Impact of Head Injury on Cognitive Functioning and Social Cognition in UK-based Female Rugby Players

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ABSTRACT

Introduction: increasing attention is focused on the potential long-term impact of sports-related mild traumatic brain injuries (SRmTBI). Evidence suggests poorer cognitive and psychosocial outcomes in SRmTBI, including increased risk of developing certain neurodegenerative conditions. Research to date has focused on males neglecting female athletes, despite evidence suggesting sex-specific differences in frequency and recovery of SRmTBI.

Aims: To explore the association between SRmTBI and cognitive functioning with a specific focus on social cognition in female rugby players.

Method: A quantitative cross-sectional design was employed allowing for thirteen female rugby players with a history of SRmTBI to complete a neuropsychological battery of general cognitive functioning and social cognition.

Results: Weaknesses relative to normative data, were found for domains of social cognition including theory of mind and cognitive empathy, despite typical scores on domains of general cognitive functioning relative to normative data. Group level analysis confirmed poorer performance for theory of mind and cognitive empathy measures in contrast to overall performance on domains of general cognitive functioning.

Discussion: Findings from this preliminary study indicate that measures of social cognition should be incorporated into routine assessment and management of SRmTBI. Further research is needed to investigate the association between social cognition and SRmTBI.

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LIST OF ACCRONYMS

bvFTD	*Behavioural variant Frontotemporal Dementia*
CDC	*Centers for Disease Control and Prevention*
CT	*Computed Tomography*
CTE	*Chronic Traumatic Encephalopathy*
D-KEFS	*Delis-Kaplan Executive Function System*
DTI	*Diffusion Tensor Imaging*
FA	*Fractional Anisotropy*
GCS	*Glasgow Coma Scale*
HIA	*Head Injury Assessment*
ImPACT	*Immediate Post-Concussion Assessment and Cognitive Testing*
K-D	*King-Devick*
LOC	*Loss of Consciousness*
MRI	*Magnetic Resonance Imaging*
mTBI	*Mild Traumatic Brain Injury*
NBD	*Neurobehavioural Disability*
PCS	*Post-Concussive Syndrome*
PFC	*Prefrontal Cortex*
PTA	*Post-Traumatic Amnesia*
PTHP	*Post-Traumatic Hypothyroidism*
QCAE	*Questionnaire of Cognitive and Affective Empathy*
RL	*Rugby League*
RmTBI	*Repeated* Mild *Traumatic Brain Injury*
RU	*Rugby Union*

SCAT	*Standardised Concussion Assessment Tool*
SIS	*Second Impact Syndrome*
SRmTBI	*Sports-Related Mild Traumatic Brain Injury*
SSQ	*Social Stories Questionnaire*
TBI	*Traumatic Brain Injury*
ToM	*Theory of Mind*
TOPF-UK	*Test of Premorbid Functioning – United Kingdom*
UK	*United Kingdom*
WAIS-IV	*Wechsler Adult Intelligence Scale – Fourth Edition*
WMS-IV	*Wechsler Memory Scale – Fourth Edition*

1. INTRODUCTION

1.1. Overview

The negative psychosocial and behavioural outcomes following a traumatic brain injury (TBI) are well established. Literature within the field of TBI has widely detailed the concerns of early return to sports following one concussive event (Giza & Kutcher, 2014), commonly referred to as a mild traumatic brain injury (mTBI). A mTBI can be defined as 'excessive force' to the head by direct impact or force transmission (Ropper & Gorson, 2007). Increasing attention recently is focused on the potential long-term effects of cumulative mTBIs, particularly in players of contact sports (Bailes et al., 2014). Players of contact sports, such as rugby, appear to be at an increased risk of mTBI due to the frequency of closed head injuries sustained throughout their sporting careers (Thornton et al., 2008). This emerging topic is of interest to researchers, sporting organisations, legislative bodies, and athletes alike. However, to date much of the already limited literature within this area is androcentric in nature, that is, female sports players have either formed a minority of participant samples or have been ignored entirely.

The prefrontal cortex (PFC) is associated with social cognitive processes such as mentalisation in social interactions (Forbes & Grafman, 2010). Functional activity within the PFC has been shown to be altered following mTBI and sub-acute mTBI and therefore susceptible to head impacts (Zhang et al., 2010). Only one research study has investigated sports-related mild traumatic brain injury (SRmTBI) and social cognition in rugby players (York-Smith, 2020). However, this study focused on male rugby players and no research has been undertaken exploring SRmTBI and social cognition in female rugby players. Owing to the novel nature of this topic area, a systematic review of the literature was not feasible. Searches conducted over five databases (APA PsycInfo, CINAHL Complete, Ovid Online, PubMed, Scopus) yielded no relevant results, reflecting the absence of research in this area. See Appendix A for literature search terms. See Appendix B for the literature search PRISMA flow diagram.

1.2. Traumatic Brain Injury

Traumatic brain injury is the most common of all neurological disorders and presents a significant public health problem. TBI is increasingly being reported not just as an acute presentation, but also as a chronic condition with long-term implications, such as an elevated risk of epilepsy and late onset neurodegeneration (Bramlett & Dietrich, 2015; LoBue et al., 2019). Globally, up to 60 million people experience a TBI annually, potentially placing an economic burden on economies (Maas et al., 2022). It is predicted that TBI will remain in the top three causes of physical disability and injury-related death until 2030 (Maas et al., 2017). In the United Kingdom (UK), approximately 350,000 people experience a TBI each year (Headway, 2018). In recent years, there has been growing public awareness of the long-term cumulative impact of sustained mTBI in prominent athletes such footballers and rugby players (Stewart, 2021; Bellomo et al., 2022).

1.2.1. Aetiology of Traumatic Brain Injury

Common causes of TBI include falls from heights (low or high), road traffic collisions, violent assaults, cycling incidents, self-injurious behaviour, and sporting injuries (James et al., 2019). In more economically developed countries, falls represent the primary cause of TBI, whereas road traffic collisions are the leading cause of TBI in economically developing countries (Li et al., 2016).

1.2.2. Definitions and Terminologies of Traumatic Brain Injury

A traumatic brain injury can be defined as *"a disruption in the normal function of the brain that can be caused by a bump, blow, or jolt to the head, or penetrating head injury"* (Centers for Disease Control and Prevention [CDC], 2020). Acute symptoms of TBI can include loss or decreased consciousness, memory difficulties, neurological deficits (e.g., muscle weakness, balance difficulties, and changes to senses such as vision), and altered mental states such as confusion and disorientation (Pavlovic et al., 2019). The sequelae of TBI are wide-ranging given cerebral complexity and the multitude of factors involved. The impact of TBI is dependent on the severity of damage to the skull and the direction and length of time exposed to the biomechanical forces (Manley et al., 2017), the impact location (Post

et al., 2015), the individual's tolerance of head impacts (Rowson & Duma, 2020), and previous experiences of TBI (Theadom et al., 2015). Other possible modifying factors include psychosocial characteristics such as age, sex, childhood adversity, drug and alcohol use, and family history of mental health to name but a few (Manley et al., 2017).

Definitions and terminologies have varied within literature, nomenclature include *"mild traumatic brain injury, postconcussion symptoms, postconcussion syndrome, chronic neurocognitive impairment, subconcussive injury, and chronic traumatic encephalopathy"* (Giza & Kutcher, 2014). Concussion has been used to reference the milder form of TBI (mTBI) where there has been a neurophysiological insult without observable macrostructural damage (Casper, 2018). In clinical neuropsychology, there has been a shift towards the usage of mTBI in lieu of terms such as 'head injury' or 'concussion', although often used interchangeably (Prince & Bruhns, 2017). Both the World Health Organization and the CDC have proposed replacing the term concussion with mTBI. However, there is continued debate regarding the interchangeability of concussion with mTBI. In general, concussion tends to be used in sporting contexts, whereas mTBI is more frequently used in medical spheres (Harmon et al., 2013; Mayer et al., 2017). Furthermore, differences exist in perception as to what these terms mean between clinicians and patients. The use of mTBI is associated with increased injury severity, whereas concussion is reported as less alarming among laypeople (Bennett et al., 2019). However, for the purposes of this study, the term mTBI will be used throughout.

1.2.3. Classifications of Traumatic Brain Injury

TBI classification is conventionally based on injury features and location (Marshall et al., 1992), and clinical urgency including number and duration of symptoms (McIntosh et al., 1996). TBI is grouped into three categories ranging from mild (concussion), moderate, to severe. It is estimated that up to 90% of all TBIs are mTBIs (Fehily & Fitzgerald, 2017).

1.2.3.1. Closed and penetrating head injuries: rudimental TBI classification distinguishes between closed (blunt) and penetrating (open) injuries. Measured by

the penetration or structural integrity of the dura mater, the tough outer layer of protective tissue covering the brain, and skull, a penetrating injury consists of the tearing of dura mater and is indicative of a severe TBI (Blennow et al., 2016). Penetrating head injuries are associated with a higher risk of seizures, infections, and death compared with closed injuries (Bullock et al., 2006), mainly due to the reduced protection of the brain, and the localised site of damage to the dura mater and brain from penetration (Harrington et al., 2020). Closed head injuries occur when neither the brain nor the dura mater is exposed and is often the result of a blunt impact to the skull (Abdelmalik et al., 2019). Closed head injuries represent the majority of TBI cases, and typically lead to diffuse axonal injury and decreased consciousness (Hammoud & Wasserman, 2002). Closed head injuries are commonly observed within contact sports such as rugby.

1.2.3.2. Primary and secondary damage: TBI comprises a complex process of anatomical and functional damage arising from both primary and secondary sources of injury (Masel & DeWitt, 2010). Primary damage is sustained immediately at the time of injury, whereas secondary damage emerges over a period ranging from hours to months after the initial injury. Primary damage causes acute functional disruption to cerebral tissue including intracranial haemorrhaging, blood vessel damage, contusion (both coup and contrecoup lesions), and axonal sheering (Werner & Engelhard, 2007; Corrigan et al., 2016). Damage is not restricted to the location of the primary trauma, expanding in a diffuse and progressive manner (Farkas & Povlishock, 2007). Secondary damage is induced by physiological responses within the body to primary damage such as inflammation, infection, ischaemia, and aerocele potentially leading to brain cell damage and loss (Bramlett & Dietrich, 2015)

1.2.3.3. Assessment and measurement of traumatic brain injury: three measures are widely used in TBI assessment, including: the Glasgow Coma Scale (GCS; Sternbach, 2000; Teasdale & Jennett, 1974); Loss of Consciousness (LOC; Kelly, 2001); and Post-Traumatic Amnesia (PTA; Fortuny et al., 1980; Wilson et al., 1999). However, no universal definition of TBI severity exists, and variation of classifications has been observed across the literature leading to discrepancies within research (Maas et al., 2010).

Developed by Teasdale and Jennett (1974) and updated by Sternbach (2000), the GCS is the most used TBI assessment tool. Clinical severity is based on measuring the patient's best eye opening, verbal performance, and motor response. Scores from these three domains are combined to produce a total score informing injury classification: mild (GCS 13-15); moderate (GCS 9-12); and severe (GCS 3-8). The GCS is a good correlation of long-term outcomes; however, it may not be sensitive in differentiating variations of recovery within mTBI (Giza & Kutcher, 2014).

Another common TBI assessment is measurement or estimation of LOC. Evidence suggests LOC post-TBI is associated with poorer long-term outcomes and greater severity of injury compared with TBI without LOC (Kelly, 2001). Clinical severity is determined by the length of time LOC is experienced: mild (LOC <30 minutes); moderate (LOC between 30 minutes to 24-hours); and severe (LOC >24-hours). Although LOC has been shown to be a helpful indicator of initial injury severity, mixed evidence exists regarding the reliability of measuring the symptom duration (Erlanger et al., 2003a).

Measures of PTA assess the impact of TBI on memory and mental states such as confusion, due to the high incidence of these symptoms post-TBI (Wilson et al., 1999). Clinical severity is determined by the duration of alterations to memory and presence of confusion/agitation and the period until reliable new memories are formed: mild (PTA <1-hour); moderate (PTA between 1-hour to 24-hours); and severe (PTA >24-hours). A universal definition of PTA is currently lacking, and although anterograde memory is impacted in PTA, PTA involves a more extensive range of cognitive deficits in attention and executive functioning that most PTA measures do not fully assess (Marshman et al., 2013). There has been a shift towards the term post-TBI syndrome to enable a more complete overview of these domains.

Increased TBI severity is generally associated with poorer physiological and psychosocial outcomes (Ownsworth et al., 2007). Survivors of severe TBI often

experience life-long health difficulties including cognitive, emotional, and behavioural changes (Masel & DeWitt, 2010). Although outcomes tend to improve with lower injury classification, relatives of TBI survivors report similar functional difficulties regardless of injury severity (Hellawell et al., 1999). Such outcomes are not limited to severe cases but can often occur following mild to moderate TBI (Maas et al., 2017). For example, at six-months follow-up, up to half of mTBI hospital-presenting cases did not return to pre-TBI indicators of health often referred to as “post-concussive syndrome” (Steyerberg et al., 2019). Only around 10% of mTBI cases are followed-up after attendance at an emergency department in Europe (Maas et al., 2022).

1.2.4. Mild Traumatic Brain Injury

Causes of mTBI often include a blunt trauma to the head with or without accelerated or decelerated biomechanical forces (Werner & Engelhard, 2007). No specific test is available to diagnose mTBI coupled with no standardised definition of mTBI (Pavlovic et al., 2019). It is generally accepted that most mTBIs are computed tomography (CT) negative, that is, no physiological abnormalities would be observed (Lannsjö et al., 2013). However, primary and secondary injurious effects are frequently observed on a cellular level which can impede on cognition (Raghupathi et al., 2002). Although mTBI mortality rate is quite rare with an incidence rate of 0.1% (Af Geijerstam et al., 2003), decreased quality of life can be experienced resulting from prolonged cognitive, emotional, and functional symptoms (Vanderploeg et al., 2007). Therefore, ‘mild’ can be misleading as it does not allude to symptom duration or distress.

Increased acknowledgement of mTBI has stemmed from observations within sporting and military combat contexts (Eme, 2017). The use of the GCS in categorising injury severity on degrees of consciousness is a somewhat rudimentary tool and may not ascertain the full picture of TBI (Maas et al., 2017). For example, the GCS is not able to distinguish the different physiological subsets of TBI. However, ascertaining accurate incidence rates of mTBI is challenging due to variations in definition and because many cases are unreported and do not result in a medical assessment (Iverson, 2005). For some, mTBI can lead to post-concussive syndrome (PCS) – a combination of general symptoms such as sleep disturbance,

headaches, anxiety and/or depression, and irritability, persisting beyond the anticipated recovery period (Chen et al., 2008). PCS is a source of controversy and debate within the literature, primarily due to there being no single definition and differing theories relating to aetiology.

1.3. Sports-Related Traumatic Brain Injury

Globally, an estimated 3.8 million sports-related mild traumatic brain injuries (SRmTBI) occur each year (Langlois et al., 2006). SRmTBI often referred to as 'sporting concussion', can relate to any head injury sustained during play and occurs in most sports (Toth et al., 2005). However, certain contact sports such as American football, ice hockey, and rugby are especially linked to increased risk of TBI (Prien et al., 2018). Injury severity depends on the type of sport, as variations exist in the use of protective gear, speed of play (acceleration and deceleration), and frequency and/or intensity of head impacts (Fernandes & Sousa, 2015). In recent decades, the way in which SRmTBI is viewed and treated by sporting organisations and legislative bodies has transformed (McAllister & McCrea, 2017). Increasing research is focused on the link between recurrent head impacts and subsequent TBI, common in many contact sports (Bailes et al., 2013). However, most earlier research focused on sports associated with higher impact blows to the head, such as boxing and the martial arts (Lockwood et al., 2018).

1.3.1. Cumulative Traumatic Brain Injury

Much of the media focus and literature to date has centred on moderate/severe sporting-related TBI, despite most head impacts classifying as mTBI (Ruff & Weyer Jamora, 2009). From the 1980s onward, media coverage largely focused on the controversial and rare Second Impact Syndrome (SIS), first coined by Saunders and Harbaugh (1984). The original study was based on an American footballer who died following a second TBI after return-to-play. It was hypothesised that the second 'unremarkable' head impact was fatal due to the brain being in a 'vulnerable' state. Although, the risk factors underlying SIS are not fully known, it is important for clinicians to be aware of SIS. However, it is relatively uncommon – a review by McCrory and Berkovic (1998) found that there were only five genuine cases of SIS

out of a total of 17 reported in all published studies at that time. To reduce the risk of SIS, guidelines have been introduced to limit premature return-to-play in athletes. There is consensus among professionals that athletes should not return-to-play until TBI symptoms have ameliorated (McCrory, 2001).

Less research has focused on the lower level and repeated mTBI (RmTBI) conventionally missed as a source of impairment. Due to the frequency of impact and possible long-term effects, SRmTBIs are a significant and emerging public health issue (Gardner et al., 2014). Recurrent head injuries, especially within the typical recovery period, can lead to neuronal loss, with similar effects observed following moderate to severe TBI (Gold et al., 2018).

1.3.1.1. Chronic traumatic encephalopathy: increasing research is focusing on chronic traumatic encephalopathy (CTE) observed in athletes who have experienced RmTBI throughout their careers (Stern et al., 2011; VanItallie, 2019). Defined as a neurodegenerative disease, CTE is characterised by exceptionally high deposits of tau, a microtubule-associated protein involved in the cytoskeletal network within neurons (Alosco et al., 2021). Four clinical stages characterise CTE including perivascular tangles in the earlier stages, to extensive build-up of tau deposits many decades later (Alosco et al., 2020). CTE appears to be limited to individuals who experience RmTBI. It is theorised that CTE represents a unique type of TBI that is non-comparable with moderate to severe TBI and presents with a different disease trajectory and endpoint. Although similar mechanisms may be involved in CTE as with other neurodegenerative conditions in relation to excessive tau deposition, CTE appears to manifest earlier in life leading to neuropathology (McKee et al., 2015). At present, the only conclusive way of determining a CTE diagnosis is via post-mortem analysis. However, imaging procedures such as positron emission tomography and CT may detect excessive tau deposition in vivo (Filippi et al., 2022). Much of the literature is limited to small and uncontrolled studies, and little is understood regarding the risk factors, incidence, and natural history of CTE (Abad et al., 2022).

1.3.1.2. Subconcussive injury: although no single definition of subconcussive injury exists, the theoretical basis is underpinned by the potential effects of biomechanical

forces inducing injury on a microstructural level without any noticeable clinical symptoms (Giza & Kutcher, 2014). There is growing concern regarding subconcussive injury in the sporting world where a high likelihood exists of sustaining several biomechanical injuries within a short period, without adequate recovery time (Mainwaring et al., 2018). Experimental evidence indicates that subconcussive events may lead to increased vulnerability, through alterations to the cerebral structure, leading to an increased risk of neurodegenerative conditions such as CTE and associated dementia (Huber et al., 2016).

Churchill et al. (2017) investigated contact sport athletes, comparing them with non-contact athletes. Diffusion tensor imaging (DTI) was used to measure white matter microstructure and global functional connectivity. Significant differences were observed in the microstructure and reduced connectivity in the contact group. Individuals with a history of SRmTBI displayed differences in white matter and functional connectivity indicating a latent cumulative impact of both contact history and SRmTBI on neurophysiology. A possible dose-response effect may exist between cumulative head impacts and increased incidence of cognitive and neuropathological impairments later in life (Zetterberg et al., 2019). Subconcussive events appear to result in a gradual 'additive' effect over time. Rugby players are more likely to experience injuries, including SRmTBI, in game play compared with training (Williams et al., 2022). Therefore, it is reasonable to suggest that there is a relationship between the number of years played and the likelihood of exposure to subconcussive events during matches. However, this is largely hypothetical due to challenges in gaining an accurate incidence of subconcussive events.

1.3.2. Traumatic Brain Injury in Rugby

In the UK, rugby encompasses both Rugby League (RL) and Rugby Union (RU) and is a popular sport with around 8.5 million (2.7 million female) players registered in over 120 countries (King et al., 2019). A collision sport (where athletes purposely hit or collide with one another with great force), rugby consists of intermittent periods of accelerated and decelerated high intensity exercise involving running, scrumming, tackling, mauling, and rucking (Suarez-Arrones et al., 2014). Players are at an elevated risk of head injury compared with other contact sports such as hockey and

American football (Gardner et al., 2014). Indeed, SRmTBIs are the most frequently cited injury comprising over one tenth of all injuries (England Professional Rugby Injury Surveillance Project Steering Group, 2018). A noticeable increase in rugby SRmTBIs has been observed in recent years (MacQueen & Dexter, 2010). This could be in part due to new players joining the sport who may be inexperienced in tackling techniques that reduce the likelihood of SRmTBI (Tierney & Simms, 2018). Up to half of all rugby SRmTBIs are sustained during tackling, and mostly impact the person initiating the tackle (Tucker et al., 2017). Position plays a role in both incidence and SRmTBI severity with forwards experiencing an increased risk of moderate to severe TBI compared to back positions (Tucker et al., 2017). Larger and stronger individuals typically play forward positions with the aim of winning possession of the ball. Back positions tend to be smaller and faster and make use of ball possessions. However, in a review of head injuries sustained at the RU World Cup in 2019, Cooke et al. (2022) found that backs were more likely to experience head impacts because of foul play; although most of these did not require the player being removed from the game. This is likely due to backs adopting the ball carrier position and being the recipient of tackling leading to possible head impacts.

In a move to reduce TBI incidence, World Rugby, the international RU governing body, developed targeted initiatives to address this in tackling during play (Raftery et al., 2021). If a TBI is suspected, a player should be removed from play and be given a Head Injury Assessment (HIA) using a standardised tool for the assessment of TBI in rugby (McCrory et al., 2005). The HIA measures a variety of TBI symptoms including memory, cognition, balance, and discomfort. However, this assessment protocol relies on having qualified side-line medical professionals available and identifying suspected TBI symptoms in players. A limitation is that TBIs do not always present immediately as symptomology can be delayed by as much as 48-hours. It is possible that many players with a TBI continue playing (Tierney & Simms, 2017). Variation exists in how these guidelines are translated into sporting contexts. Cooke et al. (2022) found that in the RU World Cup 2019, 17 cases of TBI were missed by side-line medical professionals and only four of those received a HIA. Missed TBIs in players during a match is potentially higher in non-professional settings and players due to less medical resources. However, the true extent of TBIs in non-professional rugby remains unknown. Much of this research has focused on

men's rugby with little attention in the literature on women's rugby. This is despite women's rugby being one of the fastest growing team sports in the both the UK and the world (Nyberg & Penpraze, 2016). Physiological differences between female and male athletes, such as neck-head mass and muscle composition, may increase the likelihood of SRmTBI in female rugby players following a head impact (McGroarty et al., 2020).

1.4. Sports-Related Traumatic Brain Injury in Female Athletes

Awareness is growing of the limitations of an implicit androcentric bias within neuropsychological research. Most participants are male, extending to experimental clinical trials with rodents being predominantly male (Thomas et al., 2022a). Although TBI is a primary cause of death and disability globally, biological sex differences are not fully understood in regard to TBI pathophysiology and recovery processes (Gupte et al., 2019). This presents a problem as medical care and targeted interventions are potentially limited by the lack of knowledge regarding sex differences in TBI (Mikolić et al., 2021). Terms such as 'sex' and 'gender' are often used interchangeably or inconsistently in TBI research (Madsen et al., 2017). There are important differences between them. Sex refers to an individual's biology such as having male, female, and intersex chromosomes (Peters & Norton, 2018). Whereas 'gender' is concerned with the social construction of roles and identities (Clayton & Tannenbaum, 2016). It is important to distinguish between biological sex differences and gender-related differences.

Female athletes have a higher risk of SRmTBI compared with male athletes playing the same sport (Covassin et a., 2016; Theadom et al., 2020). However, female athletes have been significantly underrepresented within research despite evidence suggesting worse outcomes post- SRmTBI (D'Lauro et al., 2022). Female athletes report longer recovery times post- SRmTBI compared with male peers (Master et al., 2021). The relationship between sex and SRmTBI appears to be mediated by injury severity – no differences exist in terms of survival and disability following moderate to severe TBI. However, female athletes do appear to experience poorer cognitive and psychological outcomes post-mTBI (Levin et al., 2021). Females reported lower

quality of life, and poorer scores on the GOS-Extended six-months post- SRmTBI (Mikolić et al., 2021). A higher frequency and severity of post-concussive symptoms have been observed in females (Cnossen et al., 2017). Interactions between sex and TBI outcomes may be connected to hormonal responses to injury (Gupte et al., 2019). Given the increasing popularity and uptake of collision sports such as women's rugby, sex differences are a crucial variable in TBI.

1.4.1. Endocrinal Factors

Research exploring the possible mechanisms involved in the relationship between sex and TBI outcomes remains limited (Duffy et al., 2021). An increasing but small evidence-base exists in relation to female sex hormones and SRmTBI in female athletes (Greco et al., 2019). It is hypothesised that SRmTBI may result in lower levels of progesterone, reducing its neuroprotective qualities. SRmTBI may trigger endocrinal dysregulation such as hypopituitarism, a deficiency of one or several hormones of the pituitary gland (Duffy et al., 2021). Commonly referred to as the 'master gland', the pituitary gland controls the production of hormones which act as a chemical regulator to produce hormones in other glands (Dorton, 2000). For example, post-traumatic hypothyroidism (PTHP) was identified nearly a century ago but was believed to be a rare phenomenon (Cyran, 1918). Emerging clinical evidence suggests that mTBI may lead to hypothalamic-pituitary dysfunction more often than previously thought, resulting in impaired recovery (Rosario et al., 2013).

In female athletes, PTHP may develop following a head impact or even from RmTBI. Factors influencing the development of PTHP include TBI severity (Javed et al., 2015), hormone levels at the time of injury (Gray et al., 2019), and genetic factors (Tanriverdi et al., 2006). Although this evidence-base remains limited. It is theorised that TBI can lead to disruptive alterations to blood flow in the brain resulting in excessive production and hormonal excretion within the pituitary gland, leading to neuroendocrine dysfunction (Yang et al., 2016). Neuroendocrine dysfunction can signify hormonal imbalances and dysfunction affecting several axes in the hypothalamic-pituitary connection. The hypothalamic-pituitary-gonadal axis is of particular interest as it controls the intersection between reproductive and endocrinal systems including hormones such as oestrogen and progesterone (DeMayo et al.,

2002; Wunderle et al., 2014). TBI may inhibit oestrogen and progesterone synthesis and the concentration of such hormones may reflect injury severity and possible recovery outcomes.

1.4.2. Menstrual Cycle

Oestrogen and progesterone levels during the menstrual cycle have been proposed as a moderator in TBI onset and recovery (Di Battista et al., 2019). If a TBI occurs during peak oestrogen levels, a rapid decrease in oestrogen concentration may ensue, amplifying negative outcomes (Snook et al., 2017). A similar process can be observed with progesterone levels during menstruation, possibly explaining sex differences in TBI outcomes. Sustaining mTBI during different stages of the menstrual cycle has also been found to impact recovery time (Wunderle et al., 2014). Injury outcomes sustained during the luteal phase of menstruation (the second menstrual phase leading to the thickening of the uterine lining), were worse than injury during the follicular phase (the first menstrual phase where the pituitary gland releases hormones stimulating follicles production on the surface of an ovary) and in those taking oral contraceptive (suppressed levels of oestrogen and progesterone). As the luteal stage is when progesterone levels are highest, these findings have suggested the Withdrawal Hypothesis. That is, TBI sustained during high levels of progesterone result in sudden reductions, leading to poorer outcomes than TBI sustained during low levels of progesterone. Over 90% of females described absent menstruation within 12-months post-TBI, compared with around 23% prior to TBI (Ripley et al., 2008). Neuroendocrine dysfunction is more likely to occur during certain stages of the menstrual cycle post-TBI.

1.4.3. Physiological Characteristics

Sexual dimorphism has also been proposed as a factor in underpinning sex differences observed in TBI. Potential physiological differences between male and female players include neck muscle strength, girth, and neck-head ratio (Streifer et al., 2019). These differences may contribute to the greater SRmTBI incidence in female athletes (Broshek et al., 2005). It is possible that biomechanical factors also underpin sex differences. Tierney et al. (2005) proposed that neck-head ratio may make it more difficult for female athletes to stabilise their head during acceleration.

Coupled with reduced neck-head mass this may lead to greater angular concentration of the head during impact contributing to greater injury severity. Following this theory, if neck muscle strength is increased, the acceleration forces on the head during impact would decrease. However, neck muscle strengthening programmes have yet to demonstrate significant reductions in TBI (Harmon et al., 2013). The benefits of increased neck muscle strength are not actualised when the athlete has not had a chance to 'prepare' for the impact, as is often the case in rugby.

1.4.4. Recovery Trajectory

Zuckerman et al. (2014) explored the experiences of both female and male athletes post- SRmTBI and found that females experienced more symptoms and exhibited longer recovery times in all the domains measured. Female athletes took an average of 2.1 additional days to return to personal baseline than males. Baker et al. (2016) examined female and male athletes post- SRmTBI and found greater symptoms and symptom severity in female athletes. Female athletes took almost twice as long to recover as males. Measures collected every 24-hours post-injury showed that female athletes reported longer recovery times despite having similar symptom severity as males (Gallagher et al., 2018). Female sex has been identified as a leading risk factor for prolonged recovery from SRmTBI (Miller et al., 2016).

Recovery differences post- SRmTBI have been observed in younger female athletes compared with male peers. Desai et al. (2019) found that on average females presented six-days later to a medical clinic post- SRmTBI (females: 15 days; males: 9 days). Females also took longer to recover in all domains, including return to baseline neurocognitive functioning, and normalisation of vision and vestibular performance. Chandran et al. (2020) explored the frequency of SRmTBI and symptomology in high school players of football (soccer). Females were around 84% more likely to experience SRmTBI following a neck or head injury. Females were significantly more likely to report symptoms such as light sensitivity and drowsiness.

1.5. Sports-Related Traumatic Brain Injury in Female Rugby Players

High injury and SRmTBI rates have been observed in women's rugby. However, there remains a paucity in research exploring the impact of injuries, specifically head injuries, in female rugby players.

1.5.1. Incidence of SRmTBI and Injury

Black et al. (2017) explored the incidence rate of SRmTBI among 759 (female: 279) university athletes from different sports between 2008 to 2011. Female athletes were significantly more likely to experience SRmTBI. Women's rugby had the highest frequency of SRmTBI accounting for 16 of the total 81 new SRmTBIs. Women's rugby also had the highest incidence rate with 20 SRmTBIs per athlete season. Black et al. (2017) proposed that the high incidence rate in women's rugby is due to the number of potential injury mechanisms and inherent absence of protective equipment. Shill et al. (2022) conducted a cohort study on injury and SRmTBI rates in 421 female high school rugby players. Female rugby players had an estimated match incidence rate of 93.7 injuries per 1,000 match hours. Around 70% of all match injuries were attributed to the tackle. Tackling was found to be the most common cause of SRmTBI with an incidence rate of 18.1 SRmTBIs per 1,000 match hours and accounted for the highest proportion of injuries in matches.

King et al. (2019) conducted a systematic review of match and training injuries in women's rugby. Only 10 articles were identified for injury incidence in women's RU. Two forms were analysed: women's-rugby 15s and women's rugby-7s. Rugby-7s is a variant consisting of two teams of seven players, instead of the traditional fifteen players. Both formats share the same objective – to score more points than the other team (Ross et al., 2014). Played on a full-sized rugby pitch, rugby-7s is typically much faster-paced and higher-scoring due to shorter match times. Injury incidence in women's rugby-15s was 19.6 per 1,000 match hours, whereas women's rugby-7 had an incidence rate of 62.5 per 1,000 match hours. Most injuries were a result of the tackle, for all rugby types. Head and face injuries were the most cited location of injury. The most common injury type included SRmTBI and sprain/strains. Professional players exhibited lower injury rates with 6.2 per 1,000 match hours

identified for the women's rugby world cup and SRmTBI accounted for 10% of all documented injuries.

King et al. (2022) conducted a systematic review with the aim of analysing and collating all published articles of match and training SRmTBIs in both women's rugby. Sixteen published articles were identified from January 1990 to July 2021. Women's RL had the highest SRmTBI incidence with a pooled match analysis of 10.3 per 1,000 match hours, compared to an incidence rate of 2.8 per 1,000 match hours for rugby 15s (RU) and 8.9 per 1,000 match hours for rugby 7s (RU). SRmTBI in women's RL was four times greater compared with rugby 15s. Incidence of SRmTBI was nine times greater in match participation compared with training in rugby 15s. The pooled average of days lost to mTBI was 33 days. This figure is above the expected 7-to-10-day timeframe outlined in the Concussion in Sport Consensus statement (McCrory et al., 2017), and described the need for such guidelines to be updated to include sex-specific differences. The estimated costs for all SRmTBIs was $1,235,101 New Zealand dollars (around £635,000 British pounds).

Yeomans et al. (2021) analysed injury trends in amateur RU, including both female and male players. Ankle ligament injuries and SRmTBI were the most cited injuries for both female and male players. Most tackle-related injuries were sustained in the second half of match play. Player fatigue may have influenced the tackle technique employed, increasing the risk of SRmTBI. SRmTBI incidence was found to be similar between female and male players (5.5 per 1,000 player hours vs. 5.6 per 1,000 player hours). However, females were underrepresented in this study, with nearly four fifths of the sample being male (959 males vs. 234 females). In this study, female players had fewer matches as one team withdrew, resulting in fewer games played and longer periods of rest between matches.

1.5.2. Effects of Cumulative Head Impacts

Black et al. (2020) conducted assessments pre- and post-season in 13 female rugby players, with the aim of assessing and measuring subtle neurological changes post-

impact. Eleven players sustained 172 impacts. Two stance-based measures, the tandem-leg stance on an unstable surface and the double-leg stance on firm surface, revealed balance deficits after a season of repetitive head impacts. Dynamic postural performance had improved post-season – an unexpected finding. It is possible that players were motivated to improve performance on this task, constituting a confounding variable of learning effect. Spinal cord excitability did not significantly change from pre- to post-season. However, players exhibited increased cross covariance of H-waves (known as the Hoffmann reflex produced by alpha-motoneuron activation in the spinal cord that exhibits fluctuations in amplitude even during repetitive stimulation), compared to normative values at baseline.

King et al. (2018) explored head impacts in female RL players over the course of a season. Twenty-one female players were fitted with a wireless impact measuring device located behind their ear. A total of 1,659 head impacts were recorded over 9 games, with a mean of 184 impacts per match and a mean of 14 per player per match. Player position influenced the mean number of subconcussive events experienced: forwards experienced more head impacts per match than backs, and these impacts were of greater magnitude. Most head impacts analysed took place at the side of the head and were experienced in the second half of match play.

1.5.3. Previous Incidence and Recurrence of Head Injury in Rugby

Bussey et al. (2019) investigated the effect of SRmTBI history on head movement control during tackling in non-professional female and male RU players. The study was laboratory-based and utilised a simulated front-on tackle with a dynamically weighted tackle bag. Twenty-seven (13 female) players participated in the study either with no SRmTBI history; SRmTBI within the past 12-months; or SRmTBI over 2 years prior to the study. A skin-mounted accelerometer was used to measure linear and rotational head acceleration. Players who had experienced a SRmTBI within 12-months had significantly greater head acceleration and decreased cervical muscle activation than the no-SRmTBI group whilst performing the front-on tackle task. Linear and rotational accelerations for female players were within similar ranges to previous studies reported in women's RL. However, female players who experienced SRmTBI within 12-months had significantly larger head accelerations,

especially rotational accelerations. These findings indicate possible disruption to neuromuscular control in rugby players with a history of SRmTBI and could be a possible mechanism for predisposition and recurrent SRmTBI incidence.

1.5.4. Neurophysiological Impact of Rugby Participation

An area of growing interest is the neurophysiological impact of head injuries within contact-sports such as rugby. Much of this research has focused on the immediate effects of such injuries. Few studies have investigated the long-term impact of participation in rugby. Advances in neuroimaging techniques and accessibility have allowed for the exploration of the neurophysiological impact associated with immediate and long-term effects of injury.

Zimmerman et al. (2021) used advanced magnetic resonance imagining (MRI) to explore the relationship between rugby participation and sub-acute mTBIs in male and female professional rugby players. Changes in the brain were measured over time in the longitudinal arm of the study. Forty-four rugby players (3 female) were recruited as either ‘non-injured’ or ‘acutely-injured’. Eighteen (9 ‘non-injured; 9 ‘acutely-injured’) of these players participated in the longitudinal arm of the study with a second visit six-months after the initial scan. Players were compared with non-sporting controls, non-collision athletic controls, and longitudinally assessed controls. Evidence of either axonal or diffuse vascular injury was observed in 23% (10/44) of players from neuroimaging alone. In ‘non-injured’ players, abnormalities were observed in both fractional anisotropy (FA; a commonly used connectivity measure in DTI) and diffusion measures. Players exhibited signs of sub-acute injury during DTI. In contrast, no abnormalities were observed in the non-collision sport controls. Players in the longitudinal arm of the study displayed reductions in white matter volume. Alterations were not associated with self-reported SRmTBI history or neuropsychological test scores, possibly indicative of neurodegeneration of white matter tracts due to sub-acute injury. However, only a small sample attended the follow-up and some of the control groups may have been underpowered. Furthermore, females were underrepresented and the sex of the 18 rugby players were not specified within the longitudinal arm of the study.

Schranz et al. (2018) investigated prefrontal white matter metabolite levels and micro-brain structure in female rugby players with and without mTBI. Non-invasive proton magnetic resonance spectroscopy and DTI were used to measure brain metabolism. Sixty-four rugby players participated and were assessed with MRI scans pre- and post-season. Players who sustained a mTBI were further assessed within 24-72 hours, three-months, and six-months post-mTBI. At the 24-72 hour and three-month follow-up, reduced glutamine (an excitatory neurotransmitter found in abundance in the cerebral cortex) was observed post-mTBI, and reduced glutamine/creatine ratio was also observed at the three-month follow-up. These changes could be indicative of neuroinflammation or remyelination. Clinical test scores, however, did not correlate with the exhibited changes suggesting that neuroimaging metrics could be more sensitive in detecting sub-acute mTBI.

Manning et al. (2019) analysed the resting-state functional MRI and DTI of university-level female rugby players. Linked independent component analysis was used to combine structural and functional imaging data. Linked components allow for a more detailed picture of the neurophysiology of head injury providing accurate information on the individual level. Fifty-two players participated in the study, with 21 having experienced SRmTBI. The players were measured at three days, three-months, and six-months post- SRmTBI. The findings from this study suggest that persistent changes to white matter microstructure and functional connectivity persist even after clinical recovery in those who experienced mTBI. In a further study by Manning et al. (2020) players of non-contact sports were compared with female rugby players and similar findings were reported – differences were observed in the microstructure and function of the brain in seemingly healthy rugby players. This provides further evidence of the effects of contact sports on the micro-changes to brain structure and activity.

1.6. Neurocognitive Impact of Sports-Related Head Injury

1.6.1. Neurocognitive Functioning and Outcomes after TBI

Changes in cognition, emotions, and behaviour are among the most debilitating features of TBI (Humphreys et al., 2013). Executive dysfunction is commonly

experienced post-TBI, particularly if there is damage to the prefrontal cortex (Stuss, 2011), an area of the brain responsible for executive functioning. Executive dysfunction can present in various ways, including difficulty with planning (Rabinovici et al., 2015); starting and/or completing tasks (Jones & Graff-Radford, 2021); decision-making (Wood & Worthington, 2017); and difficulties with emotion regulation (Stubberud et al., 2020). The chronicity and severity of executive dysfunction depends on the degree and location of the TBI (Demery et al., 2010). Some individuals may experience momentary executive dysfunction recovering from TBI, whilst others experience persistent executive dysfunction requiring ongoing management. Acute and persistent neurocognitive outcomes post-TBI include difficulties with learning and memory (Hart & Sander, 2017); attention and concentration (Dymowski et al., 2015; Vos et al., 2020); processing speed (Battistone et al., 2008); executive functioning (Pettemeridou et al., 2020); and language and communication (VanSolkema et al., 2020).

Some people experience severe changes post-TBI often referred to as neurobehavioural disability (NBD). NBD comprises a range of disabilities that are due to significant changes to an individual's character or personality (Wood, 2013). Such changes are frequently cited by family members as being a source of caregiver stress and burden, contributing to negative psychosocial outcomes (Williams et al., 2020). Individuals with NBD usually exhibit poor insight, attentional dysfunction, difficulties with awareness and social cognition, labile mood, and poor impulse control (Palmisano et al., 2020). All of which can impact an individual's decision making and capacity for social independence (Alderman & Wood,2013). NBD presents a significant barrier to psychosocial recovery post-TBI by undermining an individual's capacity for making and sustaining relationships and employment (Weber et al., 2018).

1.6.2. Neurocognitive Functioning and Outcomes in Contact Sports

Similarly, cognitive changes post- SRmTBI predominantly include executive functioning, memory and learning, attention, and processing speed – symptom severity is at its peak within 24-hours (Feddermann-Demont et al., 2017); but recovery times differ in relation to the cognitive domains impacted and their

association with non-cognitive symptoms. American football players exhibited reduced orientation to time and memory recall during the first three hours post-SRmTBI, with this also present two days post-injury, but resolved within a week. Mild decline in processing speed, verbal fluency and memory, and mental flexibility were evident two days post-injury, with more subtle changes in processing speed and verbal fluency remaining even at one-week post-injury (McCrea et al., 2003). Amateur Australian football and RU players exhibited significant attentional impairment and reduced psychomotor speed up to 32-hours post-injury, in comparison to both controls and personal baseline performance (Louey et al., 2014). Cognitive impairments in verbal and visual memory, and processing speed, may persist up to 14 days post-injury, despite other non-cognitive symptoms resolving (McClincy et al., 2006).

Kontos et al. (2014) conducted a meta-analysis exploring the effects of SRmTBI assessed by computerised neurocognitive tests one-week post-injury. Thirty-seven studies were identified with a pooled 3,960 participants from 2000-2011. A low to moderate effect size of SRmTBI on neurocognitive performance was observed. Subgroup analyses were conducted for age, neurocognitive test, and type of sport. Younger adolescents scored lower on neurocognitive testing, however SRmTBI had a low-to-moderate effect size observed across all groups. Neurocognitive domains such as code substitution, visual memory, processing speed, and memory were all negatively impacted by SRmTBI. A negative effect of SRmTBI was only observed for contact-based sports, although it was not possible to compare individual contact sports.

Prien et al. (2020) compared retired elite female football players with retired elite non-contact female athletes, to explore history of SRmTBI and heading behaviours (where the head is used to knock the ball). Although football is not considered a collision sport, players are encouraged to use their head to hit the ball. Retired footballers performed similarly to their non-contact peers in neurocognitive tests, however, they exhibited significantly lower scores on verbal memory (significantly associated with frequent heading) and verbal fluency tests (significantly associated with a history of two or more SRmTBIs). There is increasing interest in the long-term impact of cumulative head impacts over the course of an athlete’s career, and this

was one of the first studies to investigate this phenomenon in retired female athletes.

1.6.2.1. Association with neurodegenerative conditions: contact sport athletes have an increased risk of developing cognitive impairment later in life compared with non-contact sport peers (Cunningham et al., 2020). This includes retired male rugby players (Hume et al., 2017). Recent media reports of well-known retired football and rugby players developing neurodegenerative diseases have increased concerns regarding the risks of contact sports, leading to possible legal action against sporting organisations and governing bodies framed as failures in duty of care (Stewart, 2021). A meta-analysis found that compared to the general population, retired male athletes from boxing, football, and American football had increased incidence of dementia (Batty et al., 2022). Professional football and American football athletes had higher risks compared to amateur players. The mechanisms underpinning this observation are still being studied, although it is hypothesised that repeated sub-concussive events in contact sports may lead to neurodegeneration over time such as vulnerability to dementia in older age. However, the paucity of high-quality research places limitations on the conclusions of a cause-and-effect association between SRmTBIs and long-term outcomes.

1.6.2.2. Cumulative head impacts: mixed evidence exists in relation to repeated sub-concussive events and cognitive functioning such as memory, attention, and reaction time (Ntikas et al., 2022). Di Virgilio et al. (2016) found that 20 football headers during gameplay, comparable to standard head drilling (training where players use their head to keep the ball off the ground), led to reduced scores in a paired associate learning task when compared with baseline scores. Levitch et al. (2018) found that the amount of newly performed headers negatively correlated with psychomotor speed/and the number of headers performed within the past 12-months was negatively correlated with verbal learning and memory in a word-list memory test. McAllister et al. (2012) compared players of contact sports with non-contact sports on sensorimotor function and learning over a season. Contact athletes were shown to have a smaller increase in improvement on these tasks, compared to their non-contact peers, indicating possible inhibition of learning effects associated with such tasks. Koerte et al. (2017) replicated these findings in football players over the course of a season. In a study exploring the cumulative exposure of SRmTBI in

professional, amateur, and retired rugby players, a dose-dependent relationship with frequency of self-reported concussive exposure associated with reported symptomology and memory complaints was found (Thornton et al., 2008). This was not replicated in professional rugby players as concussive exposure did not seem to lead to greater symptoms or cognitive complaints. Furthermore, there were no differences in neurocognitive scores between the groups. The only reliable finding related to listening span which was significantly lower in athletes with three or more SRmTBIs.

Cognitive testing is the predominant method for assessing the impact of repeated sub-concussive events. Consideration should be given to measures employed as some tests may lack the sensitivity necessary to detect subtle changes in cognition and hence claims that there are no adverse effects of contact sports.

1.6.2.3. Neurocognitive Outcomes in Rugby: Hinton-Bayre et al. (1997) performed a battery of short cognitive tests measuring speed of information processing in rugby players post- SRmTBI. Improvements were observed in the Speed of Comprehension and Digit Symbol Substitution tests with practice, while Symbol Digit Modalities test remained unchanged. In the second part of the study, 10 RL players with SRmTBI demonstrated reduced scores in the post-acute phase on speed of information processing measures. This finding was not replicated on untimed tasks of word recognition. Players completed a repeated baseline assessment prior to SRmTBI allowing for direct comparison of scores pre- and post-injury. Speed of Comprehension demonstrated greater sensitivity to injury following head impact than the other tests.

Shuttleworth-Edwards et al. (2008) compared university rugby players with IQ-matched non-contact sports controls on attentional and memory measures pre- and post-season. Significant reductions were observed at post-season on timed visuomotor attentional measures in rugby players compared to controls. Practice effects were only observed in the control group post-season on attentional measures which typically exhibit practice improvements. Effect sizes were moderate to large and are indicative of possible neurocognitive vulnerabilities for university rugby players over time.

Gardner et al. (2010) acknowledged the conflicting findings within the literature of SRmTBIs in athletes generally, and rugby specifically. Several studies have demonstrated deleterious cognitive effects following sub-concussive events and SRmTBIs, whereas others have not replicated these findings. Discrepancies were highlighted in the testing formats used in studies in that most either utilised traditional tests (tended to show an effect after injury) or computerised tests (tended to not show an effect). Gardner et al. utilised both computerised and traditional cognitive tests of processing speed in a group of male rugby players with either three or more SRmTBIs, or no SRmTBIs. Players with SRmTBI exhibited significantly lower processing speeds than controls on both traditional and computerised measures.

1.6.3. Sex Differences in Neurocognitive Outcomes Following Sports-Related Head Injuries

Colvin et al. (2009) assessed female and male football players post-head injury. Female players were found to have slower combined reaction times on neurocognitive measures compared with males. In a similar study by Sicard et al. (2018), a cohort of asymptomatic female and male athletes were assessed six-months post-SRmTBI. Female athletes were significantly slower in a verbal working memory task than males. Although females did not differ in terms of accuracy on measures of processing speed or attention.

Covassin et al. (2012) explored the effect of SRmTBI in a cohort of high school and university football players pre- and post-injury (multiple timepoints over 14 days). The immediate post-mTBI assessment and cognitive testing (ImPACT; Lovell & Getz, 2006) tool was used to measure cognition. Female players exhibited poorer scores on visual memory measures post-SRmTBI compared with males. Covassin et al. (2013) replicated this finding with high school and university football players. Female players demonstrated poorer visual memory scores eight days post-SRmTBI compared to males. O'Connor et al. (2018) analysed archival data of 2,140 male and 856 female university athletes and observed a small but significant difference: female athletes exhibited poorer visual memory scale scores on ImPACT replicating findings from studies.

Sandel et al. (2017) analysed ImPACT data of 224 lacrosse athletes at baseline and within three days of SRmTBI. No differences in scores were observed at baseline, but post-SRmTBI females exhibited poorer performance on all ImPACT composite scores. Broshek et al. (2005) explored the impact of SRmTBI in a cohort of female and male athletes, administering the computer-based Concussion Resolution Index (Erlanger et al., 2003b) at baseline and post-injury. Female athletes exhibited significant decline from baseline cognitive measures even though female assessments were on average 24-hours later than males, which would have allowed for increased recovery time. Female athletes were 1.5 times more likely to experience cognitive impairment post-SRmTBI and once adjusted for use of protective headgear, this figure increased to twice as likely. Most studies found greater symptoms in females post-SRmTBI and this extended to poorer cognitive performance, especially in visual memory and reaction time.

1.6.4. Neuropsychological Assessment and Management

Guidelines suggest that assessment and follow-up care after a possible SRmTBI should be provided by trained healthcare professionals with the appropriate level of experience and knowledge (Yue et al., 2020). Historically, assessment was reliant on self-report and subjective measures which likely contributed to the systematic underreporting of SRmTBIs (Longworth et al., 2021). Socio-cultural and external pressures to continue playing despite injury (Cusimano et al., 2017), can lead to prolonged recovery and poorer outcomes (Asken et al., 2016). Objective measures of SRmTBI are essential for this reason.

Neuropsychologists have enabled the development and standardisation of clinical assessment tools for routine mTBI screening leading to safer return-to-play decisions (Echemendia et al., 2012). Specialist training undertaken by neuropsychologists in brain-behaviour relationships allows for detailed and comprehensive assessment of cognitive functioning and emotional state in athletes pre- and post-SRmTBI. Neuropsychologists can also identify factors which may inhibit recovery (Ott et al., 2018). However, in practice for most sports most SRmTBIs are not assessed by neuropsychologists nor is a baseline obtained to compare pre- and post-injury functioning (Feddermann-Demont et al., 2017). One study found that most athletic therapists did not adhere to international standards of assessment post-SRmTBI

(Lempke et al., 2022). No universal measure exists that is sensitive to all possible cognitive impairments following injury to aid clinical decision-making (Sussman et al., 2016). Nevertheless, multi-faceted neurocognitive testing is recommended to capture a detailed picture of injury (Glendon et al., 2022). A combination of traditional neuropsychological and computerised testing is endorsed by various sporting organisations.

1.6.4.1. On field assessment: a range of common side-line assessment tools are used in sporting contexts. The Standardised Concussion Assessment Tool (SCAT-5) is a comprehensive assessment battery that measures concussive symptoms including physical and cognitive functioning (Echemendia et al., 2017). World Rugby endorse the use of SCAT-5 to provide baseline assessments against which to compare performance pre- and post-SRmTBI. If a baseline is not available, then performance is compared with normative data (Fuller et al., 2018). However, normative data is based on only male rugby players and evidence suggests that females and males have different SCAT-5 baseline performances (Tucker et al., 2021), highlighting the need for normative data specific to females and women's rugby.

The most widely used and researched computerised assessment for SRmTBIs is the ImPACT measure developed by Lovell and Getz (2006). Compared with traditional testing, ImpACT can be a quick and efficient way of testing following a possible concussive event (Ott et al., 2018). It can be administered by non-professionals; however, the test alone is not a diagnostic tool and should be interpreted by trained healthcare professionals. Although, demographic modelling (age, estimated FSIQ, and frequency of mTBI) has been shown to be just as effective at aiding SRmTBI diagnosis as ImPACT testing alone in rugby players (Gardner et al., 2012).

Other common assessments include the King-Devick (K-D; Galetta et al., 2011) test which assesses saccades and other eye movements performed rapidly. Evidence suggests that oculomotor control is impaired following concussive events (Galetta et al., 2011); and the K-D test has exhibited good sensitivity for detecting SRmTBI on the side-line when compared with other assessments that do not include vision testing (Arca et al., 2020). The K-D test has been found to have good to excellent

reliability in testing for baseline, side-line assessment, and post-season evaluation in a group of female rugby players (King et al., 2020).

1.6.4.2. Recovery to baseline and return-to-play assessment: when assessing the recovery of an athlete post-SRmTBI, the most efficacious approach is to compare baseline functioning (prior to the injurious event) with functioning post head impact, with consideration of practice effects (Webbe & Zimmer, 2015). This can be helpful in identifying factors that may be inhibiting an athlete's recovery. However, it is rare that baseline data exists, particularly in amateur athletes. If baseline data is not available, the recommendation is to compare the individual with normative data alongside a test of premorbid functioning (Schatz & Robertshaw, 2014). However, this approach may not be sensitive enough to identify subtle changes post-SRmTBI (Conley et al., 2019). All mTBI symptoms must have abated prior to the athlete returning to play, and that should include scores on a comprehensive battery of neuropsychological functioning (Laker, 2011). An emerging area of focus in RU is the incorporation of wearable digital technologies (alongside traditional testing) in aiding return-to-play decisions (Powell et al., 2021). Digital approaches may allow for more objective measures of assessing impairments relating to SRmTBIs alongside traditional methods.

1.7. Social Cognition

Several disciplines have used the term 'social cognition', including evolutionary psychology, social psychology, cognitive neuroscience, and psychodynamic theory. Social cognition as a construct first emerged in the 1940s following Heider and Simmel's (1944) seminal study investigating how people interpreted and made sense of simple geometric shapes in an animation film. Although the shapes had no inherent personality or meaning, most participants assigned emotions to these shapes. This demonstrated our innate ability to project meaning and agency onto non-sentient objects. In clinical psychology, social cognition refers to the mechanisms underpinning the recognition, sense-making, and the interpersonal response to social stimuli. This includes cognitive processes relating to how individuals make sense of themselves and others in social situations (Frith, 2008). A

range of cognitive processes such as attention, memory, perception, judgement, and decision-making, are all activated in navigating social experiences (Beer & Ochsner, 2006). Similarly, social cognition shares parallels with 'information processing' in that many cognitive processes are involved (Mundy et al., 2009). Kunst-Wilson and Zajonc (1980) demonstrated that internal processes allow for 'affective discrimination' with minimal information, suggesting a relatively independent or modular system for social cognition. Indeed, much research has focused on the unconscious influences of social cognition.

1.7.1. Social Cognition in Clinical Psychology

Social cognition spans a range of dynamic cognitive processes, such as processing and attending to social cues, or allowing for an individual to effectively function within group settings (Mason et al., 2007). Such processes require complex cognitive functioning such as metacognition, to form an image of the self and of others (Fox & Riconscente, 2008). Social cognition is also essential in development, as perceiving and exchanging social signals allows humans to learn about the environment around them (Tomasello et al., 2005). Interpretation of social signals is believed to be an important factor in survival, as facial expressions can be a non-verbal way of expressing potential danger such as fear or disgust (Shariff & Tracy, 2011). Furthermore, attending to another's eye gaze may indicate the presence of something important or novel within the environment (Emery, 2000). By observing and replicating social signals, humans develop an ability to understand and respond to the complexities of social interactions (Frith & Frith, 2012). Poorer social cognitive performance has been found to negatively impact psychosocial functioning, leading to poorer health and psychological outcomes (Weightman et al., 2019).

Theories of Social Cognition such as theory of mind (ToM) have been developed and applied in understanding a number of presentations including autism spectrum condition (ASC) and numerous mental health conditions (Sprung et al., 2022). Such theories have enabled a greater understanding of the psychological impairments in social communication in a range of presentations. Increasing evidence suggests the use of social cognitive dysfunction as a possible clinical feature in over 30 clinical

conditions (Cotter et al., 2018). Social cognitive dysfunction has also been observed in individuals with TBI (Babbage et al., 2011). Social cognitive performance may also be a useful indicator of disease progression in a range of neurodegenerative conditions (Christidi et al., 2018), and be able to differentiate different sub-types of dementias such as behavioural variant frontotemporal dementia (bvFTD) for earlier diagnoses (Bertoux et al., 2016). For example, individuals with certain types of frontotemporal dementia demonstrate significantly poorer performance in both facial emotion recognition and ToM tasks compared to those with Alzheimer's disease (Bora et al., 2016).

1.7.2. Levels of Social Cognition

Several levels of social cognition have been identified by researchers and are often categorised based on the complexity of the cognitive processes involved. In clinical neuropsychology two dominant models have been identified which aim to explain the differing social cognitive processes (Etchepare & Prouteau, 2018). This includes an information-processing model (low- vs. high-level) and a hot-cold model focusing on the nature of the processed information (affective vs. cognitive), both form a multi-dimensional approach to social cognition. These models underpin important social processes such as perception and interpretation of social stimuli; memory for social stimuli; attribution of mental states; social knowledge; and self-referential processing (Adolphs, 1999). These two models of social cognition interconnect with one another creating a complex system for the understanding and navigation of the social world.

In relation to information-processing, Frith and Frith (2008) suggest that implicit (low-level) processes, such as emotion recognition via facial expressions and tone of voice in social interactions, are automatic, whereas explicit (high-level) processes are controlled, such as perspective taking. Although we can actively engage in explicit processes, this might be unable to override implicit social processes. Each of these processes serves a distinctive function and can either be complementary or in opposition with the other. Implicit processes enable the sharing of knowledge, feelings, and actions – encouraging altruistic behaviour as opposed to selfishness. Conversely, explicit processes tend to serve the individual and are less overtly prosocial.

Regarding the nature of processed information, cognitive and affective functioning can be differentiated (Kalbe et al., 2010). Cognitive functioning is explained by the understanding of knowledge, inferring intentions, and beliefs (Shamay-Tsoory et al., 2007). Whereas affective functioning is explained by the empathetic appreciation of emotional states (Kalbe et al., 2007). In line with the integrated model proposed by Etchepare and Prouteau (2018), subsequent research has focused on overlapping social cognitive domains such as emotion recognition, ToM, understanding of facial expressions, and empathy. Therefore, this study will address these prominent social cognitive domains.

1.7.3. Social Cognition and Traumatic Brain Injury

Problems in prosocial behaviour following moderate to severe TBI are commonly reported, with up to 72% of affected individuals reporting such changes (Baguley et al., 2006). Changes can include emotional lability, aggression, indifference, and disinhibited behaviour. Social cognitive measures have been shown to be effective in predicting social and vocational participation post-TBI (Westerhof-Evers et al., 2019).

Milders (2019) conducted a literature review exploring the relationship between social cognition and social behaviours post-TBI. Three social cognitive processes were highlighted: including understanding intentions, emotion recognition, and empathy. Each of these processes were significantly altered post-injury with poorer performance associated with more adverse outcomes. Empathy and emotion recognition exhibited the greatest effect sizes. However, much of this research has focused on social cognition following moderate to severe TBI, and little is known about the impact of mTBI on social cognition (McDonald, 2013).

1.7.4. Theory of Mind

Premack and Woodruff (1978) described ToM as the process of inferring mental states of others and ourselves. This includes processes such as metacognition, the awareness of one's own mental states, and the ability to impute emotional states to others (emotion-processing). An extensive evidence-base exists demonstrating the vital role ToM plays in the ability to communicate, help, cooperate with, and comfort others (Imuta et al., 2016). These are regarded as essential in managing social

interactions. ToM remains the predominant theory in social cognition despite being one of the most longstanding. However, Frith and Frith (2008) postulate that the term ToM can be misleading, as it may be interpreted as a high-level process. The term 'mentalising' is more accurate as it encompasses both implicit and explicit cognitive processes. Although most measures within clinical neuropsychology assess explicit mentalising components (Frith & Frith, 2012), ToM will be utilised here as it succinctly describes this process.

Critics have suggested an interpretive leap in connecting deficits on tasks which are frequently non-socially representative, to the presence of social cognitive deficits (Cole & Millett, 2019). Additionally, arbitrary categorisation and cut-off perimeters such as 'typical' and 'atypical', coupled with the risk of implicit cognitive biases being misconstrued as 'deficits', give weight to this argument. However, advanced neuroimaging techniques have enabled a greater evidence-base of the neural correlates of social cognition (Schurz et al., 2021).

1.7.4.1. Assessing theory of mind: social cognition measures predominantly focus on ToM: for example, the 'false-belief task' (Wimmer & Perner, 1983), in which children older than 4 years generally exhibit first-order false belief reasoning – the ability to understand what another person is thinking (Rubio-Fernández & Glucksberg, 2012). Some research has incorporated non-verbal aspects such as the use of mental-state cartoons (Schlaffke et al., 2015), strange stories (Apperly, 2012), and faux pas test (Martín-Rodríguez & León-Carrión, 2010). Non-verbal measures like these allow for apprehension without the confounding variable of linguistic processing (Dodell-Feder et al., 2013). Social Stories Questionnaire (SSQ), a more refined measure, was developed to detect both subtle and blatant solecisms (Lawson et al., 2004). The SSQ has good internal consistency (Francis et al., 2017) informing the rationale for its use within this study.

1.7.5. Emotion Recognition and Processing

A strong relationship exists between emotion processing and ToM (Henry et al., 2006). Various subcortical regions are involved in emotion recognition such as the amygdala, ventral striatum, thalamus, and hypothalamus (Kober et al., 2008). Ekman

and Friesen (1971) developed a measure of emotion recognition known as the 42 Ekman Face Test utilising six universal emotions: anger, fear, distrust, surprise, sadness, and happiness. Although critiques detail the lack of diverse emotions cross-culturally, within the stimuli. Such limitations have led to the development of new measures, including the Affect Naming Test (Pearson, 2009). This measure consists of 24 faces in which participants must match to Ekman's core emotions, and it has been found to correlate with other measures of facial emotion recognition (Kandalaft et al., 2012). Emotion recognition and processing may be impaired post-mTBI and possible sex-differences in emotion recognition have been identified in athletes with repeated mTBI (Léveillé et al., 2017).

1.7.6. Empathy

Empathy denotes the ability to infer and share the emotions of others (Davis et al., 1994). Empathy allows for the modification of responses to situations to incorporate the perspectives of others (Kilroy & Aziz-Zadeh, 2017). Debate continues as to whether empathy as a process is based on recognition and/or experience of emotion itself (Cuff et al., 2016). Empathic differences have been reported in clinical populations such as ASC (Mazza et al., 2014) and TBI (Milders, 2019). This does not indicate an absence of empathy but possible differences in how emotional empathy is experienced (Butera et al., 2022). Several brain regions have been identified in empathy (Fan et al., 2011). Empathic processing is commonly divided into two dimensions (Smith, 2006): cognitive empathy (the ability to mentalise how another is thinking or feeling) and emotional empathy (the ability to share and experience the emotions of others). However, no standardised definition of empathy exists, a problem reflected in the various assessments of empathy such as the empathy scale (Hogan, 1969) and the empathy quotient (Baron-Cohen & Wheelwright, 2004). The Questionnaire of Cognitive and Affective Empathy (QCAE) was developed to measure both cognitive and affective empathic domains (Reniers et al., 2011).

1.7.7. Rugby and Emotion Recognition

Social cognition underpins all group sports. For example, body language such as facial expressions are an important feature in group sports (Furley & Schweizer, 2020). In rugby, players need to communicate nonverbally with teammates

throughout play. It is therefore vital for rugby players to be able to effectively identify and reliably interpret different nonverbal signals (Eccles & Tenenbaum, 2004). When comparing rugby players from different levels, one study found no significant differences in performance on an emotion recognition task between amateur and professional male rugby players (Kruger et al., 2019).

1.8. Rationale for the Current Study

As far as the researcher is aware, only one other study has explored the role of social cognition and mTBI in rugby players, although, this study focused on males only. Male rugby players exhibited poorer performances in ToM and emotion recognition relative to performance on general cognitive measures (York-Smith, 2020). Research within this area remains limited with no studies identified focusing on the role of social cognition and mTBI in female rugby players. This is despite the growing popularity of women's rugby and female athletes potentially experiencing a greater frequency and severity of mTBIs with poorer associated outcomes relative to their male peers.

2. RESEARCH RATIONALE

The research summarised above details the clinical impact of SRmTBI, whilst highlighting the gap in the knowledgebase within women's rugby. The neurocognitive impact of SRmTBI in rugby continues to be under-researched despite the well-known risk factors as a contact sport. Further, much of this limited research has focused on males neglecting female rugby players, despite the growing popularity of women's rugby and the highlighted sex-specific differences in SRmTBI. However, there is increasing consensus of the relationship between mTBI and subconcussive injuries and subsequent neurocognitive effects, including long-term impacts such as neurodegenerative conditions. Prior studies have concentrated on general cognitive domains such as memory, attention, and executive functioning. Only one study has explored the relationship between SRmTBI and social cognition in rugby (York-Smith, 2020). However, this study solely focused on male rugby players and to the author's knowledge, no research has been conducted exploring SRmTBI and social cognition in female rugby players. Increased knowledge of the potential neurocognitive effects is vital due to the growing numbers of women participating in rugby and the associated public health implications.

Social cognitive deficits underpin many neurodegenerative conditions and constitute core clinical features in conditions such as bvFTD (Bertoux et al., 2016). It is hypothesised that deficits in social cognition are present in CTE due to the shared neural networks which have been identified in both CTE and other neurodegenerative conditions like bvFTD, despite neuropathological differences. The behavioural changes observed in many neurodegenerative conditions may result from social cognitive deficits and classification of such deficits may allow for greater understanding of disease progression. Due to the similarities in clinical features and presentation, it is hypothesised that history of repeated SRmTBIs or subconcussive injuries may lead to an increased risk of developing CTE, including longitudinal social cognitive impairments and general cognitive decline. Common behavioural and personality changes include poor insight, attentional dysfunction, difficulties with awareness and social cognition, labile mood, and poor impulse control. Such presentations are reflective of repeated impacts to the PFC. This brain region is associated with social cognitive processes such as mentalisation in social

interactions (Forbes & Grafman, 2010) and PFC functional activity is altered following mTBI and subconcussive events (Zhang et al., 2010). Therefore, timely diagnosis of social cognitive and behavioural deficits may lead to more effective treatment and better psychosocial outcomes. Furthermore, increased knowledge of the neurocognitive impact of SRmTBI in women's rugby may lead to the development of sex-specific guidelines in the identification, treatment, return-to-play decisions, and follow-up of mTBIs in female athletes.

2.1. Aims

The present study aims to investigate the neurocognitive profile of female rugby players who have experienced SRmTBI. Limited research has focused on the neuropsychological impact of SRmTBI in women's rugby. To the author's knowledge, no research has explored the relationship between SRmTBI and social cognition in female rugby players. This preliminary study therefore aims to explore the impact of SRmTBI on both general and social cognitive functioning in female rugby players. Finally, the study aims to contribute to the knowledgebase of SRmTBI in women's rugby informing sporting policies and subsequently clinical practice.

2.2. Research Questions

- What is the neurocognitive profile of female rugby players who have experienced SRmTBI?

- Is there a relationship between history of SRmTBI and performance on tasks measuring social cognitive functioning in female rugby players?

- If so, are deficits in task performance reflective of years of played, position, and number of SRmTBIs?

3. METHOD

3.1. Epistemological Positioning

Both epistemology and ontology are critical features within scientific study, thus it is essential for researchers to identify the philosophical context in how evidence has been generated. Epistemology relates to the philosophy of knowledge production and how knowledge is generated about the world including beliefs and assumptions (Greco, 2017). Epistemology extends to the scope, validity, and reliability of such claims of knowledge (Willig, 2013). Whereas ontology details the philosophy of reality including interpretations made about the world (Guarino et al., 2009). It is vital that researchers recognise the influence their epistemological stance has on the methodological design and data interpretation employed (Barker & Pistrang, 2005). A critical realist approach was utilised in the present study. A summary of the critical realist approach is summarised below.

Realism argues that the world as an entity is real and independent of one's observation and is thus measurable. The aim of adopting a realist position is that it enables the researcher to comprehend as accurately as possible properties of the world (Fletcher, 2017). Over the latter course of the 20th century, realism diverged into critical realism. Critical realism supposes the existence of a real world which is observable but is critical of the ability to comprehend reality with full certainty. Critical realism acknowledges that all scientific study is fallible and prone to human errors and cultural biases (Yucel, 2018). For the replication of research, researchers must state the methodologies employed when adopting a critical realist stance. It is also important to use multiple measures when assessing a single construct to enable a reliable and valid understanding of the reality that is being perceived.

A critical realist stance was decided to be best placed for the aim of determining phenomena within a 'real' world whilst juxtaposing knowledge within broader socio-cultural and historical contexts. Thus, conclusions from the data are susceptible to both bias and human error. The author acknowledges the social constructs underpinning the concepts explored in this report. Neuropsychological constructs such as social cognition can be explored with the possibility of such constructs being

simulated and everchanging in nature.

3.2. Methodology

3.2.1. Design

A cross-sectional correlational design was employed to explore the association between SRmTBI in female rugby players and general cognitive functioning. Social cognition is targeted and its association with other domains of cognitive functioning, SRmTBI history, and rugby exposure. The rationale for using a cross-sectional design included that it permits testing in a single group within a single time-point. Suitable for the present study, this design allows for the exploration of the relationship between variables, as opposed to identifying causal links. A control group was not required as manipulation of variables or interventions were not included. Although, the inclusion of a control group would have generated useful comparative information, due to shortage of time and resources this was beyond the scope of this study. However, as a test of optimal functioning was employed, within-subject comparisons were possible.

3.2.2. Sample Size

A review of the relevant literature determined the sample size parameters. The suggested sample size is similar to research studies exploring the association between mTBIs and neurocognitive outcomes. For example, 10 participants were recruited by Hinton-Bayre et al. (1997); 27 participants were recruited by Shuttleworth-Edwards et al. (2008); and nine participants were recruited by Fino (2016). In line with standard research practices, effect sizes will be analysed to determine the strength of relationships. Non-parametric tests will be employed where appropriate e.g., a small sample and non-normal data. Larger sample sizes are considered to yield more reliable and valid results (Button et al., 2013) and every effort was made to recruit the most participants within five months (December 2022 – April 2023). It should be noted that a larger sample size would directly lead to greater power to detect differences within the sample.

3.2.3. Ethics

3.2.3.1. Ethical approval: Ethical approval was obtained from the University of East London, School of Psychology Research Ethics Committee (see Appendix B). Online research integrity modules were completed by the researcher in line with university requirements (see Appendix C).

3.2.3.2. Informed consent: all participants were given an information sheet (see Appendix D) prior to participating explaining the purpose of the study. All participants provided written consent prior to commencing the study (see Appendix E). This detailed the aims, confidentiality, an overview of the study and what to expect, and informed them of the right to withdraw at any point of the study. At completion, all participants were given a debrief sheet (see Appendix F). Participants were asked if they had any questions and their preference of receiving a summary of the study outcomes following completion. If participation in the study elicited any concerns for the participant, they were recommended to contact the study supervisor or their registered general practitioner. Additionally, the debrief sheet contained a list of organisations in which the participant could contact if they had any concerns after participating in the study.

3.2.3.3. Confidentiality: All participants were allocated a unique participant code to uphold confidentiality. Identifiable information was kept separately to this code. All identifiable material was stored on encrypted password-protected documents, or in locked cabinets. No identifiable information was entered into electronic databases for data analysis. Materials containing identifiable information were kept separate and not linked to data stored for analysis. Participant confidentiality was explained to each participant prior to participating and at following completion of the study. Once the research study has been completed all materials containing identifiable information will be destroyed. Anonymised data within the electronic database will be kept for publication purposes for a maximum of two years after the study has been ended.

3.2.3.4. Protection from harm: breaks were offered to participants at regular intervals throughout the neuropsychological assessment to minimise the risk of any potential harm and reduce the impact of fatigue. To keep the assessment at an acceptable

time-length, only tests deemed necessary were included. As mentioned above, a full verbal debrief was provided upon study completion. Participants were given and informed of a three-week period post-study in which they could withdraw all their information from the data analysis if they so wished to.

3.2.4. Recruitment

Convenience sampling was used to recruit participants that the researcher knew with further participants recruited via a snowballing effect. A list of women's rugby clubs was identified prior to recruitment and emails were sent accordingly requesting circulation of the study to their players. A research poster (see Appendix G) was shared with potential participants and rugby clubs via email and social media. All potential participants were given the information sheet detailing the study prior to deciding whether they wished to take part or not.

3.2.4.1. Inclusion and exclusion criteria: inclusion criteria required participants to be female, aged between 18-65, and either be a current or retired rugby player at competitive level. Participants needed to be fluent in English and have experienced at least one self-reported SRmTBI. The SCAT-5 was used to determine head injury exposure by asking participants the symptoms experienced during the time of their injury.

To minimise the risk of confounding variables, exclusion criteria included males, as there is considerable evidence suggesting sex-differences following SRmTBI (Covassin et a., 2016; Theadom et al., 2020; Master et al., 2021; Levin et al., 2021; Mikolić et al., 2021). However, the study was open to rugby players who identify as trans or non-binary as there is currently no research literature within this field and owing to the exploratory nature of this study – although all recruited participants identified as cisgender women. Additional sub-analyses would have been utilised for participants who identified as either trans or non-binary. Further exclusion criteria included a non-rugby related TBI, a neurological disorder, current substance misuse, long-term mental health diagnoses, a learning disability, and a history of stroke.

3.2.5. Procedure

3.2.5.1. Neuropsychological assessment battery: the assessments were conducted

at the most convenient location for the participant, either at their rugby club or at their home. Prior to conducting the assessment, the researcher confirmed that the participant had read and understood the information sheet and checked if they had any questions. The university's lone worker policy was adhered to. Information was gathered at the start of the assessment relating to participant demographics such as age, ethnicity, learning disability, mental health history etc. information was then gathered on the participant's rugby and SRmTBI history followed by any potential confounding variables such as linguistic factors, and hearing and visual difficulties. After collecting participant qualitative information, a comprehensive neuropsychological battery was completed by participants, as shown in Table 1. This included standardised measures to assess general cognitive functioning and social cognition. To ensure the reliability of the data, all tests were conducted in accordance with test manuals. The whole assessment including demographic information-gathering lasted approximately 90 minutes. Short breaks were offered at regular intervals to minimise fatigue.

3.2.6. Measures

The assessment battery comprised of questions relating to rugby and head injury history, measures of premorbid functioning, general cognitive functioning, and social cognition. Two aims underpinned the rationale for these measures. First, to determine if any impairment in general cognitive functioning and social cognition is present in this sample with a history of SRmTBI. Second, to ascertain if performance in general cognitive functioning is predictive of performance in other cognitive domains such as social cognition. Determining an individual's cognitive baseline can be helpful in exploring the associations between variables.

Table 1

Neuropsychological Test Battery

Task Domain	Test
Optimal Ability	TOPF-UK
Processing Speed	WAIS Digit Symbol Coding
Attention and Working Memory	WAIS Digit Span Forward
	WAIS Digit Span Backward
	WAIS Digit Span Sequencing
Verbal and Visual Functions	WAIS Matrices Reasoning
	WAIS Similarities
Executive Function (Verbal)	D-KEFS Letter Fluency
	D-KEFS Category Fluency
	D-KEFS Switch Total
	D-KEFS Switch Accuracy
Verbal Learning and Memory	WMS Story Immediate
	WMS Story Delayed
	WMS Story Retention
	WMS Story Recognition
Visual Learning and Memory	WMS Visual Reproduction Immediate
	WMS Visual Reproduction Delayed
	WMS Visual Reproduction Retention
	WMS Visual Reproduction Recognition
Emotion Recognition	ACS Affect Naming
ToM (Mentalisation)	SSQ Method 1
	SSQ Method 2
Empathy	Questionnaire of Cognitive Empathy
	Affective Empathy

3.2.6.1. Sporting history and mTBI: information was gathered of mTBI history and involvement in rugby via the following questions:

i) History of mTBI

Participants were asked to detail the symptoms experienced at the time of the head injury and if they received medical assessment or intervention.

ii) Number of mTBI

All participants were asked to self-report the number of mTBIs experienced throughout their rugby involvement. Multiple mTBIs may increase the risk of neurocognitive difficulties (Gold et al., 2018).

iii) Age of first mTBI

The rationale underpinning this was to explore the relationship between age at first mTBI and performance in various neurocognitive domains. Some evidence suggests that mTBIs in younger age is linked with an increased risk of impaired cognitive functioning compared to mTBIs sustained in adults (Guskiewicz et al., 2011).

iv) Years of rugby play

Participants were asked the number of years they had been playing rugby for. It is likely that years played in rugby corresponds with a greater exposure to SRmTBI.

v) Player position

Player position was answered as either back or front. If multiple positions had been played, then the position played for the longest period was noted. Research suggests that players in front positions have an increased risk of experiencing SRmTBI (Tucker et al., 2017).

vi) Rugby type

Rugby type was either recorded as Rugby League or Rugby Union.

3.2.6.2. Optimal ability: the ability to read words with irregular spellings is generally considered resistant to cognitive decline and is indicative of general intelligence (Tallberg et al., 2006). Task performance on the Test of Premorbid Functioning UK (TOPF-UK) is compared with normative data allowing for an estimate of optimal ability (Wechsler, 2011). The task is comprised of a list of 70 irregularly spelled

words that participants read aloud. Lezak et al. (2012) suggest correlation between premorbid ability and verbal-based memory. Although, it may be less reliable in predicting optimal processing speed. Different dialect-based pronunciations are accounted for. Semantic and lexical processes are engaged during the task as opposed to phonological processes, meaning that accurate word reading is dependent on historic vocabulary knowledge instead of standard pronunciation rules. Each word is scored and if correctly pronounced, scored as one. Total scores are then compared with normative data. The TOPF-UK has good reliability and validity, but limitations include requiring typical reading development and exposure to English reading materials.

3.2.6.3. Processing speed: to measure processing speed participants undertook the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV-UK) coding subtest (Wechsler, 2010a). A visual key ranging from one to ten is presented to participants with each number corresponding to a symbol. Participants are given two minutes to complete as many number-to-symbols as possible and as quickly as they can. This task engages visual processing speed including visual perception and analysis.

3.2.6.4. Attention and working memory: attention and working memory impairments have been commonly observed post-mTBI, especially during recovery (Feddermann-Demont et al., 2017). Working memory and attention measures are considered essential in neuropsychological assessments in SRmTBI (Johnson et al., 2011). The following subtests were used from the WAIS-IV-UK (Wechsler, 2010a):

i) Digit Span Forward

This subtest assesses auditory attention span. A string of random numbers is read aloud, and participants must listen and repeat the sequence aloud in the same order. The sequences become progressively longer throughout the task.

ii) Digit Span Backward

This subtest assesses auditory verbal working memory. A string of numbers is read aloud, and participants must repeat them back in reverse order.

iii) Digit Span Sequencing

This subtest also assesses auditory verbal working memory. A string of numbers is read aloud, and participants must repeat them back in numerical order.

In all three tasks, each correct response is scored as one, and all three tasks are summed together to ascertain a total score for attention and working memory. These scores are then compared with normative data.

3.2.6.5. Verbal and visual functions: the WAIS-IV-UK Matrix Reasoning subtest was used to assess visual perception and reasoning. A pattern is presented to participants with one piece missing. Participants are required to ascertain the pattern using visual details (colour, shape, location) to identify the missing piece from five possible responses. This measures nonverbal reasoning skills.
Verbal comprehension, expression, and abstract reasoning were assessed by the WAIS-IV-UK Similarities measure. Two different words are presented verbally to participants, and they are invited to verbally determine how the words are similar e.g., *"In what way are two and seven alike?".* Abstract answers are scored two points, good connections are scored one point, poor or unrelated answers are scored zero.

3.2.6.6. Executive function (verbal): it is considered good practice to use multiple measures of executive functioning (Snyder et al., 2015). As such, word generation tasks were utilised as letter fluency deficits have been observed in mTBI (McCauley et al., 2014) and progressive neurodegenerative conditions (Levy & Chelune, 2007). Frontal lobe executive functioning is also activated during word generation tasks (Horowitz-Kraus et al., 2014). The Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001) was used to measure executive functioning. The three subtests included:

i) *Letter Fluency*

This subtest assesses word generation ability. Participants are given 60 seconds to generate as many words as possible that begin with a specific letter e.g., F, A, and S. This task can detect possible executive dysfunction as inhibition of irrelevant words is required including the development of appropriate word retrieval strategies.

ii) *Category Fluency*

This subtest assesses semantic knowledge in addition to word generation. Participants are given 60 seconds to generate as many words as possible that pertain to a specific category e.g., animals and boys' names. This task requires retrieval of knowledge from semantic stores. Category fluency is disproportionately impacted by neurodegenerative conditions like Alzheimer's likely due to the need to access temporal-lobe stores (Cerhan et al., 2002).

iii) Switching

This subtest assesses switching attention in addition to word generation. Participants are given 60 seconds to generate as many words as possible whilst switching between two categories alternately e.g., fruit and furniture.

Each correct response is given one point and a total score is generated for each of the subtests. These scores are then compared with normative data. The D-KEFS has been shown to be reliable and valid across cohorts (Shunk et al., 2006).

3.2.6.7. Verbal learning and memory: The Wechsler Memory Scale – Fourth Edition (WMS-IV) Logical Memory subtest was used to evaluate verbal memory (Wechsler, 2010b). Two separate stories were read aloud to participants, and they were required to recall each story immediately (after hearing it) and at a later timepoint (around 30 minutes later) within the assessment after completing other tasks within the assessment battery. This task requires activation of episodic memory. After completing the immediate and delayed recall, participants undertook the WMS-IV story recognition where statements (either true or false) were read aloud, and participants were required to answer either 'yes' or 'no' to each statement. One point was given to each correctly recalled piece of information of the story and including each correct response on the recognition task. Scores were then compared with normative data.

3.2.6.8. Visual learning and memory: The WMS-IV Visual Reproduction subtest was used to measure visual memory (Wechsler, 2010b). A set of five items displaying different, and progressively more complex shapes, was shown individually to the participant for 10 seconds. The item was then removed from view, and the participant was required to draw the shape from immediate memory. The drawn

items were scored in terms of accuracy. Approximately 30 minutes later, the participant was asked to reproduce the five shapes from memory. Following this, participants were asked to identify each of the previously shown items out of a range of similar but different items. This task allows for the examination of memory function without accessing words and stories. Participants were scored one point for every correctly recalled item. Scores were then compared with normative data.

3.2.6.9. Social cognition: The neuropsychological battery consisted of measures designed to assess ToM, emotion recognition, and empathy – all core features of social cognition. Consistent with current literature, the measures employed incorporated the distinction between affective and cognitive ToM (Etchepar & Prouteau, 2018) and empathy (Reniers et al., 2011). The following measures of social cognition were employed:

i) *Affect Naming Test (ANT; Pearson, 2009):* The ANT, a standardised measure, was incorporated into the test battery to assess emotion recognition from facial expressions. The ANT is not dependent on verbal ability unlike other mentalisation measures. Participants were shown the same six faces, with each of the faces portraying a range of six 'universal' emotions that were: happy, sad, angry, afraid, surprised, disgusted, and neutral (Ekman & Friesen, 1971). Participants were required to identify the emotion for each face presented. A total of 24 images were presented to participants. One point was awarded for each correct response with total scores compared with age-appropriate normed data. The ANT has been shown to be valid cross-culturally and performance on this measure correlates with other measures of social cognition (Kandalaft et al., 2012).

ii) *Social Stories Questionnaire (SSQ; Lawson et al., 2004):* The SSQ was selected to measure mentalisation via participants' comprehension of social norms within ten short stories. Many of the stories contained a situation where a character said something to another character which may have been interpreted as offensive. These possible offences are grouped into two categories, either blatant or subtle. After reading each section of the story, participants were asked to indicate if they believed

anything said in the story may have been perceived as a faux pas. Participants were required to select the sentence they believed the faux pas to have taken place. One point was scored for each correctly identified faux pas. The SSQ is comprised of 10 blatant and 10 subtle faux pas. Unlike the ANT, the SSQ is highly dependent on linguistic ability and requires an understanding of non-literal cognitive-linguistic social processes. The SSQ has been shown to have good internal consistency when applied to people with TBI (Francis et al., 2017). This measure may be suited to detect subtle deficits in early disease progression.

iii) *Questionnaire of Cognitive and Affective Empathy (QCAE; Reniers et al., 2011):* the QCAE measure was chosen to distinguish between cognitive and affective empathy. The QCAE is comprised of 31 statements and participants are required to answer each item using a four-point Likert scale, ranging from strongly agree to strongly disagree. A total score for cognitive empathy and affective empathy were calculated by adding up subtest items. The QCAE items were obtained from previous validated measures and further research has shown the measure to have valid psychometric properties (Queirós et al, 2018).

3.2.7. Analysis

Assessments were scored against respective test manuals and, where available, converted to age-scaled scores. This enabled comparisons between participant data and age-specific normative data. Data were collated and analysed using IBM SPSS Statistics (Version 28). Descriptive statistics were first generated including histograms and scatterplots to identify any missing cases, outliers, and any data inputting errors. To evaluate parametric assumptions, the data were checked for skewness and kurtosis (skewness>1, kurtosis>3). Due to the small sample size, nonparametric analyses were employed. As such, Kolmogorov-Smirnov tests were performed to investigate participants' performance in the measures of cognitive functioning and social cognition with comparison to age-scaled norms (M = 10, SD = 3). This allows for comparison of distribution of the data against a specified set of distribution parameters (Wilcox, 2003). Kolmogorov-Smirnov tests were not

performed for the TOPF-UK as the optimal ability of the sample was in line with that of the normative data (M = 10, SD = 3). Following this, a Wilcoxon-ranked test was employed to determine if there was a significant difference in composite scores for both general cognitive functioning and measures of social cognition. A non-parametric Spearman's rho correlation analysis was performed to investigate the associations between performance on subsets of general cognitive functioning and social cognition, including age. Finally, Mann-Whitney U tests were performed to ascertain if there were any significant differences between sub-group characteristic e.g., low versus high mTBI frequency, and rugby player position (Forwards versus Backs). The p-value significance threshold was set to $p < .05$ in line with standard research practices (Wilcox, 2003); alongside the use of effect sizes to determine the magnitude of results (Cohen, 2016).

3.2.8. Participant Characteristics

A total of thirteen participants between the ages of 19 and 55 were recruited in the study. A summary of participant characteristics is shown in Table 2. Nearly half of participants (*n* = 6) attended university whilst the remaining participants received education to A-level (*n* = 4). Three of the participant's highest academic achievement was either at apprenticeship or diploma level. All participants spoke English as a primary language with one participant speaking an additional language (Afrikaans). Participants predominantly identified as 'White British' (*n* = 12) with one participant identifying as 'Mixed Black Caribbean'. Two participants reported a diagnosis of ADHD, and one participant reported a diagnosis of dyslexia. Most participants played Rugby Union (*n* = 12) with one participant playing Rugby League (*n* = 1). In terms of rugby position, the sample was evenly split between Forwards (*n* = 6) and Backs (*n* = 7) reflecting that of a typical sample. Two of the thirteen participants reported that they no longer play rugby whilst the remaining participants reported being active rugby players.

Table 2

Participant Socio-demographic Data

Age (mean in years)	30.9 (range: 19-55)
TOPF^{UK}	103
Ethnicity	
White British	12 (92.3%)
Mixed Black Caribbean	1 (7.7%)
Handedness	
Right-handed	11 (84.6%)
Left-handed	2 (15.4%)
Dyslexia Diagnosis	1 (7.7%)
ADHD Diagnosis	2 (15.4%)
Education	
University	6 (46.2%)
A-Levels	4 (30.8%)
Technical Diploma	1 (7.7%)
Level 4 Apprenticeship	1 (7.7%)
Level 3 Diploma	1 (7.7%)

4. RESULTS

4.1. Rugby-Related Characteristics

A total of 13 participants were included in the main analysis. The mean age (in years) of starting rugby was similar for both Forwards (*M* = 22.7, *SD* = 13.9) and Backs (*M* = 22.3, *SD* = 12.9). However, Forwards had an older mean age at first self-reported mTBI (*M* = 25.3, *SD* = 12.3) compared with Backs (*M* = 23.9, *SD* = 13.9). Although, Forwards had a slightly higher mean of self-reported mTBI (*M* = 3.0, *SD* = 1.0) compared with Backs (*M* = 2.3, *SD* = 1.2). The mean for years of rugby play was slightly higher for Forwards (*M* = 7.3, *SD* = 5.2) than Backs (*M* = 6.2, *SD* = 4.9).

A subset of rugby-related characteristics is displayed in Table 3. From initial inspection of the data, there did not appear to be an association between the years participants played rugby and the frequency of self-reported mTBI. There did, however, appear to be an association between the age participants started playing rugby and the age of their first mTBI. Most participants experienced their first mTBI shortly after they started playing rugby.

Table 3

Participant Rugby and mTBI Descriptive Data

	Mean	SD	Min.	Max.	Skewness	Kurtosis
Age	30.92	11.65	19	55	.62	-.39
Age at Starting Rugby	22.54	12.77	12	52	1.42	1.18
Rugby Play (in Years)	6.73	4.87	2	17	1.32	.97
Number of mTBIs	2.62	1.19	1	5	.20	-0.56
Age at First mTBI	24.54	13.19	13	55	1.31	-.97

Note. SD = Standard Deviation, Min. = Minimum, Max. = Maximum.

4.2. Exploratory Data Analysis

The raw scores for each measure were coded according to their respective test manuals and converted to normative age-scaled scores (M = 10, SD = 3).

Histograms and scatterplots were generated from the raw and converted scaled scores allowing for inspection of outliers, missing cases, and correction of any data coding errors. One error was corrected; all outliers were found to be correct. The data were inspected for violations of parametric assumptions via skewness and kurtosis scores (skewness>1, kurtosis>3).

4.3. Data Analysis

Descriptive statistics were generated for each measure of general cognitive function and social cognition, as displayed in Table 4.

4.3.1. Analysis of Cognitive Functioning

From visual inspection, most mean scores for cognitive functioning were around the normative data score of 10 (see Table 4), with a small advantage for WAIS Similarities and Digit Span Sequencing, and WMS-IV Story recall: Immediate. Higher than expected scores were demonstrated on D-KEFS Category Fluency, Switching Accuracy, and Switching Output, suggesting a sample with strong verbal abilities compared with the normative population. Due to the ordinal nature of the data, non-normal distributions, and relatively small sample size, it was decided to undertake inferential analyses using non-parametric procedures by using the SPSS resampling procedures and exact tests. One-sample Kolmogorov-Smirnov tests were employed to determine if the test scores were congruent with normative data scores (M = 10, SD = 3). See Table 5 for Kolmogorov-Smirnov test results. The findings indicated that the sample were significantly higher performing than the age-scaled normative data (Z-score > 2) for D-KEFS Category Fluency and Switching Accuracy. As shown in Table 5, a medium effect size was found for Category Fluency, Switching Accuracy, and Switching Output. Scores were slightly but not reliably higher for WMS-IV Story Recall Immediate, and WMS-IV Visual Reproduction Immediate. All other cognitive tests were not different from the age-scaled normative data.

Table 4

Descriptive Statistics of Tests of General Cognition and Social Cognition Mean Scaled Scores

Tests	Mean	SD	Range	Min.	Max.	Skew.	Kurt.
TOPF^{UK}	10.54	1.05	1	9	13	1.157	1.472
Similarities	11.23	3.17	4	5	15	-.789	-.117
Matrix Reasoning	10.31	2.14	3	8	15	.738	.407
Digit Span Forward	9.92	2.63	6	6	14	.001	-1.236
Digit Span Backward	10	2.83	2	7	18	2.141	5.328
Digit Span Sequencing	11.46	2.99	4	6	17	.266	.146
Digit Span Total	10.08	3.30	3	6	19	1.593	4.184
Coding	10.46	2.47	4	6	15	.035	-.255
Story recall Immediate	11.31	1.65	3	9	14	.074	-1.281
Story recall Delayed	10.77	2.24	4	8	14	.393	-1.312
Visual Immediate	11.62	3.12	7	7	15	-.469	-1.448
Visual Delayed	10.54	3.69	6	5	18	.505	-.100
Letter Fluency	10.38	2.87	4	4	15	-.706	.705
Category Fluency	14	2.86	5	10	19	.304	-.748
Switching Accuracy	13	2.83	3	5	15	-2.168	5.250
Switching Output	12.77	3.14	5	6	16	-1.237	.377
QCAE Cognitive Empathy	8.77	3.00	6	5	14	.698	-.942
QCAE Affective Empathy	10.77	3.29	5	5	16	.125	-.589
ACS Affect Naming Test	11.15	2.19	4	8	15	.050	-1.001
Social Stories Questionnaire	7.69	2.25	2	6	14	2.061	4.959

Note. Range = Interquartile Range. SD = Standard Deviation, Min. = Minimum, Max. = Maximum, Skew. = Skewness, Kurt. = Kurtosis.

Table 5

Kolmogorov-Smirnov (K-S) scores of General Cognitive Functioning and Social Cognition compared with Normative Data, including Exact Significance

Tests	N	Effect Size (D)	K-G (Z-Score)	P-Value
WAIS Similarities	13	.303	1.09	.149
WAIS Matrix Reasoning	13	.252	.91	.322
WAIS Digit Span Forward	13	.149	.54	.894
WAIS Digit Span Backward	13	.269	.97	.253
WAIS Digit Span Sequencing	13	.293	1.1	.176
WAIS Digit Span Total	13	.269	.97	.253
WAIS Coding	13	.176	.63	.757
WMS-IV Story recall: Immediate	13	.369	1.3	.042
WMS-IV Story recall: Delayed	13	.252	.91	.322
WMS Visual Reproduction: Immediate	13	.363	1.31	.049
WMS Visual Reproduction: Delayed	13	.149	.54	.894
D-KEFS Letter Fluency	13	.246	.89	.352
D-KEFS Category Fluency	13	.594	2.14	<.001
D-KEFS Switching Accuracy	13	.611	2.20	<.001
D-KEFS Switching Output	13	.534	1.92	<.001
QCAE Cognitive Empathy	13	.363	1.31	.049
QCAE Affective Empathy	13	.209	.75	.552
ACS Affect Naming Test	13	.269	.97	.253
Social Stories Questionnaire	13	.594	2.14	<.001

4.3.2. Analysis of Social Cognitive Functioning

As with cognitive functioning, descriptive statistics and non-parametric Kolmogorov-Smirnov exact tests were employed to determine performance on social cognition tests, compared to age-matched normative data (M = 10, SD = 3). From visual inspection of Table 4, scores on the Questionnaire of Cognitive and Affective Empathy (QCAE) Cognitive Empathy scales and the Social Stories Questionnaire (SSQ) appear to be lower than the age-scaled normative data. In contrast, QCAE

Affective Empathy was in line with the normative data, and there was a small advantage on ACS Affect Naming Test (AFT). Kolmogorov-Smirnov tests confirmed that the sample scored well below expected on SSQ when compared with age-scaled normative data. A medium effect size was found for SSQ. The AFT and both subsets of the QCAE demonstrated small effect sizes.

4.3.2.1 Contrast with general cognitive functioning: As there were observed differences between the mean scaled scores for general cognition and comparative to social cognition, a Wilcoxon signed-rank test was employed to investigate whether there was a difference between the scores. The Wilcoxon signed-rank test confirmed that there was a significant difference between general cognition and social cognition for QCAE Cognitive Empathy (n = 13, Z = -2.06, p = .039) and SSQ (n = 13, Z = -2.76, p = .006). These findings indicate that participants showed weaknesses in mentalising, and cognitive empathy compared to their general cognitive functioning.

4.4. Inferential Data Analysis

4.4.1. Associations with Performance

Due to the small sample size and ordinal nature of the data, Spearman's Rho (a non-parametric test) was deemed an appropriate test for analysis. Spearman's Rho correlational analysis was employed to investigate whether there were any associations between performance on social cognition tests and other cognitive measures, including age (see Table 6).

Table 6

Spearman's Rho Correlation Coefficient Matrix Contrasting Social Cognition Measures with General Cognitive Functioning and Age

Variables	Age in Years	Affect Naming Total	SSQ 1 Total	QCAE AE Score	QCAE CE Score
Age (Years)	1.000				
Affect Naming Total	.178	1.000			
SSQ Method 1 Total	-.054	**-.369***	1.000		
QCAE Affective Empathy Score	.041	.227	-.186	1.000	
QCAE Cognitive Empathy Score	-.050	.155	-.265	.230	1.000
WAIS Digit Spans Total	.010	-.193	-.220	.206	-.045
WAIS Coding Total	.119	.332	.072	**-.336***	-.102
WMS LM Immediate Recall Total	.000	.183	.111	-.076	-.314
WMS LM Delayed Recall Total	.206	.245	.004	-.035	-.122
WMS Immediate Visual Reproduction	-.043	-.055	.171	.181	-.216
WMS Delayed Visual Reproduction	.184	**.528****	.283	.019	.065
WAIS Similarities Total	-.095	.262	-.295	.206	-.118
WAIS Matrix Reasoning Total	.131	**-.420***	**.591****	**-.428***	-.013
DKEFS Letter Fluency Total	.237	-.111	-.191	-.057	.068
DKEFS Category Fluency Total	.149	-.118	.169	**-.347***	.226
DKEFS Switching Accuracy Total	.320	-.258	**-.571****	-.009	-.058

*Note. * = Spearman's Rho correlation is significant at the 0.05 level (2-tailed), ** = Spearman's Rho correlation is significant at the 0.01 level (2-tailed).*

Correlation analysis was conducted using raw scores as age was a variable of interest. The number of self-reported mTBIs could not be included in this analysis as the range was considered too small, ranging from one to five. The analysis included correlations between and within all cognitive and social cognition tests, however, the focus of interest was to explore the association between performance on social

cognition measures and general cognitive measures. There did seem to be some associations as shown in Table 6. However, the associations did not seem to make theoretical sense, likely due to the small sample size, and so are not interpreted further here.

4.4.2. Group Contrasts

To compare performance on social cognition measures and the frequency of self-reported mTBI, a new categorical variable was created by splitting the sample into two groups: a low group (having had one or two mTBIs, *n* = 5) and high group (three, four, or five mTBIs, *n* = 8). The Mann-Whitney U, a non-parametric test, was deemed suitable for this analysis. Results indicated that there does not seem to be an association between number of mTBIs and measures of social cognition (see Table 7).

A Mann-Whitney U test was also employed to compare differences in performance on social cognition measures between Forwards (*n* = 6) and Backs (*n* = 7). Results indicated that there does not seem to be an association between rugby position and measures of social cognition (see Table 8).

Table 7

Mann-Whitney U Results Comparing Low and High mTBI Groups on Performance of Social Cognition Measures

Tests	Mann-Whitney U	Wilcoxon W	Z	Exact Sig. (2-tailed)
Affect Naming Total	17.5	32.5	-.372	.750
SSQ Method 1 Total	19.0	34.0	-.153	.883
QCAE Cognitive Empathy Score	12.0	48.0	-1.176	.258
QCAE Affective Empathy Score	17.5	32.5	-.370	.757

Table 8

Mann-Whitney U Results Comparing Forwards and Backs Groups on Performance of Social Cognition Measures

Tests	Mann-Whitney U	Wilcoxon W	Z	Exact Sig. (2-tailed)
Affect Naming Total	15.0	36.0	-.861	.432
SSQ Method 1 Total	18.5	39.5	-.361	.753
QCAE Cognitive Empathy Score	20.5	41.5	-0.73	.513
QCAE Affective Empathy Score	20.0	41.0	-.149	.494

5. DISCUSSION

5.1. Overview

The present study sought to address a gap in the literature by investigating the association between general cognitive functioning and social cognition in female rugby players who have experienced mTBI. There is growing awareness of the possible long-term effects of cumulative mTBIs, especially in contact sports (Bailes et al., 2014). Players of contact sports like rugby, seem to be at an increased risk, due to the frequency of mTBIs sustained throughout their sporting careers (Thornton et al., 2008). Subconcussive events may lead to an increased risk of neurodegenerative conditions such as CTE and associated dementia, via changes to the cerebral structure (Huber et al., 2016). Such neurodegenerative conditions are typified by emotional and behavioural changes, which are also common experiences following TBI (Stubberud et al., 2020). However, despite the increasing literature detailing psychosocial changes following TBI and neurodegenerative conditions, to date minimal research has explored the association with social cognition.

So far, research has centred on the neurophysiological and neuropsychological outcomes in rugby players following mTBI. However, most of this research has focused on male rugby players neglecting female rugby players. This is despite women's rugby being one of the fastest growing team sports in the both the UK and the world (Nyberg & Penpraze, 2016). There are endocrinal and physiological differences between female and male athletes which may increase the likelihood of SRmTBI in female rugby players following a head impact (McGroarty et al., 2020). The current study sought to address this gap in the literature and investigate the association between mTBI exposure and cognitive functioning and social cognition in female rugby players. To the researcher's knowledge, only one previous study has investigated social cognition in rugby players with a history of mTBI, which focused on male rugby players (York-Smith, 2020). The current study is the first explore the relationship between history of mTBI in female rugby players with a specific focus on social cognition.

5.2. Sample Representation

The sample consisted of thirteen female rugby players, with varying rugby histories and experiences of mTBI. The sample age range was from 19 to 55 and was generally reflective of the UK working population. This is a good range of ages considering that only 16% of women's rugby players are aged over 30 (International Rugby Players, 2018). However, most participants identified as white suggesting a less ethnically diverse sample. Only one participant played Rugby League, whereas the majority played Rugby Union. The mean age of commencing rugby play was 22.54 years old, indicating a sample with a slightly later start in rugby career. Participants had played rugby across all levels of play, from semi-professional to professional with a mean of 6.7 years active play. The mean age for first mTBI was 24.54 years which suggests that many participants experienced their first mTBI not long after commencing rugby play. The sample had a mean of 2.62 mTBI per player with a range from one to five mTBIs self-reported.

In relation to intellectual functioning, the sample was broadly reflective of the expected level of optimal functioning observed within the general population. This was also echoed in the sample's highest academic achievement with around 46% of the sample attending university which is on par with 44% of the general UK population attending university (Department for Education, 2020). In theory, this should not have given participants an advantage on measures of cognitive performance, as often performance is correlated with academic achievement (Ostrosky-Solís et al., 2004).

5.3. Summary of Results

The present study observed that a sample of female rugby players with a history of mTBI demonstrated relative weaknesses on two measures of social cognition (the SSQ and the QCAE Cognitive Empathy) comparative to normative population data. These findings occurred in a sample that demonstrated relatively strong verbal abilities compared to the general population. Results demonstrated that other domains of general cognitive functioning were typical, with mean cognitive functioning scaled scores across measures. The sample demonstrated strengths in

both the WMS-IV Story recall (Immediate) and WMS Visual Reproduction (Immediate) measures. Interestingly, age did not correlate with performance on any of the measures of social cognition. There were some associations between performance on general cognitive functioning and social cognition measures, however, these correlations were difficult to interpret. No significant differences were found in group comparisons based on frequency of mTBI. However, it should be noted that a larger sample size would have directly led to greater power to detect differences within the sample. These results are explored in further detail in the subsequent sections.

5.3.1. General Cognitive Functioning

Investigation of the sample's cognitive functioning revealed no decrements in any of the domains of general cognitive functioning. However, the sample demonstrated particular strengths in immediate verbal memory, immediate visual memory, and verbal executive functioning in comparison with age-matched normative data. The increased performance on these tasks contrasts with the sample's average optimal ability is reflective of the general population, as is their education level. These strengths in memory conflict with previous research (O'Connor et al., 2018)

These findings reflect with some previous research indicating no lasting impact to general cognitive functioning following recovery from mTBI (Thornton et al., 2008; Gardner et al., 2010; Feddermann-Demont et al., 2017). However, the results are inconsistent with much of the evidence-base which has reliably produced convincing details of the deleterious association between mTBI and sub-acute head impacts on general cognitive functioning including memory and executive functioning (Hinton-Bayre et al., 1997; Broshek et al., 2005; Shuttleworth-Edwards et al., 2008; Colvin et al., 2009; Covassin et al., 2013; Kontos et al., 2014; Prien et al., 2020)

The absence of findings pertaining to cognitive functioning might be explained by measures not being sensitive enough to identify subtle changes post-mTBI, alongside the lack of individual baseline data (Conley et al., 2019). It is also possible that these findings might be explained by a high functioning, self-selected sample. Furthermore, impairments existing on the individual level may not have been

detected due to the analysis taking place at the group-level. However, in the present study, the focus was to measure cognitive functioning in association with performance on measures of social cognition. Due to no decrements in cognitive functioning being identified, reduced performance on measures of social cognition could probably not be associated with poor performance in general cognitive functioning. Such findings further validate the 'domain specific' theory of social cognition i.e., social cognition is to some extent independent of general cognitive functioning (Zaki et al., 2010; Reniers et al., 2011; Frith & Frith, 2012; Schurz et al., 2021).

5.3.2. Social Cognition

The primary research question underpinning the present study was to investigate if female rugby players with experience of mTBI exhibit decrements in social cognition. The measures of social cognition incorporated in the study assessed self-reported affective and cognitive empathy, mental state attribution, and emotion recognition. The current sample demonstrated relative weaknesses on measures of ToM and cognitive empathy compared with normative data. The sample's performance on measures of affective empathy and emotion recognition were not different to the general population. The weaknesses in ToM and cognitive empathy occurred in the context of relative strengths in verbal functioning and no weaknesses in other cognitive domains exhibited. The present study corroborates similar findings in other research relating to social cognition post-TBI (McDonald, 2013; Milders, 2019). Further, the present study extends previous research focusing on social cognitive decrements following mTBI in a group of male rugby players (York-Smith, 2019).

5.3.2.1. Emotion recognition: The ACS Affect Naming Task (ANT) measured the capacity to identify emotions from photographs modelling a range of facial expressions. Emotion recognition is considered a low-level process, meaning the ANT is not dependent on verbal ability ordering. The ability to recognise and precisely identify another's emotions is vital for social interactions and forming and maintaining interpersonal relationships. Accurately identifying and processing another's emotion can enable interpersonal cues of their inns and subsequently allows us to process our behaviour in return.

In terms of emotion recognition, the sample performed in line with normative data on the ANT. This coheres with previous research exploring social cognition in male football players (Mehmet, 2021). However, this contrasts with weaknesses observed in emotion recognition in a group of male rugby players with a history of mTBI (York-Smith, 2020). Although conjectural, this difference may be explained by the length of time participants played rugby. In the current study, the sample had a mean of 6.73 years of playing rugby, whereas the sample in the male cohort study had a mean of 20.38 years of play. In essence, the male sample had been playing rugby three times longer than females in this sample. Further, the study investigating social cognition in male football players did not exclusively focus on players with a history of mTBI and this could explain the differences observed. It is also possible that sex-differences exist in performance on emotion recognition tasks i.e., women may be generally more accurate at identifying emotions than their male counterparts (Wingenbach et al., 2018). Additionally, there is a need for an older sample of women who have been playing rugby over a longer time period.

5.3.2.2. Theory of mind: The Social Stories Questionnaire (SSQ) comprises ten short stories that participants are required to read through and identify if a subtle or obvious social *faux pas* has been committed. Performance on this measure is dependent on an individual's ability to mentalise how each of the characters feels in the stories. This test was selected due to it being a sensitive measure of mentalisation, including identification of social norms and other higher-level cognitive processes. As the test enables the identification of subtle and complex deficits in social cognition, it is therefore suitable for administrating in individuals with no general cognitive deficits.

The sample exhibited significantly poorer performance on the SSQ compared to the general population. It is important to contextualise results on the SSQ, as performance can be influenced by factors such as reading ability, prose comprehensive, and memory. Although the SSQ is dependent on reading ability, the sample's average performance on the TOPF-UK indicates that this decrement in ToM is not explained by a weakness in reading ability. Furthermore, the sample exhibited strengths in verbal ability including verbal memory and executive function

comparative to normative data. Any weaknesses in ToM therefore cannot be directly explained by weaknesses in other domains.
These results replicated similar findings in both male football players and rugby players (York-Smith, 2020; Mehmet, 2021). Accordingly, these findings support the deficit in ToM and further add to the literature regarding the deleterious association of mTBI in contact sports such as rugby. The finding of weaknesses in social cognition on the SSQ, but with no weaknesses in general cognitive functioning adds to the evidence supporting Frith and Frith's (2012) theory of social cognition. Frith and Frith posit that both general cognition and social cognition are separate domains with their own processes as demonstrated in research which has shown executive functioning to be independent mentalisation (Lawson et al., 2004).

5.3.2.3. Empathy: Empathy denotes the ability to comprehend and connect with what someone else may be feeling. Two subdivisions of empathy are posited (Shamay-Tsoory et al., 2009): affective empathy (the capacity to identify another's emotional state) and cognitive empathy (the capacity to comprehend how another is thinking). The Questionnaire of Cognitive and Affective Empathy (QCAE) is a self-report measure of affective and cognitive empathy. This measure was selected as it distinguishes well between affective and cognitive empathy (Reniers et al., 2011) and has good validity and reliability.

The sample performance on the QCAE subset for affective empathy was in line with normative data and reflects similar performance on the ANT suggesting an overlap of the domains being measured. However, performance for the cognitive empathy subset was significantly poorer in comparison to normative data, suggesting a potential weakness in this domain in social cognition. Interestingly, cognitive empathy and ToM are taken to be similar in this literature, and this finding occurs in the context of significant weaknesses in ToM as demonstrated in the SSQ results. It should be noted that the QCAE is a subjective self-report measure and is therefore reliant on an individual's self-awareness. However, similar findings have been reported for weaknesses in cognitive empathy in individuals with TBI (de Sousa et al., 2010).

5.3.3. Correlations and Group Comparisons

Correlations between general cognitive measures and measures of social cognition yielded some associations. However, the associations did not seem to make much theoretical sense, possibly due to the small sample size. Additionally, age did not correlate with performance (raw scores) on any of the general cognitive tests or measures of social cognition.

Group comparisons on test performance did not suggest differences when the sample was split by rugby playing position (Forwards versus Backs) or by frequency of mTBI (Low versus High). On average, Backs appeared to have slightly better performances on measures of social cognition reflecting previous research where Forwards experience a greater frequency and severity of head impacts compared to Backs (Tucker et al., 2017). Although it is possible that this finding is coincidental.

5.4. Interpretation of the Results

Altogether, the findings from the study suggest that female rugby players with a history of mTBI exhibit some weaknesses in areas of social cognition; notably in cognitive empathy and cognitive ToM. Crucially, these findings occur in the context of no weaknesses in general cognition. Within the literature to date, weaknesses in social cognition have often been reported alongside or secondary to dysexecutive function. In this study, however, the sample's performance in general cognitive functioning was in line with normative data with no observable deficits in executive functioning. This is suggestive of performance in social cognition being separate to measures of general cognition.

In summary, the results demonstrate associations between female rugby players with a history of mTBI and poor performance on measures of social cognition. This study contributes to the growing evidence base highlighting the association between mTBI and sub-acute TBI decrements in neuropsychological functioning (Vanderploeg et al., 2007; Desai et al., 2019; Pettemeridou et al., 2020; Levin et al., 2021). Although, in this study, weaknesses were only observed in domains of social cognition and not general cognitive functioning. This suggests that measures of social cognition may be a more sensitive to subtle changes following mBI. Further,

as far as the as the researcher is aware, this is the first study of its kind to solely focus on the impact of mTBI on social cognition in female rugby players. The findings warrant additional research to further investigate this phenomenon and to determine if the results are replicable.

5.5. Critical Review

Despite the preliminary nature of this research, this is the first study to investigate the association between measures of social cognition and history of mTBI in female rugby players. In recent years, research has increasingly been conducted examining the association between mTBI and general cognition, however, domains of social cognition have largely been neglected with the exception of a few studies (York-Smith, 2020; Mehmet, 2021). As this study reflects the early stages of this emerging evidence base, the findings demonstrate the need for further studies within this area.

5.5.1. Methods

5.5.1.1. Strengths: Due to the preliminary nature of this research, a preliminary and cross-sectional design of the study was deemed appropriate. The study utilised age-matched normative data, bypassing the limitations often experienced with inadequate control groups (Alvarez et al., 2021), allowing for comparisons within-subjects (Mitrushina et al., 2005).

The comprehensive battery of neuropsychological tests incorporated in this study were selected from studies investigating similar concepts in other sporting contexts. This allowed for thorough exploration of relevant concepts in a standardised manner.

5.5.1.2. Limitations: Despite being out of scope for the present study, inclusion of a control group, in addition to the age-matched normative data, might have added further weight to the findings especially between players who had an mTBI versus players with no known head injury. Additionally, inclusion of an age-matched control group would have enabled between-group analyses, allowing to control for possible confounding factors such as educational history.

Due to the constraints of time and resources within the doctoral thesis, a cross-

sectional design was employed. However, it is important to highlight that definitive conclusions regarding findings from cross-sectional research cannot be generated, as deficits in social cognition may have been present prior to any experience of mTBI. Additionally, other factors which have not been taken into account within the study may influence the sample's performance on measures of social cognition, such as individual characteristics like aggression and other antisocial traits.

A longitudinal design would be considered a 'gold standard' methodology to investigate this topic area, as not only would it allow for the generation of individual baseline data but would also enable tracking of any changes over time. In this way, causal links would be able to be made adding further weight to any findings. However, as this is not feasible for most small-scale research studies given logistical and funding constraints, evidence suggests that baseline neuropsychological testing is not essential and comparison with age-scaled normative data is a suitable alternative (Merritt et al., 2017).

Further, some may critique the use of multiple statistical testing methods within this study. This could be seen as a limitation as the use of multiple testing methods may increase the risk of a type 1 error (reporting a significant finding when there in fact is not one). However, the use of multiple statistical testing methods felt justified due to the novel topic area and the exploratory nature of the study.

5.5.2. Validity & Generalisability

5.5.2.1. Strengths: The sample in the current study was broadly in line with age-matched normative data in terms of intellectual functioning and were also representative of educational attainment within the UK population. This indicates that the current sample was a fair representation of the average UK population in terms of educational and intellectual backgrounds. Further, the sample consisted of an even split of rugby player positions (Forwards and Backs) which is reflective of rugby team structures. Although the mean years of rugby play was shorter when compared with similar studies investigating male rugby players, this is nevertheless reflective of most female rugby players who have been playing for less time when compared with their male peers.

5.5.2.2. Limitations: Whilst the sample was broadly reflective of the UK in terms of educational and intellectual backgrounds, it was not representative of the ethnic composition of the UK, as the sample mainly identified as white British. It is possible that there may be an overrepresentation of white British players in women's rugby, however, all effort should be made in future research to ensure the sample is reflective of the ethnic composition of the UK. Although in the current sample, all participants identified as being cisgender female, the study was also open to anyone who identified as female. Additional areas of interest for future research could include the incorporation of rugby players who may not identify as either male or female e.g., non-binary.

In relation to the testing materials employed, it is important to note that cognitive measures designed to test a single cognitive domain frequently involve the use of additional cognitive processes. That is to say, neurocognitive tests are rarely 'pure' in measuring a single construct (Smith, 2005), and like any other area of science, can be limited or influenced by social constructs (Kinsbourne, 2000). Additionally, the implementation of cognitive measures in mTBI research contexts has been critiqued for under-reporting deficits, due to measures lacking the sensitivity to detect subtle changes in cognitive functioning (Randolph, 2011). Although, all measures employed in this study have been shown to have good validity, the incorporation of more stringent tests may help to reduce the likelihood of false-negative outcomes (Ozen & Fernandes, 2012).

Limitations also exist for the measures of social cognition employed in this study. For example, all the tests are based on fixed stimuli, that is, they lack the dynamic flow of social context. For the ANT, research has demonstrated both good reliability and validity, however, concerns still exist regarding its ecological validity e.g., it only depicts one positive emption – happiness. Possible limitations also exist for the SSQ. Due to it being solely a reading task, misinterpretations can easily be made as there is no other form of social context i.e., visual information. Performance on this test is proposed to be confirmation of explicit mentalisation abilities. However, decreased performance on this test may be reflective of a lack of socialisation to specific cultural norms (Begum, 2015). Thus, the SSQ may not actually be measuring an

individual's mentalisation ability but rather their socialisation to socio-cultural norms. The incorporation of additional measures of social cognition would help to bolster validity and allow for investigation of findings across measures. Although, additional tests would place a greater burden on participants and so careful consideration ought to be given in terms of the cost-benefit trade-off.

Limitations are inherent in the self-reporting nature of mTBI history, and therefore a more robust method of mTBI reporting would have been beneficial. The current study utilised self-reporting, and this is a potential limitation. However, corroboration via medical records contains its own limitations, in that a large proportion of mTBIs are not medically assessed and therefore unreported (Llewellyn et al., 2014).

5.5.3. Critical Reflection

No conflict of interest exists for the researcher in this subject area and the researcher has been transparent regarding the epistemological position adopted. However, it is reasonable to posit that the research questions, methodology, and area of interest chosen by the researcher are reflective of the researcher's biases and understanding of the world. By employing a critical-realist epistemological positioning, the researcher was able to objectively measure this phenomenon whilst highlighting that knowledge can be both fallible and partial. Further, concepts such as cognition are equally fallible due to the potential of being socially constructed in nature. Upon critical reflection of the present study, the researcher is cognisant of how the study may bolster social discourses around labelling certain individuals as 'impaired'. Such deficit-saturated narratives can lead to the interpretation that cognitions are static and fixed in nature, rather than being fluid and context-dependent. Although the suggestions posed for clinical practice (detailed below) are congruent with current diagnostical constructs, the researcher acknowledges that cognitive functioning is dynamic and context dependent.

5.6. Implications

5.6.1. Clinical Implications

Social cognition refers to the mechanisms underpinning the recognition, sense-

making, and the interpersonal response to social stimuli. This includes cognitive processes relating to how individuals make sense of themselves and others in social situations (Frith, 2008). As noted in the introduction, a range of cognitive processes such as attention, memory, perception, judgement, and decision-making, are all employed in navigating social experiences (Beer & Ochsner, 2006). Social cognition forms the foundation of effective communication and interpersonal functioning. Deficits in social cognition can lead to issues in interpersonal relationship maintenance, social isolation, and increased emotional lability (Ubukata et al., 2014; Cacioppo et al., 2015). There is a clear association between deficits in social cognition leading to difficulties with navigating social spheres and ultimately leading to reduced quality of life and poorer psychosocial outcomes. Additionally, increasing evidence details the link between reduced social interaction and increased cognitive decline (Lara et al., 2019).

In spite of the increasing research within the field of mTBI in sporting contexts, the potential role of social cognition on psychosocial outcomes has largely been ignored. The current study adds to the emerging evidence base that female rugby players with a history of mTBI exhibit some weaknesses in social cognition. If the weaknesses exhibited in the measures of social cognition relate to fundamental difficulties, these may manifest in numerous domains of real life. The results of the current study are preliminary in nature, and therefore necessitate further replication prior to any definitive inferences can be made. Nonetheless, it is important to discuss the possible clinical implications of these findings.

Deficits in ToM are frequently exhibited in TBI leading to difficulties in interpreting both social cues and social norms. Consequently, evidence suggests that individuals with a history of TBI have significantly reduced social networks (Flynn et al., 2019). In contrast, evidence also suggests that those living with a neurodegenerative condition that continue to be socially active exhibit greater cognitive outcomes than those who are less socially active (Sommerlad et al., 2019). The role of social cognition ought to be incorporated into routine assessment and treatment of mTBI and neurodegenerative conditions. Further, research has demonstrated changes to social cognition and personality prior to any changes in cognitive functioning in neurodegenerative conditions (Terracciano et al., 2023). It is possible that changes

in social cognition and personality may be contraindications of subsequent development of neurodegenerative conditions. Indeed, deficits in social cognition underpin many neurodegenerative conditions and constitute core clinical features in conditions such as bvFTD (Bertoux et al., 2016).

At present, measures of social cognition are not routinely incorporated into clinical practice in the assessment of neurocognitive functioning (Henry et al., 2016). Findings from this study adds to the rationale for use of social cognition measures in routine neurocognitive assessment following mTBI. Incorporation of measures of social cognition such as the SSQ and ANT in routine assessments would be manageable given their ease of administration and time-efficiency. Additionally, owing to the sensitivity of these measures in detecting subtle changes to social cognition, they would be suitable for individuals with no weaknesses in general cognitive functioning.

However, additional research would be needed to ascertain which stage of assessment and management of mTBI would be most appropriate in sporting contexts it. It is possible that measures of social cognition could help inform return to play decisions. Furthermore, measures of social cognition could be incorporated into pre-season baseline assessments for players of contact sports to allow for more detailed and reliable information of individual players over time. These findings also extend to other clinical settings. Where individuals may present with changes to their social and emotional health, clinicians should consider exploring history of contact sports with the individual.

In relation to measuring recovery and the long-term effects of mTBI in sporting contexts, a more extensive battery of measures of social cognition should be developed to help support management and intervention of mTBI. Measures of social cognition can increase an individual's understanding of themselves but can also inform clinical interventions. Preliminary evidence suggests that interventions with a focus on social cognition may inhibit the progression of certain neurodegenerative conditions (Kempnich et al., 2017). Further, measures of social cognition have been shown to be able to differentiate between different types of neurogenerative conditions (Setién-Suero et al., 2022). It is possible that measures

of social cognition could be employed to identify athletes with an increased likelihood of developing neurodegenerative conditions such as CTE, given that players of contact sports are at an elevated risk of developing such conditions (VanItallie, 2019).

To conclude, despite the study being preliminary in nature, the findings demonstrate the need for further investigation of the role of social cognition in female athletes who have experienced mTBI, especially within sporting contexts. Additionally, emphasis should be given to the role of social cognition alongside sporting history within clinical settings. Improved treatment decisions may be made through the collection of information of exposure to frequent head impacts and mTBIs in high contact sports such as rugby.

5.6.2. Wider Implications

The findings are in line with that of a similar study investigating social cognition in male rugby players with a history of mTBI (York-Smith, 2020). However, the findings from this study are especially significant from a societal perspective, as although male rugby players exhibited similar weaknesses in ToM, women face different societal pressures and expectations. Zupan et al. (2018) concluded that even when men and women with a history of TBI had similar performances for both affective and cognitive empathy, women would be more disadvantaged by this. They suggest this is due to experiencing greater social disadvantage, as typically, women without a history of TBI tend to show more empathy than men without TBI. Therefore, cultural expectations would lead to greater stigma towards women with TBI compared to that of men with TBI when they don't exhibit expected empathy. If the above findings are replicated in future research, it is possible that female athletes who play contact sports may not only experience the deleterious effects of this on their social cognitive functioning, but this may also compound negative psychosocial outcomes (unlike for their male peers). Given the possibility of greater negative psychosocial outcomes due to cultural and societal pressures, it is therefore important that more research be conducted exploring the role of mTBI and social cognition. This could lead to improved detection, assessment, and more targeted interventions specific to female athletes.

Although sports governing bodies, such as World Rugby, are demonstrating increasing acknowledgement of the issues of mTBI for its players, it is vital that they consider these findings when initiating future action. Governing bodies are central players in the assessment and management of mTBI. Although standalone neurocognitive measures have become frequently used in assessing mTBI (Lovell & Getz, 2006), comprehensive multimodal neurocognitive testing batteries are essential in providing more accurate assessments (McCrea et al., 2013). At present, assessment is solely focused on some key domains of cognitive functioning (Feddermann-Demont et al., 2017), neglecting domains of social cognition. This present study provides further evidence of the need to include a range of measures of social cognition in the routine assessment and management of mTBI in sporting contexts.

Consideration of mTBI in sporting contexts ought to be incorporated into public health policy due to the number of people potentially impacted by this issue. It is vital that sports governing bodies remain up to date with the latest evidence base regarding mTBIs. Given that World Rugby recently updated policies pertaining to acceptable tackle heights, it is therefore possible that further action can be taken to reduce the risk and frequency of mTBI experienced in rugby. This also extends to governing bodies for other contact sports. Furthermore, given that in this study, players experienced their first mTBI relatively soon after commencing rugby, it is possible to presume that this is a similar trend across rugby. With increasing numbers of young females playing rugby, and the legal tackling age set by England Rugby as eight years, the long-term impact of mTBIs on brain development is not yet fully understood. This demonstrates the need for further research to ascertain if outcomes differ in relation to functioning in cognition and social cognition between players with experience of mTBI in childhood/adolescence versus adulthood.

Psychoeducation regarding mTBI and possible long-term effects should be given to players of contact sports including risk factors and stages/timelines to recovery. The majority of sideline mTBI assessments are conducted by individuals with minimal training and knowledge of the cognitive tests administered. It is therefore possible that neuropsychologists could redress this issue by becoming training staff involved

in the sideline assessments and return to play decision making; and by providing psychoeducation; and aiding in interpretation of both measures of cognition and social cognition. Additional training and education regarding mTBI should be provided that is sex-specific to female players of contact sports.

5.7. Future Directions

Research exploring the role of social cognition following mTBI in sporting contexts remains minimal. As far at the researcher is aware, this is the first study to investigate the association between mTBI and social cognition in female rugby players. Due to the preliminary nature of the study, it is essential that the findings be replicated and extended in subsequent research. Future research could include incorporation of a control group, enabling between group analysis, increasing the impact of the findings. Only female participants were included in the current study which is important as previous research has systematically neglected the impact of mTBI in females, especially in sporting contexts. Future research may be conducted to further explore the similarities and differences between female and male athletes in relation to experience and long-term effects of mTBI. Evidence suggests that female athletes report a greater incidence of mTBI (Broshek et al., 2005; Black et al., 2017), increased mTBI symptoms (Bunt et al., 2022) and psychosocial distress (Thomas et al., 2022b), and longer recovery times following mTBI compared with their male counterparts (Master et al., 2021). Further, due to there being fewer older female rugby players at present, little is known about the long-term effects of cumulative mTBI in female rugby players. It is vital that future longitudinal research is conducted to ascertain the impact of this, given that this will be an increasing issue in the future as today's younger players become older.

Social cognition is comprised of multiple domains and therefore inclusion of additional measures of social cognition would allow for improved understanding regarding whether weaknesses are generalised across different measures of the same domain of social cognition, or just specific to the measures used in this study. There is a need for development of measures sensitive enough to detect and measure impairments following cumulative mTBI. These findings indicate the need for the current guidelines on return to play to be assessed and updated. There has

been growing concern regarding mTBI in sports in recent years, as reflected by the book titled ‘The Concussion Crisis in Sport’ (Malcolm, 2019). A number of rugby officials have voiced their need for changes to rugby to reduce rates of mTBI and long-term effects. Indeed, healthcare professionals have voiced their concern over tackling in rugby for many years now and have openly called for the banning of tackling in high school physical education (White et al., 2018). Further, these concerns have also extended to female high school rugby players where tackling is the largest source of mTBI (Shill et al., 2022). To increase safety in rugby contexts, changes to policy should take place, including exploration of other potentially beneficial actions such a tackle-training programmes and neuromuscular training.

5.8. Conclusion

The present study aimed to contribute to the currently limited literature regarding the impact of mTBIs on general and social cognitive functioning in female rugby players. As far as the researcher is aware, this is the first study to explore this novel area among female rugby players. Findings suggest that female rugby players with a history of mTBI are associated with poorer performance on measures of social cognition, in particular, ToM and cognitive empathy. These weaknesses in social cognition were observed in the context of no weaknesses in any other cognitive domains of functioning and despite some strengths, in related domains. Further research is needed to replicate these findings in larger studies with control groups. Further, attention should be paid to the longitudinal impact of mTBIs in female rugby players. Additionally, sports governing bodies such as England Rugby, are encouraged to actively review and modify their guidelines pertaining to assessment, management, and return to play decisions following mTBI. Incorporating several measures of social cognition within routine assessments is recommended.

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7. APPENDICES

Appendix A: *Literature Review Search Terms*

Neuropsychology: ("*Neuro**")

AND

Rugby: ("*Rugby*")

AND

Head-injuries: ("*Head Injur**" OR "*Traumatic Brian Injur**" OR "*Concuss**")

AND

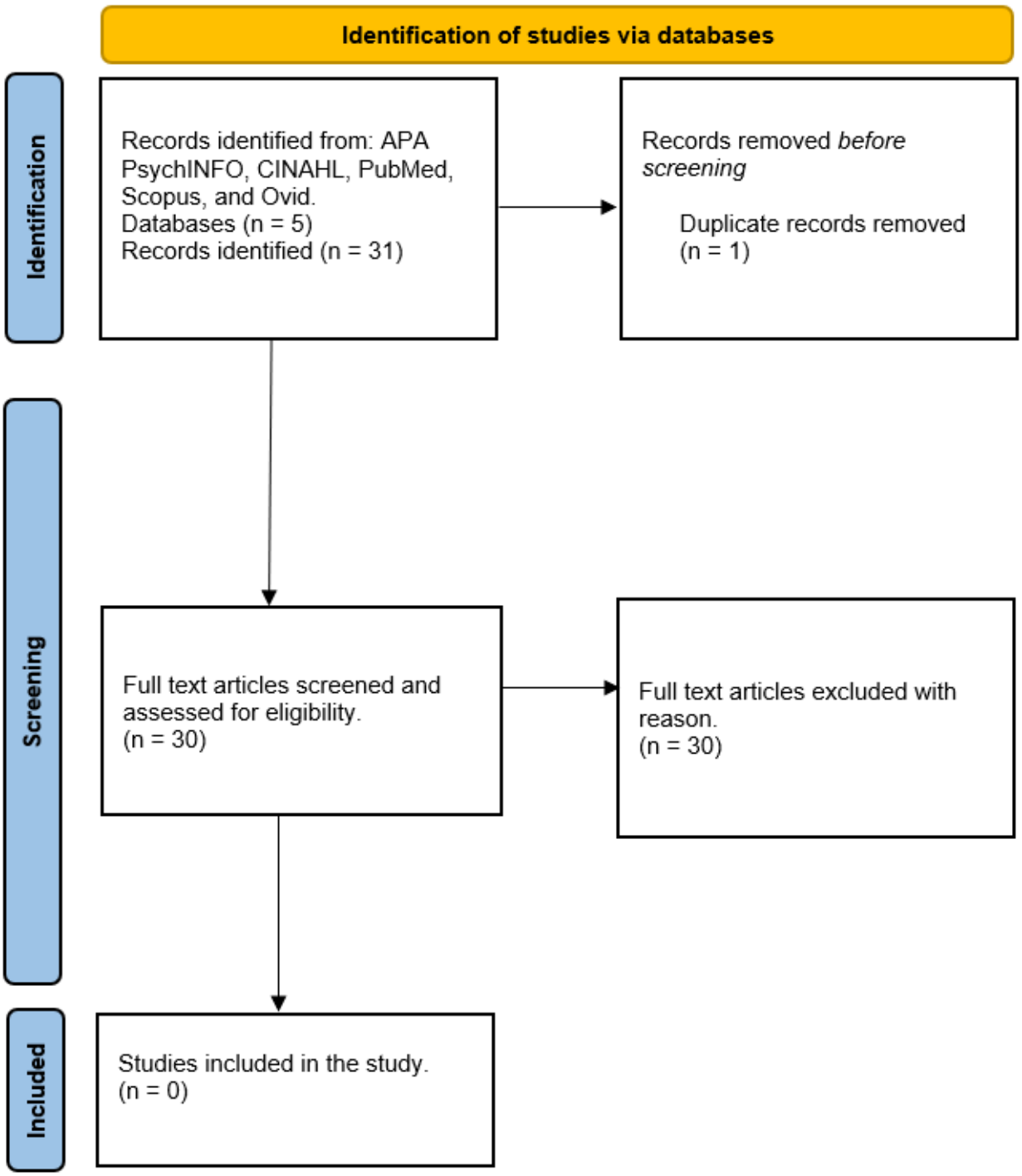
Female: ("*Female**" OR "*Woman**" OR "*Women**")

AND

Social Cognition: ("*Social Cog**" OR "*Emotion*" OR "*Empathy*" OR "*Affective*" OR "*Theory of Mind*" OR "*Facial Expression**")

Searches were conducted in APA PsychINFO, CINAHL, PubMed, Scopus, and Ovid. The search terms above yielded no publications. Therefore, a narrative review was conducted from the papers systematically identified with the above search terms, omitting the social cognition search operations.

Appendix B: *Literature Search – PRISMA Flow Diagram*



Appendix C: *School of Psychology Research Ethics Committee Ethics Application*

University of East London

School of Psychology Ethics Committee

NOTICE OF ETHICS REVIEW DECISION LETTER

For research involving human participants

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

Reviewer: Please complete sections in **blue** | **Student:** Please complete/read sections in **orange**

Details	
Reviewer:	**Fiorentina Sterkaj**
Supervisor:	**Matthew Jones Chesters**
Student:	**Ryan FLYNN**
Course:	**Prof Doc Clinical Psychology**
Title of proposed study:	**Impact of Head Injury on Cognitive Functioning and Social Cognition in UK-based Female Rugby Players**

Checklist (Optional)	YES	NO	N/A
Concerns regarding study aims (e.g., ethically/morally questionable, unsuitable topic area for level of study, etc.)	☐	☒	☐
Detailed account of participants, including inclusion and exclusion criteria	☒	☐	☐
Concerns regarding participants/target sample	☐	☒	☐
Detailed account of recruitment strategy	☒	☐	☐

Concerns regarding recruitment strategy	☐	☒	☐
All relevant study materials attached (e.g., freely available questionnaires, interview schedules, tests, etc.)	☒	☐	☐
Study materials (e.g., questionnaires, tests, etc.) are appropriate for target sample	☒	☐	☐
Clear and detailed outline of data collection	☒	☐	☐
Data collection appropriate for target sample	☒	☐	☐
If deception being used, rationale provided, and appropriate steps followed to communicate study aims at a later point	☐	☐	☒
If data collection is not anonymous, appropriate steps taken at later stages to ensure participant anonymity (e.g., data analysis, dissemination, etc.) – anonymisation, pseudonymisation	☐	☐	☒
Concerns regarding data storage (e.g., location, type of data, etc.)	☐	☒	☐
Concerns regarding data sharing (e.g., who will have access and how)	☐	☒	☐
Concerns regarding data retention (e.g., unspecified length of time, unclear why data will be retained/who will have access/where stored)	☐	☒	☐
If required, General Risk Assessment form attached	☒	☐	☐
Any physical/psychological risks/burdens to participants have been sufficiently considered and appropriate attempts will be made to minimise	☒	☐	☐
Any physical/psychological risks to the researcher have been sufficiently considered and appropriate attempts will be made to minimise	☒	☐	☐
If required, Country-Specific Risk Assessment form attached	☐	☐	☒
If required, a DBS or equivalent certificate number/information provided	☐	☐	☒
If required, permissions from recruiting organisations attached (e.g., school, charity organisation, etc.)	☐	☐	☒
All relevant information included in the participant information sheet (PIS)	☒	☐	☐
Information in the PIS is study specific	☒	☐	☐
Language used in the PIS is appropriate for the target audience	☒	☐	☐
All issues specific to the study are covered in the consent form	☒	☐	☐
Language used in the consent form is appropriate for the target audience	☒	☐	☐
All necessary information included in the participant debrief sheet	☒	☐	☐
Language used in the debrief sheet is appropriate for the target audience	☒	☐	☐
Study advertisement included	☒	☐	☐
Content of study advertisement is appropriate (e.g., researcher's personal contact details are not shared, appropriate language/visual material used, etc.)	☒	☐	☐

Decision options	
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.

APPROVED - BUT MINOR AMENDMENTS ARE REQUIRED BEFORE THE RESEARCH COMMENCES	In this circumstance, 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 at the end of this form once all amendments have been attended to and emailing a copy of this decision notice to the supervisor. The supervisor will then forward the student's confirmation to the School for its records. **Minor amendments guidance:** typically involve clarifying/amending information presented to participants (e.g., in the PIS, instructions), further detailing of how data will be securely handled/stored, and/or ensuring consistency in information presented across materials.
NOT APPROVED - MAJOR AMENDMENTS AND RE-SUBMISSION REQUIRED	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. **Major amendments guidance:** typically insufficient information has been provided, insufficient consideration given to several key aspects, there are serious concerns regarding any aspect of the project, and/or serious concerns in the candidate's ability to ethically, safely and sensitively execute the study.

Decision on the above-named proposed research study	
Please indicate the decision:	**APPROVED**

Minor amendments
Please clearly detail the amendments the student is required to make

Major amendments
Please clearly detail the amendments the student is required to make

Assessment of risk to researcher		
Has an adequate risk assessment been offered in the application form?	**YES** ☒	**NO** ☐
	If no, please request resubmission with an **adequate risk assessment.**	
If the proposed research could expose the researcher to any kind of emotional, physical or health and safety hazard, please rate the degree of risk:		
HIGH	Please **do not approve a high-risk** application. Travel to countries/provinces/areas deemed to be high risk should not be permitted and an application not be approved on this basis. If unsure, please refer to the Chair of Ethics.	☐
MEDIUM	Approve but include appropriate recommendations in the below box.	☐
LOW	Approve and if necessary, include any recommendations in the below box.	☒
Reviewer recommendations in relation to risk (if any):	Please insert any recommendations	

Reviewer's signature	
Reviewer: (Typed name to act as signature)	**D**r Fiorentina Sterkaj

Date:	**26/10/2022**
This reviewer has assessed the ethics application for the named research study on behalf of the School of Psychology Ethics Committee	

Appendix D: *Online Research Integrity Module Certificates*

OXFORD UNIVERSITY PRESS

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Certificate

Number: 0669330383

This is to certify that

Ryan Flynn

of University of East London

Successfully completed the course

Research Integrity: Core

Good research conduct	90%
Irresponsible research practices	90%
Planning your research	90%
Managing and recording your research	80%
Data selection, analysis and presentation	80%

as part of the Epigeum Online Course System with a score of 86%.

Dated: 28 April 2021

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Certificate

Number: 0669330383

This is to certify that

Ryan Flynn

of University of East London

Successfully completed the course

Research Integrity: Core

Scholarly publication	90%
Professional responsibilities	90%
Communication, social responsibility and impact	80%

as part of the Epigeum Online Course System with a score of 86%.

Dated: 28 April 2021

Appendix E: *Participant Information Sheet*

PARTICIPANT INFORMATION SHEET

Impact of Head Injury on Cognitive Functioning and Social Cognition in UK-based Female Rugby Players

Contact person: Ryan James Flynn
Email: u2075200@uel.ac.uk

You are being invited to participate in a research study. Before you decide whether to take part or not, please carefully read through the following information which outlines what your participation would involve. Feel free to talk with others about the study (e.g., friends, family, etc.) before making your decision. If anything is unclear or you have any questions, please do not hesitate to contact me on the above email.

Who am I?

My name is Ryan. I am a Trainee Clinical Psychologist based in the School of Psychology at the University of East London (UEL) and am studying for a Doctorate in Clinical Psychology. As part of my studies, I am conducting the research that you are being invited to participate in.

What is the purpose of the research?

I am conducting research into cognitive functioning (things like memory and attention) and social cognition (how we may respond in social situations) in UK-based female rugby players who have experienced rugby-related head injuries. Research suggests that involvement in contact sports and sport-related concussion is associated with neuropsychological effects. However, much of this research has focused on male sports players and very little is known about how female sports players may be affected by sports-related head injuries. More research is needed to detect and manage concussions in contact-sports, including the potential long-term consequences. This study will investigate questions around the impact of rugby-related head injuries and whether there is a relationship between this and

performance on tasks measuring cognitive and social functioning.

This research has been approved by the School of Psychology Research Ethics Committee. This means that my research follows the standard of research ethics set by the British Psychological Society.

Why have I been invited to take part?
To address the study aims, I am inviting UK-based female rugby players to take part in my research. If you are fluent in English (or highly proficient), aged over 18, and identify as a female rugby player who has experienced a rugby-related head injury, you are eligible to take part in the study.

It is entirely up to you whether you take part or not, participation is voluntary.

What will I be asked to do if I agree to take part?
If you agree to take part, you will be asked to attend a one-off interview at The University of East London or a location convenient to you (i.e. a local rugby club). This one-off interview should take approximately 1 hour, 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 may withdraw from the study at any time prior to the interview and up to three weeks after you have participated in the study. You will be verbally debriefed at the end of the study and debriefing sheet with further contact details will be provided.

While there will be no payment for your participation, you will be entered into a prize draw for a £50 Amazon voucher, as a token of appreciation for your time. Your participation would be very valuable in helping to develop knowledge and understanding of my research topic.

Can I change my mind?
Yes, you can change your mind at any time and withdraw without explanation, disadvantage, or consequence. If you would like to withdraw from the study, you can do so by informing me the researcher either during or after the study. If you withdraw, your data will not be used as part of the research.

Separately, you can also request to withdraw your data from being used even after you have taken part in the study, provided that this request is made within three weeks of the data being collected (after which point the data analysis will begin, and withdrawal will not be possible).

Are there any disadvantages to taking part?

Cognitive tests can be long and can require a great deal of energy, the principal researcher will therefore offer you short breaks throughout the testing to help with this. Cognitive tests are sometimes used to identify areas of clinical concern. In the unlikely event of a suspected area of clinical concern, the principal researcher will communicate this with you in a clear and sensitive way and advise you on how to proceed with this.

After taking part in the study, you will have a chance to discuss your experience of the study with the principal researcher at the debrief stage. Information on several support agencies will also be provided at the end of the study, and for those who withdraw from the study before the debrief stage.

How will the information I provide be kept secure and confidential?

All identifiable information will be kept securely, with hard copies stored in a locked cabinet on site and electronic data encrypted. Identifiable information will be destroyed at the end of the study, with anonymised electronic data kept for up to two years post study, for publication purposes. As information is grouped together individual feedback cannot be provided, however we are able to provide feedback of group results on request. The results of the study are planned to be published, with only anonymised information included. Published anonymised data will be readily accessible to the public.

For the purposes of data protection, the University of East London is the Data Controller for the personal information processed as part of this research project. The University processes this information under the 'public task' condition contained in the General Data Protection Regulation (GDPR). Where the University processes particularly sensitive data (known as 'special category data' in the GDPR), it does so because the processing is necessary for archiving purposes in the public interest, or scientific and historical research purposes or statistical purposes. The University will ensure that the personal data it processes is held securely and processed in accordance with the GDPR and the Data Protection Act 2018. For more information about how the University processes personal data please see www.uel.ac.uk/about/about-uel/governance/information-assurance/data-protection

What will happen to the results of the research?

The research will be written up as a thesis and submitted for assessment. The thesis will be publicly available on UEL's online Registry of Open Access Repositories (ROAR). Findings will also be disseminated to a range of audiences (e.g., academics, clinicians, public, etc.) through journal articles, conference presentations, talks, magazine articles, and blogs. In all material produced, your identity will remain anonymous, in that, it will not be possible to identify you personally.

You will be given the option to receive a summary of the research findings once the study has been completed for which relevant contact details will need to be provided.

Anonymised research data will be securely stored by Dr Matthew Jones Chesters for a maximum of 3 years, following which all data will be deleted.

Who has reviewed the research?

My research has been approved by the School of Psychology Ethics Committee. This means that the Committee's evaluation of this ethics application has been guided by the standards of research ethics set by the British Psychological Society.

Who can I contact if I have any questions/concerns?

If you would like further information about my research or have any questions or concerns, please do not hesitate to contact me.

Principal Investigator: Ryan James Flynn
Email: u2075200@uel.ac.uk

If you have any questions or concerns about how the research has been conducted, please contact my research supervisor Dr Matthew Jones Chesters. School of Psychology, University of East London, Water Lane, London E15 4LZ,
Email: m.h.jones-chesters@uel.ac.uk

or

Chair of School Ethics Committee: Dr Trishna Patel, School of Psychology, University of East London, Water Lane, London E15 4LZ.
(Email: t.patel@uel.ac.uk)

Thank you for taking the time to read this information sheet

Appendix F: *Participant Consent Form*

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Impact of Head Injury on Cognitive Functioning and Social Cognition in UK-based Female Rugby Players

Contact person: Ryan James Flynn

Email: u2075200@uel.ac.uk

	Please initial
I confirm that I have read the participant information sheet dated 27/06/2022 (version 1) for the above study and that I have been given a copy to keep.	
I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	
I understand that my participation in the study is voluntary and that I may withdraw at any time, without explanation or disadvantage.	
I understand that if I withdraw during the study, my data will not be used.	
I understand that I have three weeks from the date of my taking part in the study to withdraw my data.	
I understand that my personal information and data from the research will be securely stored and remain confidential. Only the research team will have access to this information, to which I give my permission.	
It has been explained to me what will happen to the data once the research has been completed.	
I understand that some generic group level data may be used in material such as conference presentations, reports, articles in academic journals resulting from the study and that these will not personally identify me.	
I would like to receive a summary of the research findings once the study has been completed and am willing to provide contact details for this to be sent to.	

I agree to take part in the above study.	

Participant's Name (BLOCK CAPITALS)

……

Participant's Signature

……

Researcher's Name (BLOCK CAPITALS)

……

Researcher's Signature

……

Date

……

Appendix G: *Participant Debrief Letter*

PARTICIPANT DEBRIEF SHEET

Impact of Head Injury on Cognitive Functioning and Social Cognition in UK-based Female Rugby Players

Thank you for participating in my research study on exploring the cognitive functioning and social cognition in UK-based female rugby players who have experienced rugby-related head injuries. This document offers information that may be relevant in light of you having now taken part.

How will my data be managed?

The University of East London is the Data Controller for the personal information processed as part of this research project. The University will ensure that the personal data it processes is held securely and processed in accordance with the GDPR and the Data Protection Act 2018. More detailed information is available in the Participant Information Sheet, which you received when you agreed to take part in the research.

What will happen to the results of the research?

The research will be written up as a thesis and submitted for assessment. The thesis will be publicly available on UEL's online Repository. Findings will also be disseminated to a range of audiences (e.g., academics, clinicians, public, etc.) through journal articles, conference presentations, talks, magazine articles, and blogs. In all material produced, your identity will remain anonymous, in that, it will not be possible to identify you personally as personally identifiable information will be removed.

You will be given the option to receive a summary of the research findings once the study has been completed for which relevant contact details will need to be provided.

Anonymised research data will be securely stored by Dr Matthew Jones Chesters for a maximum of 2 years, following which all data will be deleted.

What if I been adversely affected by taking part?

It is not anticipated that you will have been adversely affected by taking part in the research, and all reasonable steps have been taken to minimise distress or harm of any kind. Nevertheless, it is possible that your participation – or its after-effects – may have been challenging, distressing or uncomfortable in some way. If you have been affected in any of those ways, you may find the following resources/services helpful in relation to obtaining information and support:

Headway

Headway is the UK-wide charity that works to improve life after brain injury, providing vital support and information services.

Tel: 0808 800 2244; Email: helpline@headway.org.uk

Samaritans

Samaritans volunteers listen in confidence to anyone in any type of emotional distress, without judgement.

Tel: 116 123 (24 hours a day, 7 days a week); Email: www.samaritans.org

Mind

Mind are a charity who provide information and support on mental health issues.

Tel: 0300 123 3393 (9am to 6pm, Monday to Friday, except for bank holidays).

Email: info@mind.org.uk ; Text: 86463

Rugby Players Association

RPA members can access 24/7 confidential counselling by contacting Cognacity on 01373 858 080. Their Lift The Weight videos also provide support and advice.

Who can I contact if I have any questions/concerns?

If you would like further information about my research or have any questions or concerns, please do not hesitate to contact me.

Principal Investigator: Ryan James Flynn

Email: u2075200@uel.ac.uk

If you have any questions or concerns about how the research has been conducted, please contact my research supervisor Dr Matthew Jones Chesters. School of Psychology, University of East London, Water Lane, London E15 4LZ,

Email: m.h.jones-chesters@uel.ac.uk

or

Chair of School Ethics Committee: Dr Trishna Patel, School of Psychology, University of East London, Water Lane, London E15 4LZ.

(Email: t.patel@uel.ac.uk)

Thank you for taking part in my study.

Appendix H: *Study Advertisement Poster*

Are you a female rugby player?

Have you ever experienced a head injury during a game?

Who am I?

The study is being conducted as part of the Doctorate in Clinical Psychology, at the University of East London by Ryan Flynn.

What is the research about?

Exploring the relationships between head injuries and cognitive functioning in female rugby players. Participants will answer questions about their demographics and sporting history and complete a set of neuropsychological tests lasting approx. 1 hour.

Can I take part?

Yes, if you identify as female, are a current or ex-rugby player, aged between 18-65, fluent in English and experienced a head injury while playing rugby.

Chance to win a £50 Amazon voucher!

University of East London

Interested?

For more information, please contact **u2075200@uel.ac.uk**