile retired athletes had developed neurocognitive difficulties in later life which were potentially linked to the concussive and subconcussive injuries sustained during their career. In 2011 Omalu, reported the autopsy findings of 17 athletes, in which he found diverse forms of accumulation of tau protein, atrophy of the cerebral hemispheres, thalamus, medial temporal lobe, mammillary bodies, and brainstem. The taupathy he discovered formed a specific unique pattern, which he termed *chronic traumatic encephalopathy* (CTE). The taupathy was not consistent with those found in other known neurodegenerative disorders such as Alzheimer’s disease and dementia (Montenigro, Stein, Cantu, & Stern, 2015). Mckee et al. (2013) replicated the results in a study comparing the brains of 85 subjects, 65 of which were former athletes, and 18 controls. CTE was identified in 80% of the athletes and none of the controls. The authors concluded that CTE occurs as a consequence of repetitive mild traumatic brain injury, in which progressive clinical symptoms develop many years after retiring from the sport, with the accumulation of tau protein. In posthumously confirmed cases of CTE, patients had previously reported significant emotional, behavioural and cognitive changes which they believed were a result of concussions sustained during their sporting careers. Public interest increased following the suicides of several prominent retired NFL athletes' who were confirmed to be suffering from CTE at autopsy (Roehr, 2012).

In the UK cases of CTE have been confirmed in former football (soccer) players and rugby players. Several well-known retired football players were confirmed to have a diagnosis of dementia which has been linked to the subconcussive impacts sustained from heading the ball thousands of times throughout their career. A study which carried out post-mortem analysis on the brains of former football players found that among the six brains examines, four had signs of CTE and all six signs of Alzheimer's disease (AD) (Ling et al., 2017). In all cases, neuropathology was characterised by an abnormal build-up of tau protein. Development of CTE is thought to occur as a result of repetitive head impacts, with former high-contact athletes representing the majority of diagnosed cases (Tartaglia et al., 2014). All confirmed cases of CTE have a history of subconcussive impacts, suggesting that head impacts are necessary but not sufficient in the development of CTE (Baugh et al., 2012).

Due to the retrospective nature of diagnosing CTE, identifying the mechanism by which repetitive concussive impacts may lead the neurodegenerative process of the accumulation of tau protein is still up for debate. It is hypothesised that the trauma sustained during head impacts interrupts the assembly between tau and tubulin which initiates the breakdown of the microtubules and the development of tau-positive plaque (Lucke-Wold et al., 2014). This hypothesis is consistent with the findings from helmet acceleration studies which indicate frontal vulnerability in high-contact sport athletes.

The clinical features of CTE as with other neurodegenerative conditions vary across individuals, consisting of memory loss, mood and behavioural changes, executive dysfunction, gait impairment, parkinsonism, typically manifesting many years following the repetitive subconcussive impacts (Ling, Hardy, & Zetterberg, 2015; McKee et al., 2013). Clinically, it is difficult to distinguish between presentations of CTE and FTLD, AD and cerebellar ataxia and more than one condition has been shown to co-occur in some individuals (Tartaglia et al., 2014).

In part this may be due to the neurological similarities which exist between CTE and other neurodegenerative conditions, specifically FLTD and AD, in which the frontal and temporal and cortices and limbic system including the amygdala and hippocampus are affected.

The region's most severely affected correlate with the clinical presentations observed in confirmed cases of CTE such as significant emotional (e.g. depression and suicidality and reduced empathy) and behavioural (e.g. aggression, impulsivity and risk taking) changes and cognitive difficulties which characterise the condition (e.g. processing speed, memory loss, executive functioning impairments) (McKee, Daneshvar, Alvarez, & Stein, 2014). Despite convincing evidence of a unique tau pathology linked to concussive and subconcussive impacts there remains debate over the distinction of the neuropathology and whether it reflects AD, dementia conditions or the normal aging process (Gardner, Iverson, & McCrory, 2013). However, autopsy results indicate that AD pathology is not evident in younger cases of CTE and occurs later in disease progression (McKee et al., 2013). Furthermore, research indicating that CTE typically occurs much earlier than AD supports the distinction between CTE and AD. However, repetitive head injuries are associated with an increased risk of AD in later life (Lehman, Hein, Baron & Gersic, 2012). Research has shown that in advanced cases of CTE, a comorbid condition such as AD or FLTD occurred in around 50% of cases (McKee et al., 2013). Additionally, research indicates that TBI may increase risk of FTLD and influence clinical symptoms and severity (Deutsch, Mendez, & Teng, 2015), suggesting TBI influences the development of symptoms in FTLD.

Despite the convincing evidence for the distinction of CTE from other neurodegenerative conditions, clinically and pathologically similarities exist particularly with AD and FLTD which are all defined as proteinpathies and similarly share the pathological substrate. Behavioural and emotional changes frequently observed following TBI, concussion and CTE are particularly observed in behavioural variant of FLTD (behavioural-variant frontotemporal dementia (bvFTD)) and are attributed to frontal lobe degeneration observed in both conditions (Damasio et al., 1991; Jordan, 2013; Stuss, Gallup, & Alexander, 2001) specifically in the orbitofrontal and ventromedial prefrontal cortex, as well as insula (Tartaglia et al., 2014). In a review examining the similarities and differences of CTE compared with other neurodegenerative conditions, overlap in signs and symptoms between CTE and bvFTD was particularly identified (Tartaglia et al., 2014). The similarities identified may be due to the focal involvement of frontal networks implicated in higher cognitive functions such as personality and emotional regulation, social motivation and executive functioning. Examining findings from bvFTD and other neurodegenerative conditions may provide useful insight which individuals might be at risk of CTE and help identify potential early clinical indicators.

Despite widespread documentation of social and emotional difficulties in neurodegeneration the effects on neurodegenerative process on social cognitive functioning has received relatively little attention. The prefrontal regions that are the most afflicted by neurodegeneration and head impacts are most vulnerable to disruption, are those which play a critical role in social cognition. Studying athletes with a known history of head impacts provides a unique opportunity to study those with a documented increased risk of developing CTE and dementia.

1.3 Social Cognition

The term ‘social cognition’ has been applied across a variety of disciplines ranging from evolutionary psychology and cognitive neuroscience to psychoanalysis. Broadly speaking within clinical psychology, social cognition refers to the mental processes which underpin social interactions; such as, attention, emotion recognition and interpretation of interpersonal cues which facilitate social communication.

The construct of social cognition initially emerged from early social psychology in the1940s following an experiment where participants were shown three short video clips of geometric figures on a plain white background. Despite visual motion being the only information available, participants interpreted the movements in terms of mental state and social categories such as goals, beliefs, desires and emotions. Their interpretations were based only on the shapes’ relative motion, and demonstrate our innate capacity to attribute mental states to others (Adolphs, 1999).

Within social psychology, the study of social cognition relates to the understanding of social knowledge, social influences and processing biases (such as those which result in stereotypes and prejudice), memory for social information, and attribution of motives. In evolutionary biology, social cognition underpins theories that explain competition over food, domestication, socialisation and cooperation which occur across several species (Emery & Clayton, 2009). Developmental psychologists understand social cognition in terms of an individual's social competence and cognitive abilities. Piaget (1972) demonstrated this in his work on moral development and Vygotsky (1980) later in his work on learning in a social context. Informed by developmental psychology, social cognition has been applied in clinical psychology to explain the mechanisms which result in impairments in social functioning, such as those observed in individuals with a diagnosis of autism spectrum conditions (ASC).

1.3.1 Social Cognition in Clinical Psychology

Social cognition involves a variety of dynamic cognitive processes which enable individuals to function effectively in groups. These processes include attention, perception and interpretation of social cues, and predominately occur outside of awareness. These processes require higher-level cognitive abilities to construct representations of the self and others, which are represented neurally in the brain. Social cognitive processes are considered necessary for development, as observation and exchange of social signals enable human beings to learn about the world around them. The ability to interpret social signals is considered crucial for survival, as recognising facial expressions such as fear and disgust can warn us of potential danger (Wicker et al., 2003). Similarly, accurately following another person's eye gaze can indicate the presence of something novel or interesting in the environment. Through observation and imitation of social signals, humans learn and understand the complexities of social interactions and how to respond (Frith & Frith, 2012). The inability to effectively understand and relate to other people can lead to serious adverse outcomes such as isolation and reduced quality of life.

In clinical practice, the development of social cognitive theories shifted the focus of research in understanding autism spectrum condition (ASC), which had historically been interpreted in terms of perceptual and sensory processing impairments. Over time, accumulating evidence suggested that a psychological impairment in social cognition more accurately characterised ASC. Further research in the area of ASC has resulted in the development of several higher-level social cognitive theories; referred to as mentalising or theory of mind (ToM). Currently, impairments in ToM remain the dominant cognitive mechanism used to explain the social communications difficulties in ASC.

A growing body of evidence suggests that social cognitive impairments may be present in a wide range of conditions in neurology and psychology, with research indicating deficits in individuals with diagnoses of psychosis, neurodegenerative disorders and traumatic brain injury (TBI). The addition of impairments in social cognition in a variety of mental health difficulties results in a range of adverse outcomes including poorer mental (Jones, Greenberg, & Crowley, 2015) (Holt-Lunstad, Smith, & Layton, 2010).

In philosophy of mind, there are several distinct theories toward social cognition. In summary, these include schema theories, evolutionary psychology approaches, theory of mind (Premack & Woodruff, 1978), conceptual metaphor theory, simulation theory and embodiment theories. However, it is beyond the scope of this report to discuss the various theories of social cognition.

1.3.2 Levels of Social Cognition

A systematic review of the literature suggested that in clinical neuropsychology two dominant models are used to explain the separate dimensions within social cognition (Etchepare & Prouteau, 2018). Some studies favour a distinction between affective and cognitive functioning, where the effective element relates to the processing of emotional information. The cognitive component concerns processes relating to inferences of intention, beliefs and knowledge, or understanding of mental states, where the emotion is absent or secondary.

Others differentiate between the level of processing needed, either low-level or high-level.

Frith proposed that social cognition comprises two levels of processes, implicit and explicit (Frith & Frith, 2008). Lower level processes are mostly automatic and implicit and occur without awareness. Higher level processes are explicit and slower and require self-monitoring and reflective consciousness. Implicit or automatic low-level processing involves knowledge of primary social stimuli and low-level mental representations, such as emotion recognition through facial expressions, gestures or tone of voice (Mancuso, Horan, Kern, & Green, 2011). High-level processing requires inferences of complex mental states, perspective taking and understanding of subjective emotional states, which corresponds to explicit or more controlled functioning. High-level processing is needed to solve interpersonal difficulties, detect sarcasm, manage emotions, and pass ToM tasks, and therefore corresponds to explicit, more controlled processing. Research supports both models of understanding social cognition and suggests a distinction between the level of information processing (low and high-level) and the type of information processed (affective vs cognitive). A recently proposed model which integrates low – versus high-level processing with affective and cognitive processing in a two-dimensional model may provide a useful model to understand the different domains involved in social cognition (Etchepare & Prouteau, 2018).

Attempts have been made to assess the variety of overlapping domains within social cognition encompassing a wide range of processes including:

- reading faces
- recognising emotional expressions
- eye gaze
- perception into action
- theory of mind (mentalising)
- empathy
- deception
- morality

Social cognition comprises a wide range of components, the exploration of which is beyond the scope of this study. Within clinical neuropsychology, much of attention has focused on theory of mind, emotion perception (the recognition of emotional expressions) and empathy, as such this study will focus on these areas.

1.3.3 Social cognition and TBI

Since the development of tools to assess social cognition in assessing and understanding ASC, researchers have begun to apply these tools for use with other client groups. The aim of this is to understand further and quantify difficulties found in various clinical populations, including in TBI.

The objective measurement of emotional and social behavioural changes following TBI has been challenging given the previous lack of stringent measures. However, there has been a consensus that the social and emotional changes are strongly associated with more reduced quality of life. Studies of people who have experienced head injury or lesions demonstrate that shifts in empathy, personality and behaviour changes are frequent, especially in cases where the damage occurs in the prefrontal cortex (McDonald, 2013a)

The psychosocial changes which often occur following a TBI have wide-reaching impacts on people living with TBI and their carers. Studies estimate that between 60-80% of people with severe TBI experience changes to their behaviour and personality after their injury (McKay, 2015; Oddy, Coughlan, Tyerman, & Jenkins, 1985; Weddell & Leggett, 2006). Consequently, impact on interpersonal relationships, social integration and increasing carer burden (Wood, Liossi, & Wood, 2005). These changes may occur as a result of a loss of skills in social perception and empathy, and therefore represent a deficit in social cognitive functioning (McDonald, 2013b).

Studies have shown that people with TBI's have impairments across varying social cognition tasks. One study found that people with moderate and severe TBI performed poorly on emotion recognition tests, ToM and empathy (McCauley et al., 2014). However, there has been little research exploring if these deficits exist in people who have experienced mTBI. A study comparing the social cognition of individuals who had received a mild, moderate or severe TBI, using the Faux Pas test to assess ToM indicated that all three groups showed impairment in the ToM (Fazaeli, Yazdi, Sharifi, Sobhani-Rad, & Ehsaei, 2018). There has however beyond this been very little research specifically investigating the impact of mTBI on social cognition, despite mTBI's affecting a higher number of people.

1.3.4 Social Cognition and Neurodegenerative Conditions

Recent research has highlighted impairments in a range of neurological conditions including those with early stage Alzheimer’s disease and other neurodegenerative conditions. Behavioural changes such as reduced empathy and disregard for social norms are similar to those found in other disorders predominately characterised by social cognitive deficits (Elamin, Pender, Hardiman, & Abrahams, 2012). These observations prompted research into the area of social cognition in neurogenerative conditions, particularly in cases which are associated with right hemispheric involvement.

1.3.5 Social Cognition and Frontotemporal Lobar Degeneration

Frontotemporal lobar degeneration (FTLD) is one of the terms given to the group of neurodegenerative brain conditions characterised by atrophy of the frontal and temporal lobes. Social cognitive impairments are the defining characteristic among FLTD. The growing interest in understanding social cognitive functioning in these conditions has partly been driven by difficulties in diagnosing individuals with bvFTD. It is hypothesised that social cognitive deficits may represent the core diagnostic criteria for bvFTD and therefore, the use of social cognition assessment tools may be critical to improvements in early diagnosis and treatment. FLTD is characterised by a breakdown in behaviour and social conduct, before the onset of difficulties with executive functioning, thus hindering the diagnosis process, which is reliant on subjective reports from carers. These reports are often inconsistent and influenced by context, culture and personal experiences (Elamin, Pender, Hardiman, & Abrahams, 2012).

Studies have indicated a range of social cognitive impairment in bv-FTD patients, including impairments in ToM (particularly affective ToM), gaze detection, and recognition of facial expressions, especially negative emotions such as anger and fear (Bediou et al., 2009; Diehl-Schmid et al., 2007; Snowden et al., 2003; Torralva, Roca, Gleichgerrcht, Bekinschtein, & Manes, 2009a). These results indicate that assessment in social cognition could play a key role in improving diagnosis.

Studies have reported that bvFTD patients have impairments in recognising sarcasm, judging which actions should be taken in social dilemma situations, identifying social concepts, and differentiating between minor transgressions and major social violations. Using neuroimaging studies researchers have linked deterioration in the medial frontal cortex (MFC) and right-temporal lobes in these social processes, arguing they play a critical role in social cognition (Abu-Akel & Shamay-Tsoory, 2011; Grossman et al., 2010; Mahoney, Rohrer, Omar, Rossor, & Warren, 2011; Mendez, Anderson, & Shapira, 2005).

Additionally, studies have shown that patients with bv-FTD perform poorly on social cognition tasks which correlate with behavioural changes such as reduced empathy. These difficulties have been linked with atrophy in the superior temporal and orbitofrontal regions (Gregory et al., 2002a; Happé, Brownell, & Winner, 1999).

Additionally, emotional lability, which could be understood in terms of emotional recognition dysfunction has been identified as a potential unique sign of suspected CTE (Yuan & Wang, 2018). Research suggests that behavioural changes such as emotional lability are the first identifying factors in clinical presentations of individuals with CTE (Stern et al., 2013), with behavioural changes observed many years before the presentation of cognitive symptoms.

There is growing evidence indicating that for individuals who have a diagnosis of a neurodegenerative condition, the addition of social cognitive impairments is associated with poorer functional outcomes. In part this may be due to the breakdown in interpersonal relationships, leading to isolation and poorer quality of life (Christidi, Migliaccio, Santamaría-García, Santangelo, & Trojsi, 2018). Detection of early social impairments may aid early diagnosis in neurodegenerative diseases, providing the potential for early treatments (Elamin et al., 2012).

1.3.6 Theory of mind (ToM)

ToM was initially defined as the ability to "impute mental states on oneself and others" (Premack & Woodruff, 1978). This definition indicates that individuals should have an awareness of their own mental state (metacognition), infer the mental state of others, and recognise those mental states which signal emotion (emotional information processing). Research in the field has consistently revealed that ToM underpins the ability to communicate, cooperate, share and empathise. These abilities are considered crucial in understanding and navigating social situations. ToM is one of the earliest theories to be developed in understanding social behaviour and remains prevailing in the field of social cognition.

Frith (2008) argues that the label of ToM can lead to some misunderstandings, as it suggests a conscious process. As both implicit and explicit methods are enacted Frith suggests the term *mentalising* provides a more accurate label of the process. However, within clinical neuropsychology, most tests of ToM involve explicit mentalising (Frith & Frith, 2012) and therefore the term ToM will be used here as most accurately describes the process.

1.3.6.1 Development of theory of mind in typically developing individuals

Research into the development of social cognition appears to support a two-dimensional model, with functioning acquired hierarchically. Children initially develop an understanding of desires followed by intentions and false beliefs.

Studies analysing eye gaze patterns have shown that children around 18 months begin to understand the goals and desires of others (Liszkowski, Carpenter, Striano, & Tomasello, 2006). Infants as young as 6-months show a preference for a novel-goal, and habituation when an adult reaches from the same object repeatedly (Woodward, 1998). At a similar age, children also begin to anticipate other people's behaviour (Southgate, Senju, & Csibra, 2007), which indicates that at this early age children can attribute false beliefs; thought previously not to develop until later in childhood. Other ToM abilities appear around the same time, and children show signs of empathetic behaviour when another person is in distress. Once children turn 18 months, there is evidence of higher-level social processing, as children develop an awareness of others' goals, intentions, desires and associated mental states. Two-year-olds can deduce which toy another child wants by following their eye-gaze to a particular toy, and then selecting that toy from several possible toys shown in a picture, which indicates the ability to "mind-read" (Reniers, Corcoran, Drake, Shryane, & Völlm, 2011). One significant development in the second-year is the emergence of pretend play (Ma & Lillard, 2017).

Between the ages of 3-5 years, ToM capabilities increase rapidly, with research indicating typically developing children possess capacity to monitor their own and others intentions (Phillips, Baron-Cohen, & Rutter, 1998), understand deception, and recognise and begin to develop language to refer to mental states (Baron-Cohen et al., 1994). One seminal experiment - the so-called 'false-belief task' - relates to the understanding that different people can have disparate thoughts about the same situation (Wimmer & Perner, 1983). Once a child passes the task they are often considered to have a well-developed first-order false belief reasoning (Wellman, Cross, & Watson, 2001). Consensus has suggested that this occurs at around age four, with younger children succeeding only in implicit but not explicit false-belief tasks. By middle childhood, children begin to interpret white lies correctly. This is followed by an understanding of irony and finally sarcasm. These abilities are known as second-order false-beliefs (Peterson, Wellman, & Slaughter, 2012).

Higher-level processing requires a combination of cognitive resources, such as language and executive functioning which are not acquired in early infancy and therefore further support the hierarchical model. Research from clinical and neuroimaging studies suggest that is it possible to distinguish between low and high-level processes (Apperly & Butterfill, 2009). However, recent research in which the task was modified to improve performance has recommended that children acquire false-beliefs as young as 2-3 years old. This finding suggests it may be the complexity in the assessment which causes young children to fail the task rather than a lack of ToM. The discrepancy highlights the complexity of the evaluation of ToM, especially in infants.

1.3.6.2 Affective and Cognitive Theory of Mind

As previously mentioned, ToM divides into two sub-components, affective and cognitive. Studies indicate that individuals show differential impairment on tests of cognitive versus affective tasks supporting the hypothesis that there are two distinct processes at work. Patients with frontal-temporal dementia have been shown to have more significant impairments in affective ToM (Gregory et al., 2002b) and patients with HIV infection demonstrate more significant impairments in cognitive ToM, with results on each domain occurring independently of each other. Research indicates that those with poorer social cognition have poorer outcomes across many domains, including poorer mental and physical health (Christidi et al., 2018).

1.3.6.3 Assessment of ToM

In assessing social cognition, the majority of available measures have been designed to evaluate ToM abilities (Baron-Cohen, Leslie, & Frith, 1985). The hallmark study of Wimmer and Perner (1983) developed the ‘false-belief task’ to evaluate ToM in neurotypical children paved the way for further research in the field.

As previously mentioned, the advancement in measures of social cognition within the ToM paradigm has in part arisen to understand the mechanisms which underlie difficulties in social communication disorders (such as ASC). Typically, tests require participants to predict and understand the behaviour of others.

Consistently individuals who have ASC perform worse when compared to non-ASC controls. Early research showed that 80% of children with ASC failed the false-belief task with 85% of typically developing children succeeding (Baron-Cohen et al., 1985). As individuals who meet diagnostic criteria for ASC are unable to pass tasks, the hypothesis is that that they are unable to form mental representations of other mental states, the phenomenon defined as ToM. Therefore, ToM assessments aim to measure the specific construct of social cognition, which are the mechanisms inherent to the problems experienced in people with ASC. However, as previously mentioned the validity of these tasks has been questioned as older, high-functioning children with ASC can pass the tasks.

In response to the criticisms more advanced measures of ToM have since been developed. The introductions of verbal and non-verbal based tasks using stories and cartoons which describe social scenarios and require the participants to predict the behaviour of characters within the story. For example, one non-verbal task requires participants to pick the ending of the story from three possible options (Dodell-Feder, Lincoln, Coulson, & Hooker, 2013). To succeed in the task participants, need to understand the intentions of the character. The advantage of the non-verbal task is that it does not place demands on linguistic processes, however, few non-verbal tests have normative data available.

Other non-literal language advanced ToM tasks include Strange Stories (Dodell-Feder et al., 2013). The tasks require an understanding of the mental states of the characters within the stories, and for participants to detect white lies, persuasion, sarcasm and faux pas within the stories. Individuals with ASC demonstrate difficulties with processing the non-literal information and therefore provide inappropriate explanations for characters behaviours within the stories (Happé, 1994).

Further tasks have been developed to detect subtle social cognition deficits in ASC. The Faux Pas Test was initially developed by Baron-Cohen, O'Riordan, Stone, Jones and Plaisted (1999) with increased sensitivity to detect subtle difficulties in individuals with high-functioning ASC. Participants were asked to read vignettes and required to detect if the characters said something inappropriate or embarrassing. A more sophisticated version of this task has since been developed. The Social Stories Questionnaire (SSQ (Lawson, Baron-Cohen, & Wheelwright, 2004)), requires participants to detect both subtle and blatant faux pas scenarios. Research has indicated that the SSQ has good internal consistency and is psychometrically sound when applied to individuals with TBI (Francis, Osborne-Crowley, & McDonald, 2017). These tasks may be more appropriate to detect subtle deficits in early disease progression and may be more reliable for use with non-clinical populations. However, given the demands placed on working memory and linguistic processing, performance may be impacted by existing cognitive deficits, and therefore may not be appropriate for populations with known cognitive impairments.

1.3.6.4 Critique of Theory of Mind

It has been argued that concluding poor results in ToM tasks represent the existence of a deficit in an unobservable phenomenon (social cognition or ToM) lacks validity. Critics argue that an interpretive leap has been taken, linking observable deficits in often non-socially representative tasks and the existence of mental processes. Furthermore, the seemingly arbitrary cut off points for which scores constitute 'normal' and ‘abnormal' functioning in addition to the current lack of consensus on the neural underpinnings of social cognition contribute to the criticism. Additionally, ToM tasks are often subject to implicit cognitive biases, which could lead to misattribution of 'deficits' (e.g. stereotype bias). However, in recent years there has been an increase in studies using more advanced neuroimaging techniques, which have more reliably identified neural processes underpinnings of social cognition. These critiques highlight the importance of the use of multiple ToM tasks within the research.

1.3.7 Emotional Processing

Evidence suggests the eyes play a critical role in human social communication and perception. The direction of gaze and raising and lowering of the eyelids are thought to give essential information which can be used to interpret the emotions of others accurately. Significant correlations between emotional processing and

ToM have been reported in studies, suggesting that accurately recognising and understanding facial expressions and affect is required for understanding mental states and intentions (Dyck, Piek, Hay, Smith, & Hallmayer, 2006).

1.3.7.1 Emotional Recognition

Emotional recognition tests were developed following the seminal work of Paul Ekman, in his research Ekman conducted cross-cultural studies exploring universal emotions and the innate nature of facial expressions. His research identified six core emotions which were considered the most commonly associated emotions to specific facial expressions (Ekman & Friesen, 1971). The six core emotions he identified were; fear, sadness, anger, disgust, happiness and surprise. As a result of the research the Ekman Faces Test was developed (Ekman & Friesen, 1971), which formed the basis of measures currently used to assess emotion recognition within clinical psychology. However, his research was criticised for selecting individuals who had been exposed to western media and culture and not reflecting the diversity of emotion across culture.

The commonly used 'Reading the Mind in the Eyes' (RME) task requires participants to identify what a person is thinking based on a photograph showing only the eye-region of the face. The task was developed to assesses how well adults can make inferences of others’ mental states using emotional perception. Research indicates that those with TBI have impairments in the task when compared to controls (Muller et al., 2010). As these tasks are presented verbally in a forced choice format, they are thought to be less reliant on other cognitive factors such as memory. Additionally, participants are encouraged to ask for clarification if they do not understand the choices of emotions given. This requires only limited comprehension, which could be affected by TBI. However, emotional recognition tasks have faced criticism due to their limited normative data and poor ecological validity (Johnston, Miles, & McKinlay, 2008).

Other studies of emotional processing often involve participants identifying the affect of individuals based on their facial expressions in photographs. Early studies asked participants to choose between the six primary basic emotions;

anger, happiness, sadness, fear, disgust and surprise. Studies indicated that individuals with ASC are unable to identify these six basic emotions (Happé, 1994). Conversely, other studies dispute this and argue that some individuals with ASC can identify the facial affect and suggest the deficit is not universal within ASC (Castelli, Happé, Frith, & Frith, 2000). However, interpretations of these results lack reliability and validity, and there is a lack of normative data available for many of the emotional perception tasks.

The recently developed Wechsler's ACS Social Perception Subset (Pearson, 2009) aims to address these limitations. Participants are asked to match the six primary emotions to 24 pictures presented. Evaluation studies of the measure indicate it is psychometrically sound and correlates well with performance on the RME and other tests of facial affect recognition tasks (Kandalaft et al., 2012). Nonetheless, given that these tasks rely on static stimuli, it can be argued that they lack ecological validity. The development of more sophisticated tasks which use simulation (Bicho, Erlhagen, Louro, & Costa e Silva, 2011) may address this issue, however, require the use of high-tech equipment and therefore are not practical for use in clinical settings.

1.3.8 Empathy or Emotional Perspective Taking

Arguably empathy is one of the most important mechanisms of social cognition, enabling humans to adapt to situations based on interpretations of the actions of others (Blakemore & Frith, 2003). Lack of empathy is associated with increased levels of violence, criminality and aggression. Reduced scores on empathy measures are reported in several clinical populations, including those with a diagnosis of psychopathy, psychosis and ASC (Blair, 2005; Blair, Mitchell, & Blair, 2005; Lee et al., 1998)

Despite a common understanding of the meaning of empathy, there has until recently been a lack of consensus of a scientific, measurable definition. The debate within the field exists as to whether empathy involves merely the recognition of emotion, or if it requires the experiencing of it, or both (Bennett, 1995; Chlopan, McCain, Carbonell, & Hagen, 1985; Cohen & Strayer, 1996; Jolliffe & Farrington, 2004).

Some argue for the distinction of two separate neurocognitive processes for empathy, and propose the difference between cognitive and affective empathy (Decety & Jackson, 2006; Gini, Albiero, Benelli, & Altoè, 2007; Jolliffe & Farrington, 2006; Lawrence, Shaw, Baker, Baron-Cohen, David, 2004; & Rankin et al., 2006). Blair (2005) suggests further delineation to include motor and emotional empathy. However, standard across the varying definitions is the notion that empathy encompasses the comprehension of other people's experiences (cognitive empathy) in addition to the ability to vicariously experience the emotions of others (affective empathy). Cognitive empathy requires information to be held in mind and manipulated, switching between one's own cognitive or emotional state, and comparing, contrasting and aligning with that of the other. This shifting results in a working model which can be quickly updated. Affective empathy, on the other hand, requires a rapid recognition of the other person's body language, facial expression, gestures and voice prosody (Reniers, Corcoran, Drake, Shryane, & Völlm, 2011). Reiners et al. (2011) argue that any definition of empathy should include both factors, and exclude behavioural expressions such as sympathy. Blair (2005) likens cognitive empathy with ToM as it requires the forming of mental representations of another's mental state. However, Reiners (2011) claims that although the same underlying processes are likely responsible for both ToM and cognitive empathy, they can be distinguished as two constructs, as cognitive empathy relates to the attribution of emotions, as opposed to cognition.

1.3.8.1 Assessment of Empathy

Several questionnaires are available to assess Empathy such as the Empathy Scale (Hogan, 1969), Interpersonal Reactivity Index (M. H. Davis, 1983) and Empathy Quotient (Baron-Cohen & Wheelwright, 2004). The lack of consensus on the definition of empathy as discussed above is reflected in the measures available with different scales measuring disparate aspects of empathy. In response to some of the issues with the scales available the Questionnaire of Cognitive and Affective Empathy (QCAE) was developed, it aims to combine the definitions to reflect the multidimensional construct of empathy (Reniers et al., 2011). The measure separates cognitive empathy and affective empathy, into two subscales, reflecting the debate mentioned above regarding the two separate processes.

1.3.9 The Neural Basis of Social Cognition

Despite difficulties in disentangling the neural processes involved in social cognition compared with other cognitive processes, a growing body of evidence has identified several neural systems which appear to be responsible for social cognitive functioning.

Evidence from evolutionary studies suggests that the brains of humans may have evolved to support complex social interactions, dubbed the 'social brain hypothesis' (Dunbar, 1998). In support of this hypothesis, the volume of the neocortex correlates with the level of complexity of the primate social structure, and abilities to use deception and cooperate. These theories suggest that a larger brain may have been advantageous to support social interactions (Adolphs, 1999).

Nearly two decades of functional neuroimaging studies have indicated a distributed neural network underlying social cognitive abilities, with growing research suggesting a network view rather than a collection of isolated neural structures. Despite damage to specific regions resulting in relatively specific impairments, no social process can be attributed to a single structure. A combination of information gained from studying those who have impairments as a consequence of damage to specific regions. In addition to studying areas which are differentially activated in the brains of healthy individuals performing social tasks in an MRI scanner has highlighted the importance of the prefrontal cortex (PFC) in social cognition.

A classic example of the impairments in social cognition as a result of damage to the PFC is the case of Phineas Gage (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). The damage Phineas received, resulted in an impairment in planning and executing future activities, a reduced response to punishment and inappropriate social behaviour, which was in striking contrast to his behaviour before the injury. Similar impairments following damage to the PFC have been demonstrated in many cases since. Several other structures have been linked to social cognition; these include the medial prefrontal cortex linked to ToM abilities, and the orbitofrontal cortex in emotional processing as described below.

To date four critical distinct neural networks have been identified as having functional properties responsible for social cognitive processes:

- The social perception network, centred on the amygdala connectivity, has been shown to play a pivotal role in the following social processes; emotional influences on social decision-making, responding to socially threatening stimuli and social-affiliative behaviours (Bickart, Hollenbeck, Barrett, & Dickerson, 2012).

- The mentalising network, activated when reflecting on oneself, or thinking about others; the most prominent nodes in these networks are the dorsomedial prefrontal cortex (dmPFC) and the temporoparietal junction (Bickart et al., 2012; Daneshvar, Nowinski, Mckee, & Cantu, 2011; Mitchell, Banaji, & Macrae, 2005; Spunt & Lieberman, 2012; Van Overwalle & Baetens, 2009). With the medial frontal cortex additionally implicated in several studies (Adolphs, 1999).

- The empathy network, engaged when vicariously experiencing the emotions of others (de Vignemont & Singer, 2006) with different systems indicated for affective and cognitive empathy (Fan, Duncan, de Greck, & Northoff, 2011). The literature suggests that cognitive empathy specifically recruits the structures of the cortical midline such as the anterior mid-cingulate cortex and dmPFC (Lamm, Batson, & Decety, 2007), while regions including the insula and midbrain are shown to be activated in affective empathy. Additionally, the right anterior insula is implicated for both affective and cognitive empathy (Fan et al., 2011).

- The mirror network, activated when individuals observe the actions of other people, which is considered to play a role in observational learning

(Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Rizzolatti & Craighero, 2004; Spunt & Lieberman, 2012). Evidence suggests the cortical midline structures are involved in the mirror network, including the medial prefrontal cortex, the anterior cingulate cortex and the praecuneus.

These results support the idea of separate domains within the broader construct of social cognition, suggesting that different neural substrates are responsible for each area.

1.4 The Rationale for the Current Study

More than five million people worldwide participate in Rugby on an annual basis, with the vast majority playing at an amateur level. The UK has the second highest number of registered rugby players with around 300,000 people participating regularly (England Professional Rugby Injury Surveillance Project Steering Group, 2018). Research investigating the potential short and long-term consequences of concussive impacts has been lacking in rugby compared with other sporting populations, particularly American football. Despite varying results across studies, a consensus is building that concussive and subconcussive impacts (common in contact sports) are associated with the development of neurocognitive difficulties and in some cases neurodegenerative conditions. Previous research has focused on the traditional neurocognitive domains, e.g. memory, attention and executive functioning. To the researcher's knowledge, no other research has studied the relationship between SRC and social cognition in rugby. It is proposed that a greater understanding of the potential neurocognitive consequences is essential due to the potentially large number of people who could be affected, and the public health implications.

Impairments in social cognition characterise most neurodegenerative conditions and represent the core diagnostic features in some neurodegenerative conditions such as bvFLTD (Gregory et al., 2002b). Likewise, it is proposed that social cognitive deficits would be observed in people with CTE. This hypothesis is based on the fact that shared neural networks which are implicated in both CTE and other neurodegenerative conditions with known social cognitive deficits, particularly FLTD and AD. Social cognitive deficits in neurodegenerative disorders may underpin the behavioural changes observed, and identification of these deficits may lead to increased understanding of disease progression. Despite neuropathology differences between CTE and other neurodegenerative conditions, similarities exist in the clinical and pathological presentations of CTE and other neurodegenerative diseases, predominately Alzheimer's disease (AD) and frontotemporal dementia (FTD) (Snowden et al., 2003). As previously mentioned, social cognitive difficulties are observed in patients with FTD. Therefore, it is proposed that in individuals who have experienced multiple SRC or subconcussive injuries and who may be at risk of later development of CTE, may also have impairments in social cognition, with potential for cognitive decline over time. Impairments in social cognition would be concurrent with symptoms observed in CTE, including behavioural and personality changes, social instability, impulsive behaviour and poor judgement. These symptoms are indicative of damage from repeated trauma to the frontal temporal region of the brain. Early diagnosis of cognitive and behavioural impairments may aid treatment and offer more effective therapeutic options.

Within everyday clinical psychology, there is a rationale for further understanding and awareness of the potential consequences of sports-related mTBI. Clinical implications include the use of specific screening questions and aiding diagnosis of neuropsychological problems when working with athletes in a clinical setting. Additionally, as social cognitive deficits contribute to significant disease burden; early diagnosis, assessments of social cognition may be beneficial in the treatment and management of SRC.

1.5 Aims

Currently, there are no published studies that explicitly address the relationship between SRC and social cognition. This preliminary study aims to explore the social cognition in rugby players with a history of a least one concussion. Specifically, the study will examine if participants show deficits in cognitive deficits in ToM, empathy and emotional processing and whether these are related to general cognitive abilities.

1.5.1 Research Questions

- Do rugby players with a history of SRC have deficits in social cognitive processing?

- Do social cognition deficits relate to general cognitive abilities in rugby players with a history of SRC?

- If so, do these deficits reflect number, nature or severity of SRC?

2 METHOD

2.1 Epistemological Position

Epistemology and ontology are fundamental within scientific study; therefore it is crucial for researchers to recognise the philosophical context in which their data is obtained. Epistemology refers to the philosophy of knowledge, and how it is we, as human beings come to know things about the world, including our beliefs and assumptions (Elliott, Fischer, & Rennie, 1999). Epistemology includes the scope, validity and limits of this knowledge (Willig, 2001). On the other hand, ontology denotes the philosophy of reality, and the conceptualisation one makes of the world around them (Bunge, 1974). Researchers should acknowledge the influence the epistemological stance has on the chosen methodological design, data collection and analysis (Barker & Pistrang, 2005). The current research has been conducted within a critical realist approach, and although it is beyond the scope of this work to provide a full description and critique of the approach, a summary is provided.

Realism posits that the world is real, independent of who may be observing it, and therefore measurable. From a realist position, the researcher aims to understand as accurately as possible the properties of the world. (Voss, 2000). During the past 50 years, within psychology, this approach has evolved into a critical realist position. This approach assumes the existence of a real world which has observable regularities, yet, it is critical of the capacity to know realities with exact certainty. However, a critical realist recognises that all scientific inquiry is fallible and subject to human error and cultural bias (Trochim & Donnelly, 2001). When taking a critical realist stance, researchers should be explicit about the methods used, to enable research to be replicated. Besides, the use of multiple measures to assess the same construct is recommended to provide a reliable understanding of the ‘reality' which is being observed.

An explicit decision to adopt a critical realist stance was made with the aim of qualifying constructs within a world which is ‘real' while recognising that knowledge is situated within the broader cultural, social and historical context. Therefore, inferences made from the data, and conclusions are vulnerable to human error. In taking a critical realist approach, the researcher acknowledges the socially constructed nature of the concepts discussed within the report. This allows for consideration that the neuropsychological constructs described here are artificial and evolving in nature; these include social cognition and core neuropsychological processes described.

2.2 Design

The study uses a cross-sectional correlational design to address the relationship between SRC in rugby and core aspects of cognitive functioning. The specific focus is on the social cognition and its relationship to the other areas of cognitive functioning, concussion history and rugby exposure. A cross-sectional design was chosen as it allows examination in a single group at a single-time point. This design is appropriate for the current study as it fits with the aims of exploring the relationships between the variables, rather than identifying causal links.

The use of a control group was not deemed necessary as no manipulation of variable or interventions were provided. Although the use of a control group may have provided interesting information it was beyond the scope of this study to include a control group due to lack of time and resources. A test to estimate optimal functioning allowed for comparisons within-subjects to be made.

2.3 Sample Size

The sample size was determined by reviewing the current literature in the area. The sample size proposed is comparable to other samples used in similar studies investigating relationships between concussions and outcomes on neuropsychological testing (Alexander, Shuttleworth-Edwards, Kidd, & Malcolm, 2015; Cossette et al., 2016; Daniel et al., 1999; Hinton-Bayre & Geffen, 2002). Consistent with contemporary practice, effect sizes will be used to measure the strength of relationships. Where appropriate, statistical procedures sensitive for a small sample and non-normal data will be used, e.g. non-parametric tests with exact significance.

It is acknowledged that larger sample sizes generate more reliable and valid results (Field, 2009) and all attempts were made to recruit the highest possible number of participants within six months (October 2018- March 2019).

2.4 Ethics

2.4.1 Ethical Approval

Ethical approval was sought and obtained from the University of East London Ethics Committee (Appendix A).

2.4.2 Informed Consent

All potential participants provided written consent (Appendix B) before taking part in the study. Each participant was provided with an information sheet (Appendix C) before agreeing to take part, detailing the aims, confidentiality, procedures and advised them of their right to withdraw from the study at any time. Following completion, participants were provided with a debrief sheet, and invited to ask any questions they had, and if they wished to see a copy of the study outcomes following research completion. If participants were concerned about the results or worried about their health as a consequence of taking part in the study they were advised to contact the study supervisor or their GP. Information on organisations which could provide support to participant should have concerns following participating in the study were provided in the debrief sheet (Appendix D).

2.4.3 Confidentiality

To ensure confidentiality, all participants were assigned a unique participant code, stored in a separate location to their data. All data collected was not linked with any personally identifiable information. All data is kept in a locked cabinet, which only the researcher has access to. During the analysis only, the unique code was used. On electronic databases, only an ID number was used. Confidentiality was explained to all participants.

2.4.4 Protection from Harm

Participation involved completing a neuropsychological assessment which can cause mild fatigue. To mitigate the risk to participants, frequent breaks were offered during the assessment. The assessment was designed to limit the number of tests to those necessary to address the aim of the research. In the event that a participant’s performance on the tasks indicated a neurodegenerative condition this would be discussed with study supervisor and the participant would have been informed.

2.5 Recruitment

Participants were recruited using a convenience sample of participants known to the researcher with a snowballing effect to continue recruitment. Emails were sent to rugby clubs in the London area asking if they would be willing to circulate details about the study to their current and alumni members. Potential participants were provided with an information sheet about the study before deciding if they would participate in the study.

2.5.1 Inclusion Criteria

Participants of ages 18-65, with a history of playing rugby at a competitive level and with English as a primary language.

Participants were required to have had at least one self-reported concussion sustained while playing rugby. Participants with recent concussions were not allowed to participate until three months following their concussion. Concussion exposure was determined by asking participants to report symptoms they had experienced and comparing these to the symptom evaluation on the Sport Concussion Assessment Tool (G.A Davis, 2017)

2.5.1.1 Exclusion Criteria

To minimise the effects of confounding variables the following exclusion criteria will be applied.

- Non-fluent English
- Non-rugby related traumatic brain injury or neurological disorder
- TBI sustained while playing rugby which could be classified as moderate or severe
- Current mental health diagnosis
- Current misuse of substances
- History of stroke
- Diagnosed learning disability

In addition, their education level and years in education was recorded.

2.6 Procedures

2.6.1 Assessment

The assessments were administered at a location convenient to the participant, either the home, rugby club or the University of East London. Before completing the assessment, the researcher checked the participants had read and understood the information sheet. Lone worker policies for safety were adhered to.

The assessment process began with gathering information regarding participants demographic information (age, education level, mental health history, learning disability). Participants were then asked about their rugby and concussion history initially, and information was collected on other confounding variables such as hearing and vision difficulties and linguistic factors. Following the collection of qualitative information, participants then completed a comprehensive battery of neuropsychological tests to assess cognitive functioning to control for impairment in any cognitive domains and to assess possible correlations across any observed impairments followed by social cognition tests. All tests were administered according to test manuals to support reliability. On average assessments took one hour, with short breaks offered to prevent fatigue.

Supervision and advice were provided throughout the study to ensure correct administration and scoring and interpretation of all measures.

2.7 Measures

The study test battery consisted of questions relating to rugby and concussion history, measures of premorbid functioning and general cognitive functioning. The rationale for collecting these measures had two aims 1) to explore cognitive functioning in relation to concussion history and if impairment exists within the sample 2) performance on tests of one cognitive domain predict performance on other areas of cognitive functioning such as social cognition and memory. Establishing a cognitive baseline is beneficial in exploring the relationships between variables.

Table 1 *Utilised Neuropsychological Assessment Tools*

Cognitive Domain/ Area of Assessment		**Subset**
Optimal Functioning		TOPF
Executive Functioning	Word Generation - Verbal Fluency	DKEFS word generation
	Word Generation - Semantic Fluency	DKEFS Category Generation
	Verbal Switching	DKEFS verbal switching
	Rule Deduction and Planning	Brixton Test
Attention and Working Memory		WAIS Digit Span Forward
		WAIS Digit Span Backward
		WAIS Digit Span Sequenced
Verbal Functioning		WAIS Similarities
Visual Functioning		WAIS Matrices
Processing Speed		WAIS Coding
Social Cognition	Mentalising/ ToM	Social Stories Questionnaire
	Emotional Recognition	Affect Naming Test
	Empathy	Questionnaire of Cognitive and Affective Empathy

2.7.1 Sports-Related concussion and subconcussive impacts

A history of concussions and exposure to rugby was collected through the following questions:

i) Concussion exposure

Participants were asked to describe the symptoms they experienced at the time of their injury and these were compared with the symptom evaluation form on Sport Concussion Assessment Tool (Appendix E).

ii) Number of concussions

The number of self-reported concussions was recorded for each participant. Information about the clinical symptoms they had at the time of injury was recorded, in addition to the length of recovery time from symptoms. Research suggests that multiple concussions increase the risk of later neurocognitive problems (Maddocks et al., 2017)

iii) Age of first concussion

This information was recorded to assess if any correlation between age at first concussion and performance on neurocognitive tasks. Some studies have indicated that concussions which occur in childhood are more strongly correlated with impairments in cognitive functioning compared with those which occur in adulthood.

iv) Years played rugby

This information was collected to provide an estimate of the number of seasons participants had played rugby for. Evidence suggests that subconcussive injuries are more common during match play when compared to practice. Those participants who played rugby for more years will be more likely to have greater exposure to subconcussive injuries due to increased match play hours.

v) An estimate of rugby hours played per week.

An estimate of the number of hours played per week was collected from the participant by taking an average of the number of hours played per week including practice and match time.

vi) Position played

Position played was recorded as either front or back; if the participant changed position, the position played for the longest time was recorded. This information was collected as evidence indicates that front positions are more likely to experience concussions and subconcussive injuries (Archbold et al., 2018)

2.7.2 Optimal Functioning

The capacity to read irregularly spelt words is relatively resistant to cognitive decline (Nelson & Willison, 1991) and correlates well with measures of general intelligence. Performance in the task can be compared to normative data to provide an estimate of optimal functioning (Wechsler, 2011).

The Test of Premorbid Functioning UK (TOPF^{UK}) consists of a list of 70 atypically spelt words, e.g. (plumb, knead) that participants are asked to read aloud. Research suggests correlations between premorbid ability and memory, especially within the verbal domain (Lezak, Howieson, & Loring, 2012). However, wide confidence intervals in the test manual for processing speed suggest the test is less reliable in predicting optimal processing speed. The test allows for multiple pronunciations of words, allowing for a diversity of dialects. The task relies on semantic and lexical, as opposed to phonological domains, therefore meaning that accurately reading each word requires previous vocabulary knowledge rather than standard pronunciation rules. A score of one is given for each correctly pronounced word, with total scores compared to normative data. The measure has good reliability and validity; however, it is limited by requiring normal development of reading abilities and exposure to English reading materials.

2.7.3 Executive Function

Assessments of core executive functioning should include verbal fluency, visual sequencing and rule acquisition (Goldstein & McNeil, 2012).

2.7.3.1 Word Generation

Word generation was chosen as the task activates frontal lobe executive functioning. It is relevant for the current study as deficits in letter fluency have been associated with progression of neurodegenerative conditions such as Alzheimer's (Henry, Crawford, & Phillips, 2004) and in mTBI (McCauley et al., 2014).

The Delis-Kaplan Executive Function System (D-KEFS) verbal fluency comprising three subsets: Letter Fluency, Category Fluency and Switching.

i. Letter Fluency

This subset evaluates word generation ability. Participants are required to verbalise as many words as possible within a 60-second time-limit beginning with a specific letter (F, A, and S). The task is sensitive enough to indicate executive dysfunction decline as it requires the inhibition of irrelevant words and the development of a strategy aids accurate retrieval.

ii. Category Fluency

This subset evaluates words generation and retrieval of semantic knowledge. Participants are asked to verbalise as many words within a particular category (animals, and boys names). This task requires the initiation of action, self-monitoring and retrieval of knowledge from semantic memory.

iii. Switching

The subset evaluates word generation ability and switching attention between tasks. Participants are asked to verbalise words within two categories (fruit and furniture) alternating between each category after each word. In addition to the requirements for category fluency.

The participant receives one point for each unique correct response. Scores are then compared against the normative data which is based on a sample of 1,1750 people. The DKEFS is reliable and valid across populations (Shunk, Davis, & Dean, 2006).

2.7.3.2 Rule Deduction and Planning

The Brixton Spatial Anticipation Test (Burgess & Shallice, 1997) assesses rule acquisition, planning and switching from abstract information. Participants are presented with a blue circle which appears in one of ten spatial locations on each of the 56 pages presented. The blue circle moves location according to a rule unknown to the participant. The participant is required to infer the rule based on the pattern and predict the subsequent location.

The Brixton test has been shown to be valid and reliable. Studies show a significant difference in performance on the task between healthy individuals and individuals with a TBI (Van Dan Berg et al., 2009) and in those with frontal lesions (Burgess & Shallice, 1997). Also, the short-administration time of the task is of benefit to avoid participant fatigue.

2.7.3.3 Processing Speed

To assess processing speed participants completed the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV^{UK}) Coding (Wechsler, 2010). The participants are presented with a visual key with the numbers one to ten, and each number has a corresponding symbol. The participants are required to fill in as many symbols under their corresponding numbers as quickly as possible within a two-minute time limit. The task relies on visual processing speed in addition to visual perception and analysis.

2.7.3.4 Attention and Working Memory

Attention and working memory have consistently been shown to implicated in mTBI and concussion in the recovery phase following injury. Additionally, attention and working memory deficits can be persistent following SRC which occur in childhood (Moore et al., 2016). The literature recommends the inclusion of attention and working memory tests across neuropsychological assessments for SRC (Johnson, Kegel, & Collins, 2011).

The following measures were used:

i. The WAIS-IV^{UK} Digit Span Forwards (David Wechsler, 2010) evaluates auditory attention span. Participants are required to listen and repeat a sequence of a string of random numbers in the same order, the length of which increases as they progress through the task.

ii. The WAIS-IV^{UK} Digit Span Backwards (David Wechsler, 2010) evaluates auditory/verbal working memory. Participants are required to listen to a string of random numbers and repeat them back in reverse order.

iii. The WAIS-IV^{UK} Digit Sequencing assess additionally assesses auditory/verbal working memory. Participants are required to listen to a string of random numbers and repeat them back in numerical order.

A score of one is given for each correct response across the three tasks, and scores are summed to give a total for the attention and working memory. Scores are compared against the published normative data.

2.7.3.5 Visual Function

Visual perception and reasoning were assessed using WAIS-IV^{UK} Matrices (David Wechsler, 2010) Reasoning subset. Participants are presented with a pattern with one piece missing, and they are required to determine the pattern using visual details including, shape, colour and location. The participants are asked to choose the missing piece of the pattern from five possible response.

2.7.3.6 Verbal Function

The WAIS-IV^{UK} Similarities measures verbal comprehension, expression and abstract reasoning. Participants are verbally presented with two different words and required to explain how the words are similar (e.g. “in what way are yellow and green alike?”)

2.7.4 Learning and Memory

To assess logical learning and memory the following subsets from the WMS-IV^{UK}, immediate, delayed and recognition logical memory tasks.

Participants are required to recall two short stories presented verbally, engaging both semantic and episodic memory. In the immediate subset of the task, participants are required to recall as much as they can. Later in the assessment following a delay of around 30 minutes, participants are asked again to freely recall as much as possible from the story. In the recognition part of the task, participants are required to answer yes/no to statements if they recognise the information from the story.

2.7.5 Social Cognition

Within the social cognition test battery measures of ToM, emotional recognition and empathy were employed. In consideration of the research literature which supports the distinction of affective and cognitive ToM, with impairments differentially observed in affective and cognitive ToM, the social cognition test battery included both. The Affect Naming Task (ANT, (Pearson, 2009)) was chosen in conjunction with the SSQ task, as it does not place such demands on cognition, relying more on affective aspects of ToM and recognising affect and facial emotional expressions. In contrast, the SSQ is considered predominately verbal and relies heavily on cognitive ToM. Therefore, any impairments in language would not impact on performance in the ANT. Using both tests allowed for performance to be measured on different parts of explicit mentalising skills: cognitive ToM and affective ToM.

2.7.5.1 Mentalising

The Social Stories Questionnaire (SSQ, (Lawson et al., 2004)) assesses understanding of non-literal cognitive-linguistic social processes and requires the comprehension of social norms. The SSQ requires participants to read ten short stories within some of which utterances are made by one character in the story which could upset another character. Prompted by questions at the end of each section, participants are asked to identify remarks which could have caused upset to one of the characters in the story (selecting from multiple choice options). Within the sections ten contained subtle faux pas, ten contained blatant faux pas, and ten contained no faux pas. The task requires the participant to comprehend the perspective of the characters in a social context.

2.7.5.2 Affect Naming

The ANT (Pearson, 2009) assess facial affect naming recognition abilities. Participants are presented with 24 headshot photographs of actors, in each photo the actor expresses one of the six universal emotions: sad, angry, disgusted, afraid, happy or is emotionally neutral. Participants are required to pick which emotion they think best describes the actor’s emotion. Correct responses are scored as 1, with a maximum score of 24 for the task. Scores are then compared against age-appropriate normative values obtained from a sample of 800 representative people aged between 16-90 (Pearson, 2009).

This task was chosen as it is considered a visual task, relying on social perceptual understanding of non-verbal emotional processing. In addition, performance on the ANT correlates well with the other measures of social cognition indicating its reliability (Kandalaft et al., 2012). The ANT has been valid across cultures as it assesses the emotions which are recognised universally. Additionally, the ANT was chosen as it is one of the few standardised measures available testing affect naming.

2.7.5.3 Cognitive and Affective Empathy

The QCAE (Reniers et al., 2011) was chosen to assess empathic behaviour and emotional perspective taking. The QCAE is a self-report measure which requires participants to respond to 31 statements on a 4-point Likert scale ranging from *strongly agree* to *strongly disagree*. The QCAE items are derived from several pre-existing validated measures, and studies evaluating the validity of the measure conclude that the QCAE has sound psychometric properties (Queirós et al., 2018).

2.8 Participant Characteristics

Twenty-one male participants were recruited, between the ages of 18 and 65 years were included in the study. The group age range was representative of working-age adults in the UK. Fourteen of the twenty-one participants had a university degree suggesting a well-educated sample. Participant characteristics are described in Table 2.

Table 2 *Participants Characteristics*

	Mean	Min	Max	SD	Skewness	Kurtosis
Age	39.29	18	65	16.04	0.197	-1.44
TOPF^{UK} Estimated Full-Scale IQ	102	94	125	7.52	1.64	3.24
Years Played Rugby	20.38	5	41	10.83	0.35	-1.06
Number of Concussions	3.05	1	9	2.061	1.67	2.64
Age at first Concussion	16.62	8	30	5.78	1.41	1.54

2.8.1 Language and Ethnicity

All participants were primary English speakers; a summary of participants ethnicity is shown in Table 3.

Table 3 *Ethnicity*

	Ethnicity Frequency (Proportion)					
	A	**B**	**C**	**D**	**E**	**F**
Total	15 72%	1 4.8%	1 4.8%	2 9.5%	1 4.8%	1 4.8%

A=White British; B=White Irish; C=Black British; D=White European; E=Black African; F=Mixed

2.9 Analysis

Assessments were coded per published test manuals and converted into age scaled-scores to allow for changes in performance on cognitive tests which occur with age. The data was analysed using SPSS version 24. The analysis was conducted using nonparametric tests due to the relatively small sample size. Effect sizes and analysis procedures were as follows:

a) Descriptive statistics were generated, then histograms and scatterplots were examined for outliers and missing cases, in addition, to check for potential data coding errors.

b) Data was checked for skewness and kurtosis to assess for parametric violations (skewness>1; kurtosis>3).

c) A Kolmogorov-Smirnov test was generated to examine participant's performance in the cognitive test battery and compare scores with population age-scaled norms (M=10, SD=3). This tests if the distribution of scores is comparable with a normal distribution or a defined set of distribution parameters (Wilcox, 2003).

d) A Wilcoxon-ranked test was undertaken to assess differences between scores on general cognitive functioning and social cognition.

e) Spearman's rho correlational analysis was employed to explore the relationship between social cognition, general cognitive performance and concussion and rugby exposure variables. A non-parametric test was chosen as it does not rely on parametric normality, and is appropriate for the sample size.

f) A multivariate General Linear Model (GLM) was used to explore the effects of individual factors and covariates. A regression analysis was computed for analysis of variance of multiple dependent variables which may have an influence on performance scores for the reduced social cognition tasks. Correlational analysis and the research literature informed the choice of covariates.

The significance level of p-value was set at $p<0.05$ (Wilcox, 2003); effects sizes were in interpreted in accordance with Cohen (J. Cohen, 1992).

3 RESULTS

3.1 Exploratory Data Analysis

Table 4 Distribution and Descriptive Statistics for Participants' Test Score

Subsets (Scaled)	Mean	SD	Min	Max	Skew	Kurtosis
Digit Forward	13.05	2.36	8	18	0.04	0.63
Digit Backward	11.67	3.18	6	17	-0.37	-0.90
Digit Sequencing	9.48	2.46	5	14	0.16	-0.54
Digit Combined	11.67	2.83	6	15	-0.48	-0.88
Coding	11.10	3.05	6	19	0.51	0.83
Brixton	12.10	2.93	4	17	-0.74	1.55
Letter Fluency	10.86	3.47	7	18	0.67	-0.55
Category Fluency	12.14	3.82	6	19	0.42	-0.45
Switching Fluency	12.95	1.91	10	17	0.22	-0.25
Similarities	10.62	2.48	6	16	0.46	0.24
Matrices	10.33	2.69	5	15	0.02	-0.63
LM Story Immediate	9.48	2.14	6	14	0.22	-0.22
LM Story Delayed	9.29	2.37	5	15	0.42	0.40
LM Story Recognition	9.86	3.42	4	18	0.38	0.06
Cognitive Empathy	9.86	2.03	6	13	-0.06	-0.72
Affective Empathy	8.90	2.49	5	13	0.01	-0.83
ToM Stories	8.71	3.04	5	16	0.70	-0.05
Affect Naming	8.90	2.07	5	13	0.14	0.50

3.1.1 Analysis of Optimal Ability

The performance on the TOPF^{UK} was explored to estimate optimal ability of the research group and to assess if their optimal ability was comparable to the normative data. The mean score (M=102) suggested that the participants had comparable optimal ability (M=100) to the normative data, with an SD (SD=7.52) within normative data range (SD=15). However, the data was slightly skewed and kurtosed (skewness>1; kurtosis>3), indicating that scores were not normally distributed. A Kolmogorov-Smirnov test was undertaken and confirmed that participant data differed to normative data (D (21)=1.58, p=0.01). Sample scores concentrated around the usual mean of 100 but there were no low scores (<94) and a 'long tail' of high scores yielding a positive skew.

3.2 Analysis of Cognitive Function

Visual inspection of the mean scores for the tests of general cognitive function revealed that the research groups' mean scores were above (>10) the normative data across several domains, with lower scores only observed on measures of digit sequencing and verbal memory.

The Kolmogorov-Smirnov (K-S) test outcomes suggest that participants performed better than the normative sample (M=10, SD=3) on the following subsets: Brixton Test, DKEFS Switching and Category Fluency tests (verbal and visual executive functioning); and WAIS Digit Span Forward and Backward (attention and working memory). Effect sizes were generated to quantify the size of the differences observed between the research group and normative data, where effect sizes above .5 indicate a large effect and above .3 indicate a moderate effect. The results show that a large difference was observed between the sample and normative data on the WAIS digit forward and DKEFS switching measures. Moderate differences were observed on the Brixton test, Category Fluency and Digit Backward (see Table 5).

Across other general cognitive measures, the group scaled scores fell close to the normative mean, indicating the participants' performance was comparable to scores in the normative sample. Scores for WMS Logical Memory were slightly lower; however; see Table 5.

A mean score across the domains of cognitive functioning was computed (M=11.08, SD=1.77) with scores normally distributed (Skewness <1, Kurtosis<3). These scores were slightly above ten indicate that the research group had slightly higher levels of cognitive normative data (M=10, SD=3) than was revealed on the test of optimal functioning.

Figure 1 Participant Mean Scores on Neuropsychological Test Battery

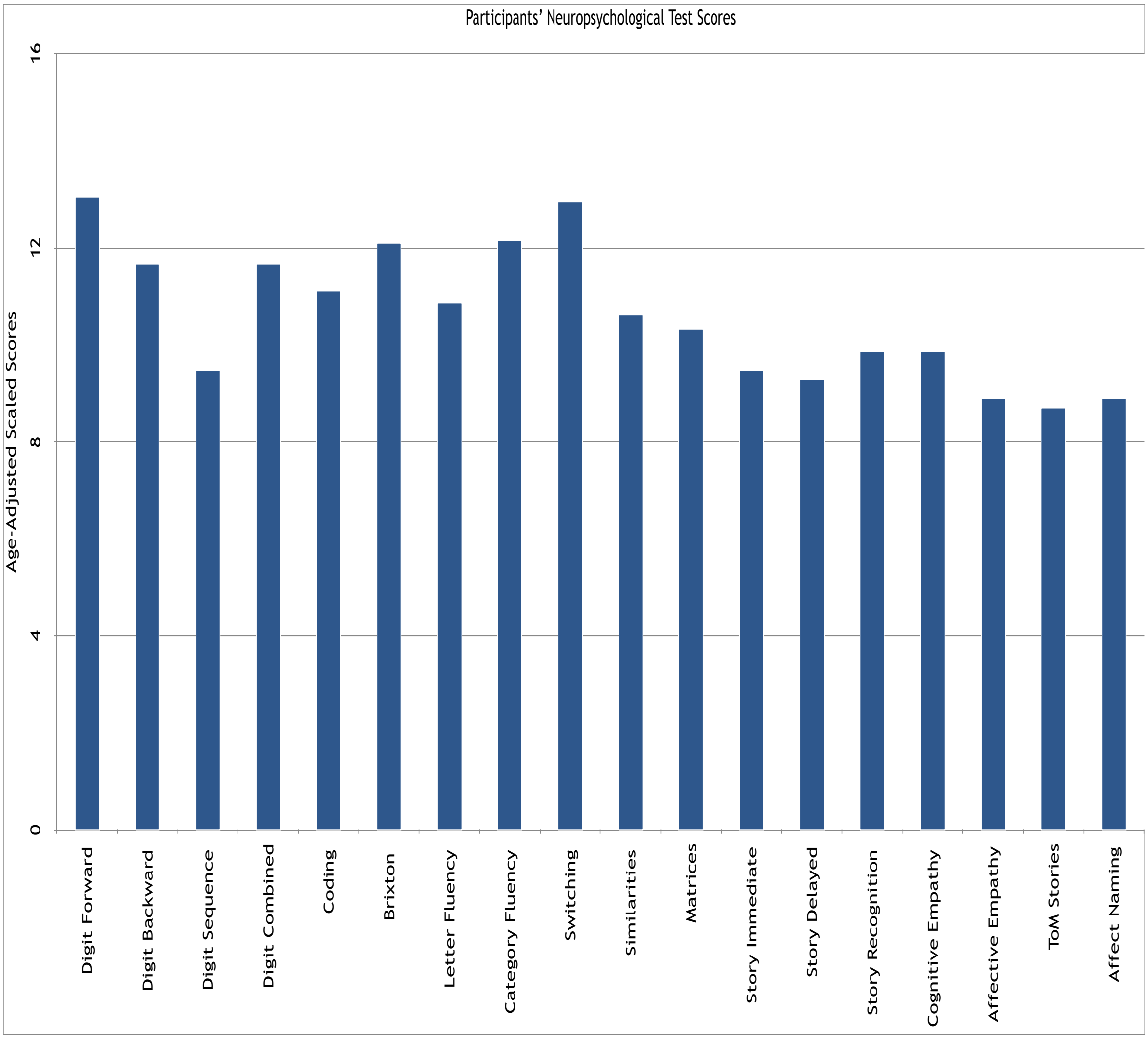

Table 5 Participants' test scores on tests of Cognitive Function compared with Normative Data.

Subsets (Scaled)	Mean	SD	Min.	Max.	K-S	Effect size (D)	P value
Digit Forward	13.05	2.36	8	18	2.77	**0.60**	**0.00**
Digit Backward	11.67	3.18	6	17	1.46	**0.32**	**0.03**
Digit Sequences	9.48	2.46	5	14	0.93	0.20	0.35
Digit Combined	11.67	2.83	6	15	1.46	**0.32**	**0.03**
Coding	11.10	3.05	6	19	1.03	0.23	0.24
Brixton	12.10	2.93	4	17	1.85	**0.41**	**0.01**
Letter Fluency	10.86	3.47	7	18	0.73	0.16	0.66
Category Fluency	12.14	3.82	6	19	1.41	**0.31**	**0.04**
Switching Fluency	12.95	1.91	10	17	2.55	**0.56**	**0.00**
Similarities	10.62	2.48	6	16	1.04	0.23	0.23
Matrices	10.33	2.69	5	15	0.55	0.12	0.93
Story Immediate	9.48	2.14	6	14	1.04	0.23	0.23
Story Delayed	9.29	2.37	5	15	1.14	0.25	0.15
Story Recognition	9.86	3.42	4	18	0.81	0.18	0.53

3.3 Analysis of Social Cognition

Descriptive statistics were generated, and Kolmogorov-Smirnov tests derived, to evaluate participants' performance scores in the social cognitive tests and to compare scores to age-matched normative data (M=10, SD=3). See Table 6.

Visual inspection of the mean scaled scores indicate that the research group showed weaknesses in the domain of social cognition, specifically, in the subcomponents of ToM stories, affect naming and QCAE affective. Although scores fell not far from the mean of ten, scores were clustered below the mean, with little variation in performance. The Kolmogorov-Smirnov test analyses confirmed that performance scores in ToM stories and affect naming differed from those expected from age-matched normative data, with moderate effect sizes for both.

Additionally, performance scores on the CQAE affective test fell below mean, with effect size falling just below 0.26, however, did not reach the threshold of 0.3 to be considered a moderate effect. Additionally, the p-value did signify significance p>0.05.

Table 6 Participants' test scores on tests of Social Cognitive Function compared with Normative Data

Subtest	**Mean**	**SD**	**Min**	**Max**	**K-S Z**	**Effect size**	p
QCAE Cognitive	9.86	2.03	6	13	0.82	0.18	0.51
QCAE Affective	8.90	2.49	5	13	1.20	0.26	0.11
SSQ	8.71	3.04	5	16	1.46	**0.31**	**0.03**
Affect Naming	8.90	2.07	5	13	1.36	**0.30**	**0.05**

3.4 Contrast with General Cognitive Functioning

Due to the difference observed in mean scaled scores in general cognition compared to social cognition a Wilcoxon signed-rank test was conducted to compare the scores. Also, as scores for the research group indicated superior performance compared with normative data, the social cognition performance was compared to the mean score of all cognitive domains.

The Wilcoxon signed-rank revealed a reliable difference between general cognition and social cognition for SSQ ($z=-2.67$, $p=0.01$), ANT ($z=-2.82$, $p=0.01$, QCAE Cognitive ($z=-2.09$, $p=0.04$) and QCAE Empathy ($z=-2,76$, $p=0.01$). These findings suggest that compared with their general level of cognitive ability, participants showed weakness in mentalising, empathy and emotional recognition.

3.5 Relationships between Cognitive Function, Social Cognition and Concussive Impacts

Spearman's rho correlational analysis was utilised to explore relationships between performance on cognitive tests, social cognitive tests and variables relating to concussion and rugby exposure. Spearman's rho is a non-parametric test and was an appropriate test for analysis due to the relatively small sample size and ordinal nature of the data. This section reports the key findings of the correlational analysis. The full correlation matrix is presented in Appendix F.

3.5.1 <u>Theory of Mind</u>

Performance on the SSQ was found to be associated with years of rugby played ($r =.466$, $p=0.02$). However, as years played could be a function of participants age, a further correlation was conducted, in which age was found to be moderately correlated with performance on the SSQ ($r=.401$, $p=.07$), with better performance among older participants.

A moderate relationship was indicated between performance on the SSQ and Digit Span Forward (r=.33, p=0.14).

SSQ score was not associated with the number of concussions, nor with age at first concussion.

3.5.2 Affect Naming

Similarly, the ANT was found to be strongly associated with years of rugby played (r =.61, p=0.00) and moderately associated with age (r=.48, p=0.02). No other correlations significant correlations with general cognitive abilities, or other concussion and rugby exposure variables. The ANT was also related to Digit Span Forward (r=0.33, p=0.14) and Digit Span Total (r=0.35, p=0.12).

3.5.3 Empathy

The QCAE cognitive scores were strongly related to Matrices Reasoning test of visual and abstraction (r=.72, p=0.00), and moderately related to the Similarities test of verbal reasoning (r=.45, p<.04). Suggesting that these all tests depend on conceptual processes (of abstract or concept formation).

The QCAE affective was moderately related to years in education (r=.30, p=0.04).

3.5.4 Correlations between Social Cognitive Tests

The SSQ was strongly correlated with ANT (r =.59, p=0.00), suggesting these measures tap into overlapping domains of social cognition. No correlation was observed with SSQ or empathy variables, suggesting they address separate subcomponents of social cognition.

The QCAE cognitive and QCAE affective variables were strongly interrelated (r=.460, p<.05) indicating that these types of empathy share common features.

3.6 General Linear Model

Regressions for both ToM stories and affect naming were included in determining the relative or unique contribution of each predictive value to the criterion. A Test of Between-Subjects was utilised to assess the influence the variables on performance scores. The inclusion of variables was based on associations revealed in the correlation analysis, in addition to concussion and rugby exposure variables as a review of the current research suggests they may influence cognitive performance. The dependent variables were SSQ and ANT age-scaled scores. The covariates were TOPF FSIQ, age of first concussion, age, education years, and years played rugby, the estimate of hours rugby played each week, and Digit Span.

The regression results suggested that after controlling for the covariates, none of the variables had a significant influence on the variance in scores for either emotion recognition or ToM, with all effect sizes falling below 0.3, with no significant findings indicated by p values. See Appendix G.

4 DISCUSSION

This study sought to explore the relationship between social cognition and SRC. Advancements in neuroimaging techniques have revealed SRC, and subconcussive impacts are associated with cerebral changes mainly in the prefrontal cortex, a region which is strongly implicated in social cognition (Koerte et al., 2015). Evidence suggests that these cerebral changes are associated with increased risk for neurodegenerative conditions such as CTE and Alzheimer’s Disease. These neurodegenerative conditions are characterised by behavioural and emotional impairments, including apathy, emotional lability, poor impulse control and depression (Baugh et al., 2012). However, despite the well documented social, emotional and behavioural changes in both TBI and neurodegenerative conditions, little research has focused on exploring the relationship with social cognition. To date, research efforts have focused on the physical and neuropsychological outcomes in SRC and neurodegenerative conditions. The present study aimed to address the gap in the research and explore whether any relationship exists between sports-related concussive exposure and social cognitive abilities. The research questions specifically sought to investigate if rugby players with a history of SRC have weaknesses in social cognition and if those deficits relate to other general cognitive abilities.

4.1 Sample Characteristics

Twenty-one male participants were recruited for the current study, with varying concussion and rugby histories, and an average of three concussions reported during their rugby careers. The age range of participants covered the UK working age range of 18-65, with participants’ ages distributed evenly. Participants who were recruited had played at all rugby levels, with some participants playing at professional and semi-professional levels, while others played at an amateur level for far fewer hours per week. Examination of mean scores showed that participants had on average played rugby for 20 years. This suggests that the sample represented a group with significant exposure to rugby at both amateur and professional levels.

Participants had average or slightly above average optimal ability comparable with that observed in the general population. However, the education level in the group was much higher than would be expected from a general population sample. This may have given participants an advantage on a number of the measures in which performance is correlated with the level of education. Education level was however not correlated with scores of optimal abilities, and this may be in part due to the lack of variability in educational level with 67% of participants holding a university or equivalent qualification.

4.2 Summary of Results

The study revealed that a sample of current and former male adult rugby players demonstrated relative weaknesses on two measures of social cognition (i.e., SSQ and ANT) when compared to general population normative data. These results occurred in the context of individuals with average or above average performance on other measures of general cognitive functioning. The results suggest that other areas of cognitive functioning remained intact. As the research group showed superior performance to normative data, their scaled scores across general cognitive measures were combined and compared to performance on social cognition tasks. Significant weaknesses were observed across all measures of social cognition in relation to general cognitive performance.

Interestingly, age and the number of years playing rugby was correlated with increased performance on ToM and emotional recognition tasks, suggesting older participants performed better when compared to younger participants. However, in regression analysis, once other factors were controlled for (i.e. education years, optimal ability), a significant effect of age or years played rugby was effect was no longer present. No other relationships between concussion variables or social cognition were found.

These findings are discussed in further detail in the subsequent sections, including the consideration of confounding factors.

4.2.1 General Cognitive Function

Exploration of the sample's general cognitive functioning suggests that the sample did not demonstrate weaknesses in any domains of cognitive functioning. The sample showed strengths relative to normative data in domains of executive function and attention and working memory. As the research group was characterised by a higher than average education level and slightly above average optimal ability, this may explain the differences observed. The higher performance scores may have been expected, as normative data is based on samples which reflect population educational levels. Of the research group, 67% had a university or postgraduate qualification. This is much higher than the UK population rates which are around 26% (Department for Education, 2017). Research studies have indicated causal links between executive function and academic performance. Individuals who perform well academically, additionally perform well on measures of executive functioning and working memory when overall academic ability and demographic factors are controlled for (Morgan et al., 2019).

These results are consistent with some of the literature regarding neuropsychological outcomes for individuals with a history of SRC which have failed to demonstrate neuropsychological impairments (Broglio, Eckner, Surma, & Kutcher, 2011; Gallant, Drumheller, & McKelvie, 2017; Jennings et al., 2015). However, the findings are inconsistent with the majority of the research in the area which has provided convincing evidence of a relationship between concussive and subconcussive impacts and cognitive decline in memory or executive functioning (Alexander, Shuttleworth-Edwards, Kidd, & Malcolm, 2015; Carman et al., 2015; Phillip H. Montenigro et al., 2017; Talavage et al., 2014; Tsushima et al., 2016). However, the ability to detect subtle changes in cognitive functioning is limited by the cross-sectional design used in this study.

Previous research has identified an association between executive functioning and cognitive ToM, with impairments in cognitive ToM considered secondary to executive function in conditions associated with cognitive decline such as HIV (Woods, Moore, Weber, & Grant, 2009). Conversely, participants scored highly on measures of both verbal and visual executive functioning. Furthermore, the failure to replicate previous findings which observe cognitive deficits in individuals with a history of SRC may in part be explained by the sample characteristics. Given that the vast majority of the sample completed further education after sustaining a concussion, this may suggest that the research group represent a more resilient group who were able to overcome any cognitive difficulties in order to gain further qualifications. The failure to find deficits in neurocognitive functioning may be a function of the lack of sensitivity in the tasks to detect subtle impairments (Bernstein, 1999). Also, the analysis was conducted at a group-level, as such any impairments which existed in a limited number of participants would not have been identified. However, the main aim of measuring general cognitive functioning in the current study was to assess interactions between social cognition and general cognition.

As no impairments were detected in any area of general cognitive functioning, poorer performance on measures of social cognition could not be attributed to general cognitive dysfunction. These results support the 'domain specific' theory of social cognition, which propose domain specificity, independent of other cognitive functions (Leekam Susan, 2016; Spunt & Adolphs, 2017; Stone & Gerrans, 2006).

4.2.2 Social Cognition

The main research question of the current study was to explore whether rugby players with a history of concussion showed impairments in social cognition. Measures of social cognition examined ToM, emotional recognition and self-reported cognitive and affective empathy. In summary, the sample performed in the 'low-average' range for both ToM and emotional recognition and within 'average' range for tests for empathy. When social cognition scores were compared with performance on general cognition significantly lower scores were observed across all subcomponents of social cognition. The weaknesses in ToM and emotional recognition occurred in the context of 'average or above average' scores across all other cognitive tests.

4.2.2.1 Affect Naming

The ANT test assessed the ability to recognise and identify emotions from facial expressions. The ability to identify others' emotions accurately is essential for social interaction and maintaining interpersonal relationships. Correctly interpreting others' emotions can provide interpersonal cues as to others' intentions and allow us to evaluate our behaviour in relation to others.

The participants achieved lower than average scores, suggesting weakened emotion recognition skills. In addition to emotion recognition skills, successful performance on the ANT relies on visuospatial abilities and reading abilities. Importantly, no equivalent disadvantages were revealed in either group means for the TOPF^{UK} measure of word reading ability or matrices task of visuospatial functioning. In addition, the correlational analysis did not reveal any association between ANT performance and other domains of general cognitive functioning, suggesting that lower performance on the ANT was independent of visuospatial function and reading ability in the research group.

Emotion recognition skills rely on a complex neural network (Adolphs, 2002) and therefore impairments are recognised in a number of neurological conditions including bvFTD (Keane, Calder, Hodges, & Young, 2002), Parkinson's disease and TBI associated with disruptions in a range of neural networks (Gray & Tickle-Degnen, 2010; Keane et al., 2002; Radice-Neumann, Zupan, Babbage, & Willer, 2007). Neuroimaging and biomechanical studies indicate that the neural networks associated with emotional recognition have been highlighted as vulnerable to the effects of SRC and subconcussive head impacts (Broglio et al., 2009; Goswami et al., 2016). If the weaknesses observed in emotional recognition in this study are linked with concussive history, the findings add to evidence which indicated the vulnerability of social cognitive neural networks.

4.2.2.2 ToM Stories – Social Stories Questionnaire

The SSQ requires participants to identify utterances made by one character which could upset another character in a verbally presented story. Success in the task relies on the ability of participants to put themselves in the position of the characters. Performance scores for participants in the research group fell in the ‘low-average’ range, suggesting weaknesses in ToM. The task relies on explicit mentalising processes and the accurate identification of social norms, in addition to several other complex cognitive processes, including memory, verbal and linguistic components. The complexity of the task allows for identification of subtle deficits and therefore is appropriate for use with individuals with no known cognitive impairments.

Results on the SSQ should be interpreted with caution given the potential for poor performance to be secondary to other areas of impairments. The SSQ relies heavily on reading ability; however, given the average performance scores observed on the TOPF^{UK}, this suggests the weakened performance was not secondary to poor reading ability. Furthermore, impairments were not observed on the verbal executive functioning tasks Letter Fluency and Category fluency. Slightly weaker scores were demonstrated on verbal memory, which could indicate difficulties with retaining information from the stories; however, these lower scores were not significant and likely represented expected variation across tasks. Moreover, the correlational analysis did not reveal associations between scores on the SSQ and any subset of general cognitive functioning.

The observation of impairments in both the SSQ and ANT measures of social cognition in the research group in the absence of detection of impairments in general cognitive functioning supports Frith and Frith's (2012) model of social cognition. They argue that although social cognition relies on general cognitive mechanisms, separate specialist processes are required. These results replicate findings from other studies in brain lesions and high-functioning autism which suggest that ToM impairments are not necessarily related to executive functioning (Baron-Cohen et al., 1994; Fine, Lumsden, & Blair, 2001) despite impairments in both domains commonly observed together.

The pattern of results is consistent with findings from studies of the biomechanical effects of head impacts sustained in sports, which show the vmPFC’s vulnerability (Crisco et al., 2010). Neuroimaging studies have demonstrated that the vmPFC has consistently shown to be activated during ToM tasks.

4.2.2.3 QCAE Subsets

The QCAE is a self-report questionnaire, comprising two subcomponents, affective and cognitive empathy. The research groups performance fell in the average range, with both scores falling just below the normative population mean. Correlational analysis revealed the two subscales correlated well with each other (r=.460); suggesting the measurement of overlapping domains of empathy. As the QCAE task is a subjective self-report measure, they are dependent on self-awareness.

Although the scores on the QCAE fell in the ‘average’ range, they were low relative to participants’ performance on other general cognitive tasks. Analyses showed that performance on cognitive and affective empathy was significantly lower than scores in general cognitive functioning. Previous findings have highlighted the association between low emotional empathy in individuals following TBI (Wood & Williams, 2008).

4.2.3 Correlations between Variables

The correlational analysis showed an association between group-level performance on the SSQ and ANT (r= .596). The results indicate that reduced performance was observed in both emotion recognition or affective ToM (ANT) and cognitive ToM (SSQ). These findings do not support previous findings which have indicated that cognitive and affective ToM are differentially affected, with studies commonly reporting deficits in only one subcomponent of ToM (Sebastian et al., 2012). However, global impairments are found in some clinical populations including FLTD, which is characterised by social and behavioural changes (Torralva, Roca, Gleichgerrcht, Bekinschtein, & Manes, 2009b).

Performance on the empathy measure did not correlate with performance on SSQ or affect naming. The results suggest that SSQ and affect naming may be underpinned by separate neurological processes. Research has indicated that impairments in one domain of social cognition are independent to each other, with the distinct neural networks activated depending on which domain a social cognitive task engages (Kilroy & Aziz-Zadeh, 2017).

4.2.3.1 Concussion and Rugby Exposure

Correlations were observed between the number of years playing rugby and scores on the SSQ (r=.49) and ANT (r=.61). Similarly, correlations were observed between age and increased performance scores on the SSQ (r=.40) and ANT (r=0.48), indicating that those who were older performed better on emotional recognition and ToM. Once regression analysis was applied controlling for age and other potential confounding variables (optimal ability, education years) the effects were no longer observed. Although it was not measured in the current study older participants were more likely to be retired from rugby and therefore no longer exposed to subconcussive impacts. If weaker scores on social cognition were related to sports-related concussive and subconcussive exposure, whether the participants were currently playing rugby may have influenced results. Further studies should compare scores for athletes currently playing contact-sports with retired contact-sport athletes.

Conversely, correlations were not found between the other concussion variables (number of concussions reported or hours played) and either measure of social cognition or general cognition.

Interestingly, no correlation was found between the age of first concussion and neurocognitive symptoms, replicating previous findings which have not identified a relationship between age of first concussion and neurocognitive symptoms (Alosco et al., 2018). The majority of participants received their first SRC in adolescence, with only three participants reporting their first concussion over the age of 25. Importantly, adolescents with mTBI tend to experience a higher number and more severe symptoms when compared to younger children and adults. Concussion in adolescents is often associated with missed days at school, and those with more significant injury severity require additional academic support (Davis et al., 2017). Research investigating the outcomes of childhood mTBI demonstrate impairments in ToM, even when controlling for pre-injury externalising behaviour (Bellerose, Bernier, Beaudoin, Gravel, & Beauchamp, 2015).

4.3 Summary and Interpretations of Study Findings

Overall, analyses of the research groups performance indicate that individuals with a history of concussion show relative weaknesses in social cognition, specifically in emotional recognition and cognitive ToM. Notably, performance on social cognition measures was not predicted by performance on other cognitive measures. In reviewing the literature, deficits in cognitive ToM are most commonly observed in the context of and secondary to executive dysfunction. However, in the current study above-average performance was observed in both verbal and visual executive functioning measures. The analysis demonstrated no pattern between social cognitive functioning and measures of premorbid functioning, suggesting that performance on social cognition was independent of other cognitive functions.

In conclusion, the findings illustrate relationships between rugby players who have a history of concussion and poor performance on social cognition tasks. This study adds to the existing body of research indicating a relationship between concussions and repeated subconcussion and neuropsychological impairments (A. J. Gardner et al., 2014; Manley et al., 2017). However, impairments observed in the current study were limited to social cognition and did not support findings from previous research which has revealed that concussions are a risk factor for cognitive impairment. The findings suggest further research is needed to explore if results are replicable.

4.4 Critical Review

4.4.1 Strengths

Although results are preliminary, this is the first study to explore the relationship between social cognition in individuals with a history of concussion. Despite the growing body of evidence investigating the neuropsychological consequences of concussion and subconcussive impacts in contact-sports athletes, thus far studies have failed to address the potential social cognitive effects. As a proof of concept study, the findings provide evidence to support the development of further studies in this area.

4.4.2 Limitations

4.4.2.1 Sample Size

The relatively small sample size in the current study, although appropriate for an exploratory study, will have reduced statistical power and sensitivity, increasing the risk for type II error (Field, 2009). In acknowledgement of the limitations of the small sample, results were interpreted with effect sizes rather than relying on statistical power analysis. Some of the correlation coefficients reported should be interpreted as trends given their moderate statistical significance, and therefore the generalisability of the study is limited. A larger sample would also have allowed for the inclusion of female participants to evaluate sex differences and within-sample differences such as ethnicity and education level. The inclusion of a control group of rugby players with no history of concussion may have proved informative about the influence of concussion on cognitive and social cognitive function. However, the sample size of the study is comparable to other studies investigating the relationship between SRC or mTBI and outcomes on neurocognitive testing (Alexander et al., 2015; Cossette et al., 2016; Daniel et al., 1999; Hinton-Bayre & Geffen, 2002).

4.4.2.2 Generalisability

When considering how generalisable the findings are from this study to the general population the demographic profile of the research group should be considered. The age range of the participants spanned the working age, and the ages of participants were spread out fairly evenly. As time since injury was not recorded no conclusions can be made about recovery time in relation to performance on social cognition tasks.

The sample represents a highly educated group, with 69% holding a university level qualification or equivalent. Although mean scores on the measure of optimal functioning suggested an optimal close to average population norms, a sample with an education level representative of general population levels would increase the generalisability of the results. Furthermore, given that a high number of the participants had been able to progress to higher education, they may represent a group which are resistant to the neurocognitive impacts of SRC reported in the research literature. Moreover, as previously mentioned level of education has a significant impact on performance in neurocognitive testing (Ostrosky-Solís, Ramirez, & Ardila, 2004). The sample was limited in terms of language, gender, ethnicity and cultural background, and future studies should consider cross-cultural variability and effects.

4.4.2.3 Study Design

Although it was not deemed necessary to include a control group due to the availability of general population age-adjusted normative data for the measures, the inclusion of a control group would have strengthened findings. Moreover, a matched control group would have allowed for analysis of between-group analyses and to control for potential confounding factors such as educational attainment. While this was considered, it was beyond the scope of the current study.

A cross-sectional design was chosen as it is appropriate for an exploratory study and minimises time and resources. It acknowledged that concrete conclusions could not be drawn from cross-sectional research, and the social cognition weakenesses may have existed before any impact exposure of head injury. Furthermore, confounding variables such as personality traits associated with risk-taking behaviour and aggression may predict ToM.

Ideally, a longitudinal study would be employed to assess neurocognitive changes across an athlete’s career. This would allow for some indication of the direction of any correlations observed between SRC and cognitive and social cognitive outcomes. However, systematic reviews within the field of SRC and neuropsychology have indicated it is not necessary for a baseline neurocognitive test, advocating for the use of neurocognitive testing with a comparison of group norms in the absence of baseline data (Manley et al., 2017).

4.4.3 Testing Materials

It is acknowledged that the test materials aim to measure specific constructs such as social cognition and general cognitive functions such as memory and attention. However, as mentioned in previous sections tests aimed at assessing one cognitive domain often require additional cognitive processes and are never ‘pure’. Neuropsychological constructs are arguably fluid and susceptible to the inherent problems which occur with socially constructed domains. One of the critiques of assessing neurocognitive functioning is the lack of ecological validity. The use of general neurocognitive battery approach in the assessment of mTBI has been criticised in the research literature due to the potential for false-negative results. Furthermore, the use of general neurocognitive measures in mTBI populations has been criticised for lack of sensitivity to detect subtle deficits (Bernstein, 1999). While the measures used within the current study have demonstrated validity, the use of more demanding measures in the domains of divided attention and information processing speed would be beneficial in future research to control for false negative results (Cicerone, 1997).

Neurocognitive assessments are also susceptible to confounding factors which are not easily controlled, such as participants effort, sleep deprivation, malingering, caffeine and nicotine. Although attempts were made to choose valid and reliable measures, the SSQ has weak norms and is mainly experimental which could influence results. However, the ANT norms were based on a sufficient norming process, and the QCAE norms are based on a large normative sample.

The limitations are pertinent when assessing social cognition, although measures of social cognition have been shown to correlate with observed social behaviours, their ecological validity is questionable. Successful social cognition in real world-situations relies on a complex interplay between general cognitive and social cognitive specific processes, which are difficult to replicate in clinical settings. The social cognition measures used within this study rely on static-stimuli, and are presented absent of social context and include only one modality of emotional information (visual information).

Although the ANT has demonstrated validity and reliability, the task only includes one positive emotion (i.e. happiness) and no self-conscious emotions (i.e. embarrassment) impacting on its ecological validity. Specific limitations relate to the SSQ task, in which participants are required to make inferences about characters within hypothetical social stories. Success in the task is understood as evidence of explicit mentalising skills. However, the SSQ could be criticised for the inclusion of outdated use of social lexicon and social norms and may explain why older participants performed better. Poor performance on the task may indicate that the participant has not been socialised to the specific social norms, and therefore unable to identify and apply these successfully. Performance may be hindered by age and exposure to social nuances required to succeed in the task. Therefore, the task performance may not be tapping into the specific domain of explicit mentalising.

The limitations described here are not confined to social cognition tasks but apply to all cognitive assessment measures available. The development of social cognitive tasks employing recent technological advancements to simulate social interactions may address concerns regarding the ecological validity of social cognition measures. These measures, however, may be unsuitable for clinical settings, and sideline assessments. To increase validity, additional measures of social cognition could be included, to explore if findings are replicated across social cognition tasks and investigate construct validity. Increasing the number of tasks places additional demands on the participant, and the benefits of doing so should be considered.

Assessment of concussion history and rugby exposure was based on retrospective self-report from participants, a more sophisticated method of assessing would have been advantageous. In the absence of corroborating information, this is a limitation of the current study. As discussed in the introduction section substantiating evidence may not provide additional information given the difficulties associated with diagnosing mTBI including concussion. Furthermore, the use of medical records to corroborate concussions would be limited given many individuals do not seek medical attention following a concussion.

4.4.4 Potential Distress to Participants

The current study did not inform participants that in the event that their performance on cognitive tasks indicated a neurodegenerative condition such as dementia that the researcher would contact them to inform them about the results. Although no participants in the current study showed cognitive deficits indicative of a neurodegenerative condition, future studies should consider how such findings would be communicated to participants. As all participants had exposure to repetitive head impacts the study group represented a population at increased risk for neurodegenerative conditions such as dementia. Participation in the study may also have highlighted difficulties in cognitive functioning and therefore could cause distress to participants. Therefore, there are ethical considerations for future studies which should be carefully considered.

4.5 Clinical Implications

Social cognition represents the knowledge we have about ourselves and our ability to interact with and understand other people (Adolphs, 1999). In particular, social cognitive processes form the fundamental basis of successful communication and interpersonal relationships. Impairments in social cognition can translate to difficulties maintaining peer relationships, social isolation, increased aggression and loneliness (Bayley, 2006; Max et al., 1998). Given that social cognition is critical in our ability to navigate the social world, social cognition dysfunction can detrimentally impact mental health and quality of life. Furthermore, those who lack social contact experience earlier cognitive decline (Cacioppo & Hawkley, 2009).

Despite recent active research in the area of SRC, studies have previously neglected to consider the potential effects on social cognition and the corresponding potential impacts on quality of life and mental health. This study provides preliminary evidence that rugby players with a history of concussion show weaknesses in social cognition. Assuming the difficulties observed in social cognition tests related to an underlying difficulty, these could translate to social communicative difficulties in many aspects of real life. Although the findings discussed here are preliminary and require replication before concrete conclusions can be drawn, the potential clinical implications should be discussed.

Impairments in ToM are commonly observed in TBI and can result in misinterpretation of social norms and the inability to interpret social cues. As a result, TBI patients' behaviour may illicit unfavourable reactions in peers, which can lead to a reduction in social networks. Research has provided evidence which suggests that individuals with impaired ToM have far fewer reciprocated friendships (Fink, Begeer, Peterson, Slaughter, & Rosnay, 2015), and have a higher rate of aggressive behaviour (Jolliffe & Farrington, 2004). Conversely, studies have shown that individuals with neurodegenerative conditions who remain socially active have better outcomes across several cognitive measures (Pillai & Verghese, 2009). Clinically, therefore, social cognition should play a prominent role in the treatment of mTBI and neurodegenerative conditions. Research in neurodegenerative conditions has concluded that ‘noncognitive' symptoms, including social cognition dysfunction, may precede cognitive symptoms. These findings suggest that social and behavioural changes may be an early risk factor for the later development of neurodegenerative conditions. These changes in behaviour can be understood as impairments in social cognition and are proposed to occur separately from general cognition deficits and may represent early disease sequelae (Cosentino et al., 2014). Similarly, a study interviewing family members of athletes diagnosed with CTE after death, indicated that 22 of the 33 had behaviour or mood problems which family members proposed were their first symptoms of difficulties associated with CTE (Mez et al., 2017).

The critical clinical implication is that social cognition measures should contribute to routinely administered assessments of cognitive functioning in SRC. Currently, the research literature suggests that neurocognitive testing should include assessments of executive functioning, attention, learning and memory

(Feddermann-Demont et al., 2017). Although assessment of mood and behaviour are mentioned in guidelines, no formal assessment of social cognition is proposed (McCrory et al., 2005). The findings from the current study indicate that the assessment of cognitive functioning is not adequate unless social cognition is also measured.

The inclusion of social cognition measures is feasible as measures such as the SSQ and ANT are quick and easy to administer. Furthermore, as social cognitive measures such as the SSQ show sensitivity for early detection of impairment in social cognition, they are appropriate for use in cohorts who do not demonstrate overt deficits in cognitive functioning. Further research is required to determine at which point in the management of SRC tests of social cognition would provide benefit. On-field assessments could include a brief measure of social cognition such as the inclusion of short-set of facial affect naming. Return to play assessments would benefit from the inclusion of social cognition which taps into several domains of social cognition. Finally, in assessing recovery and longer-term consequences a more comprehensive social cognitive battery should be included to aid treatment and management of SRC.

Currently, within clinical practice, social cognition tasks are often overlooked in assessment of neuropsychological functioning. The current study adds to the evidence which advocates for their inclusion. Social cognitive tests not only aid clinician and patients' understanding of difficulties, but additionally can aid treatment. Research has indicated that treatments focusing on social cognitive functioning can limit the progression of neurodegenerative conditions (Christidi et al., 2018). Moreover, social cognition tests have been shown to provide increased specificity in aiding differential diagnosis in neurodegenerative conditions such as CTE and bvFTD. If future studies replicate findings, information from social cognition tasks could potentially be used to help identify those athletes who may be at risk of developing degenerative conditions including CTE in the future, in this population known to be at increased risk of neurodegenerative conditions (Lucke-Wold et al., 2014)

In the clinical management of TBI populations a primary goal of rehabilitation is to enable community integration, therefore greatly depending upon social cognition abilities. Social participation is considered to be a fundamental part if this to be achieved. However, achieving social integration depends on many complex cognitive processes, including ToM.

Ideally, assessments of social cognition would be included in a pre-season baseline assessment for athletes involved in high-contact sports to enable changes over time to be detected. When working in clinical settings, information about previous exposure to contact-sports should be considered when working with patients who present with behavioural and emotional difficulties.

It is important to note that correlation is not causation. Although the sample showed weaker performance on the ToM scores, this result may be explained by other inherent characteristics of the sample. For example, individuals who engage in high-contact sports have been shown to engage in more high-risk and violent behaviour compared with non-athletes. Furthermore, these athletes display increased irritability and higher levels of disinhibition, regardless of context. Studies have proposed that physiological arousal is the mechanism which mediates impulsivity and high-risk behaviour. It may be these factors which influence poor performance on ToM tasks. Indeed, researchers in the topic propose that aggressive behaviour and disinhibition are reinforced and maintained in high-risk sports such as rugby. Further research is therefore needed to determine the direction of the relationship overserved in the current study.

Nevertheless, if rugby players represent a group who are more likely to engage in risky, antisocial behaviour, these characteristics may, in turn, increase the risk of concussion. Further, exposure to closed head injury, such as concussion and subconcussive impacts which occur with frightening regularity in rugby could cause damage to areas of the brain which play a critical role in social cognitive processing. This coupled with the potential existing physiological under-arousal observed in high-contact sports athletes could cause devasting social consequences.

In summary, although the findings in the current study are tentative, they highlight the need for further understanding in the field of social cognition. This emphasises the importance of understanding patients' history when assessing in clinical settings. Gathering information regarding exposure to high-contact sports such as rugby may provide additional information and aid understanding of patients' difficulties and inform treatment decision.

4.6 Wider implications

Sporting bodies increasingly acknowledge the risk associated with SRC and subconcussive impacts. Recommendations from governing bodies should not be reliant on the existence of irrefutable evidence but should take necessary precautions despite variability in findings within the research literature. Education on concussion should form a critical element of SRC strategy, as evidence indicates that a large proportion of athletes are unaware of the symptoms of concussion or the potential longer-term consequences. Furthermore, evidence indicated that rugby players wrongly believe that headgear protects against concussion, and may, therefore, be less sensitive to detecting concussions they receive (Menger, Menger, & Nanda, 2016).

Sporting bodies have a fundamental role in ensuring that the assessments of concussion are sufficiently comprehensive. If the results from the current study are replicated, sporting bodies must ensure social cognition measure is part of the assessment process.

Public health policy should consider the impact of SRC, especially given a large number of people who could be impacted. Sporting bodies should continually assess the current research literature and adapt sports accordingly. For example, the current research adds to evidence which questions the age at which contact-rugby should be in introduced, currently in the UK England Rugby recommend that children can start tackling at age eight. This highlights the need to establish if outcomes differ from athletes who receive their concussion in childhood and adolescence versus adulthood. This is of note given the majority of the participants in the current study received their first concussion in adolescence, in terms of brain development the adolescent brain is not considered to be fully developed until age 25. Given the added vulnerability of the developing brain during adolescence critics argue this may be too early (Pollock, White, & Kirkwood, 2017).

Athletes and sports-professionals should be given greater psychoeducation around concussion, regarding recovery expectations and risk factors. Many of those currently conducting sideline concussion assessments such as the SCAT, have little training or understanding of the cognitive measures included. Given that many of the professionals carrying out on-pitch and return to play concussion assessments are not trained in cognitive assessments, neuropsychologists could play a key role in training, education and interpreting data.

4.7 Future Directions

Little research has been conducted to understand the social and emotional and behavioural consequences of head impacts sustained in sport, with those which exist focusing on personality and behavioural outcomes. To the researcher's knowledge, no previous research has explored the relationship between SRC and social cognition. Since the study was exploratory, is it necessary to replicate the findings with a more extensive and more diverse sample. The addition of a control group would enable between-group analyses and strengthen study interpretations. The current study included only male participants, despite the growing number of female's playing rugby, men remain the vast majority. However, studies have indicated that females sustain proportionately more concussions than males (Covassin, Swanik, & Sachs, 2003; Gessel et al., 2007; Marar et al., 2012). Additionally, female athletes report higher number and increased levels of anxiety and depression post-injury, and additionally take longer to recover from their symptoms (Baker et al., 2016; Ellis et al., 2015; Fenton, McClelland, Montgomery, MacFlynn, & Rutherford, 1993; Kutcher & Eckner, 2010; Yang et al., 2015). Future research should, therefore, include both male and female participants to consider any differences as a result of gender. Furthermore, as social cognition is a multifaceted construct, the addition of different social cognitive task would be of benefit to understanding if impairments are generalisable across tasks, or specific to the measures employed in this study.

Increased understanding is needed of the neurodegenerative process and CTE progression for increased understanding of the behavioural and emotional changes observed. There is a demand for the development of measures with enough sensitivity to detect subtle impairments following repeated neurotrauma.

Nevertheless, sustaining a concussion in rugby significantly increases future injuries, with a 38% greater risk observed compared with athletes who had not sustained concussion (Rafferty et al., 2018). These findings suggest that current guidelines regarding return to play need to be evaluated. Furthermore, there have been overwhelming concerns from healthcare professionals regarding current policy in rugby, with a recent open letter calling for tackling to be banned in school-age rugby (Pollock et al., 2017)

Some rugby officials have called for changes in rugby to reduce rates of concussion and limit long-term consequences. In recent years marked changes in players physical characteristics have been observed, with rugby players with the average weight and height professional rugby player increasing during the past decade (Sedeaud, Vidalin, Tafflet, Marc, & Toussaint, 2013). These physical characteristic changes coupled with evolving changes in match play in rugby which have resulted in more frequent collisions of greater magnitude (Quarrie & Hopkins, 2007) raise concerns about the increased risk to long-term neurocognitive functioning. Further research should aim to understand how the changes in rugby may impact on outcomes.

At present, it is not known whether the emergence, course, or severity of clinical symptoms can be predicted by specific combinations of neuropathologies, thresholds for the accumulation of pathology, or regional distributions of pathologies. More research is needed to determine the extent to which the neuropathology ascribed to long-term effects of neurotrauma is static, progressive, or both. Disambiguating the pathology from the broad array of clinical features that have been reported in recent studies might facilitate and accelerate research and improve understanding of CTE.

4.7.1 Critical reflection

Arguably the research questions were influenced by the researcher’s own experience, and the choice of the methodology chosen represents the researcher’s own biases and interpretations of the world. In critically reviewing the current study the researcher acknowledges that the study may reinforce the social discourse which labels individuals as ‘impaired'. In doing so, this research may add to notions of cognitive functioning as fixed and internalised, rather than fluid, context-dependent and fluid. These discourses can limit treatment options for those diagnosed and detrimentally impact on the quality of life for individuals labelled as impaired.

4.8 Concluding Statement

The current study aimed to explore social cognition in rugby players with a history of concussion. The research hoped to contribute to the growing body of evidence examining the link between SRC and cognitive, behavioural and emotional outcomes. To the researcher's knowledge, this is the first study to explore the relationships between SRC and social cognition in rugby players. Specific neuropsychological measures were used to allow for the detection of subtle weaknesses. The present research group showed weakness in social cognition, both in relation to normative data and when compared in context against general cognitive functioning. Specifically, weaknesses were observed in ToM and emotional recognition. The relatively small sample size in the current study limits generalisability, however, the findings provide preliminary evidence to suggest further research in the area is required. In addition, the current study supports the inclusion of social cognition test batteries in the management of SRC.

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APPENDIX A: UEL Ethics Form

NOTICE OF ETHICS REVIEW DECISION

For research involving human participants

BSc/MSc/MA/Professional Doctorates in Clinical, Counselling and Educational Psychology

REVIEWER: [redacted]

SUPERVISOR: [redacted]

STUDENT: [redacted]

Course: Professional Doctorate in Clinical Psychology

Title of proposed study: TBC

DECISION OPTIONS:

1. **APPROVED:** Ethics approval for the above named research study has been granted from the date of approval (see end of this notice) to the date it is submitted for assessment/examination.

2. **APPROVED, BUT MINOR AMENDMENTS ARE REQUIRED BEFORE THE RESEARCH COMMENCES** (see Minor Amendments box below)**:** In this circumstance, re-submission of an ethics application is not required but the student must confirm with their supervisor that all minor amendments have been made before the research commences. Students are to do this by filling in the confirmation box below when all amendments have been attended to and emailing a copy of this decision notice to her/his supervisor for their records. The supervisor will then forward the student's confirmation to the School for its records.

3. **NOT APPROVED, MAJOR AMENDMENTS AND RE-SUBMISSION REQUIRED** (see Major Amendments box below)**:** In this circumstance, a revised ethics application must be submitted and approved before any research takes place. The revised application will be reviewed by the same reviewer. If in doubt, students should ask their supervisor for support in revising their ethics application.

DECISION ON THE ABOVE-NAMED PROPOSED RESEARCH STUDY
(Please indicate the decision according to one of the 3 options above)

APPROVED

Minor amendments required *(for reviewer)*:

Major amendments required *(for reviewer):*

Confirmation of making the above minor amendments *(for students)*:

I have noted and made all the required minor amendments, as stated above, before starting my research and collecting data. Student's name *(Typed name to act as signature):* Student number: Date: *(Please submit a copy of this decision letter to your supervisor with this box completed, if minor amendments to your ethics application are required)*

ASSESSMENT OF RISK TO RESEACHER *(for reviewer)*

Has an adequate risk assessment been offered in the application form?

YES / NO

Please request resubmission with an adequate risk assessment

If the proposed research could expose the researcher to any of kind of emotional, physical or health and safety hazard? Please rate the degree of risk:

☐

HIGH

Please do not approve a high risk application and refer to the Chair of Ethics. Travel to countries/provinces/areas deemed to be high risk should not be permitted and an application not approved on this basis. If unsure please refer to the Chair of Ethics.

☐ MEDIUM (Please approve but with appropriate recommendations)

☐ LOW

Reviewer comments in relation to researcher risk (if any).

Reviewer *(Typed name to act as signature)*: John Read

Date: 10.7.18

This reviewer has assessed the ethics application for the named research study on behalf of the School of Psychology Research Ethics Committee

RESEARCHER PLEASE NOTE:

For the researcher and participants involved in the above named study to be covered by UEL's Insurance, prior ethics approval from the School of Psychology (acting on behalf of the UEL Research Ethics Committee), and confirmation from students where minor amendments were required, must be obtained before any research takes place.

For a copy of UELs Personal Accident & Travel Insurance Policy, please see the Ethics Folder in the Psychology Noticeboard

APPENDIX B: Consent Form

School of Psychology

Consent Form

UEL
University of East London

Consent Form for Participation in the Research Study

Researcher:
Supervised by:

Please initial box

1. I confirm that I have read and understood the information provided; I understand what the study is about, how it is being done, and why.
2. I understand that my participation is voluntary and that I may withdraw at any time, without giving any reason, and without any consequences.
3. I agree to short quotes from my answers being used in the write-up of this study, and that my anonymity will still be protected at all times.
4. I give permission for the individuals named above, and examiners at the university to have access to the data generated by my participation.
5. I voluntarily consent to take part in the above study and consent to the audio-taping of my answers.

I agree to the terms.
Respondent's name (print):
Respondent's signature:
Date:
I agree to the terms:
Researcher's name (print):
Researcher's signature:
Date:

APPENDIX C: Information Sheet

UNIVERSITY OF EAST LONDON

School of Psychology
Stratford Campus
Water Lane
London E15 4LZ

The Principal Investigator(s)

[redacted]
Contact Details: u1622906@uel.ac.uk

Consent to Participate in a Research Study

This information sheet will provide you with information about the research study to enable you to decide if you wish to participate. This research is being conducted as part of my Professional Doctorate in Clinical Psychology at the University of East London.

The purpose of this letter is to provide you with the information that you need to consider in deciding whether to participate a research study. The study is being conducted as part of my Professional Doctorate in Clinical Psychology at the University of East London.

Project Title

Social Cognition in Sports-Related Concussion

Project Description

Research suggests that involvement in contact sports and sport-related concussion is associated with neurological effects. More research is required to manage and detect concussions in contact-sports, including the potential long-term consequences. This study will investigate if any relationship exists between involvement in contact sports and social cognition.

What will happen if I decide to take part?

If you agree to take part you will be asked to attend one interview which should take approximately 1 hour in total, with a break if required. You will be asked to provide some information about your age, education, and sports history. You will then be asked to complete a range of psychological tests such as problem solving, memory and concentration. You are allowed to withdraw from the study at any time during the study.

Confidentiality of the Data

All the information you provide with remain strictly confidential and will be anonymised using a unique identification number, any identifiable details will be kept separate to the information gathered during the study. All data will be kept in locked cabinet and will only be accessible by the research team. All electronic data will be encrypted.

What will happen to the results of the research study?

We plan to publish the results of the study. When published all identifiable information will be removed and your data will be kept confidential and anonymised. As all the information is grouped together individual feedback cannot be provided, however we are able to provide you with feedback of group results if requested.

What will happen afterwards?

The researcher will be available to answer any questions or concerns you may have before, during or after the assessment session.

Location

All appointments will be arranged at the University of East London.

Disclaimer

You are not obliged to take part in this study and should not feel coerced. You are free to withdraw at any time. Should you choose to withdraw from the study you may do so without disadvantage to yourself and without any obligation to give a reason.

Please feel free to ask me any questions. If you are happy to continue you will be asked to sign a consent form prior to your participation. Please retain this invitation letter for reference.

If you have any questions or concerns about how the study has been conducted, please contact the study's supervisor:

Dr Matthew Jones-Chester, School of Psychology, University of East London, Water Lane, London E15 4LZ.

(Tel: 020 8223 4603. Email: m.h.jones-chesters@uel.ac.uk)

or

Chair of the School of Psychology Research Ethics Sub-committee:

Dr. Mark Finn, School of Psychology, University of East London, Water Lane, London E15 4LZ.

(Tel: 020 8223 4493. Email: m.finn@uel.ac.uk)

Thank you in anticipation.

Yours sincerely,

[redacted]

Trainee Clinical Psychologist

APPENDIX D: Debrief Sheet

DEBRIEF SHEET

Social Cognition in Sports-Related Concussion

Thank you for agreeing to take part in the research, your time and effort is greatly appreciated.

Project aims

Research suggests that involvement in contact sports and sport-related concussion is associated with neurological effects. More research is required to understand the longer-term consequences of being involved in contact sports. This study will investigate if any relationship exists between involvement in contact sports and social cognition.

Confidentiality of the Data

All the information you provide with remain strictly confidential and will be anonymised using a unique identification number, any identifiable details will be kept separate to the information gathered during the study. All data will be kept in locked cabinet and will only be accessible by the research team. All electronic data will be encrypted. You have the right to withdraw your data until February 2018 at which point the data will be analysed.

What will happen to the results of the research study?

We plan to publish the results of the study. When published all identifiable information will be removed and your data will be kept confidential and anonymised. As all the information is grouped together individual feedback cannot be provided, however we are able to provide you with feedback of group results if requested.

Further information

If you have any questions or concerns about how the study has been conducted, please contact the study's supervisor:

Dr Matthew Jones-Chester, School of Psychology, University of East London, Water Lane, London E15 4LZ.

(Tel: 020 8223 4603. Email: m.h.jones-chesters@uel.ac.uk)

or

Chair of the School of Psychology Research Ethics Sub-committee:

Dr. Mark Finn, School of Psychology, University of East London, Water Lane, London E15 4LZ.

(Tel: 020 8223 4493. Email: m.finn@uel.ac.uk)

Further information and support

Please feel free to ask the researcher any further questions or concerns you may have.

In the event that you feel worried about your health or are feeling distressed we encourage you to contact your GP.

England rugby

Engalndrugby.com
England rugby provide guidelines on preventing and management of concussions in rugby

Headway – headway.org.uk Tel: 0808 800 2244
Headway support individuals affected by head injury, including those related to sports.

Samaritans – samaritans.org Tel: 116 123
Samaritans provide emotional support to anyone in emotional distress, struggling to cope, or at risk of suicide.

APPENDIX E: Sport Concussion Assessment Tool

OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: ______________________

Date / time of injury: ______________________

Years of education completed: ______________________

Age: ______________________

Gender: M / F / Other

Dominant hand: left / neither / right

How many diagnosed concussions has the athlete had in the past?: ______________________

When was the most recent concussion?: ______________________

How long was the recovery (time to being cleared to play) from the most recent concussion?: ______________________ (days)

Has the athlete ever been:

Hospitalized for a head injury?	Yes	No
Diagnosed / treated for headache disorder or migraines?	Yes	No
Diagnosed with a learning disability / dyslexia?	Yes	No
Diagnosed with ADD / ADHD?	Yes	No
Diagnosed with depression, anxiety or other psychiatric disorder?	Yes	No

Current medications? If yes, please list:

____

____

____

____

____

____

Name: ______________________

DOB: ______________________

Address: ______________________

ID number: ______________________

Examiner: ______________________

Date: ______________________

2

STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ **Baseline** ☐ **Post-Injury**

Please hand the form to the athlete

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

Total number of symptoms:	of 22
Symptom severity score:	of 132
Do your symptoms get worse with physical activity?	Y N
Do your symptoms get worse with mental activity?	Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?	

If not 100%, why?

____

____

____

Please hand form back to examiner

Echemendia RJ, *et al. Br J Sports Med* 2017;**51**:851–858. doi:10.1136/bjsports-2017-097506SCAT5

APPENDIX F: Scoring Reference for Scaled Scores

Conversion Table 1

Scaled	Standard	T-score	%ile	Label	%ile Range
19	145	80	99.9	Very-Superior	>98th
18	140	77	99.6		
17	135	73	99.0		
16	130	70	97.7	Superior	91 – 98th
15	125	67	95.2		
14	120	63	90.9		
13	115	60	84.1	High-Average	75 – 90th
12	110	57	74.8		
11	105	53	63.1	Average	50 – 74th
10	100	50	50.0		
9	95	47	36.9		25 – 49th
8	90	43	25.3		
7	85	40	15.9	Low-Average	10 – 24th
6	80	37	9.1		
5	75	33	4.8	Below-normal	2 – 9th
4	70	30	2.3		
3	65	27	1.0	Impaired	<2nd
2	60	23	0.4		
1	55	20	0.1		

APPENDIX G Correlation Matrix

Subsets (scaled)		QCAE Cognitive Empathy	QCAE Affective Empathy	Affect Naming	SSQ
Age	Rho	0.19	-0.29	**0.48**	**0.40**
	P	0.39	0.20	0.02	0.07
Age at first concussion	Rho	-0.13	-0.27	0.24	0.01
	P	0.57	0.24	0.29	0.97
Years played rugby	Rho	0.17	-0.16	**0.61**	**0.49**
	P	0.45	0.48	0.00	0.02
Estimated hours played in total	Rho	-0.15	0.15	-0.18	-0.02
	P	0.52	0.53	0.44	0.92
Education Years	Rho	-0.04	**0.30**	0.04	0.29
	P	0.85	0.19	0.86	0.20
TOPF-UK	Rho	0.28	0.09	0.26	0.05
	P	0.23	0.71	0.25	0.82
WAIS Digit Span Forward	Rho	-0.14	0.06	**0.33**	**0.34**
	P	0.54	0.79	0.14	0.14
WAIS Digit Span Backward	Rho	0.14	0.28	0.26	0.05
	P	0.55	0.22	0.26	0.82
WAIS Digit Span Sequencing	Rho	0.13	0.16	0.28	0.22
	P	0.59	0.50	0.22	0.35
WAIS Digit Span	Rho	0.04	0.22	**0.35**	0.23
	P	0.87	0.33	0.12	0.31
WAIS Coding	Rho	0.25	-0.07	0.23	-0.01
	P	0.28	0.76	0.32	0.98
Brixton Test	Rho	0.06	0.04	-0.09	0.02
	P	0.79	0.88	0.69	0.93
DKEFS Letter Fluency	Rho	0.25	0.19	0.20	-0.18
	P	0.28	0.42	0.38	0.43

DKEFS Category Fluency	Rho	0.38	0.06	0.21	-0.12
	P	0.09	0.81	0.37	0.62
Subsets (scaled)		QCAE Cognitive Empathy	QCAE Affective Empathy	Affect Naming	SSQ
DKEFS Switching Output	Rho	0.57	0.29	-.18	-.124
	P	0.81	0.21	0.45	0.59
DKEFS Switching Accuracy	Rho	0.06	0.17	-0.23	-0.15
	P	0.79	0.46	0.32	0.50
WAIS Similarities	Rho	**0.45**	0.05	0.18	-0.18
	P	0.04	0.82	0.43	0.43
WAIS Matrices Reasoning	Rho	**0.72**	0.29	0.24	0.15
	P	0.00	0.21	0.29	0.53
WMS LM Immediate Recall	Rho	0.11	0.17	0.05	0.05
	P	0.63	0.46	0.84	0.83
WMS LM Delayed Recall	Rho	0.02	0.24	0.04	0.07
	P	0.93	0.29	0.86	0.76
WMS LM Recognition	Rho	0.03	-0.03	0.32	0.08
	P	0.90	0.91	0.16	0.73
QCAE Cognitive Empathy	Rho	1.00	**0.46**	0.18	0.14
	P		0.04	0.45	0.56
QCAE Affective Empathy	Rho	**0.46**	1.00	-0.01	0.06
	P	0.04		0.98	0.81
Affect Naming	Rho	0.18	-0.01	1.00	**0.60**
	P	0.45	0.98		0.00
SSQ Method 1	Rho	0.14	0.06	**0.59**	1.00
	P	0.56	0.81	0.00	

APPENDIX H Multivariate General Linear Model

	Variable	Mean Square	F	p Value	Partial Eta
Emotional Recognition	Age	5.24	1.92	0.19	0.14
	First Concussion	0.35	0.13	0.73	0.01
	Rugby hours	3.38	1.24	0.29	0.09
	Education Years	10.20	3.74	0.08	0.24
	Years Played	7.39	2.71	0.13	0.18
	TOPF FSIQ	1.01	0.37	0.55	0.03
	Digit Span Forward	1.17	0.43	0.52	0.03
	Digit Span	0.02	0.01	0.93	0.00
ToM	Age	17.56	1.88	0.20	0.14
	First Concussion	2.19	0.23	0.64	0.02
	Rugby Hours	4.86	0.52	0.49	0.04
	Education Years	2.45	0.26	0.62	0.02
	Years Played	2.78	0.30	0.60	0.02
	TOPF FSIQ	0.03	0.00	0.96	0.00
	Digit Span Forward	3.74	0.40	0.54	0.03
	Digit Span	0.24	0.03	0.88	0.00