

Understanding sport-related concussion in Ladies Gaelic Football: prevalence, management practices, and clinical assessment



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A thesis submitted for the award of PhD.

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Author Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of PhD is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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List of Abbreviations

ADHD	Attention deficit hyperactivity disorder
AUC	Area under the curve
CAI	Concussion Attitude Index
CISG	Concussion in Sport Group
CKI	Concussion Knowledge Index
CP	Clinical Profiles
<i>d</i>	Cohen's <i>d</i>
FTN	Finger-to-nose
GAD-7	Generalised Anxiety Disorder-7
GSC	Graded Symptom Checklist
HHD	Hand-held dynamometry
HVOR	Horizontal vestibular-ocular reflex
ICC	Intraclass correlation coefficient
ICC (1,k)	Intraclass correlation coefficient one-way random effects model for average measurements
ICC (2,1)/ICC (2,k)	Intraclass correlation coefficient two-way random effects model for single/average measurements
ICC (3,1)/ICC (3,k)	Intraclass correlation coefficient two-way mixed effects model for single/average measurements
ImPACT®	Immediate Post-Concussion Assessment and Cognitive Testing
LCCC	Lin's concordance correlation coefficient
LD	Learning disorder
LGF	Ladies Gaelic Football
LGFA	Ladies Gaelic Football Association
mBESS/BESS	Modified Balance Error Scoring System /Balance Error Scoring System
MIDAS	Migraine Disability Assessment
mTBI	Mild Traumatic Brain Injury
N	Newtons
N/kg	Newtons per kilogram body mass
NBQ	Neck Bournemouth Questionnaire
NPC	Near point of convergence
OR	Odds ratio

PCSS	Post-concussion symptom scale
PHQ-9	Patient Health Questionnaire-9
PSQI	Pittsburgh Sleep Quality Index
r	Pearson's correlation
RCI	Reliable change index
RoCKAS	Rosenbaum Concussion Knowledge and Attitudes Survey
RTL	Return-to-learn
RTP	Return-to-play
RTS	Return-to-school
SAC	Standardised Assessment of Concussion
SCAT/SCAT2/SCAT3/SCAT5	Sport Concussion Assessment Tool/2 nd /3 rd /5 th Edition
SDiff	Standardised error of the difference
SEM	Standardised error of measurement
SRC	Sport-related concussion
β	Beta
SSS	Symptom severity score
TG	Tandem gait
TSS	Total symptom score
V	Cramer's V
VMS	Visual motion sensitivity
VOMS	Vestibular-ocular motor screening
VVOR	Vertical vestibular-ocular reflex
Weighted κ	Weighted Kappa
χ^2	Chi-square
κ	Kappa
ρ	Spearman's rho

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List of Outputs

Accepted journal articles

Leahy R, Rochfort KD, Whyte EF, Kontos AP, Collins MW, O'Connor S. Concussion in Ladies Gaelic Football: self-reported history, clinical profiles, and management behaviour. Clin J Sport Med. 2022.

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Educational pieces developed for the LGFA

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Abstract

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Thesis title: Understanding sport-related concussion in Ladies Gaelic Football: prevalence, management practices, and clinical assessment.

Background: Ladies Gaelic Football (LGF) is a popular Irish female sport. Sport-related concussion (SRC) has been identified as a concern in LGF, however little is known about its prevalence and management in LGF. A lack of normative and reliability data on multi-domain assessments in female, community-sport athletes increases the clinical challenges of managing SRC in LGF.

Aim: (i) Examine SRC prevalence and management practices in LGF, (ii) Investigate factors associated with SRC management behaviour, (iii) Develop normative data for a multi-domain SRC assessment in LGF players, and (iv) Assess the test-retest reliability of this assessment after six- and twelve-months.

Methods: We collected data on 657 LGF players' previous experiences with SRC using an online survey. We developed a multi-domain SRC assessment to capture the full range of SRC signs and symptoms. One hundred and thirty-eight participants completed an initial assessment. Forty-seven participants were re-assessed after six months and a separate group of 72 participants were re-assessed after twelve months.

Results: A suspected SRC was sustained by 17.5% during the previous season and SRCs were often poorly managed. The main factor associated with appropriate management behaviour was being diagnosed by a medical professional. Normative data were presented on a multi-domain SRC assessment. Adolescent participants demonstrated worse scores on several cognitive and vestibular measures compared with adult participants ($p < 0.05$), however no differences in baseline were reported based on playing level or concussion history. Test-retest reliability for the GSC, CP Screen, PHQ-9, and GAD-7 was moderate after six and twelve-months, however all other tests showed inadequate reliability.

Conclusion: SRC is an issue in LGF and may be poorly managed, putting players at risk of complications. Clinicians should consider utilising a multi-domain assessment to assist in diagnosing and rehabilitating SRC. However, due to poor test-retest reliability, there may be limited applicability for baseline testing.

1 Introduction

1.1 Background and justification

Ladies Gaelic Football (LGF) is a native Irish sport played exclusively by female athletes (1). It closely resembles men's Gaelic Football, although several rule differences exist between the male and female sports (1). It is one of the most popular female team sports in Ireland (2). LGF is also played outside of Ireland, with communities existing across Europe, the Middle East, North America and Asia (3). Similar to other Gaelic games, LGF is played on an amateur basis at all levels of play (4).

LGF is similar in style of play to Australian Football, soccer, and rugby (5). A field-based team sport involving two teams of fifteen players, it is played using a spherical leather ball slightly smaller than a soccer ball. Players attempt to pass the ball either above or below the crossbar of a H-shaped goalpost (6). Goals are scored by kicking the ball below the crossbar of the goalpost, while points are attained if the ball passes above the crossbar. A goal is equivalent to three points and the winning team is the team with the highest cumulative number of points at the end of the game (6). Adolescent and adult matches last sixty minutes and are played on a pitch measuring 130 to 145m by 80 to 90m (4,6). Teams consist of six forwards, two midfielders, six defenders and a goalkeeper (6). LGF is fast-paced and multi-directional, requiring players to have a wide range of skills including sprinting, kicking, tackling, soloing, jumping, turning, hand-passing and catching. While it is very similar to its counterpart, men's Gaelic Football, there are several notable rule differences between the sports (7). For example, in LGF players are allowed to lift the ball from the ground with their hands while male players are not, while shoulder-to-shoulder contact is permitted in the men's game but not the women's (7).

The Ladies Gaelic Football Association (LGFA) is the international governing body for LGF (8). It is responsible for organising and managing LGF at all levels of play, in Ireland and abroad. LGF is played at multiple levels, emphasising its central role as a community sport. "Nursery LGF" and "Go Games" are non-competitive or semi-competitive activities available for younger players, with the aim of introducing children to the essential skills of the sport (9,10). From the age of twelve, players can participate in organised competitions. Juvenile competitions are divided into age group categories of under thirteen, fourteen, fifteen, sixteen and eighteen (also referred to as the "minor" age group) (11). Adult competitions consist of an under twenty-one age group and three skill-based group levels, of which senior is the highest level followed by intermediate and junior levels (11). In addition to being divided into age and skill-based group competitions, LGF is played at club, county, provincial and educational levels (11). Club competitions are played between individual clubs, which are typically based in local parishes, while county and provincial competitions are played between regional teams comprising players who also play with their own individual clubs (11). Educational competitions are played between secondary schools, which have three junior and three senior

divisions, and higher education institutes, where there are six skill-based divisions (1,12). This multi-tiered structure of LGF competition means that many players may simultaneously play for several teams during the same season. Regardless of age group or level of play, the major LGF competitions are the league and championship competitions (1,11). Club seasons typically run between March and October, encompassing both a club league and championship. County seasons begin in January and run until July (personal communication, June 2022). The length of the season is dependent on how far teams progress in each competition. Educational competitions take place during the academic year. These seasons are approximately the same regardless of the level of play (e.g., senior or junior). Although county players are not paid for playing LGF, the county level is regarded as an elite level of play. County Gaelic games players typically train more often and have more matches, with the intensity of training and matches being higher, and typically have greater access to resources (e.g., medical personnel) than club players (13,14). However, unlike elite, professional athletes they generally also work or study full-time and may have other non-sporting commitments. This possibly increases their overall workload, which may increase injury risk and impair recovery (15). Therefore, elite professional or semi-professional LGF players may not be directly comparable to elite athletes competing in many other sports.

A risk of injury is present in all sport (16). LGF is a non-contact sport, however collision between the player and another player/s, the ball, or with the surrounding environment (e.g., the ground or the goalpost) may nevertheless occur. Therefore, contact-related injuries may result (17). One contact injury of particular concern is sport-related concussion (SRC), a mild traumatic brain injury that may be caused when impulsive forces are transmitted directly (e.g. from a head impact) or indirectly (such as during an impact to another area of the body) to the brain (18). SRC is characterised by functional impairment across multiple domains without physical brain damage; it presents with signs and symptoms relating to cognition, post-traumatic migraine, vestibular-ocular deficits, mood, the cervical spine, and sleep (18–20). SRC is usually self-limiting and most players recover within one month of injury, however between 6% and 28% report impairments that persist beyond this timeframe (21–23). This may lead to difficulty returning to academic and sporting activity (21–23). There has also been concern over the potential long-term consequences of multiple concussions (24–26). While a distinct neuropathology termed chronic traumatic encephalopathy has been retrospectively linked with repeated head trauma (24), a link between repetitive head trauma and multiple other clinical entities, including depression, cognitive impairment and neurodegenerative disorders, has also been proposed (25,26).

Given that the long-term consequences of concussion are poorly understood and that the associated impairments may have far-reaching effects beyond the sporting context, SRC is a serious concern in many sports. In 2018, the LGFA reported that a needs analysis identified SRC as an area of key concern for players, management staff and officials in LGF (27). However, while SRC is anecdotally

perceived to be a major concern in LGF, very little data currently exists on the prevalence or management of SRC among LGF players. Only one prospective study of injuries in LGF has reported that 8.9% of injuries sustained during two collegiate seasons were SRCs (17). Retrospective studies have shown that 57.5%-61.0% of adolescent and adult club athletes believe they may have previously sustained an SRC while playing LGF, however these studies included male and female Gaelic games players and did not report results separately for LGF players (28,29). Nevertheless, they suggest that SRC may be an issue in LGF. Although the LGFA endorse a modified version of international SRC management guidelines (30), it is unknown how closely these guidelines are followed. The potential lack of access to on-site medical personnel in the sport is likely an obstacle to players receiving appropriate medical treatment for SRC. Therefore, a key priority should be establishing the prevalence of SRC and examining SRC management behaviour in LGF.

An additional challenge for clinicians working with LGF players is the highly individualised presentation and trajectory of SRC. Best practice recommends the use of a multi-domain SRC assessment to diagnose and monitor recovery (18–20). Such assessments may incorporate objective measures of neurocognitive function, postural instability, and vestibulo-ocular impairment, as well as subjective self-report measures of mood changes, migraine symptoms, neck dysfunction, and sleep quality (31,32). These assessments are important for identifying players who may be at risk of a prolonged SRC recovery; there are particularly important for clinicians working with female players, who appear to take longer to recover from SRC than male players (33). However, no research has been carried out on multi-domain SRC assessments in LGF, or other female, community sports. SRC assessments may be used in two different ways: (i) by comparing post-SRC results to normative data from a similar population, or (ii) by assessing healthy players at baseline and subsequently comparing post-SRC results against individual pre-injury results (18–20). Therefore, there is a need for (i) normative data from LGF players on a multi-domain SRC assessment, and (ii) test-retest reliability data on a multi-domain SRC assessment to ensure tests are suitable for use as serial assessments.

1.2 Main Aim

This thesis aims to improve SRC management in LGF by examining the prevalence and management of SRC in LGF, presenting normative data on a multi-domain SRC assessment in LGF players, and examining the test-retest reliability of a multi-domain concussion assessment in LGF players.

1.3 Aims and Objectives

Study 1: Concussion prevalence, injury characteristics, and management behaviour in Ladies Gaelic Football

Aim: To describe self-reported concussion history, injury characteristics, and concussion management behaviour in LGF players.

Objectives:

- To examine self-reported concussion history in LGF players and identify differences in self-reported concussion history between elite and non-elite LGF players.
- To identify the characteristics of SRCs experienced by LGF players.
- To describe the clinical profiles of SRCs in LGF players.
- To assess SRC management behaviour in LGF players and differences in possible SRC management based on level of play and whether or not the SRC was diagnosed or suspected.

Study 2: Factors associated with concussion management behaviour in Ladies Gaelic Football players

Aim: To examine factors associated with management of suspected SRCs in LGF.

Objectives:

- To determine whether demographic, concussion history, and psychosocial factors are associated with acute behaviours following a possible SRC.
- To identify whether demographic, concussion history, and psychosocial factors are associated with subacute behaviours following a possible SRC.

Study 3: Normative data for a multi-domain concussion assessment in Ladies Gaelic Football players

Aim: To generate normative data on a multi-domain SRC assessment in healthy LGF players.

Objectives:

- To present descriptive data on a multi-domain SRC assessment in healthy LGF players.
- To report percentiles scores for a multi-domain SRC assessment in healthy LGF players.
- To determine the proportion of players who meet clinical cut-off thresholds on baseline multi-domain SRC assessment measures.
- To examine differences in baseline SRC measures between (i) adult and adolescent players, (ii) elite and non-elite players, and (iii) players with and without a previous diagnosed concussion.

Study 4: Test-retest reliability of a multi-domain assessment for sport-related concussion

Aim: To examine the test-retest reliability of a multi-domain concussion assessment over (i) six- and (ii) twelve-months in LGF players.

Objectives:

- To assess the relative reliability of a multi-domain SRC assessment over six- and twelve-months in LGF players.

2 Literature Review

2.1 Introduction to the Literature Review

Research examining the prevalence of SRC, SRC management practices, and multi-domain clinical assessments for SRC in LGF players is currently lacking and urgently required. Such information would greatly help clinicians to identify, manage, and rehabilitate potential SRCs in LGF. While a considerable body of SRC research already exists, it has mainly focused on athletes participating in US high school or collegiate sports or on professional athletes. Unlike community sports, many of these sports benefit from sophisticated medical infrastructure with on-site medical professionals, clear referral pathways, and follow-up guidelines (34–36). Managing SRC in LGF and other community sports, where medical cover may be unavailable, presents additional challenges. The SRC literature has also traditionally focused on male athletes, and although this is changing, many existing studies fail to report data separately by gender. Considering that female athletes may be at an increased risk of prolonged SRCs (33), combined data for male and female athletes may be of limited benefit. This literature review will therefore focus, where possible, on data from female athletes participating in team sports. It will review the epidemiology of SRC, normative and test-retest reliability data for a multi-domain SRC assessment, and SRC management practices.

2.2 Description of sport-related concussion

2.2.1 Definition of sport-related concussion

Concussion is a biomechanically-induced brain injury involving transient neurological dysfunction without physical brain damage (20,37–39). Although the terms mild Traumatic Brain Injury (mTBI) and concussion are sometimes used interchangeably (19,39), they differ in diagnostic criteria, with mTBI reflecting a broader spectrum of injury that may include focal neurological pathologies (18,38,40). Diagnostic criteria for mTBI include a Glasgow Coma Scale score of 13–15 30 minutes post-injury, combined with at least one of the following: altered mental status at the time of injury, loss of consciousness ≤ 30 minutes duration, post-traumatic amnesia that resolves within 24 hours, and focal neurological deficits (40). Conversely, concussion is typically diagnosed on the basis of a clinical assessment that may involve measures of neurocognitive and postural dysfunction and subjective symptom reporting (37,38). SRC refers to concussions sustained in a sporting context. Due to the specific population and challenges associated with SRC (i.e., returning to sporting activity and the potential for repeated head impacts), there exists a distinct SRC subfield within the mTBI literature.

Clear SRC definitions are essential as they facilitate the development of diagnostic and management guidelines. Multiple definitions of SRC have been suggested by national and international medical bodies (see Table 1) (20,37–39,41,42). They have typically focused on characteristics such as the mechanism of injury, injury onset, and the possible occurrence of loss of consciousness. The definition developed by the Concussion in Sport Group (CISG) has been widely adopted by sporting

bodies, including the LGFA (30,36). It describes the mechanism, onset, nature of impairment, imaging findings, presence of loss of consciousness, duration and resolution of SRC, and clarifies that symptoms should not be explained by another condition (37). In addition, it advises that an SRC assessment should include an evaluation of cognitive, somatic, and affective symptoms, neurocognitive function, balance, vestibular and ocular impairments, and sleep (18).

Table 1: Sport-related concussion definitions

Author (Year)	Definition	Characteristics of Definition	Suggested Clinical Assessment
Congress of Neurological Surgeons (1966)	"A clinical syndrome characterised by the immediate and transient post-traumatic impairment of neural function such as alteration of consciousness, disturbance of vision or equilibrium due to mechanical forces." (42)	• Traumatic mechanism. • Acute onset. • May involve LOC.	• Not reported.
American Academy of Neurology (1997, 2013)	"Concussion is a trauma-induced alteration in mental status that may or may not involve loss of consciousness. Confusion and amnesia are the hallmarks of concussion. The confusional episode and amnesia may occur immediately after the blow to the head or several minutes later." (41,43)	• Traumatic mechanism. • Acute onset. • May involve LOC.	• Symptoms. • Neurocognitive function. • Balance problems.
National Athletic Trainers Association (2014)	"Trauma-induced alteration in mental status that may or may not involve loss of consciousness." (39)	• Traumatic mechanism. • May involve LOC.	• Concussion and personal/family medical history. • Symptoms. • Mental status. • Eye examination. • Muscle strength. • Motor control. • Neurocognitive function.
Concussion in Sport Group (2017)	"SRC is a traumatic brain injury induced by biomechanical forces. Several common features that may be used in clinically defining the nature of a concussive head injury include: • SRC may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head. • SRC typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours. • SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies. • SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases symptoms may be prolonged. The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc) or other comorbidities (e.g. psychological factors or coexisting medical conditions) (18)."	• Traumatic mechanism. • Acute onset. • Involves functional impairments. • Negative imaging findings. • May involve LOC. • Sequential resolution. • Symptoms may be prolonged. • No other explanations for signs and symptoms.	• Medical history. • Mental status. • Cognitive, somatic, and emotional symptoms. • Physical signs (e.g., LOC). • Motor control. • Vestibular function. • Ocular function. • Neurocognitive function. • Sleep difficulties.
American Medical Society for Sports Medicine (2019)	"A traumatically induced transient disturbance of brain function that involves a complex pathophysiologic process. Concussion is a subset of mTBI which is classified based on acute injury characteristics at the less severe end of the brain injury spectrum. The clinical signs and symptoms of concussion cannot be otherwise explained by drug, alcohol, medication use, other injuries (such as cervical injuries or peripheral vestibular dysfunction), or other comorbidities (psychological or medical conditions (20))."	• Traumatic mechanism. • Acute onset. • No other explanation for signs and symptoms.	• Physical signs. • Symptoms. • Cervical spine. • Neurocognitive function. • Vestibular function. • Ocular function.

<i>Author (Year)</i>	<i>Definition</i>	<i>Characteristics of Definition</i>	<i>Suggested Clinical Assessment</i>
Team Physician Consensus Statement (2021)	“SRC is a traumatic brain injury, a pathophysiological process affecting the brain, induced by direct or indirect biomechanical forces. Common features include the following: • Rapid onset of usually short-lived neurological impairment, which typically resolves spontaneously. • Acute clinical symptoms that usually reflect a functional disturbance rather than structural injury. • A range of clinical symptoms that may or may not involve LOC. • Routine neuroimaging studies (e.g., traditional CT or MRI) are typically normal. Signs or symptoms that are not explained by other medical issues (e.g., alcohol, drugs, medications, cervical spine injury, peripheral vestibular dysfunction, psychological disorder) or other co-morbidities.” (19)	• Traumatic mechanism. • Acute onset. • Spontaneous resolution. • Involves functional impairments. • May involve LOC. • Negative imaging findings. • No other explanation for signs and symptoms.	• Concussion and medical history. • Physical signs. • Cognitive, somatic, and emotional symptoms. • Cranial nerves. • Neurocognitive function. • Balance.

LOC: Loss of consciousness; SRC: Sport-related concussion; mTBI: Mild traumatic brain injury; CT: computerised tomography; MRI: magnetic resonance imaging.

2.2.2 Biomechanics of sport-related concussion

SRCs are caused when external forces are transmitted to the head during an impact, causing the head to undergo linear and rotational accelerations (44–46). These accelerations may damage the neural tissue if they exceed an injury threshold (47). In team sports, most impacts that lead to SRCs involve contact between players, with a piece of equipment (e.g., the ball), or with the surrounding environment (e.g., the ground or a fence) (48–50). Linear and rotational accelerations were originally studied separately and were thought to result in different types of traumatic brain injury. Linear accelerations were associated with increased intra-cranial pressure and severe traumatic brain injuries (51,52), while rotational accelerations were associated with shearing of the brain tissue and concussive injuries (53). However, it is now acknowledged that linear and rotational accelerations of the head rarely occur in isolation, and that SRCs likely involve both (54).

Researchers have attempted to uncover a threshold of acceleration at which SRCs may occur by using accelerometers embedded in helmets to measure head impacts. Most of this research has focused on male athletes participating in American football, rugby, and ice hockey (55). In comparison, only one study has focused on female athletes and found that female collegiate ice hockey players diagnosed with an SRC had sustained mean impacts of $43.0 \pm 11.5g$ linear acceleration, and $4030 \pm 1435 \text{ rad/s}^2$ rotational acceleration (56). However, only four participants in this study sustained an SRC that was associated with a single impact. The incidence of SRC is higher in female than male athletes. It is possible that female athletes may sustain SRCs at lower thresholds than male athletes (55,56), however further research is needed in this area. This may assist in developing injury prevention strategies. For example, it has been suggested that neck strength is correlated with SRC risk, with stronger neck muscles potentially protecting against SRC by providing resistance against rotational accelerations of the head (57). Increased understanding about injury thresholds may assist in the development and evaluation of neck strengthening programmes for decreasing the risk of SRC.

2.2.3 Pathophysiology of sport-related concussion

Animal studies have provided insight into the suggest pathophysiology of SRC (58). During an SRC, mechanical disruption of the neurons impairs their ability to function normally and triggers a complex metabolic reaction (58–60). Neuronal shearing leads to an initial uncontrolled flow of ions, caused by mechanoporation of the cell membrane (61,62). The loss of the partition between the cell interior and exterior sees the gradients of ionic species between the cell interior and exterior disturbed; with intracellular stores of potassium ions leaking from the cell interior to the extracellular space, while extracellular levels of sodium and calcium ions travel in the opposite direction. The loss of these ionic gradients leads to a process of diffuse depolarization (61,62). Depolarization enables communication between nerves by triggering the release of substances called neurotransmitters (63). Widespread depolarization triggers the release of the excitatory neurotransmitter glutamate, which

initiates a cycle of further depolarization through its action on ion channels (64,65). In an attempt to restore ionic balance, the sodium-potassium ion pumps in the cell membranes require increased energy and dramatically increase their energy consumption (66). This increase in energy consumption coincides with a reduction in cerebral blood flow, leading to a dependence on glycolysis and ultimately an energy crisis (66–69). Multiple other secondary pathophysiological effects of concussion have been reported, including changes in excitatory and inhibitory neurotransmitters (70,71), cytoskeletal and axonal damage (72,73), and immunoexcitotoxicity(74) (see Table 2).

Researchers have attempted to correlate these pathophysiological processes with the clinical presentation of SRC (58). The initial ionic flux observed following the onset of a concussion has been likened to the spreading depression observed in migraines, consisting of a slow wave of depolarization and a subsequent reduction in neural activity (58,75). This mechanism has been suggested to be responsible for migraine auras, which share some symptoms of SRC (such as headaches, photophobia, phonophobia and nausea), although they also present with an array of visual disturbances and sensory phenomena not reported in SRC (31,75). Furthermore, it has been suggested that the energy crisis reported following an SRC may contribute to a window of increased vulnerability to further injury or delayed recovery (58,76). This corresponds with findings that athletes who do not rest immediately following a concussion have longer recovery times than those who take immediate rest (77). Additional suggested mechanisms for cognitive and mood-related disturbance following an SRC are presented in Table 2. While it has been theorised that specific pathophysiological processes may correlate with distinct SRC symptoms, it is important to note that the existing data are not conclusive: many of the studies highlighted have involved animal models and have not verified their hypotheses in human participants (78–80), have included a spectrum of TBI severity (81,82) or have measured physiological processes indirectly (81,82).

Table 2: Pathophysiology of concussion and possible corresponding clinical manifestations

Stage	Mechanism	Timeframe	Description	Suggested Clinical Manifestation
Ionic Flux	Shearing of neurons damages the cell membrane through mechanoporation.	Immediate (65).	- Potassium is released into the extracellular space, inducing diffuse depolarization (61,62)). - During depolarization, excitatory neurotransmitters, such as glutamate, are released (65). - Glutamate binds to two ionic channels (NMDA and AMPA), triggering further depolarization (70,71).	Migraine-type symptoms (e.g. headache, nausea, photophobia, phonophobia, dizziness) (58,75).
	Excitatory neurotransmitter release.	Immediate release that returns to normal within minutes, followed by region-specific impairments from 72 hours to 2 weeks post-injury (45).	- Calcium and sodium flow into the cell, causing damage to cells and impairment of the mitochondria (83). - Widespread neuronal impairment, termed “spreading depression” results (58).	
Energy Crisis	Increased energy demands combined with reductions in cerebral blood flow.	30 minutes to 6 hours post-injury (66).	- To re-establish the balance caused by potassium efflux and sodium and calcium influx, sodium-potassium (Na⁺/K⁺) pumps in the cell membrane activate. They require high levels of glucose and rapidly deplete cell energy stores (66). - Cells therefore need to rely on glycolysis, a form of anaerobic energy production, resulting in an accumulation of lactate (66). - Cerebral blood flow is simultaneously reduced (68,69).	- Possible window of vulnerability to further injury (58,76). - Reductions in glucose metabolism correspond with working memory impairments in rats (78). - Associated with impairments in spatial learning in animals (79).
		7 to 10 days post-injury (66,67).	Combined with the increased energy demands, this reduction in blood flow leads to uncoupling between energy availability and demand, and a subsequent energy crisis (66,67).	
Alterations in Neuro-transmission	Mechanical damage to neurons damages ion channels.	Immediate (65).	- Glutamate receptor NMDA alterations are associated with changes in calcium flux, phosphorylation and gene activation (71). - GABA and its receptors have been reported (84).	- Changes in glutamatergic neurotransmission may affect working memory (58,85–87). - GABA-disruption may be associated with development of post-TBI anxiety (80).
Axonal and Cytoskeleton Injury	Shearing of the neuron and glia.	Begins 6 hours post-injury, peaking at 24 hours post-injury (88,89).	- Neurofilaments and microtubules are disrupted, impairing axonal transport and reducing neurotransmission (90,91). - Cell death not reported following mTBI (78).	- mTBI-associated axonal damage is associated with impairments in novel object recognition in rats (78). - White matter damage is correlated with neurocognitive impairment in more severe TBI (81,82).
	Calcium flux into cells.		- Excessive amounts of calcium also lead to microtubule damage (88,89). - Accumulation of calcium in the cells may damage neurofilament side-arms through phosphorylation (72,73).	
Inflammation	Physical damage to nerve cells.	-	Increased immune receptor activity may increase oxidative stress (immunoexcitotoxicity) (74,92).	-
Blood-Brain Barrier Disruption	Shearing of endothelial cells.	6-72 hours post-injury (93).	Increased permeability of blood-brain barrier and reduction in junctional adhesion proteins.	-

NMDA: N-methyl-D-aspartate; AMPA: D-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid; GABA: Disruption of γ -aminobutyric acid; TBI: Traumatic brain injury; mTBI: Mild traumatic brain injury.

2.2.4 *Persistent post-concussion symptoms*

While SRCs are expected to resolve clinically within two to four weeks (18,20,38), 10.3%-17.3% of athletes experience symptoms beyond this timeframe (see Table 3). This may lead to difficulty in resuming academic, sporting, and other activities. The CISC have defined persistent post-concussive symptoms as symptoms that do not resolve within the anticipated timeframes (18). The median time to symptom resolution following an SRC has been reported to be between eight and nine days in collegiate athletes (94,95), while adolescent athletes have been shown to remain symptomatic for means of 11.0-15.1 days (96). Number of days until unrestricted return-to-play as determined by medical personnel have ranged from medians of 12.8-17.0 days in collegiate athletes (94,95,97,98) and means or medians of 11.0-21.7 days in adolescent athletes (22,23,96,99). However, 13.1% of collegiate athletes do not fully return to academics by 28 days post-SRC (94), and 6.0%-28.2% of adolescent athletes (21,23,99) and 13.0%-26.7% of collegiate athletes do not fully return to sport by 28 days post-SRC (94,95,98). Certain pre-existing and post-injury factors may increase the risk of prolonged symptoms following an SRC. Female and younger athletes appear to take longer to recover from SRC than male and older athletes. Between 7.6% and 28.2% of female athletes have not returned to full contact play 28 days post-SRC, compared with 6.0%-19.6% of male athletes (21–23,98,99). A meta-analysis comparing recovery in high school and collegiate athletes found self-reported symptom resolution occurred 15 days post-injury in high school compared with six days post-injury in collegiate athletes (100). Medical history (e.g., a previous concussion, migraine, depression or anxiety, learning disorder (LD) or attention deficit hyperactivity disorder (ADHD)), in addition to factors relating to the injury incident (e.g., symptom burden) and management (e.g., continuing to play with symptoms) may also be associated with longer recovery times (33). Athletes with prolonged symptoms may require more targeted treatment beyond rest and graded increases in activity. Targeted treatment is typically individualised and addresses symptoms using specific modalities (e.g., vestibular therapy to address balance problems).

Table 3: Sport-related concussion recovery timeframes

Author (Year)	Participant Characteristics		Symptom Resolution		Return-to-academics		Return-to-sport	
			Days	Prolonged	Days	Prolonged	Days	Prolonged
O'Connor (2017) (21)	High school athletes from 147 schools.	All: Male: Female:	-	- 10.3% ≥ 28 days 14.8% ≥ 28 days	-	-	-	23.0% ≥ 28 days 14.7% ≥ 28 days 28.2% ≥ 28 days
Bretzin (2018) (22)	3322 SRCs reported in high school athletes. 66.0% male.	Male: Female:	-	-	-	-	Mean: 12.0 ± 12.1 Mean: 13.8 ± 12.9	-
Schneider (2018) (99)	143 SRCs reported in youth ice hockey players. 84.6% male. Males: 26.4% age 13-14, 73.6% age 15-17; females: 40.9% age 13-14; 59.1% age 15-17.	Male: Female:	-	-	-	-	Median: 17 Median: 19	19.8% ≥ 30 days 18.2% ≥ 30 days
Tamura (2020) (96)	726 SRCs reported by high school athletes. 62.5% male; mean age=15.5±1.2.	All: Age 14: Age 15: Age 16: Age 17:	Mean: 13.6 ± 10.6 Mean: 14.6 ± 11.2 Mean: 15.1 ± 11.2 Mean: 14.5 ± 11.0 Mean: 11.0 ± 9.6	-	-	-	Mean: 20.5 ± 14.3 Mean: 21.7 ± 15.6 Mean: 21.4 ± 12.4 Mean: 21.4 ± 14.5 Mean: 17.0 ± 14.3	-
Bretzin (2021) (94)	1,974 collegiate athletes. 61.3% male; mean age- male=19.96±1.3, female=19.57±1.2.	All: Male: Female:	Median: 9 Median: 8 Median: 9	15.6% ≥ 28 days 14.4% ≥ 28 days 17.3% ≥ 28 days	Median: 8 Median: 7 Median: 9	13.1 % ≥ 28 days 11.9% ≥ 28 days 14.9% ≥ 28 days	Median: 16 Median: 15 Median: 17	25.1% ≥ 28 days 19.6% ≥ 28 days 26.7% ≥ 28 days
Covassin (2021) (23)	15821 SRCs reported in high school athletes. 65.6% male	All: Male: Female:	-	-	-	-	Median: 11	6.5% ≥ 28 days 6.0% ≥ 28 days 7.6% ≥ 28 days
Master (2021) (97)	1071 SRCs reported in collegiate athletes.	All: Male: Female:	-	-	-	-	Median: 11.8 Median: 13.5	-
Brogli (2022) (98)	1751 collegiate athletes. 63.0% male. Mean age=19.2±1.3.	All: Male: Female:	-	-	-	-	Median: 12.8	15.0% ≥ 28 days 13.0% ≥ 28 days 18.0% ≥ 28 days
Wiebe (2022) (95)	1715 collegiate athletes. 68.4% male; median age=20.	All:	Median: 8	-	Median: 6	-	Median: 14	21.2% ≥ 28 days

SRC: Sport-related concussion.

2.3 Epidemiology of sport-related concussion

2.3.1 Prevalence of sport-related concussion in Ladies Gaelic Football

Currently, very little epidemiological research exists on the prevalence of SRC in either male or female Gaelic football (see Table 4). Only three studies have examined SRC prevalence in LGF (28,29,101). Two of these studies were retrospective cross-sectional studies that included male and female athletes participating in Gaelic games and did not report data separately for LGF players (28,29). These studies reported that 57.5% of adolescent Gaelic games athletes and 72.7% of adult Gaelic games athletes believed they had previously sustained a possible SRC, but that only 31.0% of these adolescents and 39.8% of these adults had been diagnosed with an SRC by a medical professional. However, these studies recruited participants using convenience sampling, which may have resulted in participants with a history of SRC being overrepresented. Furthermore, they relied on self-report and did not provide a standardised definition of SRC. One prospective study has examined injury rates in collegiate LGF athletes, and reported that 8.9% of injuries over two seasons were SRCs (17). While this study suggests that SRC is a problem in LGF, there is a need for more research that specifically examines SRC in LGF players and includes both adolescent and adult county (elite) and club (non-elite) players in order to improve our understanding of SRC in the sport.

Table 4: Epidemiology of sport-related concussion in Ladies Gaelic Football

Author (Year)	Participant Characteristics	Study Design	Concussion Definition	Findings
O'Connor (2019)	113 male and female adolescent Gaelic games athletes. 69.9% male. 21.2% were under 14, 39.8% were under 16, and 38.9% were under 18.	Retrospective cross-sectional survey administered to local clubs.	Not provided.	57.5% of participants reported a previous suspected or diagnosed SRC. 31.0% of participants had previously been diagnosed with an SRC.
Leahy (2020)	231 male and female Gaelic games athletes. 48.5% male.	Retrospective cross-sectional survey administered online.	Not provided.	72.7% of participants reported a previous suspected or diagnosed SRC. 39.8% of participants had previously been diagnosed with an SRC.
O'Connor (2021)	Collegiate LGF players (season 1 n=50, season 2 n=82).	Two-season prospective study of collegiate LGF teams.	Diagnosed by student athletic therapists and a qualified clinician (Certified Athletic Therapist or Chartered Physiotherapist).	10.13% of time-loss injuries involved the head. - SRC comprised 8.86% of time-loss injuries - SRCs resulted in 24.91 days absent per 1000 hours.

SRC: Sport-related concussion; LGF: Ladies Gaelic Football.

2.3.2 Prevalence of sport-related concussion in female, team sports

Overall, epidemiological research focusing on SRC in other female, team sports is limited. Only two studies have examined SRC in women's Australian Football, which resembles LGF in playing style (102,103). One study compiling injury information from multiple sources (including insurance claims, emergency department presentations, hospital admissions and self-reported injuries during the West Australian Women's Football League), found that concussions accounted for 1% of insurance claims, 3.2% of emergency department presentations, 9.8% of hospital admissions and 32.7% of self-reported injuries (103). Another study found that 6% of women's Australian Football players reported that their worst injury of the previous season had been a concussion (102). The design of these studies limits an accurate understanding of SRC prevalence or incidence in women's Australian Football from being attained.

Six prospective studies have examined SRC epidemiology in female rugby and soccer players (see Table 5) (104–109). Two studies included collegiate athletes (105,106), two included amateur adult athletes (109,110), one focused on international adult athletes (107), and one examined adolescent athletes (108). SRCs comprised between 14.3% and 30.0% of reported injuries in these studies (107,108,111). A systematic review including several of these studies also concluded that the incidence rate of SRC was 2.8 per 1000 hours of match play for female rugby-15s and 8.9 per 1000 hours of match play for female rugby-7s (111). SRC incidence and prevalence has been well-researched in American female high school and collegiate soccer players. Since 2015, three prospective studies have examined SRC epidemiology in female collegiate athletes (48,112,113), and five prospective studies have examined SRC epidemiology in female high school athletes (21,23,49,114,115), however none have focused on community sport. Injury rates of 18.30-19.38 per 10000 athletic exposures have been reported for collegiate athletes (48,112,113), while among high school athletes injury rates have ranged from 12.80-18.90 SRCs per 10000 AEs (21,23,114,115). An AE is defined as a single athlete taking part in one match or training session (116). It has also been reported that SRCs account for 10.7% of injuries sustained during matches among collegiate athletes (112), while 14.6%-24.5% of match injuries in high school athletes are SRCs (115). While these studies show that SRC is common in female team contact sports, it is unclear how relevant the findings are to LGF. Based on the lack of available evidence on SRC incidence in female team sports, more research is warranted; particularly in sports such as LGF in which there has been no research conducted in either adolescent or adult players, or at the elite and non-elite levels.

Table 5: Prospective studies of sport-related concussion in soccer and rugby

Author (Year)	Participant Characteristics	Findings
<i>Rugby</i>		
Kerr (2008)	Male and female collegiate rugby union players.	• SRC injury rate of 1.58 per 1000 player-game hours (n=25) for matches. • SRC injury rate of 0.30 per 1000 AEs (n=7) for training.
Peck (2013)	129 female collegiate rugby players.	• SRC injury rate of 4.37 per 10000 (n=30) AEs.
Lopez (2020)	61 female under-19 rugby-7s teams. Mean age=16.7±1.2.	• 14.3% (n=30) of injuries were SRCs.
Fuller (2021)	1562 female international rugby-7s players	• 15.6% of injuries were SRCs.
King (2021)	69 female amateur rugby union players.	• SRC injury rate of 0.3 per 1000 training hours (n=1). • Injury burden of 30 days.
Yeomans (2021)	Female amateur rugby union players. ¹ Mean age=27.2±5.3.	• 5.5 SRCs per 1000 player-hours. • Median of 21 days missed per SRC.
<i>Soccer</i>		
Zuckerman (2015)	Female collegiate athletes.	• Injury rate of 19.38 SRCs per 10000 AEs of match play. • Injury rate of 2.14 SRCs per 10000 AEs of match play. • 52.9% due to contact with another player. • 12.5% of SRCs were recurrent.
Roos (2016)	Female collegiate athletes.	• Injury rate of 1.83 SRCs per 1000 AEs of match play. • Injury rate of 0.20 SRCs per 1000 AEs of training. • 10.7% of injuries during matches are SRCs. • 3.5% of injuries during training are SRCs.
Covassin (2016)	Female high school athletes.	• Injury rate of 18.90 SRCs per 10000 AEs of match play. • Injury rate of 2.41 SRCs per 10000 AEs of match play. • Mean time loss of 9.33 ± 8.54 days.
Khodaei (2017)	Female high school athletes.	• 19.0% of injuries were SRCs. • 51.1% of SRCs occurred due to contact with another player.
O'Connor (2017)	Female high school athletes.	• Injury rate of 17.16 SRCs per 10000 AEs for matches. • Injury rate of 2.96 SRCs per 10000 AEs for training.
Schallmo (2017)	Female high school athletes.	• Injury rate of 3.58-9.10 SRCs per 10000 AEs. • 15.2%-34.5% of injuries were SRCs.
DiStefano (2018)	Female high school athletes.	• Injury rates of 0.09-0.23 SRCs per 1000 AEs for training. • Injury rates of 1.28-1.91 SRCs per 1000 AEs for matches. • 14.6%-24.5% of match injuries were SRCs.
Chandran (2021)	Female collegiate athletes.	• Injury rate of 18.53 SRCs per 10000 AEs for matches. • Injury rate of 3.42 SRCs per 10000 AEs for training.

SRC: Sport-related concussion; AE: Athletic-exposure.

2.4 Baseline concussion assessments

2.4.1 Models of sport-related concussion management

In recent years, concussion has increasingly been recognised as a complex, heterogenous injury that may cause impairment across multiple domains of neurological function (31,32,117,118). Dysfunction may manifest as cognitive impairments (119), post-traumatic migraine (120), vestibular and ocular deficits (121), low mood (122), sleeping difficulties (123), cervicogenic injuries (124), or autonomic nervous system disturbances (125). Understanding more about the risk factors, presentation, and clinical trajectories associated with these domains may allow clinicians to develop individualised treatment plans for players with SRC. Two models that attempt to explain the different clinical presentations of SRC have been developed (31,117). The Post-Concussion Disorders model suggests that there may be three subtypes of SRC based on differing underlying pathophysiologies (117), while the Clinical Profiles (CP) model describes five possible post-SRC clinical trajectories (31).

2.4.1.1 The Post-Concussion Disorders model

The Post-Concussion Disorders model, developed by Ellis and Leddy, aims to explain persistent post-SRC symptoms (see Figure 1). It theorises that there are three subtypes of Post-Concussion Disorder: cervicogenic, vestibulo-ocular, and physiological (117). According to the model, cervicogenic Post-Concussion Disorder arises when a cervical spine injury co-occurs with an SRC. This may result in somatosensory dysfunction and present with symptoms of headache, neck pain, dizziness, and postural instability. Vestibulo-ocular Post-Concussion Disorder refers to impairments of the vestibular and ocular systems, which may lead to dizziness, postural instability, and visual problems. Physiological Post-Concussion Disorder is purported to occur due to changes in cerebral metabolism and is characterised by autonomic nervous system dysfunction, such as an increased heart rate, headaches, nausea, and sensitivity to light and noise. Unlike the cervicogenic and vestibulo-ocular Post-Concussion Disorders, symptoms of physiological Post-Concussion Disorders are aggravated by cognitive and aerobic physical activity. Players with SRC are classified as having a physiological Post-Concussion Disorder if they experience symptom aggravation while completing a graded exercise treadmill test (126). Different rehabilitation methods have been suggested for the individual Post-Concussion Disorders (e.g., manual therapy for cervicogenic Post-Concussion Disorder, vestibular and ocular therapy for vestibulo-ocular Post-Concussion Disorder, and sub-symptomatic aerobic exercise for physiological Post-Concussion Disorder). However, evidence for the existence of these separate Post-Concussion Disorders is lacking. One study that compared symptoms between players diagnosed with physiological Post-Concussion Disorder and those diagnosed with cervicogenic or vestibular-ocular disorder did not find any differences between groups (126). Furthermore, the model does not account for all documented SRC signs and symptoms (e.g., sleep difficulties) and no studies have attempted to validate the model in players with persistent post-SRC symptoms.

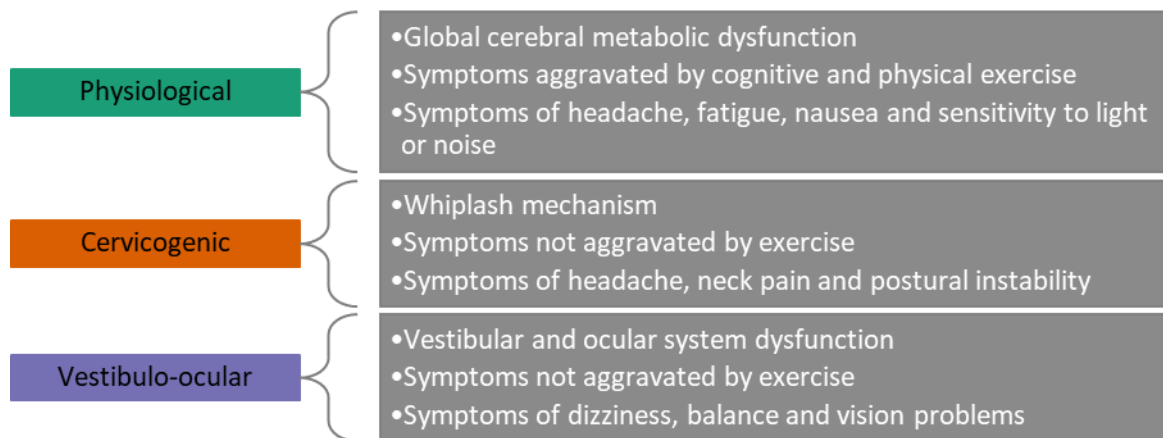


Figure 1: The post-concussion disorders model developed by Ellis and Leddy (117)

2.4.1.2 Clinical Profiles model

According to the CP model developed by Kontos and Collins, SRCs may present as one or more of five clinical profiles (see Figure 2) (31). These profiles comprise dysfunction across cognitive, post-traumatic migraine, vestibular, ocular, and mood domains. Profiles are associated with distinct risk factors, symptoms, and clinical findings, and may be used to guide rehabilitation (e.g., players with cognitive dysfunction may require academic adjustments, while vision therapy may be used to treat players experiencing an ocular profile). Cervical spine and sleep-related factors are incorporated into the CP model as “modifiers” as they represent domains of post-SRC dysfunction, affect other domains of function, and can be modified (e.g., sleep difficulties frequently occur following an SRC (127) and may exacerbate cognitive impairment (128), however sleep quality can also be improved through behaviour).

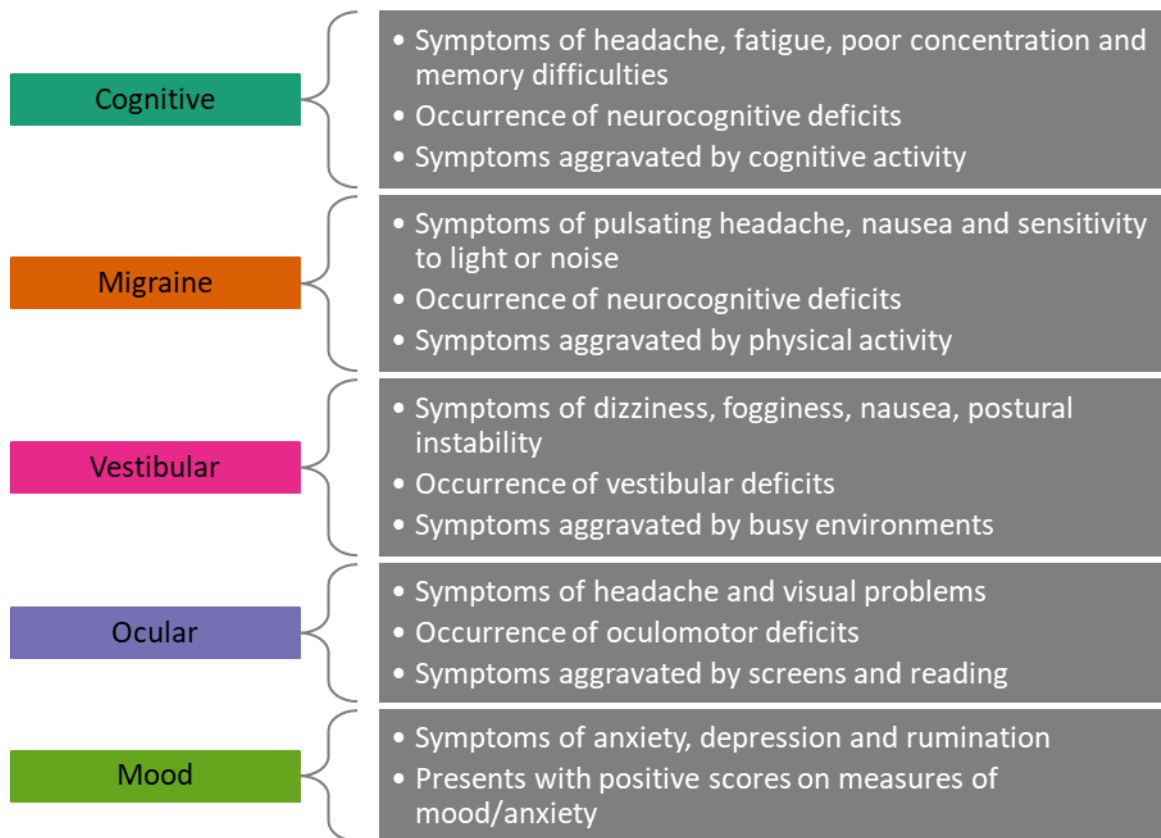


Figure 2: The clinical profile models developed by Kontos and Collins (31)

The CP model was primarily developed based on clinical experience and it has only been partially validated. One study performed an explanatory factor analysis of the Post-Concussion Symptom Scale (PCSS) in a large sample (n=1438) of athletes within one week following an SRC, and identified four symptom factors: cognitive-fatigue-migraine, affective, somatic, and sleep-arousal (see Figure 3)(129). The authors suggested that the acute post-concussion period may be characterised by general cognitive, fatigue and migraine symptoms, which may then diverge into distinct clinical trajectories (129,130). However, no research on clinical profiles in the subacute or chronic phases of injury have been carried out. While the above findings support the existence of multiple symptom trajectories following an SRC, there is a need for further validation research in the CP model. Unlike the Post-Concussion Disorders model, the CP model incorporates a broader range of SRC signs and symptoms. It also describes the risk factors, clinical assessment findings, and outcomes for each profile in greater detail, making it more useful for clinicians working with players with SRC.

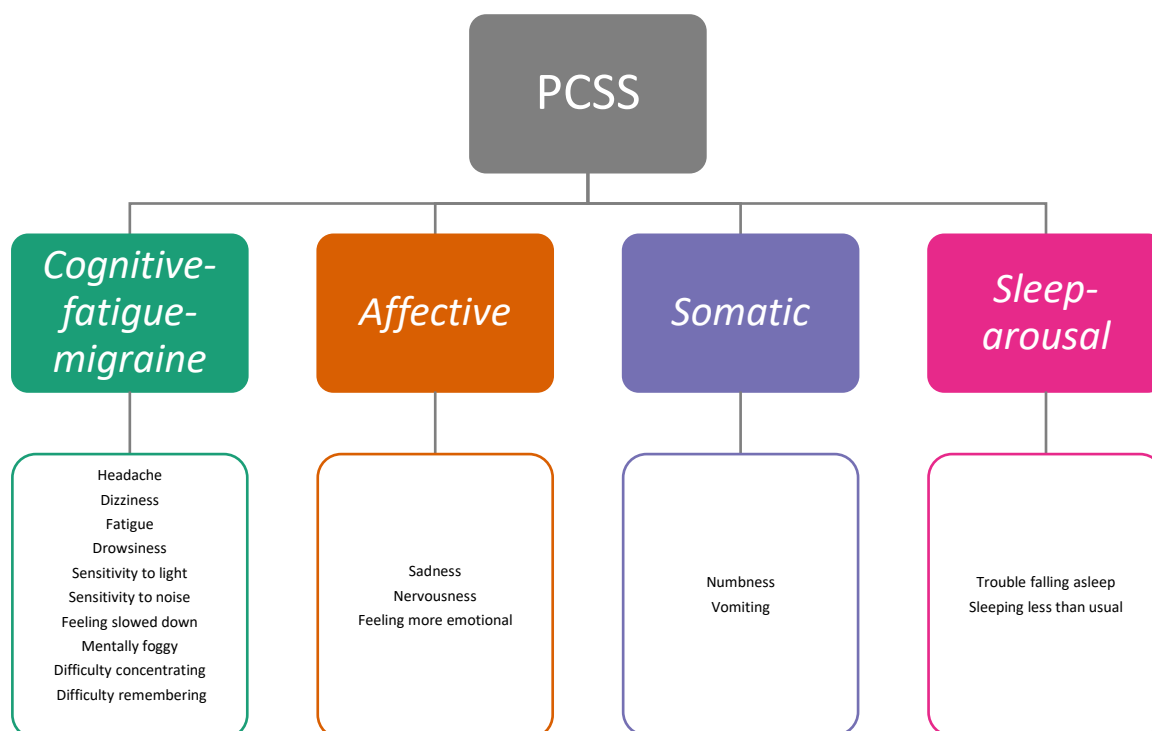


Figure 3: Post-concussion symptom factors derived from the Post-Concussion Symptom Scale (PCSS) (129)

2.4.1.2.1 Clinical Profiles screen

The Clinical Profiles (CP) Screen may assist clinicians in identifying post-SRC clinical profiles. The CP Screen is a 29-item symptom report form that was developed based on the CP model (131). Unlike other SRC symptom report forms (e.g., the Graded Symptom Checklist (GSC) (132) or the Post-Concussion Symptom Scale (PCSS) (133)) which assess general symptoms of SRC and provide an overall symptom score, the CP Screen focuses on the specific clinical profiles and produces seven subscale scores for the profiles and modifiers. The CP Screen has demonstrated high internal validity among athletes with ($\alpha=0.92$) and without ($\alpha=0.87$) SRC (131). The five CP Screen profile scores have also shown adequate accuracy in distinguishing between players with and without SRC (cognitive- area under the curve (AUC)=0.81; migraine- AUC=0.93; vestibular- AUC=0.85; ocular- AUC=0.88; mood- AUC=0.71) (131). However, the control and SRC groups were not well matched on several demographic characteristics in this study, with the SRC group being significantly older and containing a higher proportion of female participants and participants with a history of concussion and migraine than the control group. Currently, no studies have examined the test-retest reliability of the CP Screen or presented normative data on it in any population. This information is required for clinicians who may wish to incorporate the CP Screen into SRC assessments.

2.4.2 Criteria for inclusion in a clinical assessment

Clinical assessments allow clinicians to diagnose, manage, and/or treat SRC. When selecting tests to include in a clinical assessment, consideration should be given to the test psychometric properties, such as test validity and reliability. Validity describes whether a test measures what it is intended to measure, while reliability refers to the degree to which a test produces consistent measurements (134–136). Conducting pre-season baseline assessments is often considered the best practice for managing SRC as (i) it allows clinicians to identify players who may be at an increased risk of SRC or a prolonged recovery, and (ii) it provides a pre-injury standard against which post-injury scores can be compared for each player. However, baseline assessments are expensive and time-consuming to carry out, and the capacity to conduct baseline testing in community sports may be limited due to the lack of medical professionals. Although the baseline-retest approach may be the most accurate method of identifying SRC (137,138), using population-specific normative data has been shown to be an adequate alternative when the baseline data is unavailable (137,139). The advantages and disadvantages of both approaches are described in Table 6.

Table 6: Comparison of the baseline-retest and normative data approaches

	Baseline-Retest Approach	Normative Data Approach
Advantages:	• May identify players at a greater risk of SRC or SRC complications (33). • Provides an individual pre-injury standard and may be more accurate in identifying SRCs (137,138).	• Easy to implement. • Normative data drawn from a similar population has adequate accuracy in identifying SRC (137,139).
Disadvantages:	• Resource- and time-limited. • Serial re-assessments may be associated with practice effects. • Low test-retest reliability for the relevant timeframe may make interpretation of test scores difficult (140).	• Normative data may not be available for the population. • Normative data drawn from a different population may not be accurate (141).

SRC: Sport-related concussion.

2.4.2.1 Validity

Validity refers to a test's ability to measure what it claims to measure (135,142,143). It is a property of how a test is interpreted as opposed to the test itself; therefore, validity should be established for each intended use of a test (e.g., the Generalized Anxiety Disorder scale (GAD7) should be validated separately for uses in patients with anxiety and patients who have an SRC) (134). Validity can be broadly categorised as content, construct, criterion, and diagnostic accuracy validity. Content validity refers to the ability of a test to measure the entirety of a construct, whereas construct validity is a measure of whether the test assesses the construct it is supposed to assess. Criterion validity examines whether test results correspond with other tests measuring similar constructs (135,142,143), and diagnostic accuracy evaluates whether a test can distinguish between patients with and without a condition (144). It is recommended that researchers examine several types of validity depending on the intended uses of a test. The types of validity and their uses are described in detail in Table 7.

Table 7: Types of validity

Type of Validity	Explanation	Types	Description	Measure	Examples from the SRC Literature
Content	The degree to which a test measures an entire construct.	Content validity	Refers to whether a test contains all relevant content and excludes irrelevant content. Initial step in validation process.	Determined by a literature review or panel of experts. Agreement between raters can be assessed using an Index of Content Validity or a Content Validity Ratio.	Content validity for the CP Screen was established through a review of the literature and discussions with experts. 80% of experts had to agree for an item to be retained (131).
		Face validity	Refers to whether an instrument appears to measure what it claims to measure and whether the test appears relevant to participants.	Not measured statistically.	Not typically reported.
Construct	The degree to which a test measures the relevant construct. Used when a test is based on a theory. Hypotheses should be formed and tested about the correlations with other tests.	Convergent	Assesses the extent to which a test correlates with another test. Can be used if no gold-standard tests for comparison exist.	Correlation coefficient.	- The SCAT3 symptom report, SCAT5 symptom report and the Brief Symptom Inventory 18 were examined for convergent validity (145). - Convergent and discriminant validity of individual ImPACT domains and other neuropsychological tests were examined (146).
		Divergent/Discriminant	Assesses the extent to which a test does not correlate with another test.	Correlation coefficient.	
		Factorial	Examines the underlying dimensions or factors of a test.	Factor analysis: - EFA: identifies possible factors. - CFA: tests data for the existence of possible, specified factors.	EFA examined factor structure of the PCSS and suggested groupings of symptoms (129).
Criterion	The degree to which test results correspond with results from other tests that measure similar constructs.	Concurrent	Compares outcome of a new test against the outcome of a gold-standard test measuring the same construct. If a gold-standard already exist, the necessity of a new test should be questioned.	Correlation coefficient or MANOVA.	- A version of the BESS using force plates was compared with original BESS test (147). - CP Screen scores were compared with the PCSS (131).
		Predictive	Examines whether a test can predict a future outcome.	Correlation coefficient.	Sensitivity and specificity of ImPACT in predicting recovery less than and longer than 14 days examined (148).
Diagnostic Accuracy	The ability of a test to differentiate patients with a condition from patients without a condition.	Sensitivity	Ability of a test to correctly identify a condition when it is present. A test with high sensitivity is useful for ruling out a condition if a patient has a negative result.	Expressed as a percentage or proportion.	The sensitivity of ImPACT 24-48 hours post-SRC was calculated (149).
		Specificity	Ability of a test to correctly identify that a condition is not present. A test with high specificity is useful for ruling in a condition if a patient has a positive result.	Expressed as a percentage or proportion.	The specificity of ImPACT 24-48 hours post-SRC was calculated (149).

<i>Type of Validity</i>	<i>Explanation</i>	<i>Types</i>	<i>Description</i>	<i>Measure</i>	<i>Examples from the SRC Literature</i>
		ROC curve	Provides sensitivity and specificity values for different cut-off points of a test by plotting the true positive rate (sensitivity) on the y-axis against its false positive rate (100 – specificity) on the x-axis. Increasing the cut-off value decreases sensitivity and increases specificity.	AUC describes the overall sensitivity and specificity at all cut-off points. An AUC of 0.5 suggests no diagnostic ability, while 1 suggests perfect ability to diagnose a condition.	ROC curves were computed to determine the most accurate cut-off points of the VOMS items (150).

SRC: Sport-related concussion; CP: Clinical profiles; SCAT3/SCAT5: Sport Concussion Assessment Tool 3rd/5th Edition; EFA: Explanatory factor analysis; CFA: Confirmatory factor analysis; ImPACT: Immediate Post-Concussion Assessment and Cognitive Testing; PCSS: Post-Concussion Symptom Scale; MANOVA: Multivariate analysis of variance; BESS: Balance Error Scoring System; ROC: Receiver operating characteristic; AUC: Area under curve.

2.4.2.2 *Reliability*

Reliability provides a measure of test score consistency across assessments (151). A test score consists of an individual's true score combined with its measurement error (151,152). Measurement error may be random or systematic (152–154). Sources of random error include chance, natural variability in biological measurements, and inconsistencies in data collection, while systematic error refers to a tendency of measurements to differ in a specific, predictable direction (e.g., selection bias or practice effects) (153,155). Therefore, a large amount of measurement error will reduce reliability. As some measurement error always exists, it is important that clinicians are aware of test reliability when selecting clinical tests. There are several types of reliability, however test-retest reliability is most relevant to SRC assessments. This is because SRC assessments may be performed annually during the pre-season and at multiple subsequent time points if a player sustains an SRC (156–158). Test-retest reliability declines over time (159) and it is therefore important to understand how reliable a measure is over various timeframes. Reliability can be measured using relative (i.e., the consistency of participants' rankings in a sample across assessments) or absolute (i.e., the variability of individual measurements across assessments) measures (153). There are multiple ways to calculate reliability, depending on the type of reliability required and the nature of the data (see Table 8). It is important to note that not all studies have used the most appropriate methods (160,161). For example, selecting an inappropriate model of ICC may substantially alter correlation coefficients (162).

Table 8: Methods of determining reliability

<i>Relative reliability</i>				
Type	Type of Data	Description	Interpretation	Limitations
<i>Pearson's correlation coefficient I</i>	Continuous, bivariate	Examines linear correlations between two variables. Most suitable for examining correlations between different classes of variables.	<0.20: Very weak ≥0.21-0.40: Weak ≥0.41-0.60: Moderate 0.60-0.80: Strong ≥0.80: Very strong (163)	- Cannot be used when examining more than two assessments. - Sensitive to outliers. - Assumes variables follow normal distribution. - May be significant at low levels of correlation with large sample sizes. - Proportional to spread of values- low inter-subject variability reduces r. - Cannot measure systematic error.
<i>Intraclass correlation coefficient</i>	Continuous, univariate	Examines correlations within one type of data over two or more tests.	<0.60: Poor 0.60-0.69: Marginal 0.70-0.79: Adequate 0.80-0.89: High ≥0.90: Very high >0.80: Good (164)	- Assumes variables follow normal distribution. - Cannot measure systematic error (153). - Low variability reduces correlation coefficient (153).
One-way random (1,k)		Each subject is tested by different, randomly chosen raters.		
Two-way random (2,k)		Subjects are tested by randomly selected raters; used to generalize to raters with similar characteristics.		
Two-way mixed (3,k)		Subjects are tested by the only raters of interest.		
<i>Lin's concordance correlation coefficient</i>	Continuous, univariate	Examines the agreement between two measurements of the same variable.	<0.20: Very weak ≥0.21-0.40: Weak ≥0.41-0.60: Moderate 0.60-0.80: Strong ≥0.80: Very strong (163)	Cannot be used when examining more than two assessments.
<i>Cohen's Kappa</i>	Categorical, univariate	Examines agreement between two categorical variables while correcting for chance. When assessing agreement across more than two assessments, pairwise Cohen's Kappa can be calculated- a Cohen's Kappa is calculated for each pair of measurements and an average is used.	<0: No agreement 0.01-0.20: None to slight 0.21-0.40: Fair 0.41-0.60: Moderate 0.61-0.80: Substantial 0.81-1.00: Almost perfect (165)	May underestimate agreement in highly homogenous samples.
<i>Percentage of Agreement</i>	Categorical	The percentage of scores that are the same from one test to another.	-	Does not take random error into account
<i>Absolute reliability</i>				
Type	Type of Data	Description	Interpretation	Limitations
<i>Standard Error of Measurement</i>	Interval	The degree of spread of an individual's score around the true score over repeated measurements due to measurement error.	Lack of clarity over how it should be interpreted, although lower values indicate higher reliability.	- Lack of clarity over interpretation. - May underestimate reliability in highly homogenous samples. - Assumes data is homoscedastic- can only be used with interval and not ratio data.
<i>Reliable Change Index</i>	Interval	Describes the minimal change in a score that represents a clinically meaningful difference- the change should be large relative to the error variance of the test. A modified version takes practice effects into account by subtracting a constant from the RCI score (166).	Z-scores of 1.28, 1.65 and 1.96 have been suggested, corresponding to CIs of 80%, 90% and 95%, respectively. RCIs are smaller when reliability is high.	- Assumes variables follow a normal distribution. - Overly conservative.

2.4.2.3 Normative Data

Normative data provides a baseline distribution of a test score in a healthy population. This may assist clinicians in interpreting clinical data by providing a reference point for test scores in a similar population to an individual patient (167). Due to the wide variety of factors, such as age (168), gender (169), and existing medical conditions (170), that may affect clinical test results, it is essential that clinicians refer to normative data for the appropriate population when interpreting clinical tests. There are several limitations associated with normative data. Firstly, many clinical tests are amenable to influence from procedural (such as testing environment and administration method (171)) or subject-related (such as motivation and attitude (172)) factors. These factors may be difficult to measure or control for during data collection. Secondly, information about relevant pre-existing medical conditions is often collected informally via self-report (versus medical records) during the generation of normative data (168,173,174); therefore, the medical history make-up of an apparently healthy normative dataset may not be accurate. Thirdly, normative datasets with fewer than fifty participants tend to contain positively skewed data, resulting in artificially inflated mean scores and meaningless standard deviations (167). There is therefore a need for comprehensive normative datasets for SRC clinical tests.

2.4.3 Clinical profiles and assessments

2.4.3.1 Sport Concussion Assessment Tool 5th Edition

The Sport Concussion Assessment Tool (SCAT) was developed by the CISG in 2004 (175,176), with the aim of providing a standardised tool to assist in diagnosing SRC in a sideline setting. The CISG consists of clinicians and researchers with expertise in SRC. Consensus statements and the SCAT are updated every four years based on the findings from systematic reviews which address relevant research questions (18). However, it is unclear how exactly authors are selected, and the process by which the CISG agree to make changes to the SRC recommendations has not been described. The original SCAT was compiled based on expert opinion and contained questions about concussion signs, modified Maddocks questions to assess orientation, a symptom checklist and a neurological screen (175,176). It also incorporated the Standardized Assessment of Concussion (SAC), a brief cognitive assessment of orientation, immediate memory, concentration and delayed memory, that was previously developed to assess concussions based on the Colorado and American Academy of Neurology guidelines (41,177,178). Subsequent versions of the SCAT were released in 2009 (SCAT2) (176), 2013 (SCAT3) (179), and 2017 (SCAT5) (132), based on an expanding understanding of SRC and increased evidence about the usefulness of the individual SCAT components. Changes to each version of the SCAT were determined following systematic reviews of the current literature (180,181) and agreed upon at subsequent CISG meetings.

While all versions of the SCAT have included several core components (e.g., a symptom evaluation form, the SAC, neurological tests and the modified Balance Error Scoring System (mBESS)),

differences in scoring between the earlier (SCAT and SCAT2) and more recent (SCAT3 and SCAT5) versions make comparison difficult (see Table 10 for a description of SCAT versions). Therefore, this section will focus on the SCAT3 and SCAT5. There is no SCAT4 as at the fifth meeting a decision was made to match version numbers of the SCAT with the number of the meeting at which it was released (i.e., the SCAT5 was released following the fifth CISG meeting). There are several differences between the SCAT3 and SCAT5. The SCAT3 asks athletes to rate their current symptoms on the GSC, while the SCAT5 asks them to rate how they typically feel. The SCAT5 also allows a choice between a five- and 10-word list for the immediate memory and delayed recall components of the SAC, whereas the SCAT3 includes only a five-word list (132,182). The SCAT components have demonstrated varying accuracy; the GSC (AUC=0.82) (158) and tandem gait test (AUC=0.70) (183) have shown adequate accuracy in identifying SRC within 48 hours of injury, however the overall accuracy of the SAC (AUC=0.56) and mBESS (AUC=0.58) is poor (see Table 9) (158).

Table 9: Overview of components of the Sport Concussion Assessment Tool 5th Edition

SCAT Component	Domain Assessed	Validity
Graded Symptom Checklist	Self-reported symptoms.	Symptom severity score has a sensitivity of 73.0% and a specificity of 80.0% (AUC=0.82) within 48 hours of SRC (158).
Standardised Assessment of Concussion	- Immediate memory. - Delayed memory. - Concentration.	SAC total score has a sensitivity of 61.0% and a specificity of 48.0% (AUC=0.56) within 48 hours of SRC (158).
Modified Balance Error Scoring System	Static balance.	Sensitivity of 29.0% and specificity of 85.0% (AUC=0.58) within 48 hours of SRC (158).
Tandem Gait	Motor coordination.	Sensitivity of 63.2.% and specificity of 60.5% (AUC=0.70) within 48 hours of SRC (183).

AUC: Area under the curve; SRC: Sport-related concussion.

Table 10: Versions of the Sport Concussion Assessment Tool and their major components

Version	Background Information	Sideline Assessment	Symptom Checklist	Cognitive Assessment	Neurological Assessment	Scoring	Return To Play Advice
SCAT	None	- On-field signs - Modified Maddock's questions	17-symptom checklist	SAC	- Speech - Eye motion and Pupils - Pronator Drift - Gait Assessment	None	Graded RTP programme
SCAT2	Basic demographic information	- On-field physical signs - GCS - Modified Maddock's Questions	22-symptom checklist - Symptom severity rated	- SAC - Includes orientation questions	- mBESS - Finger-to-nose test	- Total score out of 100 - Symptoms (22)- reverse scored - Physical signs (2) - GCS (15) - Maddock's questions (5) - SAC (30) - mBESS (30)- reverse scored - Finger-to-nose test (1)	- Signs to watch for - Graded RTP programme
SCAT3	- Basic demographic information - Brief medical history	- On-field signs - GCS - Modified Maddock's Questions	22-symptom checklist - Symptom severity rated	SAC	- Neck Examination - mBESS - Optional tandem gait test - Finger-to-nose test	- Each section is scored separately - Symptoms (22) - Symptom severity score (132) - Orientation (5) - Immediate memory (15) - Concentration (5) - mBESS (30) - Tandem Gait (seconds) - Delayed recall (1)	- Signs to watch for - Graded RTP programme
SCAT5	- Basic demographic information - Brief medical history	- Red flags - On-field signs - Modified Maddock's Questions - GCS - Cervical spine assessment	22-symptom checklist - Symptom severity rated	- SAC 10-word option for word recall	- Neck Examination - Tandem gait test - Finger-to-nose test - mBESS	- Each section is scored separately - Symptoms (22) - Symptom severity score (132) - Orientation (5) - Immediate memory (15) - Concentration (5) - Neurological Exam (5) - mBESS (30) - Delayed recall (1)	- Signs to watch for - Graded RTP programme - Graded RTS advice

SCAT: Sport Concussion Assessment Tool; GCS: Glasgow Coma Scale; SAC: standardised assessment of concussion; mBESS: modified Balance Error Scoring System; RTP: return-to-play; RTS: return-to-school.

2.4.3.1.1 Test-retest reliability of the Sport Concussion Assessment Tool

Three studies examined the test-retest reliability of the SCAT3 and SCAT5 in male and female athletes (see Table 11) (158,184,185). One study assessed reliability after 196 days post-baseline as well as a further seven days later (184), one study assessed reliability one-year post-baseline (158), and one study assessed reliability after one- and two-years post-baseline (185). Two of these studies focused on adult participants (158,185), while one included both adolescent and adult participants (184). ICCs ranged from 0.43-0.62 for the Symptom Severity Score (SSS), from 0.39-0.47 for the SAC, and from 0.41-0.68 for the BESS, suggesting that the test-retest reliability of the individual SCAT components was low to fair (158,184,185). The study that assessed reliability at two time points (baseline-196 days, and 196 days-7 days later) found slightly higher reliability for the second reliability assessment across all components of the SCAT (184), which may suggest practice effects were present after the short retest timeframe. However, none of these studies assessed reliability separately for gender or by age groups. Although existing research suggests that the test-retest reliability of the SCAT is inadequate over long periods of time, reliability data on the SCAT components that focuses on adolescent and adult female athletes is needed.

Table 11: Test-retest reliability of the Sport Concussion Assessment Tool

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Version</i>	<i>Timepoints</i>	<i>TSS</i>	<i>SSS</i>	<i>SAC</i>	<i>BESS</i>
Chin (2016)	Subgroup (n=164) of 2018 high school and collegiate athletes. Overall sample was 76.9% male; mean age=17.8±1.92. Mean of 0.65±0.94 previous concussions.	SCAT3	Baseline-196 days: 196 days-1 week later:	-	ICC (3) = 0.43 ICC (3) = 0.62	ICC (3) = 0.39 ICC (3) = 0.42	ICC (3) = 0.54 ¹ ICC (3) = 0.56 ¹
Broglia (2018)	Subgroups (1-year n=2894-4360; 2-year n=323-581) of 4874 collegiate athletes. 58.9% male; mean age=19.2±1.2. Mean of 0.4±0.8 previous concussions.	SCAT3	Baseline-1 year (316.1±83.4 days): Baseline-2 year (627.5±99.8 days):	κ= 0.40 κ= 0.42	κ= 0.41 κ= 0.41	ICC (3,1) = 0.39 ICC (3,1) = 0.34	ICC (3,1) = 0.41 ² ICC (3,1) = 0.42 ²
Ferris (2022)	A subgroup (n=424) of 3958 collegiate athletes. 52.3% male; mean age=19.44±1.48.	SCAT3	Baseline-1 year:	-	ICC (2,k) = 0.53	ICC (2,k) = 0.47	ICC (2,k) = 0.68 ¹

TSS: Total symptom score; SSS: Symptom severity score; SAC: Standardised assessment of concussion; BESS: Balance Error Scoring System; SCAT3/SCAT5: Sport Concussion Assessment Tool 3rd Edition/Sport Concussion Assessment Tool 5th Edition; ICC (3): Intraclass correlation coefficient two-way mixed model, measures not specified; ICC (3,1): Intraclass correlation coefficient two-way mixed model for single measures; ICC (2,k): Intraclass correlation coefficient two-way random model for average measures; κ= Kappa coefficient; 1. Modified BESS; 2. Full BESS.

2.4.3.1.2 Normative data for the Sport Concussion Assessment Tool

Seven studies have reported normative data for the SCAT3 and SCAT5 in female athletes (see Table 12) (184,186–191). Two of these studies focused on adolescent athletes (186,192), four studies focused on adult athletes (187,188,190,191), and one study included both adolescent and adult athletes (184). A broad range of scores for the Total Symptom Score (TSS) (median=0 (186), mean=8.27 (192)) and SSS (median=0 (186), mean=14.74 (192)) were reported for female adolescent athletes, while female adult athletes scored a mean of 1.38-3.30 on the TSS and 1.61-5.90 on the SSS (184,187,188,190,191). Overall mean SAC scores were in the range of 26.4-27.46 (out of a possible total score of 30) for female athletes when the five-word memory list was used instead of the ten-word list (184,186–188,191). When the five-word memory list was used, mean immediate memory (14.3-15) and delayed recall (3.0-4.45) scores were close to the maximum possible scores of 15 and five, respectively (see Table 13) (184,186,191). Two studies that used the ten-word list reported a mean of 20.53 and median of 21 for the immediate memory (out of a maximum score of 30), and a mean of 6.58 and medians of 3-4 for delayed recall (out of a maximum score of 10) (190,192). Overall mean mBESS scores ranged from 2.40-4.19. The single-leg stance component had the most errors (highest score) across all studies (see Table 14). Only one study presented data on the tandem gait test. Elite female adult rugby players took a mean of 12.4 seconds to complete the four repetitions of the tandem gait test (191). While these studies had large sample sizes and should adequately represent baseline SCAT values, only one study of adolescent athletes provided normative data by both gender and age. In addition, participants consisted of high school (184,186,192), collegiate (184,187,188,190), or elite (191) athletes. Normative data on the SCAT is required for adolescent and adult female participating in community sport.

Table 12: Normative data for the Sport Concussion Assessment Tool

Author (Year)	Participant Characteristics	Version	Demographic Group	TSS		SSS		SAC		mBESS	
				Male	Female	Male	Female	Male	Female	Male	Female
Adolescent											
Snedden (2017)	758 high school athletes. 75.3% male; mean age=15.3±1.1.	SCAT3	All:	0 (0-2) ¹	0 (0-1) ¹	0 (0-3) ¹	0 (0-2) ¹	26.0 ± 2.3	26.4 ± 2.0	3 (1-5) ^{1,2}	3 (2-5) ^{1,2}
Black (2020)	380 high school rugby players. 55.3% male; median age- male: 16.9 (15.2-18.7), female: 16.5 (15.1-18.1). 30.0% of female and 38.6% of males had a previous concussion.	SCAT5	All:	6.54 ± 5.02	8.27 ± 5.42	10.46 ± 9.78	14.74 ± 12.68	-	-	6 (0-20) ¹	3 (0-13) ¹
			Age 15-16:	6.16 ± 4.93	8.28 ± 5.70	9.81 ± 9.79	15.46 ± 14.05			6 (0-20) ¹	3 (0-13) ¹
			Age 17-18:	6.93 ± 5.12	8.25 ± 4.92	11.13 ± 9.77	13.42 ± 9.66			5 (0-20) ¹	4 (0-12) ¹
			ConHx:	7.30 ± 5.24	8.16 ± 5.27	12.22 ± 11.40	13.84 ± 10.81			6 (0-17) ¹	4 (0-12) ¹
			No ConHx:	6.05 ± 4.84	8.32 ± 5.51	9.34 ± 8.46	15.13 ± 13.43			5 (0-20) ¹	3 (0-13) ¹
Adult											
Chin (2016)	2018 high school and collegiate athletes. 76.9% male; mean age=17.8±1.9. Mean of 0.65±0.94 previous concussions.	SCAT3	All:	1.12 ± 0.79	1.38 ± 0.80	1.32 ± 0.96	1.61 ± 0.97	26.96 ± 1.94	27.46 ± 1.72	3.20 ± 2.50	2.85 ± 2.48
Downey (2018)	524 collegiate athletes. 63.7% male; mean age=19.2±1.9. 47.6% had a previous concussion.	SCAT3	All:	3.64 ± 4.05	2.94 ± 3.69	5.95 ± 7.68	4.98 ± 7.18	26.27 ± 2.63	26.96 ± 1.94	3.34 ± 3.32	3.06 ± 3.12
Katz (2018)	15,681 collegiate athletes. 59.0% male. 30% of males and 26.0% of females had a previous concussion.	SCAT3	All:	2.3 ± 3.6	3.3 ± 3.9	4.1 ± 7.7	5.9 ± 8.9	27.0 ± 2.1	27.4 ± 1.9	13.5 ± 6.5 ³	12.5 ± 5.9 ³
Petit (2020)	462 collegiate athletes. 54.1% male; mean age - male=19.4±1.4, female=20.0±1.2. 22.1% had a previous concussion.	SCAT5	All:	1.92 ± 3.29	2.00 ± 3.47	3.14 ± 6.65	3.77 ± 8.65	34.72 ± 5.31 ⁴	35.64 ± 5.10 ⁴	4.35 ± 3.99	4.19 ± 3.89
Iverson (2021)	117 elite female rugby players. Mean age=25.9±5.5.	SCAT5	All:	-	3.2 ± 4.7	-	5.4 ± 8.2	-	26.9 ± 2.1	-	2.4 ± 2.2

TSS: Total symptom score; SSS: Symptom severity score; SAC: Standardised assessment of concussion; BESS: Balance Error Scoring System; SCAT3/SCAT5: Sport Concussion Assessment Tool 3rd Edition/ 5th Edition; 1. Presented as medians and interquartile ranges; 2. Use the full Balance Error Scoring System; results from firm floor presented here; 3. Used the full Balance Error Screening System; 4. Used the 10-word option for recall sections of SAC.

Table 13: Normative data for the Standardised Assessment of Concussion

Author (Year)	Participant Characteristics	Version	Demographic Group	Orientation		Immediate Memory		Concentration		Delayed Recall	
				Male	Female	Male	Female	Male	Female	Male	Female
Chin (2016)	2018 high school and collegiate athletes. 76.9% male; mean age=17.8±1.9. Mean of 0.65±0.94 previous concussions.	SCAT3	All:	4.91 ± 0.31	4.94 ± 0.24	14.34 ± 0.92	14.54 ± 0.77	3.35 ± 1.15	3.53 ± 1.04	4.35 ± 0.90	4.45 ± 0.80
Snedden (2017)	758 high school athletes. 75.3% male; mean age=15.3±1.1.	SCAT3	All:	5 (4-5) ¹	5 (5-5) ¹	15 (14-15) ¹	15 (14-15) ¹	3 (2-4) ¹	3 (2-4) ¹	4 (3-5) ¹	4 (4-5) ¹
Black (2020)	380 high school rugby players. 55.3% male; median age- male: 16.9 (15.2-18.7), female: 16.5 (15.1-18.1). 30.0% of female and 38.6% of males had a previous concussion.	SCAT5	All: Age 15-16: Age 17-18: ConHx: No ConHx:	5 (2-5) ¹ 5 (205) ¹ 5 (2-5) ¹ 5 (2-5) ¹ 5 (2-5) ¹	5 (3-5) ¹ 5 (3-5) ¹ 5 (4-5) ¹ 5 (4-5) ¹ 5 (3-5) ¹	20 (9-28) ^{1,2} 20 (9-28) ^{1,2} 20 (10-26) ^{1,2} 21 (13-26) ^{1,2} 20 (9-28) ^{1,2}	21 (9-29) ^{1,2} 21 (9-29) ^{1,2} 21 (14-28) ^{1,2} 21 (14-29) ^{1,2} 21 (9-27) ^{1,2}	4 (0-5) ¹ 4 (0-53) ¹ 3 (1-5) ¹ 4 (0-5) ¹ 3 (1-5) ¹	4 (1-5) ¹ 4 (1-5) ¹ 3 (1-5) ¹ 4 (1-5) ¹ 3 (1-5) ¹	6 (0-20) ^{1,2} 6 (0-20) ^{1,2} 5 (0-20) ^{1,2} 6 (0-17) ^{1,2} 5 (0-20) ¹	3 (0-13) ¹ 3 (0-13) ^{1,2} 4 (0-12) ^{1,2} 4 (0-12) ^{1,2} 3 (0-13) ^{1,2}
Petit (2020)	462 collegiate athletes. 54.1% male; mean age - male=19.4±1.4, female=20.0±1.2. 22.1% had a previous concussion.	SCAT5	All:	4.95 ± 0.22	5.00 ± 0.00	19.88 ± 3.43 ²	20.53 ± 3.35 ²	3.63 ± 1.20	3.56 ± 1.07	6.26 ± 1.94 ²	6.58 ± 1.94 ²
Iverson (2021)	117 elite female rugby players. Mean age=25.9±5.5.	SCAT5	All:	-	4.8 ± 0.4	-	14.3 ± 1.0	-	3.8 ± 1.2	-	3.0 ± 1.0

SCAT3/SCAT5: Sport Concussion Assessment Tool 3rd Edition/5th Edition; 1: Presented as medians and interquartile ranges; 2: Used the 10-word option.

Table 14: Normative data for the modified Balance Error Scoring System and Tandem Gait

Author (Year)	Participant Characteristics	Version	Demographic Group	Double-Leg Stance		Single-Leg Stance		Tandem Stance		Tandem Gait	
				Male	Female	Male	Female	Male	Female	Male	Female
Black (2019)	380 high school rugby players. 55.3% male; median age- male: 16.9 (15.2-18.7), female: 16.5 (15.1-18.1). 30.0% of female and 38.6% of males had a previous concussion.	SCAT5	All: Age 15-16: Age 17-18: ConHx: No ConHx:	0 (0-1) ¹ 0 (0-1) ¹ 0 (0-1) ¹ 0 (0-1) ¹ 0 (0-1) ¹	0 (0-2) ¹ 0 (0-1) ¹ 0 (0-2) ¹ 0 (0-2) ¹ 0 (0-1) ¹	3.5 (0-10) ¹ 3 (0-10) ¹ 4 (0-10) ¹ 4 (0-10) ¹ 3 (0-10)	2 (0-10) ¹ 2 (0-10) ¹ 3 (0-10) ¹ 2 (0-10) ¹ 2 (0-10) ¹	2 (0-10) ¹ 2 (0-10) ¹ 2 (0-10) ¹ 2 (0-9) ¹ 1 (0-10) ¹	1 (0-7) ¹ 1 (0-7) ¹ 1 (0-6) ¹ 1 (0-6) ¹ 1 (0-7) ¹	-	-
Petit (2020)	462 collegiate athletes. 54.1% male; mean age - male=19.4±1.4, female=20.0±1.2. 22.1% had a previous concussion.	SCAT5	All:	0.0 ± 0.0	0.0 ± 0.0	3.11 ± 2.97	3.06 ± 2.74	1.24 ± 2.06	1.13 ± 2.04	-	-
Iverson (2021)	117 elite female rugby players. Mean age=25.9±5.5.	SCAT5	All:	-	0.0 ± 0.0	-	1.8 ± 1.5	-	0.6 ± 1.0	-	12.4 seconds

SCAT3/SCAT5: Sport Concussion Assessment Tool 3rd Edition/5th Edition; ConHx: Concussion history; 1: Presented as medians and interquartile ranges.

2.4.3.2 Cognitive profile

The cognitive clinical profile is characterised by subjective memory and concentration difficulties, a feeling of mental foggiess, and fatigue aggravated by cognitive activity (31,130). Objective deficits in memory (119), attention (193), reaction time (119), and executive function (193) may also be evident on clinical testing. SRC-related cognitive impairment is typically assessed using computerised neurocognitive testing. Computerised neurocognitive testing has multiple advantages over traditional “pen and paper” neuropsychological tests (e.g., the Trail-Making Test and Symbol Digits Modalities Test), which are time and labour-intensive (140). Computerised neurocognitive testing does not require neuropsychological expertise to administer, can be administered to multiple players simultaneously, and provides immediate test results. Additionally, computerised neurocognitive testing often contains alternative, randomised content to reduce practice effects and may incorporate validity measures to identify players who are providing low effort (194,195). Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®; ImPACT® Applications, Pittsburgh, PA, USA), Axon Sports CogState Test (CogState Ltd, Melbourne, Australia), Concussion Vital Signs (CNS-VS; CNS Vital Signs LLC, Morrisville, NC, USA), and Headminder Concussion Resolution Index (Headminder Inc, New York City, NY, USA) are examples of computerised neurocognitive testing that have been developed to assess post-SRC cognitive deficits. The overall sensitivity of computerised neurocognitive testing has been shown to range from 51.3% to 78.6% (see Table 15). However, the validity of ImPACT® has been more comprehensively assessed than the validity of other computerised neurocognitive tests (119). ImPACT® is the most widely used computerised neurocognitive test among clinicians working with US collegiate players (34,35). Pre-season ImPACT® testing is also currently being piloted in elite Gaelic games players, including LGF players (196).

Table 15: Overview of computerised neurocognitive testing for concussion

<i>Test</i>	<i>Cognitive Domains Assessed</i>	<i>Validity</i>
Immediate Post-Concussion Assessment and Cognitive Testing	• Verbal memory • Visual Memory • Visual-motor processing speed • Reaction	• Overall sensitivity of 62.5%-83.0% (reliable change in at least one score) (149,197). • Overall specificity of 55.9%-62.5% (149). • Sensitivity of 29.3%-75.6% for individual composite scores (119).
CogState Test	• Processing speed • Learning • Attention • Working memory speed	• 51.3% sensitivity (149). • 71.5% specificity (149).
Concussion Vital Signs	• Verbal memory • Visual memory • Psychomotor speed • Executive function • Cognitive flexibility • Reaction time	• 58.7% sensitivity (149). • 53.2% specificity (149).
Concussion Resolution Index	• Processing speed • Simple reaction time • Complex reaction time	• Overall sensitivity of 78.6% (198). • Sensitivity of 50.0%-71.4% for individual scores (198).

2.4.3.2.1 Test-retest reliability of Immediate Post-Concussion Assessment and Cognitive Testing

Twelve studies have examined the test-retest reliability of ImPACT® (see Table 16). Two of these studies assessed reliability over a short timeframe ($\leq$ two weeks post-baseline) (199,200), five assessed reliability over a medium timeframe (four weeks to 50 days post-baseline) (156,173,199,201,202), and six assessed reliability over a long timeframe (six months to three years post-baseline) (185,203–207). Samples assessed over short and medium timeframes consisted of recreational adolescent athletes (200) or healthy collegiate students (156,173,199,201,202), while long-term reliability was assessed in youth (203) and professional ice hockey (206), and high school (205,207) and collegiate (185,204) athletes. The majority of these studies (206) included both male and female players (173,185,199,200,202–205,207), with males comprising 19.5%-84.5% of these samples. However, none performed separate analyses for males and females. Four studies focused on adolescent players, and one of these analysed younger (aged 11-14) and older (aged 15-18) adolescents separately (203). Reliability was primarily examined using ICCs and varied greatly across studies. Short-term ICCs ranged from 0.41-0.91, medium-term ICCs from 0.23-0.89, and long-term ICCs from 0.46-0.90, denoting low to very high reliability (163,208). Overall, higher ICCs were reported for visual-motor speed (ICC=0.38-0.90) and reaction time (ICC=0.39-0.88) than verbal (ICC=0.23-0.79) and visual memory (ICC=0.26-0.85). However, ICC models varied between study. While two-way models for single measurements (ICC (2,1)) are the most suitable method for analysing computerised neurocognitive testing test-retest reliability (164), some studies used one-way models (199,202) or two-way models (173,201,204,205,207) for average measures. Using an incorrect model may artificially inflate or deflate the ICC, making it difficult to interpret these studies (162). Direct comparison between studies is further complicated by differences in participant characteristics (e.g., age, gender, and athletic level), and varying timeframes between assessments. While these studies suggest that ImPACT® may have inadequate test-retest reliability, there is a need for further research that focuses on different populations (e.g., female, community athletes) and uses the most suitable reliability analyses.

Table 16: Test-retest reliability of Immediate Post-Concussion Assessment and Cognitive Testing

Author (Year)	Participant Characteristics	Version	Timepoints	Verbal Memory	Visual Memory	Visual-Motor Speed	Reaction Time	Post-Concussion Symptom Scale
<i>Short-Term Reliability (<2 weeks)</i>								
Resch (2013)	92 non athlete students in Irish (G1) and US (G2) universities. G1 (n=46): 54.3% male; mean age=22.4±1.9 G2 (n=45): 37.8% male; mean age=20.9±1.7. None had a history of ADHD, LD, psychiatric condition or concussion <6 month previously.	Format (online/desktop) not specified. Forms 1, 2 & 3 used. Word Memory Test used to measure effort in G2.	G1: Baseline-1 week	ICC (1,k) = 0.56	ICC (1,k) = 0.26	ICC (1,k) = 0.78	ICC (1,k) = 0.84	-
			G1: Baseline-2 weeks (mean=6.8±1.9 days)	ICC (1,k) = 0.59	ICC (1,k) = 0.53	ICC (1,k) = 0.71	ICC (1,k) = 0.78	-
			G1: Baseline-2 weeks	ICC (1,k) = 0.41	ICC (1,k) = 0.85	ICC (1,k) = 0.84	ICC (1,k) = 0.88	-
O'Brien (2018)	53 recreational athletes from multiple sports. 83.0% male; mean age=12.4 (range=11-14). None had a history of ADHD, LD or concussion in previous 6 months.	Online; identical baseline administered twice.	Baseline-2 weeks (mean=14.6 days; range=10-23 days)	ICC (2,1) = 0.58 SEM=5.69	ICC (2,1) = 0.54 SEM=8.37	ICC (2,1) = 0.84 SEM=2.49	ICC (2,1) = 0.54 SEM=0.05	ICC (2,1) = 0.90 SEM=3.48
<i>Medium-term reliability (2 weeks-6 months)</i>								
Broglia (2007)	44 healthy student volunteers. Gender not specified; mean age=21.4±2.8. 16.4% had a history of concussion and none had a history of ADHD, LD or concussion in previous 6 months.	Desktop version; ImPACT, CRI & Sentinel tests completed in one session, with random administration.	Baseline-45 days (mean=45.1±1.6 days)	ICC (2,1) = 0.23 SEM=6.17	ICC (2,1) = 0.32 SEM=6.91	ICC (2,1) = 0.38 SEM=4.96	ICC (2,1) = 0.39 SEM=0.04	-
			Day 45-Day 50 (mean=5.6±0.9 days)	ICC (2,1) = 0.40 SEM=5.33	ICC (2,1) = 0.39 SEM=8.25	ICC (2,1) = 0.61 SEM=4.39	ICC (2,1) = 0.51 SEM=0.04	-
Resch (2013)	92 non athlete students in Irish (G1) and US (G2) universities. G1 (n=46): 54.3% male; mean age=22.4±1.9 G2 (n=45): 37.8% male; mean age=20.9±1.7. None had a history of ADHD, LD, psychiatric condition or concussion <6 month previously.	Format (online/desktop) not specified. Forms 1, 2 & 3 used. Word Memory Test used to measure effort in G2.	G2: Baseline-45 days (mean=47.3±2.7 days)	ICC (1,k) = 0.45	ICC (1,k) = 0.52	ICC (1,k) = 0.76	ICC (1,k) = 0.57	-
			G2: Baseline-50 days	ICC (1,k) = 0.37	ICC (1,k) = 0.52	ICC (1,k) = 0.74	ICC (1,k) = 0.49	-
			G2: 45-50 days (mean=6.9±1.1 days)	ICC (1,k) = 0.40	ICC (1,k) = 0.55	ICC (1,k) = 0.66	ICC (1,k) = 0.71	-

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Version</i>	<i>Timepoints</i>	<i>Verbal Memory</i>	<i>Visual Memory</i>	<i>Visual-Motor Speed</i>	<i>Reaction Time</i>	<i>Post-Concussion Symptom Scale</i>
Schatz (2013)	25 non athlete students. 24.0% male, age not given. None had a history of ADHD, LD, concussion, or treatment for headaches, migraines, seizures or neurologic/psychiatric illness.	Online; baseline & post-injury 1.	Baseline-4 weeks	ICC (3,k) =0.79 80% RCI=12 95% RCI= 8	ICC (3,k) = 0.60 80% RCI=8 95% RCI=4	ICC (3,k) = 0.88 80% RCI=20 95% RCI=16	ICC (3,k) = 0.77 80% RCI=8 95% RCI=4	ICC (3,k) = 0.81 80% RCI=8 95% RCI= 8
Nakayama (2014)	85 active college students. 60.0% male, age not reported. 21.2% had a history of concussion & none had a history of ADHD, LD or concussion in previous 6 months.	ImPACT version & form not specified. 15-item Rey memory test included to measure effort.	Baseline-45 days	ICC (2,k) = 0.76 80% RCI= 11 (+10,-1) 95% RCI= 9 (+8,-1)	ICC (2,k) = 0.72 80% RCI= 11 (+9,-2) 95% RCI= 5 (+3,-2)	ICC (2,k) = 0.87 80% RCI= 15 (+13,-2) 95% RCI= 10 (+8,-2)	ICC (2,k) = 0.67 80% RCI= 15 (+7,-8) 95% RCI= 6 (+2,-4)	-
			Day 45-Day 50	ICC (2,k) = 0.69	ICC (2,k) = 0.66	ICC (2,k) = 0.88	ICC (2,k) = 0.81	-
			Baseline-50 days	ICC (2,k) = 0.65	ICC (2,k) = 0.60	ICC (2,k) = 0.85	ICC (2,k) = 0.71	-
Resch (2018)	41 non-athlete students. 19.5% male; mean age=20.0±2.8. None had a history of ADHD, LD, psychiatric disorder or concussion in previous 6 months.	ImPACT form not specified. Other groups completed ANAM or CNS Vital Signs. Green’s Word Memory Test used to measure effort.	Baseline-45 days (mean= 47.0±2.46 days)	ICC (1,1) = 0.19	ICC (1,1) = 0.45	ICC (1,1) = 0.81	ICC (1,1) = 0.57	-
			Day 45-Day 50 (mean=7.2±2.26 days)	ICC (1,1) = 0.63	ICC (1,1) = 0.47	ICC (1,1) = 0.89	ICC (1,1) = 0.59	-
<i>Long-Term Reliability (> 6 months)</i>								
Schatz (2010)	95 varsity collegiate athletes from multiple sports. 54.0% male; mean age=18.8±0.6.	Desktop; test type not specified.	Baseline-2 years (mean=1.9±0.6 years)	ICC (3,k) = 0.46 80% RCI = 8 (+6,-2) 95% RCI = 5 (+3,-2)	ICC (3,k) = 0.65 80% RCI = 13 (+11,-2) 95% RCI = 9 (+7,-2)	ICC (3,k) = 0.74 80% RCI = 7 (+4,-3) 95% RCI = 4 (+2,-2)	ICC (3,k) = 0.68 80% RCI = 7 (+4,-3) 95% RCI = 5 (+3,-2)	ICC (3,k) = 0.43 80% RCI = 8 (+3,-5) 95% RCI = 6 (+3,-3)
Elbin (2011)	369 varsity high school athletes from multiple sports. 45.5% male; mean age=14.8±0.9 (range=13-18). 6.2% had a history of concussion, 4.1% had ADHD & 2.2% had an I.D.	Online; test form not specified.	Baseline-1.2 years (range: 0.5-2.4 years)	ICC (3,k) = 0.62 80% RCI= 10 (+6,-4) 95% RCI= 5 (+3,-2)	ICC (3,k) = 0.70 80% RCI= 10 (+7,-3) 95% RCI = 5 (+4,-1)	ICC (3,k) = 0.85 80% RCI= 13 (+11,-2) 95% RCI = 8 (+7,-1)	ICC (3,k) = 0.76 80% RCI= 10 (+8,-2) 95% RCI = 8 (+6,-2)	ICC (3,k) = 0.57 80% RCI= 8 (+4,-4) 95% RCI = 8 (+4,-4)

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Version</i>	<i>Timepoints</i>	<i>Verbal Memory</i>	<i>Visual Memory</i>	<i>Visual-Motor Speed</i>	<i>Reaction Time</i>	<i>Post-Concussion Symptom Scale</i>
Bruce (2014)	283 professional ice hockey players, with first languages of English (n=127), French (n=47), Czech (n=45), Swedish (n=29), Russian (n=24), Finnish (n=22) & German (n=11). 100.0% male; mean age=25.6±4.9. No history of ADHD or LD.	Online; ImPACT version for native language used.	Baseline-1 year (mean=373.4±13.9 days)	ICC (2,1) = 0.45	ICC (2,1) = 0.52	ICC (2,1) = 0.76	ICC (2,1) = 0.64	ICC (2,1) = 0.49
Brett (2016)	1510 high school athletes from multiple sports (G1=250, G2=1146, G3=114). 65.4% male; mean age=15.1±1.9 (range=13-18). 6.8% had ADHD & 1.7% had dyslexia.	Online; form not specified.	G1: Baseline-1 year (mean=11.6±2.11 months):	ICC (3,k) = 0.46 95% RCI= 6.2 (+4.4,-2.0)	ICC (3,k) = 0.67 95% RCI= 6.0 (+3.2,-2.8)	ICC (3,k) = 0.87 95% RCI= 5.8 (+1.6,-4.4)	ICC (3,k) = 0.67 95% RCI= 5.2 (+2.8,-2.4)	ICC (3,k) = 0.71 95% RCI= 6.0 (+2.8,-3.2)
			G2: Baseline-2 years (23.2±1.2 months):	ICC (3,k) = 0.53	ICC (3,k) = 0.66	ICC (3,k) = 0.83	ICC (3,k) = 0.59	ICC (3,k) = 0.53
			G3: Baseline-3 years (33.8 ± 2.5 months):	ICC (3,k) = 0.36	ICC (3,k) = 0.63	ICC (3,k) = 0.90	ICC (3,k) = 0.70	ICC (3,k) = 0.56
Broglia (2018)	3659 collegiate players (G1=3154; G2=505). 58.9% of larger sample were male; mean age=19.2±1.2.	Not specified.	G1: Baseline- 1 year (316.1±83.4 days):	ICC (3,1) = 0.5	ICC (3,1) =0.58	ICC (3,1) = 0.72	ICC (3,1) = 0.47	-
			G2: Baseline- 3 years (627.5±99.8 days):	ICC (3,1) = 0.47	ICC (3,1) =0.47	ICC (3,1) = 0.66	ICC (3,1) = 0.34	-
Womble (2016)	200 ice hockey players. 84.5% male; mean age=14.6±1.9 (range=11-18). 21.5% had a history of concussion. Age 11-14: n=91, 79.1% male; age 15-18: n=109, 89.0% male.	Online; alternate forms used at two testing sessions.	Baseline-6 months (all ages):	ICC (3,1) = 0.48	ICC (3,1) = 0.59	ICC (3,1) = 0.75	ICC (3,1) = 0.62	ICC (3,1) = 0.63
			Baseline-6 months (age 11-14):	ICC (3,1) = 0.55	ICC (3,1) = 0.54	ICC (3,1) = 0.63	ICC (3,1) = 0.54	ICC (3,1) = 0.63
			Baseline-6 months (age 15-18):	ICC (3,1) = 0.35	ICC (3,1) = 0.61	ICC (3,1) = 0.75	ICC (3,1) = 0.61	ICC (3,1) = 0.63

G1/G2/G3: Group 1/Group 2/Group 3; ADHD: Attention deficit hyperactivity disorder; LD: Learning disorder; ICC (1,k)/ICC (1,1): Intraclass correlation coefficient one-way random effects model for average/single measures; ICC (2,k)/ICC (2,1): Intraclass correlation coefficient two-way random effects model for average/single measures; ICC (3,k)/ICC (3,1): Intraclass correlation coefficient two-way mixed effects model for average/single measures; SEM: Standard error of measurements; ImPACT: Immediate Post-Concussion Assessment and Cognitive Testing; CRI: Concussion Resolution Index; ANAM: Automatic Neuropsychological Assessment Metrics; CNS Vital Signs: Concussion Vital Signs; RCI: Reliable change index. Presented as the proportion of participants who exceeded cut-off points; + denotes the proportion with an improved score at the retest, while – denotes the proportion with a poorer score at the retest.

2.4.3.2.2 Normative data for Immediate Post-Concussion Assessment and Cognitive Testing

Nine studies have reported normative data on the ImPACT® in female athletes, and are presented in Table 17 (169,170,174,209–214). Five studies focused on adolescent participants (170,174,211,213,214), three focused mainly on adult participants (169,212,215), and one included both adolescent and adult participants (209). Three of these studies stratified normative data by age group (e.g., 13-15 years vs 16-18 years) and gender (209,212,214), while an additional three presented data based either on concussion history (n=2) (170,210) or a medical history of ADHD (n=1) (169,213). Overall, adolescent female athletes attained verbal memory scores of 82.3-87.0, visual memory scores of 67.6-75.4, visual-motor speed scores of 31.7-40.3, and reaction time scores of 0.57-0.66. Adult female players scored in the range of 82.5-99.1 on verbal memory, 73.9-82.1 on visual memory, 37.4-44.0 on visual-motor speed, and 0.52-0.60 on reaction time. This normative data suggests that adults display better neurocognitive function as measured by ImPACT® compared with adolescents. Pooled analyses of male and female athletes have shown greater verbal memory (211), visual-motor speed (174,211), and reaction time (174,211) scores in the 16-18 year old versus 13-15 years old athletes, as well as increased visual-motor speed scores in collegiate athletes compared with high school athletes (216). However, no studies have analysed differences in ImPACT® scores between adolescent and adult players in a female only sample. Neurocognitive function may be impaired by LDs (217), ADHD (169), or previous concussion (218). While several studies have reported normative ImPACT® data separately in female players with ADHD (213) and previous concussions (170,210), they did not take age into account. Additionally, studies that did not present normative data based on relevant medical history may have been biased if a large proportion of participants had a history of ADHD or concussion. Normative data for ImPACT® that is presented by gender, age, and medical history would greatly assist clinicians in interpreting results in players with possible concussions.

Table 17: Normative data for Immediate Post-Concussion Assessment and Cognitive Testing stratified by gender

Author (Year)	Participant Characteristics	Demograph ic Group	Verbal Memory		Visual Memory		Visual Motor Speed		Reaction Time		PCSS	
Adolescents												
			Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
McKay (2014)	704 youth ice hockey players; median age=15 (range: 13-17). 37.6% of males and 28.3% of females had a ConHx.	Age 13-15: Age 16-17:	83.7 ± 9.4 84.6 ± 9.6	84.4 ± 10.6 88.4 ± 8.3	74.5 ± 12.2 74.1 ± 12.5	75.4 ± 13.7 77.9 ± 12.1	35.4 ± 6.0 38.3 ± 5.9	36.4 ± 7.0 39.3 ± 6.2	0.60 ± 0.08 0.59 ± 0.09	0.60 ± 0.08 0.57 ± 0.07	-	-
Brooks (2015)	698 high school athletes (males, ADD =249; males, no ADD=249; females, ADD=100; females, no ADD=100). 50.0% male; mean age=15.9±1.3 (male), 16.0±1.3 (female). Mean previous concussions: 0.4±0.8 (male), 0.4±0.9 (female). 34.0% of males & 41.0% of females with ADD used medication.	ADD: No ADD:	81.0 ± 10.5 82.5 ± 9.0	83.4 ± 9.3 84.7 ± 9.6	70.2 ± 14.7 72.8 ± 13.0	67.6 ± 12.7 71.3 ± 11.8	33.9 ± 8.1 35.3 ± 8.0	33.9 ± 6.4 37.8 ± 6.9	0.62 ± 0.09 0.60 ± 0.08	0.62 ± 0.08 0.60 ± 0.09	7.3 ± 10.3 4.9 ± 9.0	13.3 ± 15.1 7.4 ± 11.6
Henry (2015)	4500 adolescent athletes. 50.0% male; age range=13-21 (250 participants of each age). None had ADHD or LD.	Age 13-15: Age 16-18:	84.1 ± 9.1 84.4 ± 10.0	85.5 ± 9.4 87.0 ± 8.9	72.6 ± 13.5 72.0 ± 14.4	71.2 ± 12.8 71.9 ± 13.1	35.2 ± 6.5 36.7 ± 7.1	36.5 ± 6.2 40.3 ± 6.1	0.60 ± 0.08 0.61 ± 0.09	0.59 ± 0.07 0.57 ± 0.07	-	-
Brooks (2018)	9314 adolescent soccer players. 50.9% male; mean age=14.8±1.2 (range=13-18). 5.0% had ADHD, 2.4% had an LD. 14.4% had a ConHx (males: none: n=4012, 1+: n=527, 2+: n=130, 3+: n=73; females: none: n=3963, 1+: n=457, 2+: n=97, 3+: n=55)	No ConHx: 1+ ConHx: 2+ ConHx: 3+ ConHx:	82.4 ± 9.8 82.9 ± 10.0 81.9 ± 8.7 82.8 ± 9.9	84.8 ± 9.8 84.5 ± 10.1 84.7 ± 10.4 82.5 ± 10.0	74.2 ± 13.2 73.7 ± 13.5 71.9 ± 14.4 72.7 ± 14.8	72.6 ± 13.1 73.0 ± 13.5 71.0 ± 14.4 69.2 ± 14.9	34.2 ± 7.1 34.5 ± 7.5 34.0 ± 7.2 33.1 ± 8.4	34.8 ± 6.6 35.0 ± 6.5 36.0 ± 7.2 34.8 ± 7.6	0.63 ± 0.11 0.63 ± 0.11 0.63 ± 0.12 0.65 ± 0.15	0.62 ± 0.10 0.62 ± 0.10 0.62 ± 0.08 0.63 ± 0.14	3.5 ± 6.6 3.8 ± 6.4 6.1 ± 7.3 7.0 ± 9.7	5.3±8.7 7.5±11.4 7.9±9.9 11.3±12.8
French (2019)	1000 athletes. 74.5% male; mean age=12.25±1.88 (age 10-12: n=604; age 13-15: n=333; age 16-18: n=63). 6.4% had ADHD, 2.1% had an LD & 15.1% had a ConHx.	All	84.6 ± 10.7	87.0 ± 9.1	75.1 ± 13.4	74.9 ± 13.0	32.8 ± 7.4	31.7 ± 7.3	0.67 ± 0.12	0.66 ± 0.11	1.9 ± 4.1	2.3 ± 4.6

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Demograph ic Group</i>	<i>Verbal Memory</i>		<i>Visual Memory</i>		<i>Visual Motor Speed</i>		<i>Reaction Time</i>		<i>PCSS</i>	
Tsushima (2020)	5741 high school athletes, 57.5% male (age 13-15: male n=2024, female n=1573; age 16-18: male n=1289, female n=855). Mean age=15.1 ± 1.2. 11.3% had a previous concussion.	All:	82.1 ± 9.9	82.3 ± 10.0	72.3 ± 12.9	71.2 ± 13.1	34.4 ± 7.1	36.4 ± 6.7	0.62 ± 0.09	0.61 ± 0.09	7.4 ± 11.1	8.5 ± 11.7
<i>Adults</i>												
Covassin (2010)	188 high school & collegiate athletes. 53.2% male; mean age=18.35±2.77 (male), 18.29±2.24 (female). ConHx: males: none: n=25, 1+: n=25, 2+: n=25, 3+: n=25; females: none: n=25, 1+: n=25; 2+:n=23, 3+: n=15). None had ADHD or LD.	No ConHx: 1+ ConHx: 2+ ConHx: 3+ ConHx: All:	90.1 ± 6.9 88.5 ± 6.9 82.8 ± 6.9 81.7 ± 6.9 85.8 ± 7.9	93.1 ± 7.0 89.9 ± 7.6 91.3 ± 6.0 89.4 ± 9.5 99.1 ± 7.4	82.0 ± 11.4 76.9 ± 10.3 77.4 ± 8.5 73.2 ± 8.1 77.4 ± 10.0	82.1 ± 10.6 80.5 ± 8.2 81.1 ± 10.8 77.2 ± 9.3 80.6 ± 9.8	36.7 ± 7.8 40.0 ± 6.8 37.9 ± 4.3 41.7 ± 6.7 39.8 ± 6.6	41.1 ± 8.4 41.2 ± 5.7 42.8 ± 6.1 43.2 ± 4.4 40.8 ± 6.6	0.56 ± 0.08 0.55 ± 0.07 0.55 ± 0.08 0.56 ± 0.07 0.56 ± 0.07	0.53 ± 0.06 0.54 ± 0.06 0.54 ± 0.06 0.52 ± 0.05 0.55 ± 0.07	-	-
Henry (2015)	4500 adolescent athletes. 50.0% male; age range=13-21 (250 participants of each age). None had ADHD or LD.	Age 19-21:	86.1±9.7	87.9 ± 9.3	76.1 ± 12.5	73.9 ± 13.0	40.6 ± 6.9	41.2 ± 5.9	0.56 ± 0.07	0.56 ± 0.06	-	-
Cottle (2017)	503 collegiate athletes. 65.0% male; mean age=18.9±1.3. 8.1% had ADHD.	All:	84.6 ± 9.9	87.7 ± 9.5	76.0 ± 12.9	75.0 ± 13.6	39.5 ± 6.0	41.5 ± 5.7	0.59 ± 0.08	0.57 ± 0.06	4.0 ± 7.8	5.3 ± 10.1
Walton (2020)	952 student athletes (males, age <19=186; females age <19=165; males age 19+=351; females age 19+=240). 57.5% male; mean age=19.2±1.4 (range=17-29).	Age <19: Age 19+	88.1 ± 9.6 88.4 ± 8.6	90.9 ± 8.2 89.4 ± 8.9	81.3 ± 8.2 79.8 ± 11.9	81.3 ± 10.7 77.6 ± 12.8	42.9 ± 6.2 42.4 ± 6.1	44.0 ± 5.5 43.3 ± 5.7	0.54 ± 0.05 0.54 ± 0.06	0.55 ± 0.06 0.55 ± 0.06	-	-

ConHx: Concussion history; ADD: Attention deficit disorder; ADHD: Attention deficit hyperactivity disorder; LD: Learning disorder.

2.4.3.3 Vestibular profile

The vestibular clinical profile presents with symptoms of dizziness or lightheadedness, motion sickness, nausea, and discomfort in busy surroundings (31,130). Vestibular impairment is also associated with balance and coordination difficulties (219). The vestibular system has two major functions: vestibulospinal function refers to the body's ability to control balance and posture, while vestibulo-ocular function involves gaze control during head movements (220). However, SRC assessments for vestibular dysfunction (e.g., mBESS or the Sensory Organisation Test) have traditionally focused only on vestibulospinal impairment (221,222). The mBESS has poor discriminative validity for SRC, while the validity of the Sensory Organisation Test in players with SRC has not been investigated (see Table 18). It is important for clinicians to examine vestibulo-ocular impairment in addition to vestibulospinal impairment following an SRC to enable a comprehensive, targeted approach to rehabilitation. Vestibulo-ocular motor screening (VOMS) was developed to evaluate post-SRC vestibulo-ocular impairment by assessing whether stimulating the vestibular and ocular systems provokes symptoms (121). The vestibular components of the VOMS assess the vertical vestibular-ocular reflex (VVOR), the horizontal vestibular-ocular reflex (HVOR) and visual motion sensitivity (VMS) (223). Several methods of classifying VOMS symptoms have been suggested (150,223,224), with varying sensitivity and specificity for individual items (see Table 18). However, the cut-off points suggested by Kontos have demonstrated the highest AUCs (0.80-0.90) for the vestibular items, indicating high validity (150).

Table 18: Overview of concussions tests assessing vestibular impairment

Test	Vestibular Function Assessed	Validity
Modified Balance Error Scoring System	Vestibulospinal	- AUC: 0.52-0.58 (158). - Sensitivity of 0.10-0.29 (158). - Specificity of 0.85-0.93 (158).
Sensory Organisation Test	Vestibulospinal	Validity has not been investigated
Vestibular-Ocular Motor Screening	- Vestibulo-ocular - VVOR - HVOR - VMS	Various cut-off points for individual items have been suggested. - Mucha (2014) (121): - Individual item scores: - VVOR AUC: not included - HVOR AUC: 0.78 - VMS AUC: 0.73 - Elbin (2021) (224): - Individual item scores: - VVOR AUC: 0.66 - HVOR AUC: 0.67 - VMS AUC: 0.71 - Kontos (2021) (150): - Individual item scores: - VVOR AUC: 0.90 - HVOR AUC: 0.90 - VMS AUC: 0.89 - Overall score: - AUC: 0.91

AUC: Area under the curve; VVOR: Vertical vestibular-ocular reflex; HVOR: Horizontal vestibular-ocular reflex; VMS: Visual motion sensitivity.

2.4.3.4 Ocular profile

Symptoms of the ocular clinical profile include blurred or double vision, headaches, and an inability to focus the eyes (31,219). The ocular profile may manifest clinically as oculomotor dysfunction, such as convergence insufficiency, and accommodation and eye tracking problems (31,219). As the vestibular and ocular systems are physically linked (220), the ocular and vestibular profiles are related and may occur together (31,219). Post-SRC ocular dysfunction has been assessed using the King-Devick test, which has a sensitivity of 86% and a specificity of 90% (225). However, it focuses entirely on saccadic movements. In order to gain a more comprehensive understanding of post-SRC ocular symptoms and develop a targeted rehabilitation plan, it is necessary for clinicians to assess other aspects of oculomotor function. In addition to assessing vestibular dysfunction, the VOMS evaluates symptom provocation in response to eye movements (e.g., smooth pursuits, saccades, convergence, and near point of convergence (NPC) distance) (121). Varying cut-off points for the VOMS have been suggested. Two studies that developed cut-off points in adolescents demonstrated poor discriminative validity for most individual ocular items ($AUC \leq 0.70$) (121,224,226) (see Table 19). However, another study that suggested cut-off points in an adult sample found high discriminative validity ($AUC \geq 0.90$) for all ocular items other than NPC distance ($AUC = 0.58$) (150).

Table 19: Overview of concussion tests assessing ocular symptoms

Test	Domain Assessed	Validity
King-Devick Test	Saccadic movements	• Sensitivity of 86% (225). • Specificity of 90% (225).
Vestibular-Ocular Motor Screening	Vestibulo-ocular function • Smooth pursuits • Saccadic movements • Convergence	Various cut-off points for individual items have been suggested. • Mucha (2014) (121): ○ Individual item scores: ▪ Smooth pursuits AUC: 0.64 ▪ Horizontal saccades AUC: 0.68 ▪ Vertical saccades AUC: 0.65 ▪ NPC AUC: 0.64 ○ NPC distance: ▪ AUC: 0.73 • Elbin (2021) (224): ○ Individual item scores: ▪ Smooth pursuits AUC: 0.55 ▪ Horizontal saccades AUC: 0.60 ▪ Vertical saccades AUC: 0.63 ▪ NPC AUC: 0.62 ○ NPC distance: ▪ AUC: 0.58 • Kontos (2021) (150): ○ Individual item scores: ▪ Smooth pursuits AUC: 0.90 ▪ Horizontal saccades AUC: 0.90 ▪ Vertical saccades AUC: 0.90 ▪ NPC: 0.90 ○ NPC distance: AUC: 0.51

NPC: Near point of convergence; AUC: Area under the curve.

2.4.3.4.1 Test-retest reliability of Vestibular-Ocular Motor Screening

Four studies have assessed the test-retest reliability of the VOMS (158,185,227,228). Two studies re-assessed the VOMS after a one-year interval (158,185), one study re-assessed the VOMS after a 60-minute interval (227), and one study carried out a pre-season assessment followed by two re-assessments on the same day (immediately after removal from play and five minutes later) during the season (see Table 20) (228). Study samples consisted of high school (n=2) (227,228) or collegiate (n=2) (158,185) athletes, with males comprising more than half of each sample. Studies are difficult to compare due to differences in retest intervals and methods of analysing reliability. While two studies of high school athletes reported moderate to high levels of agreement (68.9%-100.0%) for ocular items, and moderate to high levels of agreement (48.9%-100.0%) for vestibular items (227,228), the percent agreement method does not take the possibility of change agreement into consideration (229). In addition, the retest intervals in these studies were short (ranging from 60 minutes (227) to a mean of 41 days (228)), and one study reported separate scores for individual symptoms instead of total symptoms for each item, which may have inflated agreement scores (227). A separate study of over 500 collegiate athletes reported unweighted Kappa coefficients of 0.30-0.51 for ocular items and 0.35-0.38 for vestibular items, indicating fair to moderate test-retest reliability after one year (185,229). This lower reliability over a longer timeframe may suggest that the VOMS is not suitable for inclusion in baseline assessments. However, existing research has not examined test-retest reliability by age, gender, or medical history. Reliability data based on these demographic characteristics is required before recommendations to clinicians on the use of the VOMS in female, community sport players can be made.

Table 20: Test-retest reliability of vestibular-ocular motor screening

Author (Year)	Participant Characteristics	Timepoints		Smooth Pursuits	Horizontal Saccades	Vertical Saccades	NPC	NPC Distance	HVOR	VVOR	VMS	TSS
Yorke (2017)	21 high school students; 76.2% male; age: 15.5±1.2.	Baseline-60 minutes.	Headache: 100.0% Dizziness: 90.0% Nausea: 100.0% Fogginess: 95.0%	100.0% 90.0% 100.0% 95.0%	100.0% 100.0% 100.0% 90.0%	100.0% 100.0% 100.0% 95.0%	95.0% 95.0% 100.0% 100.0%	ICC (2,1) = 0.95 SEM=1.5cm MDC=4.0cm	100.0% 85.0% 100.0% 95.0%	95.0% 100.0% 100.0% 100.0%	100.0% 90.0% 100.0% 100.0%	-
Broglio (2018)	525 student athletes; 58.9% male; age: 19.2±1.2; history of 0.4±0.8 concussions.	Baseline-1 year (316.1±83.4 days):		κ=0.3 ¹	κ=0.29 ¹	κ=0.28 ¹	κ=0.36 ¹	κ=0.51 ¹	κ=0.38 ¹	κ=0.38 ¹	κ=0.35 ¹	-
Worts (2018)	45 high school student athletes; 53.3% male; age: 16.11±1.43. 20.0% had a previous concussion, 30.0% migraine and 16.3% motion sickness. Participants with concussion <9 months ago or ocular disorders excluded.	Baseline-pre-practice during season (41.7 6 ±18.5 days):		100.0%	84.4%	64.4%	75.6%	ICC (1,k)=0.87	62.2%	60.0%	64.4%	-
		Baseline-within five minutes of removal during season (41.7 6 ±18.5 days):		91.1%	80.0%	57.8%	68.9%	ICC (1,k)=0.76	64.4%	57.8%	68.9%	-
		Pre-practice- within five minutes of removal:		88.9%	80.0%	68.9%	77.8%	ICC (1,k) =0.94	68.9%	73.3%		-
		All 3 times:		88.9%	73.3%	51.1%	64.4%	ICC (1,k) =0.91	53.3%	48.9%		-
Ferris (2022)	424 collegiate athletes. 52.3% male ² ; age: 19.4±1.5.	Baseline-1 year		-	-	-	-	-	-	-	-	ICC (2,k) = 0.36

NPC: Near point of convergence; HVOR: Horizontal vestibular-ocular reflex; VVOR: Vertical vestibular-ocular reflex; VMS: Visual motion sensitivity; TSS: Total symptom score; ICC (2,1): Intraclass correlation coefficient two-way random effects model for single measures; SEM: Standard error of measurements; MDC: Minimal detectable change; κ: Kappa coefficient; ICC (1,k): Intraclass correlation coefficient one-way random effects model for average measures; 1: Scores categorised as 0, 1, 2 or ≥3; 2: Of overall, larger sample.

2.4.3.4.2 Normative data for Vestibular-Ocular Motor Screening

Five studies have presented baseline VOMS data in players without SRC (227,230–232). Three studies focused on adolescents (227,231,232), one study focused on adults (230), and the remaining study included both adolescent and adult participants (233). Mean baseline values for individual VOMS items ranged from 0.00-0.50 for smooth pursuits, 0.02-0.61 for horizontal saccades, 0.00-0.66 for vertical saccades, 0.00-0.61 for NPC, 0.07-0.72 for horizontal VOR, 0.07-0.66 for vertical VOR, 0.07-0.90 for VMS, and 1.35-2.32cm for NPC distance (see Table 21) (227,230–233). In addition, four of these studies and one other study have reported the proportion of participants who obtained a positive score on each item using the original cut-off values (≥ 2 on individual items or an NPC distance ≥ 5 cm) (227,230–232,234). Overall, between 4.8% and 24.8% of participants met the cut-off threshold for a positive score on individual VOMS items. False positive VOMS results may be more common in individuals with a history of migraine (235) or motion sickness (230). The highest false positive scores were found for NPC distance (9.7%-24.8%), while 4.8%-14.4% of participants obtained positive scores on the remaining items (see Table 21). Although all five studies included male and female players, only one presented data separately by gender. This study reported similar false positive rates between male and female players across all items (231). However, participants ranged in age from 8-14 years. As baseline vestibular symptoms are more common in females (236,237), there is a need for separate normative VOMS data in adolescent and adult female athletes. Future research should also examine the proportion of participants reporting false positive scores at baseline using the alternative classification systems for cut-off scores.

Table 21: Normative data for vestibular-ocular motor screening

Author (Year)	Participant Characteristics	Demographic Group	Smooth Pursuits	Horizontal Saccades	Vertical Saccades	NPC	NPC Distance (cm)	HVOR	VVOR	VMS
<i>Descriptive statistics</i>										
Kontos (2016)	263 collegiate athletes from multiple sports. 63.1% male; age: mean=19.9 ± 1.4; range=18-24. 25.3% had a previous concussion and 3.4% had motion sickness. None had a concussion <6 months ago.	-	0.35 ± 1.39	0.36 ± 1.39	0.36 ± 1.39	-	2.09 ± 2.89	0.37 ± 1.52	0.35 ± 1.51	0.41 ± 1.53
Yorke (2017)	105 high school students. 50.5% male; mean age=15.4 ± 1.2. None had a concussion <3 months ago.	-	0 (0-2) ¹	0 (0-3) ¹	0 (0-5) ¹	0 (0-4) ¹	3.0 (0-20.7) ¹	0 (0-5) ¹	0 (0-5) ¹	0 (0-3) ¹
Moran (2018)	423 youth American football and soccer players. 65.7% male; mean age=11.0 ± 1.5, range=8-14. None had a concussion <6 months ago.	All: Age 8-11: Age 12-14:	0.49 ± 1.6 0.49 ± 1.8 0.48 ± 1.2	0.55 ± 1.6 0.51 ± 1.5 0.61 ± 1.7	0.61 ± 1.8 0.62 ± 1.9 0.61 ± 1.8	0.60 ± 2.1 0.61 ± 2.0 0.59 ± 2.2	1.50 ± 2.6 1.35 ± 2.5 1.7 ± 2.7	0.70 ± 1.9 0.71 ± 1.9 0.68 ± 1.9	0.63 ± 1.8 0.63 ± 1.9 0.64 ± 1.6	0.71 ± 2.1 0.70 ± 2.0 0.72 ± 2.2
Moran (2019)	423 youth American football and soccer players. 65.7% male; mean age=11.0 ± 1.5, range=8-14. None had a concussion <6 months ago.	Male: Female:	0.50 ± 1.8 0.46 ± 1.2	0.53 ± 1.5 0.60 ± 1.7	0.58 ± 1.8 0.66 ± 1.8	0.55 ± 1.9 0.71 ± 2.5	1.52 ± 2.7 1.45 ± 2.4	0.72 ± 1.9 0.66 ± 1.9	0.66 ± 2.0 0.58 ± 1.4	0.61 ± 2.0 0.90 ± 2.4
Wallace (2020)	80 high school (47.5%) and collegiate (52.5%) athletes. 45% male; mean age = 17.74 ± 2.7. 66.7% had anxiety and/or depression.	Control: Anxiety/ Depression:	0.0 ± 0.0 0.0 ± 0.0	0.07 ± 0.4 0.02 ± 0.1	0.02 ± 0.1 0.0 ± 0.0	0.0 ± 0.0 0.05 ± 0.3	1.67 ± 1.9 2.32 ± 4.5	0.07 ± 0.4 0.17 ± 0.6	0.07 ± 0.4 0.12 ± 0.5	0.07 ± 0.3 0.12 ± 0.6
Author (Year)	Participant Characteristics	Demographic Group	Smooth Pursuits	Horizontal Saccades	Vertical Saccades	NPC	NPC Distance (cm)	Horizontal VOR	Vertical VOR	VMS
<i>Percentage of participants meeting cut-off points (≥2 or ≥5cm NPC distance):</i>										
Kontos (2016)	263 collegiate athletes from multiple sports. 63.1% male; age:	-	7.0%	7.0%	7.0%	6.0%	11.0%	7.0%	6.0%	8.0%

	mean=19.9 ± 1.4; range=18-24. 25.3% had a previous concussion and 3.4% had motion sickness. None had a concussion <6 months ago.									
Yorke (2017)	105 high school students. 50.5% male; mean age=15.4 ± 1.2. None had a concussion <3 months ago.	-	4.8%	5.7%	6.7%	4.8%	24.8%	10.5%	6.7%	9.5%
Moran (2018)	423 youth American football and soccer players. 65.7% male; mean age=11.0 ± 1.5, range=8-14. None had a concussion <6 months ago.	-	9.6%	11.1%	10.4%	10.6%	10.6%	13.4%	12.5%	12.5%
Moran (2019)	423 youth American football and soccer players. 65.7% male; mean age=11.0 ± 1.5, range=8-14. None had a concussion <6 months ago.	Male: Female:	10.0% 8.9%	10.8% 11.7%	9.3% 12.4%	10.0% 11.7%	9.7% 11.0%	12.9% 14.4%	11.8% 13.7%	10.8% 15.8%
Eagle (2021)	378 collegiate athletes. 49.7% male; mean age=19.2 ± 1.1 (range: 17-25). 5.8% had a history of migraine and 21.7% had a previous concussion.	-	5.8%	5.3%	5.8%	5.6%	15.9%	9.0%	9.0%	8.5%

NPC: Near point of convergence; HVOR: Horizontal vestibular-ocular reflex; VVOR: Vestibular vestibular-ocular reflex; VMS: Visual motion sensitivity; 1: Median and interquartile range.

2.4.3.5 Mood profile

Players experiencing the mood clinical profile may report anxiety, low mood, irritability, hypervigilance, or rumination about their symptoms (31,238). Although mood changes are well-documented following an SRC (122), no specific assessments for SRC-related mood dysfunction exist. Several symptom report measures (e.g., the GSC and PCSS) include mood symptoms, such as feeling more emotional, anxiety, and irritability (132,133). However, in order for clinicians to gain a complete understanding of a player's emotional state and create an appropriate treatment plan, more detailed mood assessments are necessary. Post-SRC mood changes are complicated as they may be influenced by the physiological effects of the SRC, players' pre-existing mental health conditions, how players respond to the injury psychologically, and environmental factors (238). Multiple measures of mood have been developed and validated in clinical populations that may be useful for clinicians managing players with SRC (see Table 22). Unlike SRC symptom checklists, these measures have been developed based on a theoretical understanding of mental health conditions and provide detail about the severity of mood symptoms (239–243). They may be useful for identifying players with pre-existing conditions that may be modifiers post-SRC or for monitoring players with mood dysfunction following an SRC (31). High sensitivity ($\geq 80\%$) and specificity ($\geq 78\%$) have been reported for the Patient Health Questionnaire-9 (PHQ-9) (241) and the Generalised Anxiety Disorder-7 (GAD-7) (244) for identifying clinical depression and anxiety, respectively. While the PHQ-9 and GAD-7 have not been validated in sporting populations, they nevertheless may assist clinicians in managing SRC players who report mood dysfunction.

Table 22: Overview of mood assessments

Test	Domain Assessed	Validity
Profile of Mood States	• Tension-anxiety. • Depression-dejection. • Anger-hostility. • Vigour-activity. • Fatigue-inertia. • Confusion-bewilderment.	• Demonstrated factorial validity (245,246).
Patient Health Questionnaire-9	• Depression.	• Sensitivity of 88% (241). • Specificity of 78% (241).
Beck Depression Inventory-II	• Depression.	• Sensitivity of 70.0%-86.8% (247). • Specificity of 56.8%-92.0% (247).
Centre for Epidemiological Studies Depression Scale	• Depression.	• Demonstrated factorial validity (242). • High correlation with trait anxiety, suggesting poor discriminative validity (242).
Generalised Anxiety Disorder-7	• Anxiety.	• Sensitivity of $\geq 80\%$ (244). • Specificity of $\geq 80\%$ (244).
State-Trait Anxiety Inventory	• State anxiety. • Trait anxiety.	• Correlates with other measures of anxiety (0.73-0.85) (243).
Beck Anxiety Inventory	• Anxiety.	• Correlates with other measures of anxiety ($r=0.51-0.81$) (239).
Hospital Anxiety and Depression Scale	• Anxiety. • Depression.	• Anxiety scale has a sensitivity of 66%-94% and a specificity of 73%-93% in primary care and general medicine populations (248). • Depression scale has a sensitivity of 66%-85% and a specificity of 90%-97% in primary care and general medicine populations (248).

2.4.3.5.1 Test-retest reliability of the Patient Health Questionnaire-9 and Generalised Anxiety Disorder-7

No studies have assessed the test-retest reliability of the PHQ-9 or the GAD-7 in a sporting or healthy population. This may be because these measures are not typically included in SRC assessments. Test-retest reliability may be less important for measures that are used in acute settings and are not assessed repeatedly (249). Three studies have examined the test-retest reliability of the PHQ-9 and GAD-7 in clinical populations over a two-week timeframe, and reported high reliability (250–252) (see Table 23). However, as participants had specific medical conditions (e.g., arthritis), were considerably older than most athletes, and were re-assessed after a short timeframe, these studies have little application to SRC research. Information on the test-retest reliability of the PHQ-9 and GAD-7 over longer timeframes in female, community sport athletes is necessary to assist clinicians who may wish to incorporate these measures into baseline assessments.

Table 23: Test-retest reliability of the Patient Health Questionnaire-9 and the Generalised Anxiety Disorder-7

Author (Year)	Participant Characteristics	Timepoints	PHQ-9	GAD-7
Marrie (2017)	A subgroup (n=158) of 253 patients with multiple sclerosis. 18.6% male; mean age= 51.0 ± 12.9.	Baseline-2 weeks.	ICC = 0.85	ICC = 0.76
Bernstein (2018)	A subgroup (number not specified) of 242 adult patients with inflammatory bowel disease. 37.0% of the overall sample was male; mean age= 47.5 ± 14.8.	Baseline-2 weeks.	ICC = 0.85	ICC = 0.76
Hitchon (2020)	A subgroup (n=115) of 150 arthritis patients. 15.3% of overall sample male; mean age= 59.8 ± 11.7	Baseline-2 weeks.	ICC = 0.86	ICC = 0.81

PHQ-9: Patient Health Questionnaire-9; GAD-7: Generalised Anxiety Disorder-7; ICC: Intraclass correlation coefficient, type not specified.

2.4.3.5.2 Normative data for the Patient Health Questionnaire-9 and Generalised Anxiety Disorder-7

Only four studies have presented normative values for the PHQ-9 (range: 0-27) or the GAD-7 (range: 0-21) in female athletes (253–256) (see Table 24). All of these studies included male and female collegiate athletes, however only two presented separate data for females (255,256). Overall, mean PHQ-9 scores of 0.99-1.34 and mean GAD-7 scores of 1.07-1.24 were recorded. Two studies also reported the proportion of participants who met the clinical cut-off threshold for the PHQ-9 (≥ 5), while one reported the proportion of participants who met the clinical cut-off threshold for the GAD-7 (≥ 5). Between 8.8% and 30.0% of female athletes were classified as having mild depression based on the PHQ-9, and 35.8% met the criteria for mild anxiety on the GAD-7. The study reporting the larger proportions exceeding clinical cut-off values also reported high levels of sleep dysfunction (256). As mental health and sleep are related (257), it is possible that this sample does not accurately reflect mood in female, collegiate athletes. Additional normative data on the PHQ-9 and GAD-7 in

female athletes that takes medical history into account is required. There is also a need for normative data on the PHQ-9 or GAD-7 in adolescent female athletes.

Table 24: Normative data for the Patient Health Questionnaire-9 and the Generalised Anxiety Disorder-7

Author (Year)	Participant Characteristics	Demographic Group	PHQ-9 Score			GAD-7 Score		
			Mean $\pm$ SD	Score ≥ 5	Score ≥ 10	Mean $\pm$ SD	Score ≥ 5	Score ≥ 10
Putukian (2015)	263 collegiate athletes. 66.9% male; mean age=20.3 $\pm$ 1.7. 32.3% had a previous concussion.	-	1.03 $\pm$ 1.85			1.07 $\pm$ 2.12		
Putukian (2018)	1152 collegiate athletes. 69.0% male; mean age= 19.5 $\pm$ 1.4. 27.7% had a previous concussion and 3.0% 55epressression or anxiety.	-	0.99 $\pm$ 1.80			1.24 $\pm$ 2.12		
LoGalbo (2020)	1209 collegiate athletes. 63.0% male; mean age=19.3 $\pm$ 1.6 (range: 17-27).	All: Male: Female:	1.32 $\pm$ 2.15 1.31 $\pm$ 2.09 1.34 $\pm$ 2.24	7.4% 7.6% 8.8%	-	-		-
Duffield (2021)	137 collegiate athletes. 61.3% male; median age= 20. 28.3% of females and 23.8% of males had a previous concussion.	All: Male: Female:	-	30.0% 29.7% 30.0%	8.0% 9.5% 5.6%	-	30.0% 25.0% 35.8%	9.4% 7.0% 13.2%

PHQ-9: Patient Health Questionnaire-9; GAD-7: Generalised Anxiety Disorder-7; SD: Standard deviation.

2.4.3.6 Migraine profile

The migraine clinical profile involves a pulsating headache accompanied by photophobia, phonophobia and nausea, which may worsen after exercise (31). Beyond general SRC symptom report checklists (132,133) and the clinical interview, specific migraine tests are rarely included in SRC assessments. However, as acute post-traumatic migraine may predict a prolonged recovery from SRC (120,258), it is important that clinicians can track migraine symptoms following an SRC. A pre-existing personal or family history of migraine may also be associated with post-traumatic migraine (259,260). Therefore, incorporating a measure of migraine severity into baseline assessments may help clinicians to both identify players who may be at risk of experiencing a migraine profile if they sustain an SRC, and to determine when players with post-traumatic migraine have recovered. Several self-report measures for migraine have been developed (see Table 25). The Migraine Screen Questionnaire and ID-Migraine have been used to identify migraines; the Migraine Screen Questionnaire has a sensitivity of 92.8% in the general population but has not been validated in SRC patients (261), while the ID-Migraine has shown moderate sensitivity (63.2%-84.2%) for individual items in mTBI patients (262). However, these measures do not provide a measure of migraine severity. The Migraine Disability Assessment (MIDAS) (263,264), which grades migraines according to the number of days dysfunction experienced during the preceding three months, may be beneficial for clinicians working with players with prolonged post-traumatic migraine following an SRC.

Table 25: Overview of migraine assessments

<i>Test</i>	<i>Domain Assessed</i>	<i>Validity</i>
Migraine Disability Assessment Test	Disability due to migraine.	- Correlated with physicians' clinical judgements (265). - Items correlated with a migraine diary in migraine patients ($\rho=0.41-0.76$) (266).
Migraine Screen Questionnaire	Diagnosis of migraine.	- Sensitivity of 92.8% in general population (261). - Specificity of 81.4% in general population (261).
ID-Migraine (9 or 3 item) Officially the 3-item is used- the 9-item was used preliminarily & reduced to the 3 questions, however a study on migraine in mTBI found that the 9-item had greater sensitivity & specificity	Diagnosis of migraine.	- Sensitivity of 63.2%-84.2% for individual items in mTBI patients (262). - Specificity of 40.9%-54.6% for individual item in mTBI patients (262).

mTBI: Mild traumatic brain injury.

2.4.3.6.1 Test-retest reliability of the Migraine Disability Assessment

Other than an initial development study (267), no studies have examined the test-retest reliability of the MIDAS in any population. This study examined the test-retest reliability of the MIDAS over a 21-day timeframe in migraine patients and healthy controls (267). High reliability ($\rho=0.84$) for the overall score was found, with no differences in reliability between cases and controls. Test-retest reliability data on the MIDAS in sporting populations is needed. Reliability should also be assessed over a longer timeframe to better reflect the possible timeframe (up to one year) between baseline and post-SRC assessments.

2.4.3.6.2 Normative data for the Migraine Disability Assessment

No studies have reported normative data on the MIDAS in healthy populations. In case pre-injury data are not available, clinicians require normative data from the appropriate population to inform their interpretations of test results. Research is needed to establish normative data on MIDAS scores in female, community sport players without a recent SRC. This could then be used to monitor the recovery of players who experience a migraine profile following an SRC.

2.4.3.7 Sleep profile

Sleep is considered a modifier in the clinical profiles model (31,130). Post-SRC sleep difficulties include trouble falling or staying asleep, hypersomnia, and sleepiness during the day (31,127). These sleep difficulties may occur due to circadian rhythm disturbances that result from SRC (127). However, sleep also modifies the other clinical profiles. Poor sleep is associated with neurocognitive deficits, low mood and migraine symptoms in athletes with (128,268) and without SRC (269–271), while a history of pre-injury sleep complaints predicts SRC severity (157,260). Behavioural changes (e.g., changes to daily routine and less exercise) and psychological responses (e.g., worry about the injury) following an SRC may affect an athlete's sleep, which may subsequently worsen other symptoms (31). Clinicians working with athletes with SRC should therefore examine sleep alongside

other symptoms. Polysomnography is an objective assessment of sleep that uses a combination of techniques, including electroencephalography, electrooculography, and electromyography, to record stages of sleep, leg movements, respiration, heart rate, and blood oxygen levels (272). It is considered the gold-standard for diagnosing sleep disorders, however it requires specialised equipment and is expensive and time-consuming to carry out. Subjective measures of sleep quality are more practical for clinicians to implement in athletes with SRC. The Pittsburgh Sleep Quality Index (PSQI), Epworth Sleepiness Scale, and Insomnia Severity Index have all demonstrated known-group validity for various sleeping problems (see Table 26), however the PSQI assesses a wider range of constructs (e.g., sleep latency and duration). Therefore, the PSQI may be most useful for assessing general sleep difficulties related to SRC.

Table 26: Overview of sleep assessments

<i>Test</i>	<i>Domain Assessed</i>	<i>Validity</i>
Polysomnography	• Stages of sleep. • Leg movements. • Respiratory rate. • Heart rate and rhythm. • Blood oxygen levels.	• Gold standard for assessing sleep disorders (272).
Pittsburgh Sleep Quality Index	• Subjective sleep quality. • Sleep latency. • Sleep duration. • Sleep efficiency. • Sleep disturbance. • Use of sleep medication. • Daytime dysfunction.	• Known-group validity for sleep problems in clinical and non-clinical samples ($p<0.0001$, $I^2=93\%$) (273). • Correlates with other sleep quality measures (>0.7) (273).
Epworth Sleepiness Scale	• Excessive daytime sleepiness.	• Known-group validity for patients with sleep apnoea, narcolepsy and idiopathic hypersomnia (274).
Insomnia Severity Scale	• Amount of disturbance to sleep pattern. • Effects of sleep difficulties. • Distress relating to sleep difficulties.	• Moderate correlation with sleep diary ($r=0.32-0.55$) in insomnia patients at baseline (275). • Low to moderate correlation with polysomnography ($r=0.07-0.45$) in insomnia patients at baseline (275).

2.4.3.7.1 Test-retest reliability of the Pittsburgh Sleep Quality Index

Only one study has evaluated the test-retest reliability of the PSQI in athletes (see

Table 27), reporting low reliability (ICCs=0.45-0.55) (276). This is also the only study that has examined test-retest reliability of the PSQI in a healthy, non-clinical population. Reliability was examined at three time-points (short-, medium-, and long-term) with participants being assessed between two and five times. However detailed information was not provided about the time between assessments or what participants were included in each group. Furthermore, although demographic information about the overall sample was provided, the demographic characteristics of the subgroup who were re-assessed is unknown. Follow-up research should evaluate the test-retest reliability of the PSQI in both adolescent and adult female athletes at clearly defined timepoints.

Table 27: Test-retest reliability of the Pittsburgh Sleep Quality Index

Author (Year)	Participant Characteristics	Timepoints	PSQI Global Score
Halson (2022)	A subgroup (n=80) of 479 Olympic athletes who were assessed two to five times (31 short-term, 35 medium-term, 38 long-term). 22.5% male; median age- male= 24 (21-27); female= 19 (17-24).	Short-term (Baseline-2 to 3 months); Medium-term (3 months-1 year); Long-term (>1 year):	ICC (2,1) = 0.45 ICC (2,1) = 0.51 ICC (2,1) = 0.55 SEM= 2

ICC (2,1): Two-way mixed intraclass correlation coefficient.

2.4.3.7.2 Normative data for the Pittsburgh Sleep Quality Index

Eleven studies reported baseline data on the PSQI from samples that included female athletes (256,276–285) (see Table 28). Eight studies focused on adult participants (256,276,280–285) and the remaining three focused on adolescent participants (277–279). Studies that reported data separately for female athletes found that the mean global PSQI scores ranged from 5.0 to 8.2 in adults (276,281,283–285), and was 4.4 in adolescents (277). In comparison, global PSQI scores between 4 and 5.4 were reported in adult males (276,281,283,285), while scores of 4.0 were reported in male adolescents (277). Only two studies reported the proportion of female athletes (55.8%-83.0%) (276,282) who exceeded the cut-off score of ≥ 5 and were classified as poor sleepers (286). However, the studies that presented the highest PSQI scores (e.g., global score of 8.2, 83.0% meeting the criteria for poor sleepers) for female athletes contained low numbers of female participants (n=23-24) (282,284). It is possible that these sample sizes are inadequate to accurately capture PSQI scores and that these results are outliers. Overall, while PSQI scores have been well-documented in adult female athletes, there is limited data available on adolescent female athletes. The only study that separately presented PSQI scores for male and female adolescent athletes contained mostly male participants (277). In addition, only one of the studies reviewed here included recreational athletes (285). Normative data on female athletes, and in particular adolescent females, participating in community sport are required.

Table 28: Normative data for the Pittsburgh Sleep Quality Index

Author (Year)	Participant Characteristics	Demographic Groups	PSQI Global Score	Proportion meeting cut-off score		
				≥5	≥6	≥8
Swinbourne (2015)	175 collegiate athletes. 86.6% male.	All: Male: Female:	5.9 ± 2.6 5.6 ± 2.3 8.2 ± 3.3	- - -	- - -	- - -
Mah (2018)	628 collegiate athletes. 54.6% male; mean age= 19.6±1.3	All: Male: Female:	5.38 ± 2.45 5.4 ± 2.4 5.3 ± 2.5	42.4% - -	- - -	- - -
Yeomans (2019)	A subgroup (n=64) of 137 rugby players. 82.5% male; mean age- male=22.7±3.9; female= 25.6±4.9.	Male: Female:	- -	59.0% 83.0%	- -	- -
Anderson (2020)	196 high school athletes.79.6% male; mean age=15.7±1.3.	All: Male: Female:	4.1 ± 2.3 4.0 ± 2.2 4.4 ± 2.5	32.0% - -	- - -	- - -
Carter (2020)	121 collegiate athletes. 53.7% male; mean age- male=21±1; female=21±1.	All: Male: Female:	- 5 5	35.0% - -	- - -	- - -
Leduc (2020)	138 male and female college students (65 students, 73 student-athletes). Mean age=22.0 ± 3.1.	All:	6.89 ± 3.03	65.0%	-	-
Potter (2020)	272 youth athletes (40.4% poor sleep group, 59.6% good sleep group). 55.1% male; poor sleep group median age: 15.3 (15.1-15.6); good sleep group median age: 15.1 (14.9-15.4). 21% of poor sleep group and 39% of good sleep group had a previous concussion.	Poor sleep group (≥5): Good sleep group (<5):	6.6 ± 2.0 2.3 ± 1.3	- -	- -	- -
Duffield (2021)	137 collegiate athletes. 61.3% male; median age= 20. 28.3% of females and 23.8% of males had a previous concussion.	All: Male: Female:	- - -	- - -	53.0% 54.7% 51.0%	33.5% 28.5% 21.7%
Randall (2021)	313 recreational, competitive, national, and elite athletes. 77.6% male; mean age=27.0±8.	All: Male: Female:	5.0 ± 2.4 5.0 ± 2.4 5.4 ± 2.6	55.0% - -	- - -	- - -
Stockbower (2021)	186 high school athletes (92 low specialization, 64 moderate specialization, 30 high specialization). 50.0% male; mean age-low specialization=15.3±2.0; moderate specialization=15.3±1.3; high specialization=15.7±1.1. 84.9% had a previous orthopaedic injury.	History of injury: No history of injury:	4.4 ± 2.9 4.2 ± 2.3	- -	- -	- -
Halsen (2022)	479 Olympic athletes. 22.5% male; median age- male= 24 (21-27); female= 19 (17-24).	Male: Female:	4 (3-6) 5 (3-6)	45.3% 55.8%	- -	- -

PSQI: Pittsburgh Sleep Quality Index.

2.4.3.8 Neck profile

Neck dysfunction is a modifier in the clinical profiles model (31). Neck injuries and SRCs may occur simultaneously due to similar mechanisms of injury (287,288). In addition to presenting with neck pain, stiffness, and loss of strength, neck injuries may be associated with headaches, vestibular dysfunction, cognitive impairments, and anxiety (289–291). As these symptoms may mimic or influence the symptoms of other SRC profiles, it is important that clinicians examine neck dysfunction as part of the SRC assessment. Self-report measures, such as the Neck Bournemouth Questionnaire (NBQ), the Neck Disability Index, and the Neck Functional Disability Scale, may provide a quick and easy method of screening for subjective neck dysfunction (see Table 29). The NBQ assesses multiple domains of neck dysfunction, such as pain intensity, disability, mood, and behavioural factors (292). Unlike several other measures of neck dysfunction, it is also highly sensitive to detecting improvements in neck dysfunction (292). It has also been suggested that increased neck strength may reduce the risk of sustaining an SRC by stabilising the head during impacts (57). Therefore, objectively examining baseline neck strength may be useful in identifying players at a greater risk of SRCs. Players identified as being at high risk of an SRC could then undergo a neck strengthening programme. While isokinetic dynamometry is regarded as the gold-standard method for measuring isokinetic neck strength (293), the cost and size of equipment mean that it is not feasible for most clinicians to use. Hand-held dynamometry (HHD) is a possible alternative. HHD is a convenient way to assess strength and has been found to demonstrate adequate convergent validity with isokinetic testing for multiple muscle groups, including the neck muscles (294,295).

Table 29: Overview of neck assessments

Test	Assesses	Validity
Isokinetic dynamometry	Isokinetic strength.	Considered the gold-standard for measuring isokinetic strength (293).
Hand-held dynamometry	Isometric strength.	- Correlates with isokinetic dynamometry for multiple muscle groups ($r=0.43-0.99$) (294). - High correlation with isokinetic dynamometry for neck strength ($r=0.99$) (295).
Neck Bournemouth Questionnaire	- Pain intensity. - Function- activities of daily living. - Function- social. - Anxiety. - Depression. - Fear-avoidance. - Locus of control.	- Sensitivity of 97.8%-100.0% for individual subscales in detecting a clinically significant improvement (score ≥ 1) (296). - Specificity of 37.5%-66.7% for individual subscales in detecting a clinically significant improvement (score ≥ 1) (296).
Neck Disability Index	- Pain intensity. - Disability.	Improvements are moderately correlated with the Global Rating of Change Scale ($r=0.52-0.58$) (297).
Neck Functional Disability Scale	Disability.	High correlation with patient global assessments ($r=0.89$) (298).

2.4.3.8.1 Test-retest reliability of neck dynamometry

Two studies have examined the test-retest reliability of HHD in healthy male and female participants (see Table 30) (299,300). One of these studies examined reliability over three sessions with a minimum of five days between sessions (300), while the other study examined reliability after one week (299). Both studies assessed neck flexion, extension and right- and left-side lateral flexion, however one performed assessed each of these movements using three different methods (a lying push test, a seated push test, and a seated pull test) (299). Overall, high test-retest reliability was reported, with ICCs ranging from 0.60-0.97. One study reported reliability separately for male and female participants; female participants demonstrated ICCs of 0.60-0.91 (300). While these studies suggest that the short-term test-retest reliability of HHD for neck strength is acceptable, information about reliability over a longer period is required. This is particularly important as neck strength may fluctuate depending on training and the time in the season. Future research should also focus on athletes, who may differ in neck strength variability than the general population. In addition, reliability analyses should be conducted separately based on age and gender.

Table 30: Test-retest reliability of neck dynamometry

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Protocol</i>	<i>Timepoints</i>	<i>Demographic Groups</i>	<i>Neck Flexion</i>	<i>Neck Extension</i>	<i>Right Lateral Flexion</i>	<i>Left Lateral Flexion</i>
Vannebo (2018)	58 healthy participants. 48.3% male; mean age-male=27.4±7.4; female-26.4±7.0.	Participants performed three trials of each test and had a one-minute break between trials. Each trial last 3-5 seconds.	Three sessions with at least 5 days between each session.	All: Male: Female:	ICC = 0.94, 0.96 ICC = 0.81, 0.86 ICC = 0.82, 0.91	ICC = 0.94, 0.97 ICC = 0.83, 0.93 ICC = 0.85, 0.88	ICC = 0.91, 0.92 ICC = 0.79, 0.82 ICC = 0.60, 0.84	ICC = 0.92, 0.91 ICC = 0.82, 0.73 ICC = 0.67, 0.89
Krause (2019)	30 healthy participants. 50.0% male; mean age=23.8.	Participants performed three, three-second trials for each test and had a 30-second rest between trial. Strength was assessed using three methods: a lying push test, a seated push test, and a seated pull test	Baseline-1 week:	Lying push test: Seated push test: Seated pull test:	ICC (3,k) = 0.90 ICC (3,k) = 0.76 ICC (3,k) = 0.90	ICC (3,k) = 0.93 ICC (3,k) = 0.63 ICC (3,k) = 0.88	ICC (3,k) = 0.89 ICC (3,k) = 0.90 ICC (3,k) = 0.89	ICC (3,k) = 0.95 ICC (3,k) = 0.87 ICC (3,k) = 0.85

ICC: Intraclass correlation coefficient, model not specified; ICC (3,k): Intraclass correlation coefficient two-way mixed model, average measures.

2.4.3.8.2 Normative data for neck dynamometry

Six studies have reported baseline values for neck strength measured using HHD in female participants (see Table 31) (300–305). Five of these studies focused on adolescent (n=3) (301,305,306) or adult (n=2) (303,304) athletes, while one included healthy adult participants (300). Differences in equipment, protocols followed, and units of measurement make comparison between studies difficult. Neck strength was measured in pounds (n=1), kilograms (n=3), Newtons (n=1), or Newtons normalised to body mass (n=1). Studies presenting neck strength separately for female participants reported mean neck flexion values of 79 N or 7.4-8.7kg, neck extension values of 131 N or 12.5-14.0kg, and lateral flexion values of 108-113 N or 7.5-9.1kg (300,302). However, the values expressed in Newtons were not recorded in athletes (300). It may be most appropriate to express neck strength values relative to body mass to account for differences in body size. Currently, there is a lack of normative data on neck strength in female, community sport athletes. Future research should stratify normative data by age, gender, and level of play. It should also present baseline neck strength data as Newtons per kilogram body mass to allow for comparison across age and gender.

Table 31: Normative data for neck dynamometry

Author (Year)	Participant Characteristics	Demographic Group	Neck Flexion	Neck Extension	Lateral Flexion		Rotation		SCM	
					Right	Left	Right	Left	Right	SCM
Gutierrez (2014)	17 female high school soccer players. Mean age=15.9±0.9, height=1.65±0.06m, mass=59.0±5.6kg.	-	20.9 ± 5.7 lb	25.9 ± 10.1 lb	18.6 ± 5.5 lb	18.5 ± 5.4 lb	-	-	-	-
Vannebo (2018) ¹	58 healthy participants. 48.3% male; mean age-male=27.4±7.4; female-26.4±7.0. Mean height-male=181±7kg, female=170±6kg. Mean mass- male= 79.3±11.4, female=66.2±14.0kg.	Male: Female:	160 ± 34 N 79 ± 18 N	228 ± 52 N 131 ± 27 N	191 ± 39 N 108 ± 22 N	195 ± 37 N 113 ± 24 N	-	-	-	-
Porfido (2021)	92 male and female collegiate athletes. 54.3% male; mean age=19.29±1.15.	All:	12.4 ± 5.1 kg	12.4 ± 4.3 kg	-	-	8.7 ± 2.1 kg	8.3 ± 2.1 kg	7.9 ± 2.6 kg	8.0 ± 2.6 kg
Deng (2022) ¹	40 elite female Australian football or soccer athletes. Mean age=24.4±5.3; height=170.0±5.0cm; mass=67.2±6.3kg.	Intervention: Control:	1.3 ± 0.2 N/kg 1.4 ± 0.2 N/kg	1.6 ± 0.3 N/kg 1.8 ± 0.4 N/kg	1.2 ± 0.2 N/kg 1.5 ± 0.3 N/kg	1.2 ± 0.2 N/kg 1.5 ± 0.2 N/kg	1.2 ± 0.2 N/kg 1.4 ± 0.2 N/kg	1.2 ± 0.2 N/kg 1.4 ± 0.2 N/kg	-	-
Peek (2022)	58 adolescent athletes. 59.6% male. Intervention (n=31): mean age=14.35±0.29. Control (n=21): men age=14.95±0.21	All- Intervention: All- Control: Male- Intervention: Male- Control: Female- Intervention: Female- Control:	8.4 kg 13.7 kg 9.3 kg 16.2 kg 7.4 kg 8.7 kg	13.7 kg 21.5 kg 14.6 kg 25.3 kg 12.5 kg 14.0 kg	8.7 kg 12.7 kg 9.8 kg 14.6 kg 7.5 kg 8.9 kg	9.0 kg 13.4 kg 9.9 kg 15.5 kg 8.0 kg 9.1 kg	-	-	-	-
Nutt (2022) ³	358 adolescent athletes. 70.0% male; mean age=14.56±2.90.	All:	15.8 ± 5.8 kg	24.1 ± 9.1 kg	17.6 ± 6.3	17.6 ± 6.2				

SCM: Sternocleidomastoid; 1: Reliability study, baseline values reported; 2: Intervention study, baseline values reported; 3: Values are also presented by gender, age and sport in the original study and are not presented here due to space limitations.

2.4.3.8.3 Test-retest reliability of the Neck Bournemouth Questionnaire

One study describing the development of the NBQ examined the test-retest reliability (ICC=0.65) in a sample of patients presenting to a clinic with non-specific neck pain (292). However, patients were retested on the same day they answered the baseline questionnaire and were considerably older (mean age=45.4±14.8) than most athletes, and it is unclear how many participants were included in the re-assessment (292). Therefore, these results may not accurately reflect the reliability of the NBQ in female, community sport athletes. The test-retest reliability of the NBQ should be assessed in healthy, female athletes over a longer timeframe to determine its usefulness as a component of SRC baseline assessments.

2.4.3.8.4 Normative data for the Neck Bournemouth Questionnaire

No studies have described normative values for the NBQ in any demographic group. The NBQ has been used to examine neck-related dysfunction in patients with pre-existing neck pain (296,307,308). This data has little applicability to healthy sporting populations. Clinicians working with female, community sport athletes would benefit from the availability of normative data on the NBQ in this population.

2.4.4 Accuracy of clinical assessment batteries in identifying sport-related concussion

In spite of the highly variable presentation of SRC and multiple available clinical tests, the diagnostic accuracy of clinical assessment batteries has been poorly investigated. Only three studies have examined the combined diagnostic accuracy of two or more clinical tests in identifying SRC (158). One study of male and female collegiate athletes reported that SCAT components (TSS, SSS, BESS firm surface score, and SAC total score) best identified SRC within 72-hours following injury when using a baseline-retest approach. Including ImpACT and the BSI-18 did not improve accuracy between either 1-24 hours (F1 of 0.53 vs 0.66) or 24-72 hours (F1 of 0.56 vs 0.56) post-SRC (309). However, additional studies have found improved diagnostic accuracy of the SCAT3 when used alongside the VOMS in collegiate athletes (0.85 vs 0.81) (310), while the PCSS and VOMS demonstrated better accuracy (AUC of 0.85) than the PCSS, ImpACT, VOMS, and full BESS (AUC of 0.84) in adolescent athletes (311) (see Table 32). These findings suggest that multi-domain assessments for SRC, especially those incorporating the VOMS, may be more useful than assessments focusing on one domain. However, differences in the included tests and demographic characteristics (e.g., age) in these studies mean that further research is needed to determine the optimal multi-domain SRC assessment.

Table 32: Accuracy of clinical test batteries in identifying sport-related concussion

Author (Year)	Tests	Accuracy
Broglio (2019)	• SCAT TSS and SSS • SAC • Full BESS, BESS foam surface, BESS firm surface • BSI-18 • ImPACT	• TSS, SSS, BESS firm surface score, and the SAC total score best identified SRC 72-hours post-injury • Including ImPACT and BSI-18 scores did not improve accuracy between 1-24 hours (F1 of 0.53 vs 0.66) or 24-72 hours post-SRC (F1 of 0.56 vs 0.56)
Ferris (2021)	• SCAT3 (SSS, SAC and full BESS) • VOMS	• Combined AUC of 0.85 • Adding VOMS to SCAT3 significantly increased sensitivity by 9% and specificity by 3%
Sherry (2021)	• PCSS • ImPACT • VOMS • Full BESS	• AUC of 0.85 for PCSS and VOMS (78.3% sensitivity and 91.2% specificity) • ImPACT and full BESS did not significantly contribute to diagnostic accuracy

SCAT: Sport Concussion Assessment Tool; TSS: Total Symptom Score; SSS: Symptom Severity Score; SAC: Standardised Assessment of Concussion; BESS: Balance Error Scoring System; BSI-18: Brief Symptom Inventory-18; ImPACT: Immediate Post-Concussion Assessment and Cognitive Testing; SRC: Sport-related concussion; F1: F-score; SCAT3: Sport Concussion Assessment Tool 3rd Edition; VOMS: Vestibular-ocular motor screening; AUC: area under the curve; PCSS: Post-concussion symptom scale.

2.5 Management of sport-related concussion

2.5.1 Recommended management guidelines

Several sports medicine consensus groups have developed SRC management guidelines (18–20,39). The three most recent sets of guidelines (developed since 2017) include the CISG consensus guidelines (18), the Team Physician consensus statement (38), and the American Medical Society for Sports Medicine position statement (20). They are outlined in detail in Table 33. The Team Physician and American Medical Society for Sports Medicine guidelines are based on the CISG consensus statement; therefore, they share some key elements. Overall, SRC management guidelines emphasise a conservative approach, with some of the key recommendations outlined as follows:

- It is advised that players with a suspected SRC should be immediately removed from play and assessed on-site by a healthcare professional if available.
- Players who are diagnosed with an SRC should subsequently rest for 24-48 hours before they may begin asymptomatic aerobic exercise.
- The graded RTP programme is implemented once players have returned to baseline levels of symptoms, cognition, and postural stability. The graded RTP programme is a six-stage protocol which incrementally increases a player's activity level from symptom-limited exercise to full match play (see Table 34). Players should wait for 24 hours after completing each stage; if they experience symptom aggravation they should return to and repeat the previous stage, otherwise they may proceed to the next stage. Therefore, players should not return to match play for at least seven days post-injury.
- Return-to-learn (RTL) guidelines have also been developed for players resuming academic activities (see Table 35). Similar to the RTP programme, the RTL guidelines endorse gradually

increasing cognitive activity until normal academic activities can be resumed (18,20,38). Although female and younger athletes may experience longer recoveries from SRC than male and adult athletes (33), the same RTP and RTL protocols are recommended for all athletes. It is important to note that the graded RTP and RTL programmes were developed based on expert opinion and their efficacy has not been examined.

Many international and national sporting bodies base their SRC management protocols on the CISC consensus statement (36). The LGFA's SRC management guidelines mainly align with the CISC consensus statement, however they have modified the graded RTP programme based on recommendations from the Gaelic Athletic Association Medical, Scientific and Welfare Committee (see Figure 4) (30). This modified version of the graded RTP programme recommends that players spend four days instead of 24 hours at stages two to four (see Figure 4) and advises that players should not return to full match play until at least 14 days following the injury. It also excludes the symptom-limited activity step, instead incorporating the initial rest period as the first step. The decision to modify the graded RTP programme was based on the evidence that female players take longer to recover than male athletes (30).

Table 33: Sport-related concussion management guidelines

	CISG 5th International Consensus Statement	Team Physician Consensus Statement	American Medical Society for Sports Medicine
Initial management	• Players should be immediately removed from play if they are suspected to have sustained an SRC. • A healthcare professional should perform on-site evaluation using standard emergency medicine principles, including a cervical spine assessment. • Sideline assessments for SRC should be performed. • Players should be supervised following the injury and monitored for signs of deterioration over the several hours. • Players with SRC should not return-to-play on the day of injury. • If a healthcare professional is not available, the player should be immediately referred to a physician.	• Players should be immediately removed from play if they are suspected to have sustained an SRC. • Players with a suspected SRC should be examined on-field for level of consciousness, airways, breathing, and circulation, and on-field SCAT components. • Players with SRC should not return-to-play on the day of injury. • Players may RTP if a healthcare professional determines that they do not have an SRC. • If no healthcare professional is available, the player should not RTP even if symptoms resolve. • Players should be supervised until a decision on disposition has been made (e.g., hospital).	• Players should be immediately removed from play if they are suspected to have sustained an SRC. • Players with a suspected SRC should be examined in a distraction-free setting. • Players should be examined by a health care professional, including a brief history of the event, memory, concentration, balance, and cervical spine palpation and range of motion.
Follow-up medical evaluation	• Medical history and a detailed examination, including cognitive, vestibulo-ocular, postural and sleep assessments, should be carried out. • The clinical status, including improvements or deteriorations, of the player should be evaluated. • The player may be referred for neuroimaging to exclude more serious brain injuries.	• Medical history and a detailed examination, including SRC symptom, cognitive, and cranial nerve assessments, should be carried out in a distraction-free setting.	• If a player is suspected of having sustained an SRC following an initial evaluation, a more in-depth examination should be carried out. • The office examination should include a medical history, neurological assessment, symptom evaluation, and assessment of cognitive, vestibular-ocular, postural, sleep and cervical spine impairments.
Rest	• Players should rest for the initial 24-48 hours post-injury. • After the rest period, physical and cognitive activity can be gradually introduced as long as symptoms are not provoked.	• Players should rest for the initial 24-48 hours post-injury. • After the rest period, physical and cognitive activity can be gradually introduced as long as symptoms are not provoked. • Progressive aerobic exercise can be carried out during the first week.	• Players should rest for the initial 24-48 hours post-injury. • After the rest period, physical and cognitive activity can be gradually introduced as long as symptoms are not provoked. • Progressive aerobic exercise can be carried out during the first week.
Return-to-sport	• Players should follow a graduated RTP programme under the supervision of a healthcare professional. • Players should spend at least 24 hours at each step. They should return to the previous step if the current step aggravates SRC symptoms. • A healthcare professional should provide clearance before returning to full contact sport.	• Players should follow a graduated return-to-play programme under the supervision of a healthcare professional. • They can begin the RTP programme when they return to their baseline level of symptoms, cognition, and balance.	• Players should follow a graduated return-to-play programme under the supervision of a healthcare professional.

	<i>CISG 5th International Consensus Statement</i>	<i>Team Physician Consensus Statement</i>	<i>American Medical Society for Sports Medicine</i>
Return-to-academics	• Players should be monitored by a healthcare professional when returning to academics. • Temporary academic absences or accommodations may be required. • Players should follow a return-to-learn programme, that incrementally increases cognitive activity. • RTL should occur before clearance for full RTP.	• Players should be monitored by a healthcare professional when returning to academics. • Temporary academic absences or accommodations may be required. • Players should follow a return-to-learn programme, that incrementally increases cognitive activity. • RTL should occur before clearance for full RTP.	• School personnel should be informed of the player's SRC. • Players should follow a return-to-learn programme, that incrementally increases cognitive activity. • Temporary academic absences or accommodations may be required (e.g., increased breaks, additional time to complete assignments, limited use of screens). • RTL should occur before clearance for full RTP.
Return-to-driving	• No reference to driving.	• Currently no protocols have been developed. • Decision should be made by the healthcare professional.	• Currently no protocols have been developed.
Medication use	• Medication for acute SRC has limited efficacy. • Players should not RTP while taking medication for SRC signs and symptoms.	• Medication for acute SRC signs and symptoms are not usually required and have limited efficacy.	• No evidence to support the use of nutraceuticals.
Rehabilitation of prolonged symptoms	• Treatment should be targeted to the player's symptoms. • There is preliminary evidence supporting sub-symptomatic aerobic exercise programmes, cervical spine or vestibular therapy, and cognitive behavioural therapy.	• Treatment should be targeted to the player's symptoms. • Rehabilitation may include cervical spine treatment, aerobic exercise programmes, vestibular and oculomotor therapy, cognitive behavioural therapy, academic adjustments and lifestyle modifications (e.g., sleep, nutrition, and hydration).	• Treatment should be targeted to the player's symptoms. • Rehabilitation may include cervical spine treatment, aerobic exercise programmes, vestibular and oculomotor therapy, cognitive behavioural therapy, and lifestyle modifications (e.g., sleep, nutrition, and hydration).

CISG: Concussion in Sport Group; RTP: Return-to-play. SRC: Sport-related concussion; RTL: Return-to-learn; SCAT: Sport Concussion Assessment Tool.

Table 34: Graded return-to-play programme

Stage	Activity	Aim
1. Symptom-limited activity	Daily activities that do not aggravate symptoms.	Gradually introduce normal activities.
2. Light aerobic exercise	Walking or slow-medium pace cycling.	Increase heart rate.
3. Sport-specific exercise	Running or skating drills. No activities involving head impacts.	Add movement.
4. Non-contact training drills	More difficult training drills. Can commence progressive resistance training.	Exercise, coordination, and thinking skills.
5. Full contact practice	Participation in full contact training after medical clearance has been obtained.	Increase confidence and allow coaches to assess functional skills.
6. Return-to-play	Normal match play.	-

Table 35: Return-to-learn programme

Stage	Activity	Aim
1. Daily activities at home that do not provoke symptoms	Normal activities that do not provoke symptoms (e.g., reading, texting, screentime). Gradually build up from 5-15 minutes at a time.	Gradually return to normal activities.
2. School activities	Homework, reading, or other cognitive activities outside of the classroom.	Increase tolerance to cognitive activity.
3. Return-to-school part-time	Partial re-introduction of schoolwork.	Increase academic activities.
4. Return-to-school full time	Gradual progression of school activities until a full day can be completed.	Return to full academic activities.

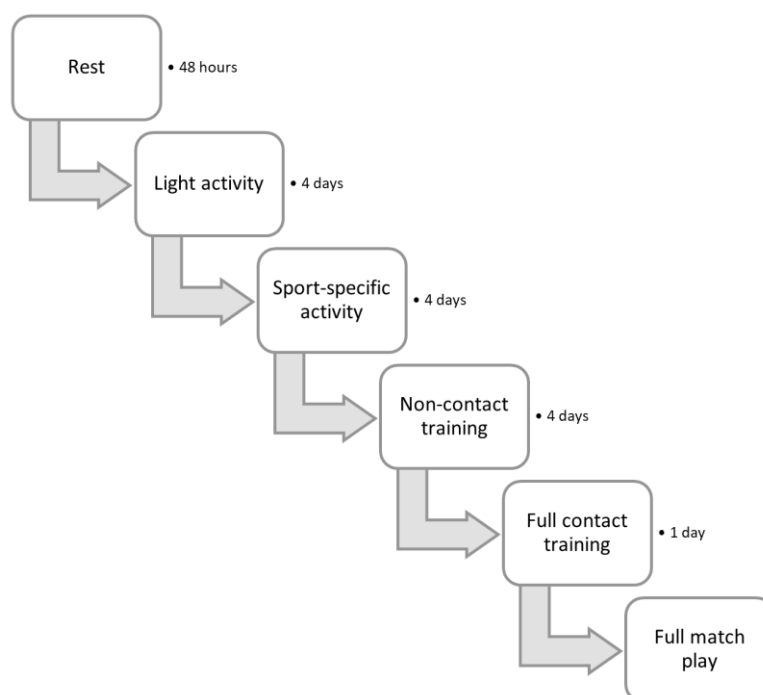


Figure 4: Graded return-to-play programme for Ladies Gaelic Football

2.5.2 Current management behaviour

It is important that SRC management guidelines are adhered to in order to maximise players' chances of making a prompt recovery. Delayed removal from play following an SRC has been associated with longer recovery times, with one meta-analysis finding that players who delayed disclosing a suspected SRC took a mean of 5.4 days longer to recover than those who immediately disclosed a suspected SRC (312). In addition, there may be an association between the duration spent continuing to play following an SRC and recovery time; a study of collegiate athletes reported that the time in minutes spent playing following an SRC was significantly associated with both the number of days until players were asymptomatic ($\beta=0.193$) and the number of days until they were cleared to return to full contact play ($\beta=0.156$). Female athletes who continued to play for longer durations also experienced more severe cognitive, ocular, and affective symptoms than male athletes, suggesting that prolonged participation in sport following SRC may be more detrimental to female athletes (313). The majority of research examining management behaviour post-SRC has focused on whether player's disclosure SRC symptoms following a head impact, however in community sport disclosure may not be sufficient to ensuring SRCs are managed appropriately. Inconsistent access to medical care may mean that even players who report SRCs may not follow SRC management guidelines, such as completing a graded RTP programme and receiving medical clearance to RTP.

2.5.2.1 Prevalence of sport-related concussion non-disclosure

Twelve studies that have examined SRC non-disclosure in female team sports are reported in Table 36 (28,29,314–323). Four of these studies presented findings separately for male and female athletes (28,314,315,324), while the remaining eight studies presented findings collectively (29,316,317,319,321–323). Eight studies focused on adult athletes (28,315,317,319–321,323,324), three focused on adolescent athletes, and one included both adolescent and adult athletes. In addition, six studies included Irish athletes, the majority of whom participated in Gaelic games (28,29,314,315,320,324). A wide range in the proportion of athletes who had not disclosed a previous suspected SRC was found. Between 26.5% and 83.1% of adolescent athletes (29,314,316,322) and 16.0%–47.6% of adult athletes (28,315,317,319,320,323,324) who believed they had previously sustained one or more SRCs had a history of non-disclosure. While these results suggest that SRC non-disclosure may be prevalent among athletes who participate in a range of sport, all of these studies recruited participants using convenience sampling, with low response rates (10.0%–52.8%) (29,316,317,321) or response rates not reported (28,314,315,319,320,322–324). This may have resulted in a selection bias. Studies also varied in how they defined SRC non-disclosure: not reporting symptoms to a coach or medical professional (314,316), not reporting symptoms to anyone (coach, medical professional, parent, or teammate) (319,320), not reporting symptoms generally (28,29,317,321,323), or continuing to play following a suspected SRC (315,322,324) were all considered as measures of SRC non-disclosure. These differences in definitions may have led to

different interpretations of non-disclosure (e.g., a player may continue to play following a suspected SRC but later report it to a coach or medical professional). To better understand SRC non-disclosure and management in female, community sport, population-specific research that clearly defines non-disclosure and other management behaviours is needed.

Table 36: Sport-related concussion non-disclosure rates

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Sampling</i>	<i>Measure</i>	<i>Findings</i>
Register-Mihalik (2013)	167 high school athletes. 58.1% male, 32.9% female, 3.0% not specified; mean age=15.7±1.4.	Convenience sample of high schools in nine US states. 10.0% of athletes from these schools chose to participate.	- Number of suspected SRCs or bell-ringers experienced in matches that were reported to a coach or medical professional during high school years. - Number of suspected SRCs or bell-ringers experienced in training that were reported to a coach or medical professional during high school years. - Number of suspected SRCs that were reported to a coach or medical professional during high school years. - Number of bell-ringers that were reported to a coach or medical professional during high school years. - Continued playing in a match while experiencing SRC symptoms during high school years. - Continued playing in training while experiencing SRC symptoms during high school years.	53.3% of participants sustained one or more previous suspected SRC or bell-ringer. - Only 16.9% of participants reported all previous suspected SRCs or bell-ringers to a coach. 48.4% of suspected SRCs were reported. 12.3% of bell-ringers were reported. 22.8% of suspected SRCs or bell-ringers during matches were reported. 11.5% of suspected SRCs or bell-ringers were reported during training.
Kroshus (2015)	328 collegiate athletes. 47.0% male	Convenience sample with 25.0% response rate.	- Previous diagnosed SRC during the previous season. - Continued to play following a suspected SRC in the previous season.	8.6% of participants were diagnosed with an SRC during the previous season. 47.6% of participants continued to play after a suspected SRC during the previous season.
Chinn (2016)	986 collegiate athletes. 76.0% male, 23.0% female, 0.31% other.	All athletes who attended the mandatory pre-season assessment.	Number of suspected SRCs regardless of whether they were diagnosed by a physician.	38.0% of participants had sustained a suspected SRC. 64.0% of participants with a previous suspected SRC reported all previous suspected SRCs.
Sullivan (2017)	80 Gaelic games athletes. 27.5% male, mean age=19.2±3.5.	Convenience sample recruited online and in-person.	Previously sustained a suspected SRC but continued to play.	40.9% of male participants had continued to play following a suspected SRC¹. 17.2% of female participants had continued to play following a suspected SRC¹.
Sullivan (2021)	435 adolescent athletes. 47.8% male; mean age=14.6±1.7. 30.1% played Gaelic football.	Convenience sample.	Experienced cognitive, somatic, or sensory symptoms of SRC following a head impact but did not immediately tell a coach or medical professional.	57.4% of participants did not immediately report symptoms of SRC. 57.5% of male participants did not immediately report symptoms of SRC. 57.4% of female participants did not immediately report symptoms of SRC.
O'Connor (2019)	113 adolescent Gaelic games athletes. 69.9% male; 21.2% under 14, 39.8% under 16, and 38.9% under 18.	Convenience sample with a response rate of 52.8%.	- Number of previous suspected SRCs. - Number of diagnosed SRCs.	26.5% of participants with a previous suspected SRC were not diagnosed.

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Sampling</i>	<i>Measure</i>	<i>Findings</i>
Doucette (2020)	161 elite club, high school, or collegiate athletes. 71.1% male; mean age=17.6±4.0.	Not reported.	Sustained a suspected SRC but continued to play.	44.0% had sustained a suspected SRC and continued to play.
Leahy (2020)	216 Gaelic games athletes. 51.9% male of initial sample (n=231).	Online convenience sample.	- Number of previous suspected SRCs. - Number of diagnosed SRCs.	72.7% (82.1% male, 63.6% female) of participants had ≥1 previous suspected SRC. 39.8% (44.3% male, 35.5% female) of participants had ≥1 previous diagnosed SRC. 28.7% (30.1% male, 27.0% female) of participants did not report their most recent suspected SRC. 64.1% (63.2% male, 65.2% female) of participants continued to play during their most recent suspected SRC.
O'Connor (2020)	268 Irish collegiate athletes. 47.4% male; mean age=21.5±2.2. 39.9% played Gaelic football.	Convenience sample recruited online and in-person.	- Sustained a suspected SRC that they did not report. - Continued to play while experiencing symptoms of SRC.	25.4% had sustained a suspected previous SRC that they did not report. 24.4% of male participants had sustained a suspected previous SRC that they did not report. 26.2% of female participants had sustained a suspected previous SRC that they did not report.
Rawlins (2020)	247 collegiate athletes. 119 DI athletes: 18.5% male, 45.4% female, 36.1% missing; mean age=19.0±2.0 ² . 128 DII athletes: 0.8% male, 1.6% female, 97.7% missing; mean age=20.0±1.5 ² .	Convenience sample with a response rate of 40.1%.	- Number of suspected SRCs in previous 365 days. - Number of suspected SRCs reported to a medical professional or coach in previous 365 days. - Number of bell-ringers in previous 365 days. - Number of bell-ringers reported to a medical professional or coach in previous 365 days.	25.4% of suspected SRCs in the previous 365 days were not reported. 74.2% of bell-ringers in the previous 365 days were not reported. - When combined, 58.7% of suspected SRCs and bell-ringers in the previous 365 days were not reported.
Anderson (2021)	741 collegiate athletes. 60.5% male; mean age=19.9±1.3.	Convenience sample.	Number of previous suspected SRCs that were not reported to a coach, athletic trainer, parent, or teammate.	16.0% of participants sustained a suspected SRC that they did not report.
Beidler (2021)	964 US (62.3% male), 302 Irish (48.0% male), and 129 Jordanian (73.6% male) collegiate athletes.	Convenience sample.	Number of previous suspected SRCs that were not reported to a coach, athletic trainer, parent, teammate, or anyone else.	29.6% of US athletes, 31.8% of Irish athletes, and 2.3% of Jordanian athletes sustained a previous diagnosed SRC. 15.5% of US athletes, 25.2% of Irish athletes, and 0.0% of Jordanian athletes sustained a previous suspected SRC that they did not report.

1: Significant differences between males and females; 2: Calculated from non-missing data for age; SRC: Sport-related concussion; DI/DII: Division I/Division II.

2.5.2.2 *Demographic factors associated with sport-related concussion non-disclosure*

Multiple studies have retrospectively examined the association between demographic characteristics and previous SRC non-disclosure (see Table 37) (314,315,319,323–327). Studies have examined the association between SRC non-disclosure and gender (n=6) (314,315,319,323–325), age (n=1) (319), number of years eligibility completed in collegiate sport (n=1) (325), previous concussion history (n=4) (315,319,323,327), and previous use of SRC education material (n=1) (326). Gender and previous concussion history were the only factors that were linked with SRC non-disclosure, although findings were contradictory. Two out of the six studies examining gender and SRC non-disclosure reported that male adult athletes were less likely to disclose suspected SRCs than female adult athletes (319,324), while the remaining four studies did not report any differences between males and females (314,315,323,325). In addition, three of the four studies that focused on concussion history reported that a history of concussion was associated with an increased likelihood of SRC non-disclosure (315,319,327), while the other study found the opposite (323). However, the latter study regarded both suspected and diagnosed concussions as concussion history, while the other three studies only examined history of diagnosed concussion. It is possible that athletes who had previously been diagnosed with an SRC perceived there to be negative consequences associated with the management process, such as time missed from sport. Understanding how demographic characteristics influence SRC non-disclosure behaviour is important as it may highlight groups who would most benefit from intervention. However, further research that explores the reasons for differences in behaviour between demographic groups is required in order to develop targeted interventions. There is also a need for more research on reporting behaviour based on age and the number of years spent playing sport. Only one study examined the association between age and SRC non-disclosure, however participants demonstrated low variability in age (319). No studies have examined the association between number of years spent playing sport and SRC non-disclosure, however one study assessed whether number of years eligibility completed with a collegiate sport affected reporting behaviour (325). However, it has limited applicability to sport outside of the US collegiate system.

Table 37: Association between demographic characteristics towards sport-related concussion non-disclosure

Author (Year)	Participant Characteristics	Measure	Definition of Non-Disclosure	Findings
<i>Gender</i>				
Chinn (2016)	986 collegiate athletes. 76.0% male, 23.0% female, 0.31% other.	Male vs female.	Not defined.	Gender was not associated with SRC disclosure.
Sullivan (2017)	80 Gaelic games athletes. 27.5% male, mean age=19.2±3.5.	Male vs female	Sustained a suspected SRC and continued to play.	Males more frequently reported continuing to play following a suspected SRC than females (40.9% vs 17.2%, p=0.026)
Weber (2019)	828 collegiate athletes. 45.9% male; mean age= 19.7±1.4. 27.9% had completed zero years of eligibility, 24.9% had completed one year of eligibility, 24.6% had completed two years of eligibility, and 22.6% had completed three years of eligibility.	Male vs female	Indirect (experienced SRC symptoms after an impact during the previous 365 days and did not tell a coach or medical professional) and direct (number of suspected SRCs or bell-ringers that were not reported to a medical professional or coach in the previous 365 days) reporting behaviour.	No differences in previous SRC reporting behaviour were found between males and females.
O'Connor (2020)	268 Irish collegiate athletes. 47.4% male; mean age=21.5±2.2. 39.9% played Gaelic football.	Male vs female	Sustained a suspected SRC and continued to play without telling anyone.	Gender was not significantly associated with SRC non-disclosure.
Sullivan (2021)	435 adolescent athletes. 47.8% male; mean age=14.6±1.7. 30.1% played Gaelic football.	Male vs female	Experienced cognitive, somatic, or sensory symptoms of SRC following a head impact during the current season but did not tell a coach or medical professional immediately or the next day (if they continued to experience symptoms).	No differences in SRC reporting behaviour between males and females.
Anderson (2021)	741 collegiate athletes. 60.5% male; mean age=19.9±1.3.	Male vs female	Sustained a suspected SRC and did not tell a coach, athletic trainer, parent, or teammate.	Being male was significantly associated with SRC non-disclosure (OR= 2.3).
<i>Age</i>				
Anderson (2021)	741 collegiate athletes. 60.5% male; mean age=19.9±1.3.	Self-reported age.	Sustained a suspected SRC and did not tell a coach, athletic trainer, parent, or teammate.	Age was not significantly associated with SRC non-disclosure.
<i>Years playing sport</i>				
Weber (2019)	828 collegiate athletes. 45.9% male; mean age= 19.7±1.4. 27.9% had completed zero years of eligibility, 24.9% had completed one year of eligibility, 24.6% had completed two years of eligibility, and 22.6% had completed three years of eligibility.	Number of years of eligibility completed with college team.	Indirect (experienced SRC symptoms after an impact during the previous 365 days and did not tell a coach or medical professional) and direct (number of suspected SRCs or bell-ringers that were not reported to a medical professional or coach in the previous 365 days) reporting behaviour.	Number of years of eligibility completed was not associated with SRC disclosure.
<i>Concussion history</i>				
Chinn (2016)	986 collegiate athletes. 76.0% male, 23.0% female, 0.31% other.	Number of previously sustained concussions that may or may not have been diagnosed by a doctor.	Not defined.	Concussion history was positively associated with SRC disclosure (OR=1.63 of SRC disclosure for each suspected concussion previously sustained).

<i>Author (Year)</i>	<i>Participant Characteristics</i>	<i>Measure</i>	<i>Definition of Non-Disclosure</i>	<i>Findings</i>
Register-Mihalik (2017)	167 high school athletes. 58.1% male, 32.9% female, 3.0% not specified; mean age=15.7±1.4.	Number of SRCs participants thought they had sustained during high school.	Sustained a suspected SRC and did not tell a medical professional or coach during high school years.	Increased number of previous SRCs was associated with reductions in SRC disclosure and increases in playing with symptoms during training and matches.
O'Connor (2020)	268 Irish collegiate athletes. 47.4% male; mean age=21.5±2.2. 39.9% played Gaelic football.	Previous diagnosis of SRC.	Sustained a suspected SRC and continued to play without telling anyone.	A previous diagnosis of SRC was significantly associated with SRC non-disclosure (OR=2.6).
Anderson (2021)	741 collegiate athletes. 60.5% male; mean age=19.9±1.3.	Number of SRCs diagnosed by a physician or athletic trainer were dichotomised as “yes” or “no”.	Sustained a suspected SRC and did not tell a coach, athletic trainer, parent, or teammate.	A previous diagnosed SRC was significantly associated with SRC non-disclosure (OR=2.3).
<i>SRC Education</i>				
Callahan (2021)	341 collegiate athletes. 51.3% male.	Previous exposure to SRC education sources (e.g., video, talking to a coach, talking to a medical professional, or other). Classified as exposure to one or multiple sources.	Proportion of suspected SRCs sustained based on a definition that were not reported to a medical professional or person in authority.	Previous exposure to SRC education materials was not associated with disclosing all suspected SRCs, or ever continuing to play or stopping playing with a suspected SRC

SRC: Sport-related concussion; OR: Odds ratio.

2.5.2.3 Psychosocial factors associated with sport-related concussion non-disclosure

Much of the research examining players' motivations for not disclosing a possible SRC has focused on SRC knowledge (28,320,323,328–330). This approach assumes that poor management behaviour following an SRC is due to a lack of awareness about SRC signs and symptoms and the potential consequences of poor SRC management. However, behaviour may be influenced by multiple factors. The Theory of Planned Behaviour is a theoretical model that attempts to explain the factors driving behaviour (see Figure 5) (331). It has been extensively applied in health research (332,333). According to the Theory of Planned Behaviour, the most important factor in predicting a behaviour is the intention to carry out that behaviour. Intention reflects attitudes towards a behaviour, subjective norms about the behaviour, and perceived behavioural control. Knowledge does not feature in the Theory of Planned Behaviour. It has been suggested the Theory of Planned Behaviour may explain SRC reporting behaviour. In this context, the intention to report future possible SRCs is thought to predict subsequent reporting behaviour. Attitudes towards disclosing an SRC, perceived pressure from others not to disclose a possible SRC, and beliefs about one's ability to disclose a suspected SRC are considered important factors in understanding SRC non-disclosure (334). However, the Theory of Planned Behaviour has not been universally adopted in the SRC literature, with many studies focusing only on the association between attitudes or knowledge and SRC non-disclosure (28,316,320,323,324).

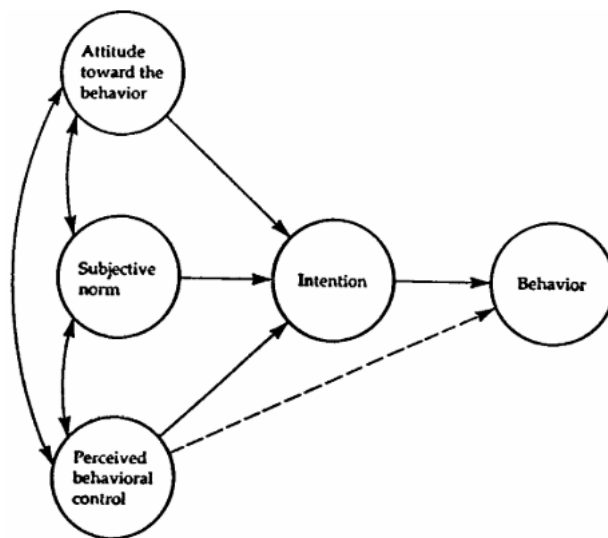


Figure 5: The Theory of Planned Behaviour model developed by Ajzen (331)

2.5.2.3.1 Association between sport-related concussion knowledge and non-disclosure

Eight studies have examined the association between SRC knowledge and non-disclosure (see Table 38), with all reporting results collectively for male and female athletes (28,315,316,319,321–324). Six studies focused entirely on adult athletes (28,315,319,321,323,324), one focused on adolescent athletes (316), and one included both adolescent and adult athletes (322). In addition, three studies

included Gaelic games athletes (28,315,324). Five of these studies reported no association between SRC knowledge and non-disclosure of suspected SRCs (28,315,321–323), while the remaining studies reported conflicting findings. One study of high school athletes reported that increased SRC knowledge was associated with reporting a suspected SRC or bell-ringer during training but not matches, or reporting bell-ringers only in any scenario (316). The term “bell-ringer” is a colloquial term for a mild SRC, however the authors did not provide a definition for either SRC or bell-ringers. Conversely, higher SRC knowledge scores were related to increased odds of non-disclosure in collegiate athletes (319), and a history of continuing to play following a suspected SRC predicted higher knowledge scores in Gaelic games athletes (324). However, methodological limitations mean that it is difficult to interpret these studies. All studies retrospectively examined SRC non-disclosure, meaning that it is not possible to determine whether there is a causal relationship between SRC knowledge and non-disclosure. Studies also differed in how they defined SRC non-disclosure (see Table 38) and the measures used to assess knowledge are severely limited. The RoCKAS is the only survey of SRC knowledge that has been assessed for construct validity (335). One study used the original RoCKAS (324), and two others modified the RoCKAS but did not validate the modified versions (322,323). No or inadequate information about psychometric properties was reported for the remaining surveys (28,315,316,319,321). It is therefore uncertain how well the majority of these studies assessed SRC knowledge. As education programmes are often suggested as a way to improve SRC management, it is important to understand the association between knowledge and behaviour. While it appears that SRC knowledge is not associated with non-disclosure, further research is required that uses a validated survey, such as the RoCKAS.

Table 38: Association between sport-related concussion knowledge and non-disclosure

Author (Year)	Participant Characteristics	Measure	Definition of Non-Disclosure	Findings
Register-Mihalik (2013)	167 high school athletes. 58.1% male, 32.9% female, 3.0% not specified; mean age=15.7±1.4.	Questionnaire including 35 questions about SRC symptoms, the effect of multiple SRCs, and general knowledge about SRC (range: 0-35). Face validity was established by three experts and test-retest agreement after 30 minutes for individual items was between 60% and 100%. Internal consistency was acceptable (Cronbach's $\alpha=0.72$).	Sustained a suspected SRC and did not tell a medical professional or coach during high school years.	- Mean knowledge score=27.9 ± 2.8 (range: 20-34). - A 2.8-point increase in knowledge score was associated with 2.3 times prevalence increase of reporting a suspected SRC or bell-ringer during training. - A 2.8-point increase in knowledge score was associated with a 1.9 times prevalence increase in reporting bell-ringer only events. - Knowledge score was not associated with continuing to play a match with a suspected SRC, reporting a suspected SRC or bell-ringer during a match, or reporting SRCs only.
Chinn (2016)	986 collegiate athletes. 76.0% male, 23.0% female, 0.31% other.	RoCKAS CKI (range: 0-43). ¹	Not defined.	- Mean CKI score=33. - CKI score was not associated with SRC non-disclosure.
Sullivan (2017)	80 Gaelic games athletes. 27.5% male, mean age=19.2±3.5.	RoCKAS CKI (range: 0-25).	Sustained a suspected SRC and continued to play.	Mean CKI score=18.3 ± 2.8 (range: 9-23). A history of continuing to play with SRC was associated with higher CKI scores ($\beta=0.42$).
Doucette (2020)	161 elite club, high school, or collegiate athletes. 71.1% male; mean age=17.6±4.0.	Modified version of the RoCKAS CKI. Instead of being unscored, distractor symptoms in the symptom identification sections are assigned one point if unselected and no points if selected (range: 0-33).	Sustained a suspected SRC and continued to play without telling anyone.	- Mean CKI score=20.0 ± 3.5. - Significant differences in mean CKI scores between males (19.3 ± 2.9) and females (22.0 ± 4.0). - CKI score was not associated with SRC non-disclosure.
O'Connor (2020)	268 Irish collegiate athletes. 47.4% male; mean age=21.5±2.2. 39.9% played Gaelic football.	Modified version of survey developed by Register-Mihalik, with an additional eight questions on SRC symptoms (range: 0-43).	Sustained a suspected SRC and continued to play without telling anyone.	- Mean knowledge score=20.1 ± 2.5 (range: 14-25). - Knowledge score was not associated with SRC non-disclosure.
Leahy (2020)	216 Gaelic games athletes. 51.9% male of initial sample (n=231).	Six questions from a 30-question survey, modified from a survey used in Irish jockeys. Questions were modified to reflect Gaelic games (range: 0-29).	Not defined.	- Mean knowledge score=20.1 ± 3.5 (range: 5-28). - Knowledge score did not differ between participants who disclosed or did not disclose their most recent suspected SRC. - Knowledge score did not differ between participants who continued to play following their most recent suspected SRC and those who did not.
Rawlins (2020)	247 collegiate athletes. 119 DI athletes: 18.5% male, 45.4% female, 36.1% missing; mean age=19.0±2.0 ² . 128 DII athletes: 0.8% male, 1.6% female, 97.7% missing; mean age=20.0±1.5 ² .	11 questions used in several previous surveys. Responses were rated on a seven-point Likert scale (1= strongly disagree, 7= strongly agree).	Sustained a suspected SRC or bell-ringer in the previous 365 days and did not tell a medical professional or coach.	- Mean knowledge score for each question=5.0 ± 0.6 ("somewhat agree"). - Increased knowledge score was associated with reduction of 23% in the odds of disclosing an SRC.
Anderson (2021)	741 collegiate athletes. 60.5% male; mean age=19.9±1.3.	Modified version of survey developed by Register-Mihalik, with an additional seven questions on SRC symptoms (range: 0-49). ¹	Sustained a suspected SRC and did not tell a coach, athletic trainer, parent, or teammate.	- Mean knowledge score=41.02 ± 4.42 (range: 22-48). - Increased knowledge significantly associated with SRC non-disclosure in a multi-variable regression ($\beta=0.07$, OR=1.07).

SRC: Sport-related concussion; Cronbach's α = Cronbach's alpha; RoCKAS: Rosenbaum Concussion Knowledge and Attitudes Survey; CKI: Concussion knowledge index; β : Beta coefficient; DI/DII: Division I/Division II; OR: Odds ratio; 1: Survey was modified, however modifications were not fully described.

2.5.2.3.2 Association between sport-related concussion attitudes and non-disclosure

Only three studies have evaluated the association between attitudes about SRC and previous SRC non-disclosure behaviour (see Table 39), with each of these studies including male and female participants (316,321,324). Two studies focused on adult samples (321,324), while one used a sample of adolescent participants (316). Additionally, one study focused on athletes participating in Gaelic games (324). These studies demonstrate preliminary evidence that safer attitudes towards SRC management and reporting may translate into safer behaviour. Higher (i.e., safer) attitudes scores were associated with a reduction in athletes continuing to play follow a suspected SRC in both training and matches, as well as an increase in disclosure of bell-ringers (316). Similarly, Gaelic games athletes who had previously continued to play following a suspected SRC in the past, demonstrated attitude scores that were 0.26 points lower than those who had not continued to play (324). However, it is important to note the limitations of these studies. As they all used a retrospective design, it is not known whether participants' reported attitude scores reflect their attitudes regarding SRC at the time of injury. Furthermore, only one study used a measure of attitude that had been examined for construct validity (324). The extent to which the remaining studies adequately assessed SRC attitudes is therefore unknown. Additional research that uses validated measures of SRC attitudes and prospectively examines SRC non-disclosure behaviour is required.

Table 39: Association between sport-related concussion attitudes and non-disclosure

Author (Year)	Participant Characteristics	Measure	Definition of Non-Disclosure	Findings
Register-Mihalik (2013)	167 high school athletes. 58.1% male, 32.9% female, 3.0% not specified; mean age=15.7±1.4.	14 seven-point Likert items about attitudes towards SRC, SRC education, and reporting (range: 14-98). Three experts assessed face validity. A test-retest study after 30 minutes found a mean of 0.4 difference between assessments. Internal consistency was high (Cronbach's α =0.80).	Sustained a suspected SRC and did not tell a medical professional or coach during high school years.	• Mean attitude score= 78.3 ± 11.5 (range: 40-98). • An 11.5-point increase in attitude score was associated with a decrease in the prevalence of athletes participating in a match (PR=0.74) or training (PR=0.67) with a suspected SRC, and a 1.5 times increased prevalence in reporting bell-ringers in matches or training. • Attitude score was not associated with reporting suspected SRCs or bell-ringers during matches or training, or reporting SRC events only.
Sullivan (2017)	80 Gaelic games athletes. 27.5% male, mean age=19.2±3.5.	RoCKAS CAI included 15 five-point Likert scale items that assessed attitudes about SRC management and RTP (range: 15-75).	Sustained a suspected SRC and continued to play.	• Mean CAI score=61.8 ± 7.2 (range: 43-75). • A history of continuing to play with a suspected SRC was associated with lower CAI scores (β=-0.26). • Gender was not associated with CAI scores.
Rawlins (2020)	247 collegiate athletes. 119 DI athletes: 18.5% male, 45.4% female, 36.1% missing; mean age=19.0±2.0 ² . 128 DII athletes: 0.8% male, 1.6% female, 97.7% missing; mean age=20.0±1.5 ² .	Eight questions from several previous surveys about the consequences of disclosing suspected SRCs. Responses were rated on a seven-point Likert scale (1= strongly disagree, 7= strongly agree).	Sustained a suspected SRC or bell-ringer in the previous 365 days and did not tell a medical professional or coach.	• Mean attitude score= 5.0 ± 0.8 for individual items ("Somewhat agree"). • Attitude score did not feature in the final model for reporting behaviour.

SRC: Sport-related concussion; PR: Prevalence ratio; Cronbach's α = Cronbach's alpha; RoCKAS= Rosenbaum Concussion Knowledge and Attitudes Survey; CAI= Concussion attitudes index; RTP: Return-to-play; β : Beta coefficient; DI/DII: Division I/Division II.

2.6 Summary of Literature Review

Research on SRC in LGF, as well as in female, community sport generally, is extremely limited. While it has been reported that 8.9% of all injuries recorded over two collegiate LGF seasons were SRCs (17), high quality studies on the prevalence of SRC in club LGF players is lacking. Similarly, studies examining SRC management in LGF and other sports have been of low methodological quality, inconsistent definitions, and unvalidated questionnaires to assess knowledge and attitudes (28,29,314–316,322–324). Studies evaluating SRC management behaviour in both Gaelic games and other sports have mainly focused on SRC non-disclosure, presumably based on the assumption that players who report SRCs subsequently receive appropriate medical treatment. However, in community sport with limited access to medical care, reporting a suspected SRC to either a coach or medical professional does not guarantee that players will adhere to management guidelines, such as following a graded RTP programmes and obtaining medical clearance to return to full contact play.

It is recommended that clinicians examine players with a suspected SRC using a comprehensive, multi-domain assessment. This assessment should include tests for cognitive, vestibular, and ocular deficits, as well as self-report measures of mood, migraine, neck dysfunction, and sleep (31,32). While multiple studies have reported normative data in female athletes on neurocognitive and vestibular-ocular measures, few have included community athletes (170,174,209,213,230,234). In addition, minimal normative data is available on self-reported mood, migraine, neck, and sleep measures in sporting populations generally. Normative data from female, community sport athletes on these measures is urgently required as clinicians working with these athletes may not have done a pre-injury baseline assessment. Furthermore, test-retest reliability of SRC assessments in this population is lacking. This means that even if LGF players have completed a pre-injury baseline assessment, the utility of these assessments, particularly over longer periods of time, is unknown. This research will aim to address these gaps in the literature by examining the prevalence and management of SRC in LGF, as well as by generating normative and test-retest data on a multi-domain SRC assessment in adolescent and adult LGF players.

3 Sport-related concussion prevalence, injury characteristics, and management behaviour in Ladies Gaelic Football

3.1 Introduction

SRC is a form of mild traumatic brain injury that presents with a broad range of functional neurological impairments without structural brain damage (18). These impairments commonly include headaches, amnesia, difficulty concentrating, nausea, vision problems, poor balance, insomnia and low mood (122,336–339). LGF is a highly popular (2) Irish community team sport that is comparable to Australian football in style of play. Contact between players may occur in LGF, potentially resulting in SRCs (4). However, the only prospective study on injuries in LGF reported that SRCs accounted for 9% of all injuries among collegiate players (101), while head and neck injuries comprise approximately 4% of injuries in elite male Gaelic football players (13). Similar to other female community sports, very little research on LGF exists and information on the prevalence, characteristics and management behaviour relating to SRC in the sport is extremely limited. Therefore, it is difficult to understand the extent of SRC in LGF and determine whether interventions are needed.

Although most SRCs are self-limiting and are expected to resolve within ten to fourteen days of injury in adults (18), 6-16% of patients experience symptoms lasting longer than one month (94,340). Signs and symptoms that persist beyond the expected timeframe for recovery have been generally regarded as persistent post-concussive symptoms (18) and may be associated with negative outcomes. For example, 13% of collegiate athletes do not fully return to academics and 9-25% do not fully return to contact sport within four weeks post-concussion (94,340). While multiple risk factors for persistent symptoms have been suggested, one major modifiable risk factor is poor concussion management (33). Poor SRC management, such as continuing to play with symptoms, may be a risk factor for a prolonged recovery (77,341,342). In a prospective study of male and female collegiate athletes who sustained SRCs, athletes who were immediately removed from play were cleared to return-to-play three days sooner (341) and had a 47% lower likelihood of requiring 21 days until return-to-play than players with a delayed removal from play (341). Recommended SRC management has traditionally been conservative, emphasising immediate removal from play, mental and physical rest, and a controlled increase in activity before full return-to-play (18). However, this approach has been criticised for considering SRC to be a homogenous injury. It is now acknowledged that the inter-individual clinical presentation of SRC may vary greatly and that a more targeted approach to SRC management is needed (31,130). One of the frameworks that aims to classify SRC is the Clinical Profiles model (31,130). The Clinical Profiles model classifies SRCs into symptom-based profiles which require specific assessments and treatment (31,130). According to the model, following an initial period of general cognitive symptoms, SRCs may diverge into one or more trajectories: cognitive, migraine, vestibular, ocular, and mood. Neck and sleep-related symptoms also

feature in the model as modifiers (31,130). While this model has not been validated, targeted SRC management has the potential to improve outcomes for patients beyond the traditional approach (130,343).

SRC management is particularly challenging in the community sport setting where medical supervision may be limited. Therefore, this study will increase our knowledge about SRC in LGF players, which will provide valuable insights about SRC in the broader context of female community sports. It aims to (i) examine self-reported concussion history in elite and non-elite LGF players, (ii) describe the injury characteristics, including the clinical profiles, of SRCs experienced by elite and non-elite LGF players, and (iii) examine SRC management behaviours in LGF players who were diagnosed with concussion and those with suspected concussions.

3.2 Methods

3.2.1 Development of the Survey

A group of six concussion researchers developed an online survey to address the study aims. These researchers included:

- The primary researcher (Róisín Leahy, BSc., Certified Athletic Therapist; three years' research experience)
- An Associate Professor in Athletic Therapy and Training (Dr. Siobhán O'Connor, PhD., Certified Athletic Therapist; 13 years' experience)
- An Assistant Professor in Athletic Therapy and Training (Dr. Enda Whyte, PhD., Certified Athletic Therapist and Chartered Physiotherapist; 24 years' experience)
- An Assistant Professor in Biomedical Sciences (Dr. Keith Rochfort, PhD.; 14 years' experience)
- A research director of the University of Pittsburgh Medical Center Sports Medicine Concussion Program and an Associate Professor in Sports Medicine (Dr. Anthony P. Kontos, PhD.; 16+ years' experience)
- A research director of the University of Pittsburgh Medical Center Sports Medicine Concussion Program and clinical neuropsychologist (Dr. Michael W. Collins, PhD.; 20+ years' experience)

Following a literature search of existing SRC surveys, the primary researcher compiled a draft of the survey. The survey was designed to address the aims of the study described in this chapter, as well as the study in Chapter 4. The group reviewed the survey to ensure content validity for an Irish context and included questions if all researchers agreed they were relevant to the study. The survey was piloted in twenty LGF players, who provided feedback on the clarity of the questions, survey layout, and time taken to complete the survey. The total survey took approximately ten minutes to answer. The survey consisted of the following sections:

- Demographic characteristics
- Relevant medical history
- Concussion history and management
- Concussion signs and symptoms
- Concussion education
- Rosenbaum Concussion Knowledge and Attitudes Survey (RoCKAS)

The sections relevant to this study are: (i) demographic characteristics, (ii) concussion history and management, (iii) concussion signs and symptoms, and (iv) concussion education.

3.2.2 Ethical Approval

Ethical approval for this study was granted by DCU Research Ethics Committee in March 2019 (DCUREC/2019/010). Participants clicked “yes” in response to a series of questions to provide informed consent at the start of the online survey.

3.2.3 Participant Recruitment

Adult players who had played LGF in 2019 were eligible to participate and were recruited through convenience sampling. Screening questionnaires were included at the start of the survey to ensure participants were (i) aged 18 or older, and (ii) had played the previous year (2019).

We attempted to recruit a nationwide sample of both elite and non-elite players. Initially, a database of all LGF clubs and available contact details in Ireland was compiled. We contacted LGF clubs via a direct email or via an email sent through the local administrative boards. We directly contacted clubs for which contact details were available online (722 out of approximately 1000). We also asked local administrative boards to forward our email to all clubs in their jurisdiction and received confirmation from 25 of 32 boards that they had done so. The email contained a brief description of the survey, a link to the online survey and a request for club secretaries to distribute it to all adult club players. Posts on the website and social media accounts of the official administrative body for the LGF, the LGFA, also promoted the study. The survey was open from July to December 2020. Sample size calculations determined that the main outcome measures, the proportion of respondents who sustained a suspected SRC while playing LGF in 2019 and the total number of suspected SRCs ever sustained while playing LGF, required a minimum sample size of 190 and 375, respectively, to attain an alpha level of 0.05 and power of 80%.

3.2.4 Data Collection

Survey data were collected using a Google Form (Google, California, US). The survey form was pre-set to require participants responded to each question. Survey sections are described in more detail below, however not all sections were analysed in this study. The relevant sections to this study are: (i) demographic characteristics, (ii) concussion history, (iii) concussion signs and symptoms, and (iv) concussion education. The entire survey is available in Appendix A.

3.2.4.1 Demographic Characteristics

Participants answered questions on their level of play, age, county, number of years playing LGF, and the position they most often played. Age doubled as a screening question to ensure that participants were aged at least eighteen years.

3.2.4.2 Medical History

Participants were asked whether they experienced various health conditions that may modulate concussion risk or outcomes. The following response options were provided: “Yes, but I HAVE NOT

been diagnosed by a doctor or medical professional”, “Yes, and I HAVE been diagnosed by a doctor or medical professional”, and “No”.

3.2.4.3 Concussion History and Management

A standardised definition of concussion was modified from a previous study and provided at the beginning of this section. As the existing definition stated that concussion occurs due to a direct blow to the head, we specified that that it can also be caused by indirect impacts:

“Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. But, in reality, a concussion has occurred anytime you have had a direct or indirect blow to the head that caused you to have symptoms for any amount of time. These include: blurred or double vision, seeing stars, sensitivity to light or noise, headache, dizziness or balance problems, nausea, vomiting, trouble sleeping, fatigue, confusion, difficulty remembering, difficulty concentrating, or loss of consciousness. Whenever anyone gets a ding or their bell rung, that too is a concussion.” (344)

Based on this definition, participants reported: (i) the total number of concussions (including SRCs and concussions sustained outside of sport) they thought they had ever sustained, (ii) the total number of SRCs they thought they had ever sustained playing LGF, and (iii) whether they believed they had sustained an SRC while playing LGF in 2019. Participants who reported sustaining an SRC in 2019 answered additional questions pertaining to the injury characteristics of this SRC and how they managed it, which are outlined in Table 40.

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Table 40: Concussion history and management questions

	Questions
Injury characteristics	• Number of days symptoms lasted • Number of days until return to full contact training • Time during the season (e.g., pre-season, during the season) • Type of training session (e.g., team or individual) • Mechanism of injury (e.g., contact with another player, the ground, a fence, or the ball) • Location of impact on the body
Management behaviour	• Continuing to play on with a possible concussion • Telling a coach or manager • Same day RTP • Symptomatic RTP • Following a graded RTP programme • Following a graded RTP programme under supervision by a medical professional • Being medically cleared before RTP • Following a graded RTS programme

We referred to “diagnosed SRCs” if the participant reported receiving a diagnosis from medical personnel, or “suspected SRCs” if the participant believed they had sustained an SRC based on the definition provided but had not received a diagnosis.

3.2.4.4 Concussion signs and symptoms

Participants who reported an LGF-related SRC in 2019 answered a modified version of the CP Screen (131). The CP Screen is a symptom report questionnaire that assesses the five clinical profiles and two modifiers. Participants rated 29 concussion symptoms on a scale from 0 (none) to 3 (severe) (131). Symptoms were scored for each profile and a mean score for each profile was calculated. Usually, the CP Screen is used to assess how players with an SRC currently feel, however we used it retrospectively. In addition, we asked participants to select how long they had experienced each symptom (didn’t experience the symptom, up to three days, three to seven days, more than one week). Finally, participants answered whether or not they had experienced a list of on-field signs and symptoms, such as loss of consciousness and amnesia.

3.2.4.5 Concussion Education

This section assessed participants’ previous use of LGFA concussion resources and their interest in future concussion education. Data from this section was not analysed as part of this thesis, however it was used to guide the development of LGFA concussion education materials.

3.2.4.6 Rosenbaum Concussion Knowledge and Attitudes Survey

The RoCKAS consists of a concussion knowledge index (CKI) and concussion attitudes index (CAI) (335). Twenty-five questions contribute to the CKI: correct responses are assigned a score of one and incorrect responses are assigned a score of zero. Responses are summed to give a possible score range of 0-25. The CAI involves fifteen concussion scenarios to which participants rate their level of agreement on a five-point Likert scale (i.e., strongly disagree, disagree, neutral, agree, strongly agree). Responses are scored from 1-5, so that lower scores indicate less safe behaviour and higher

scores indicate more safe behaviour. Scores for the fifteen scenarios are summed, providing a possible CAI range of 15-75. The RoCKAS also includes a Validity Scale, which is composed of three “true” or “false” general knowledge questions. Validity scale scores less than two may suggest that a participant displayed low effort or carelessness when answering the survey (335). It is recommended that data for participants with a validity score less than two should be removed.

3.2.5 Statistical Analysis

3.2.5.1 Data Cleaning and Processing

We exported raw survey data from Google Forms (Google, California, US) as a csv file. This file was then imported into RStudio (version 4.1.0; RStudio, Boston, MA, US). There were no missing data as we set the Google Forms to mandate a response for each question.

3.2.5.2 Descriptive Statistics

Descriptive statistics were presented as proportions for categorical variables (self-reported SRC history, injury characteristics, clinical profiles, SRC management behaviour). Continuous variables were described in terms of means and standard deviations (clinical profile scores), or medians and interquartile ranges (number of days symptoms were experienced and the number of days until full return-to-play). Three responses to injury characteristic questions were unclear as participants selected the “other” response option and provided more than one answer; these responses were coded as missing.

3.2.5.3 Between-Group Analyses

Chi-square tests of independence were used to examine the association between (i) level of play and the total number of suspected SRCs ever sustained playing LGF, (ii) level of play and the occurrence of a suspected SRC while playing LGF in 2019, (iii) level of play and injury characteristics, (iv) playing position and injury characteristics, (v) individual clinical profiles, and (vi) immediate response to a possible SRC and management behaviour. When the expected number of observations per cell was below 5, Yates’ correction was used. Odds ratios with a Wald approximation or Cramer’s V were calculated for significant results as a measure of effect size (345).

Three-way log-linear analyses were used to examine the relationships between level of play, diagnostic status, and SRC management. The most parsimonious model was selected for each analysis and significant effects were further evaluated using post-hoc chi-square tests of independence with odds ratios (345). One respondent who answered that she did not remember whether her concussion had been diagnosed or suspected was excluded from the log-linear analyses. Due to the low numbers who answered “Don’t Remember” to SRC management questions, these responses were considered as missing data and only “yes” or “no” responses were analysed. An alpha level of 0.05 was set a priori for all analyses. The variables included in Chi-square and log-linear analyses are outlined in Table 41.

Table 41: Analyses of concussion prevalence, injury characteristics, clinical profiles, and management behaviour

Variable 1	Variable 2	Variable 3
Chi-square analyses		
Level of play	Total number of SRCs ever sustained playing LGF	-
	Occurrence of a possible SRC while playing LGF in 2019	
	Activity at time of injury	
	Mechanism of injury	
	Time during season	
	Location of impact on body	
Playing position	Activity at time of injury	
	Mechanism of injury	
	Time during season	
	Location of impact on body	
Migraine CP Score	Ocular score	
	Vestibular score	
	Cognitive score	
	Anxiety/Mood score	
Ocular CP Score	Vestibular score	
	Cognitive score	
	Anxiety/Mood score	
Vestibular CP Score	Cognitive score	
	Anxiety/Mood score	
Cognitive CP Score	Anxiety/Mood score	
Log-linear analyses		
Level of play	Diagnostic status	Telling a coach or manager
		Same day RTP
		Symptomatic RTP
		Following a graded RTP programme
		Following a graded RTP programme under supervision by a medical professional
		Being medically cleared before RTP
		Following a graded RTS programme

CP: Clinical profile; RTP: Return-to-play; RTS: Return-to-school.

3.3 Results

3.3.1 Participants

There were 1049 responses to the survey. Three hundred and ninety-two were removed as participants did not play LGF in 2019 (n=92), were under eighteen years (n=156), or duplicated responses (n=144). The final sample contained 657 elite (20.4%) and non-elite players (79.6%), representing an estimated 1.95% of all adult players in Ireland. Elite players were younger than non-elite players ($A=0.36$; $p<0.001$) but did not differ on any other demographic characteristics ($p>0.05$), as reported in Table 42.

Table 42: Demographic characteristics of survey participants

	<i>Total</i> <i>(n=657)</i>	<i>Elite</i> <i>(n=134)</i>	<i>Non-Elite</i> <i>(n=523)</i>
Age, mean (SD)	24.0 (5.6)	22.2 (4.8)	24.4 (5.7)
Number of Years Playing Experience, mean (SD)	13.2 (5.1)	13.0 (4.1)	13.3 (5.4)
Playing Position, % (n)			
Forward	38.2 (251)	39.6 (53)	37.9 (198)
Midfield	12.5 (82)	16.4 (22)	11.5 (60)
Back	42.3 (278)	37.3 (50)	43.6 (228)
Goalkeeper	7.0 (46)	6.7 (9)	7.1 (37)
Region, % (n)			
Leinster	48.6 (319)	49.3 (66)	48.4 (253)
Ulster	21.3 (140)	15.7 (21)	22.8 (119)
Munster	17.4 (114)	20.1 (27)	16.6 (87)
Connaught	12.8 (84)	14.9 (20)	12.2 (64)

SD: Standard deviation

3.3.2 Prevalence of Sport-Related Concussions

Over half of respondents reported previously sustaining an SRC while playing LGF (52.5%, n=345), with 17.5% (n=115) sustaining an LGF-related SRC in 2019. A greater proportion of elite players sustained an SRC in 2019 than non-elite players ($X^2(1)=8.65$, $p<0.01$; OR (95% CI): 1.96 (1.24-3.08)), but no difference in the lifetime total number of SRCs sustained playing LGF was found between groups ($X^2(3)=1.38$, $p=0.71$) (see Figure 6).

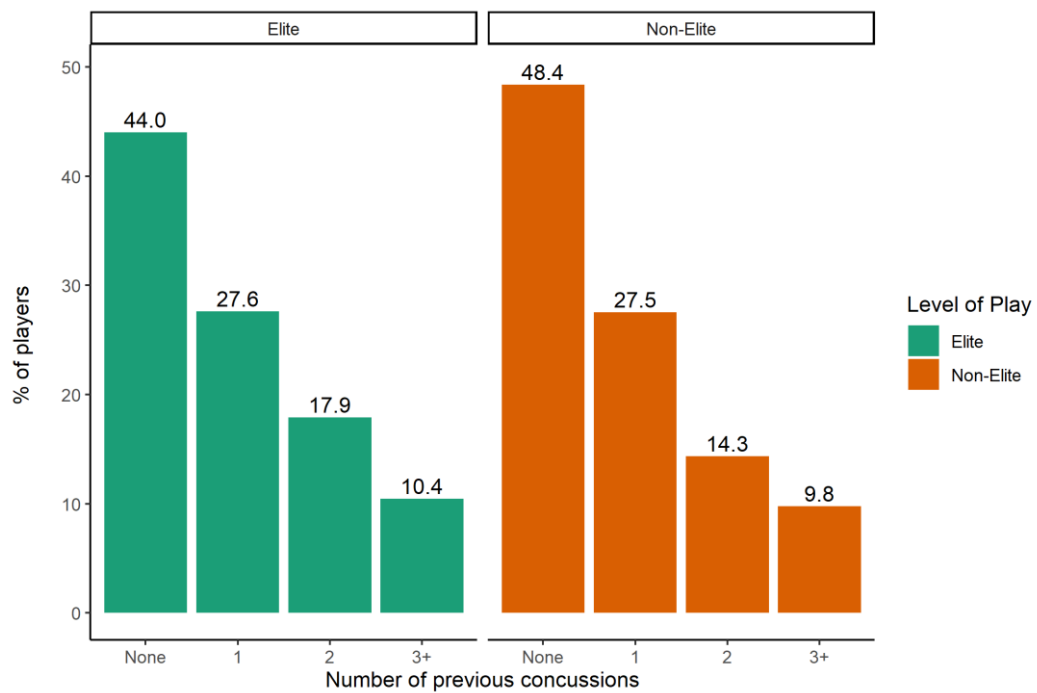


Figure 6: Percentage of elite and non-elite players who previously sustained a possible sport-related concussion while playing Ladies Gaelic Football

3.3.3 Injury Characteristics of Sport-Related Concussions

Among players who sustained an SRC while playing LGF in 2019, the majority sustained it during a match (85.8%, n=97), with the most common mechanism involving contact with another player (62.6%, n=72). Almost all SRCs resulted from a direct impact to the head or neck (96.5%, n=111), with the remaining resulting from indirect impacts (e.g., impact to the torso, whiplash mechanism; 2.6%, n=3) or unknown mechanisms (0.9%, n=1). Injury characteristics did not differ between elite and non-elite players ($p>0.05$; see Table 43). Mechanism of injury differed significantly based on playing position ($X^2(9) = 27.19$; $p=0.001$), with a small effect size (Cramer's $V = 0.28$). Compared with other playing positions, midfield players more frequently sustained an SRC from contact with another player and less frequently from contact with the ground. Players in defensive positions more frequently sustained an SRC from contact with the ground, while goalkeepers more often sustained SRCs from contact with a ball or with the fence or goalpost compared with other playing positions. Other injury characteristics did not differ based on playing position (see Table 43).

3.3.4 Clinical Profiles of Sport-Related Concussions

The ocular clinical profile had the highest mean score (1.53 ± 0.78), followed by the migraine (1.46 ± 0.76) and cognitive (1.37 ± 0.83) profiles (see Figure 7). All clinical profiles were significantly associated with each other. The highest associations were found between the migraine and ocular profiles (OR (95% CI): 23.4 (8.8-62.5)), ocular and vestibular profiles (OR (95% CI): 22.3 (8.0-62.1)), and migraine and vestibular profiles (OR (95% CI): 21.7 (7.5-63.2)) (see Table 44).

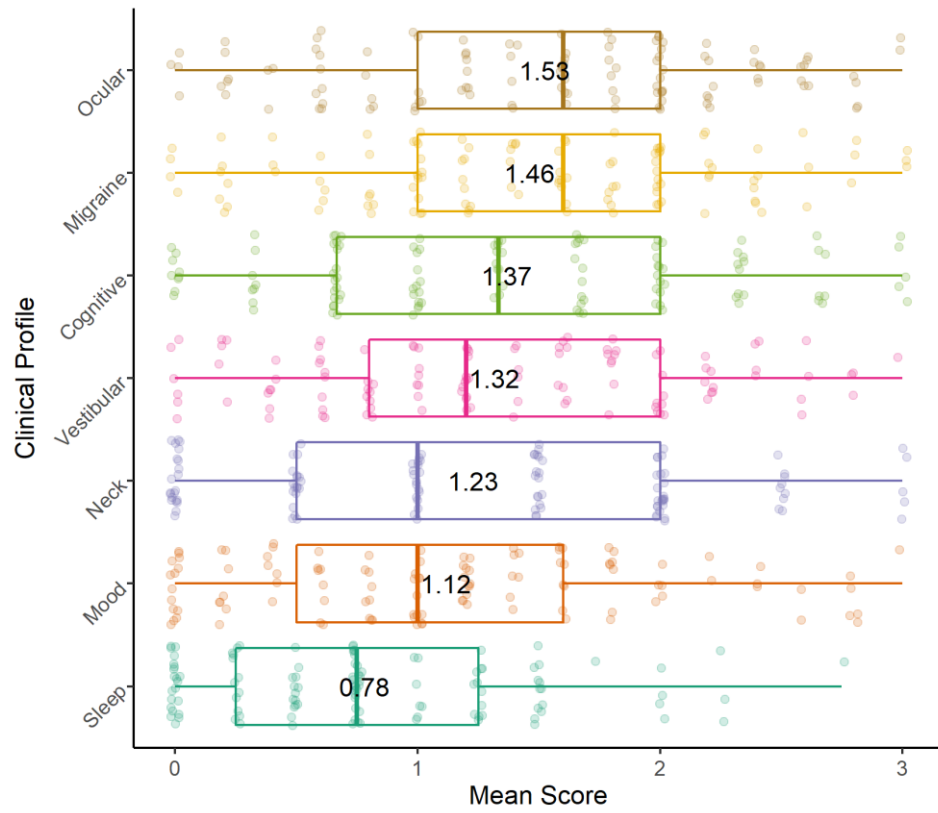


Figure 7: Mean clinical profile scores reported by participants with a sport-related concussion

Table 43: Characteristics of concussions by playing level and playing position

	Playing Level		Playing Position				
	Elite (n=35) % (n)	Non-Elite (n=80) % (n)	Forward (n=44) %, n	Midfield (n=16) %, n	Back (n=46) %, n	Goalkeeper (n=9) %, n	Overall (n=115) %, n
Activity (n=113)							
Match	85.3 (29)	86.1 (68)	86.4 (38)	86.7 (13)	86.7 (39)	77.8 (7)	85.8 (97)
Team training session	8.8 (3)	13.9 (11)	11.4 (5)	13.3 (2)	11.1 (5)	22.2 (2)	12.4 (14)
Don't remember	2.9 (1)	0.0 (0)	2.3 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.9 (1)
Trials	2.9 (1)	0.0 (0)	0.0 (0)	0.0 (0)	2.2 (1)	0.0 (0)	0.9 (1)
Missing	2.9 (1)	1.3 (1)	0 (0)	1 (6.3)	1 (2.2)	0.0 (0)	2 (1.7)
Mechanism (n=115)							
Contact with player	62.9 (22)	62.5 (50)	61.4 (27)	87.5 (14)	56.5 (26)	55.6 (5)	62.6 (72)
Contact with ground	22.9 (8)	27.5 (22)	34.1 (15)	6.2 (1)	30.4 (14)	0.0 (0)	26.1 (30)
Contact with ball	5.7 (2)	7.5 (6)	2.3 (1)	0.0 (0)	8.7 (4)	33.3 (3)	7.0 (8)
Contact with fence or goalpost	2.9 (1)	1.3 (1)	0.0 (0)	6.2 (1)	0.0 (0)	11.1 (1)	1.7 (2)
Unknown	5.7 (2)	1.3 (1)	2.3 (1)	0.0 (0)	4.3 (2)	0.0 (0)	2.6 (3)
Time during season (n=114)							
During the season	91.4 (32)	91.1 (72)	83.7 (36)	93.8 (15)	97.8 (45)	88.9 (8)	91.2 (104)
Pre-season	8.6 (3)	6.3 (5)	11.6 (5)	6.2 (1)	2.2 (1)	11.1 (1)	7.0 (8)
Don't remember	0.0 (0)	2.5 (2)	4.7 (2)	0.0 (0)	0.0 (0)	0.0 (0)	1.8 (2)
Missing	0.0 (0)	1.3 (1)	1 (2.3)	0.0 (0)	0.0 (0)	0.0 (0)	1.0 (0.9)
Location of impact (n=115)							
Head or Neck	94.3 (33)	97.5 (78)	97.7 (43)	100.0 (16)	95.7 (44)	88.9 (8)	96.5 (111)
Torso	5.7 (2)	1.3 (1)	2.3 (1)	0.0 (0)	2.2 (1)	11.1 (1)	2.6 (3)
Don't remember	0.0 (0)	1.3 (1)	0.0 (0)	0.0 (0)	2.2 (1)	0.0 (0)	0.9 (1)
Duration of symptoms (n=115), median (IQR)							
	5.0 (18.0)	5.0 (9.0)	6.0 (11)	5.5 (14)	5.0 (12)	3.0 (6.0)	5.0 (12)
Days until return-to-play (n=115), median (IQR)							
	14.0 (31.5)	7.0 (17.3)	14 (17)	7.0 (29)	7.0 (16)	14 (14)	7.0 (18)

IQR: Interquartile range.

Table 44: Associations between clinical profiles

<i>Clinical Profile</i>	<i>Profile</i>	<i>X²</i>	<i>P-value</i>	<i>OR</i>	<i>95% CI</i>
Migraine	Ocular	49.1	<0.001	23.4	8.8-62.5
	Vestibular	42.2	<0.001	21.7	7.5-63.2
	Cognitive	28.7	<0.001	10.2	4.1-25.5
	Anxiety/Mood	19.1	<0.001	8.4	3.0-24.0
Ocular	Vestibular	45.3	<0.001	22.3	8.0-62.1
	Cognitive	35.7	<0.001	13.6	5.4-34.6
	Anxiety/Mood	23.5	<0.001	10.4	3.6-29.8
Vestibular	Cognitive	37.5	<0.001	13.8	5.6-33.9
	Anxiety/Mood	20.1	<0.001	7.0	2.8-17.3
Cognitive	Anxiety/Mood	16.5	<0.001	5.7	2.4-13.7

X²: Chi-square; OR: Odds ratio; 95% CI: 95% confidence interval.

3.3.5 Management of Sport-Related Concussions

Only 3.5% of players with either a diagnosed or suspected SRC followed all management guidelines, and between 10.4% and 61.7% followed specific guidelines. Players most often followed guidelines to not RTP on the day of injury (61.7%; diagnosed: 74.6%, suspected: 47.1%) and to not RTP with symptoms (59.1%; diagnosed: 61.9%; suspected: 56.9%). They least frequently followed a medically supervised graded RTP programme (27.8%; diagnosed: 44.4%, suspected: 7.8%), obtained medical clearance prior to full contact RTP (22.6%; diagnosed: 38.1%, suspected: 3.9%), and completed a return to school programme (10.4%; diagnosed: 15.9%, suspected: 3.9%). Elite players more frequently reported a diagnosed versus a suspected SRC compared with non-elite players ($X^2(1) = 7.39$, $p = 0.007$; OR (95% CI): 3.28 (1.36-7.89)). Regardless of playing level, a greater proportion of participants with a diagnosed SRC informed their coach about the SRC ($X^2(1) = 9.03$, $p = 0.003$; OR (95% CI): 3.41 (1.51-7.70)), followed a graded RTP programme ($X^2(1) = 17.83$, $p < 0.001$; OR (95% CI): 6.78 (2.64-17.42)), followed a medically supervised graded RTP programme ($X^2(1) = 14.29$, $p < 0.001$; OR (95% CI): 8.22 (2.51-26.91)), and received medical clearance before RTP ($X^2(1) = 18.77$, $p < 0.001$; OR (95% CI): 15.43 (3.41-69.74)) than players with a suspected SRC. Fewer diagnosed players also returned to play on the same day than players with a suspected SRC ($X^2(1) = 8.55$, $p = 0.003$; OR (95% CI): 0.31 (0.14-0.69)).

Table 45: Elite and non-elite players' management of diagnosed and suspected concussions

	<i>All Players (n=115)¹</i>			<i>Elite Players (n=35)</i>			<i>Non-Elite Players (n=79)</i>		
	<i>Diagnosed Concussion (n=63)</i>	<i>Suspected Concussion (n=51)</i>	<i>Diagnosed or Suspected Concussion (n=115)</i>	<i>Diagnosed Concussion (n=26)</i>	<i>Suspected Concussion (n=9)</i>	<i>Diagnosed or Suspected Concussion (n=35)</i>	<i>Diagnosed Concussion (n=37)</i>	<i>Suspected Concussion (n=42)</i>	<i>Diagnosed or Suspected Concussion (n=79)</i>
Told coach or manager, % (n)									
Yes	60.3 (38)	33.3 (17)	47.8 (55)	65.4 (17)	22.2 (2)	54.3 (19)	56.8 (21)	35.7 (15)	45.0 (36)
No	30.2 (19)	56.9 (29)	41.7 (48)	23.1 (6)	77.8 (7)	37.1 (13)	35.1 (13)	52.4 (22)	43.8 (35)
Don't remember	7.9 (5)	7.8 (4)	8.70 (10)	7.7 (2)	0 (0)	5.71 (2)	8.1 (3)	9.5 (4)	10.0 (8)
N/A	1.6 (1)	2.0 (1)	1.74 (2)	3.9 (1)	0 (0)	2.86 (1)	0 (0)	2.4 (1)	1.25 (1)
Returned to play on the same day, % (n)									
Yes	23.8 (15)	49.0 (25)	35.7 (41)	15.4 (4)	66.7 (6)	28.6 (10)	29.7 (11)	45.2 (19)	38.8 (31)
No	74.6 (47)	47.1 (24)	61.7 (71)	80.8 (21)	33.3 (3)	68.6 (24)	70.3 (26)	50.0 (21)	58.8 (47)
Don't remember	1.6 (1)	3.92 (2)	2.61 (3)	3.9 (1)	0 (0)	2.86 (1)	0 (0)	4.8 (2)	2.50 (2)
Returned to play with symptoms, % (n)									
Yes	31.7 (20)	39.2 (20)	35.7 (41)	30.8 (8)	44.4 (4)	34.3 (12)	32.4 (12)	38.1 (16)	36.3 (29)
No	61.9 (39)	56.9 (29)	59.1 (68)	61.5 (16)	44.4 (4)	57.1 (20)	62.2 (23)	59.5 (25)	60.0 (48)
Don't remember	6.4 (4)	3.9 (2)	5.22 (6)	7.7 (2)	11.1 (1)	8.57 (3)	5.4 (2)	2.4 (1)	3.75 (3)
Followed a GRTP programme, % (n)									
Yes	50.8 (32)	13.7 (7)	33.9 (39)	50.0 (13)	22.2 (2)	42.9 (15)	51.4 (19)	11.9 (5)	30.0 (24)
No	46.0 (29)	84.3 (43)	63.5 (73)	50.0 (13)	66.7 (6)	54.3 (19)	43.2 (16)	88.1 (37)	67.5 (54)
Don't remember	3.17 (2)	2.0 (1)	2.61 (3)	0 (0)	11.1 (1)	2.86 (1)	5.41 (2)	0 (0)	2.50 (2)
Followed a GRTP programme with medical supervision, % (n)									
Yes	44.4 (28)	7.8 (4)	27.8 (32)	46.2 (12)	11.1 (1)	37.1 (13)	43.2 (16)	7.14 (3)	23.8 (19)
No	36.5 (23)	52.9 (27)	44.3 (51)	42.3 (11)	44.4 (4)	42.9 (15)	32.4 (12)	54.8 (23)	45.0 (36)
Don't remember	3.2 (2)	9.8 (5)	6.09 (7)	0 (0)	33.3 (3)	8.57 (3)	5.4 (2)	4.8 (2)	5.00 (4)
N/A	15.9 (10)	29.4 (15)	21.7 (25)	11.5 (3)	11.1 (1)	11.4 (4)	18.9 (7)	33.3 (14)	26.3 (21)
Received medical clearance before RTP, % (n)									
Yes	38.1 (24)	3.9 (2)	22.6 (26)	50.0 (13)	11.1 (1)	40.0 (14)	29.7 (11)	2.4 (1)	15.0 (12)

No	55.6 (35)	88.2 (45)	70.4 (81)	42.3 (11)	88.9 (8)	54.3 (19)	64.9 (24)	88.1 (37)	77.5 (62)
Don't remember	4.8 (3)	0 (0)	2.61 (3)	3.9 (1)	0 (0)	2.86 (1)	5.4 (2)	0 (0)	2.50 (2)
N/A	1.6 (1)	7.8 (4)	4.35 (5)	3.9 (1)	0 (0)	2.86 (1)	0 (0)	9.5 (4)	5.00 (4)
Followed a RTS programme, % (n)									
Yes	15.9 (10)	3.9 (2)	10.4 (12)	19.2 (5)	0 (0)	14.3 (5)	13.5 (5)	4.8 (2)	8.75 (7)
No	60.3 (38)	68.6 (35)	64.3 (74)	65.4 (17)	100 (9)	74.3 (26)	56.8 (21)	61.9 (26)	60.0 (48)
Don't remember	4.8 (3)	5.9 (3)	5.22 (6)	3.9 (1)	0 (0)	2.86 (1)	5.4 (2)	7.1 (3)	6.25 (5)
N/A	19.0 (12)	21.6 (11)	20.0 (23)	11.5 (3)	0 (0)	8.57 (3)	24.3 (9)	26.2 (11.0)	25.0 (20)

GRTP: Graded return-to-play; RTP: Return-to-play; RTS: return-to-school; 1: One respondent answered that they did not remember whether their concussion was suspected or diagnosed and has been excluded.

3.4 Discussion

The purpose of this study was to determine the prevalence, clinical profiles, and management behaviours of SRC in elite and non-elite LGF players. Currently, information about SRC in LGF, as well as in female, community sports in Ireland generally, is extremely limited. This information is urgently needed to describe the extent of SRC in the sport, and if necessary, to guide the development of concussion management interventions and policies. The findings suggest that SRC is a significant problem in LGF, with 17.5% of respondents reporting a suspected or diagnosed SRC during the previous season. Moreover, overall adherence to concussion management guidelines was poor, with only 3.5% of these players following all specific management recommendations. Players who had received some clinical care following a self-reported SRC (i.e., those with a medically diagnosed versus a suspected, undiagnosed SRC) more often followed management recommendations, although management beyond the initial phase of injury remained poor.

3.4.1 Prevalence of Sport-Related Concussions

Almost one-fifth of respondents reported sustaining an SRC in 2019, while over half reported a lifetime history of at least one LGF-related SRC. This is lower than the self-reported lifetime prevalence of SRC that has previously been reported in male and female Gaelic games athletes (72.7%) (28). However, as the previous study did not analyse data by gender and sport, had a smaller sample size, and did not report demographic information such as age, playing level and location, our study's findings may be more accurate for LGF players. SRC is also prevalent among female athletes participating in contact sports at the collegiate (101,112,115,116), professional (103), and amateur (104) levels, accounting for 8.9-30.0% of reported injuries. In our study, elite LGF players had almost double the odds of sustaining a self-reported SRC in 2019 compared with non-elite players (26% vs 15%), although there were no significant differences in lifetime SRC history. Between-group differences in lifetime SRC history may not have been apparent due to recall bias or because we only considered participants who played at the county level in 2019 as elite, regardless of their playing level prior to this. Differences in SRC prevalence between elite and non-elite players may reflect differences in player or game characteristics modulating SRC risk (e.g. the speed and style of play or players' skills and fitness (346–348)), differences in exposures, or discrepancies in access to medical care leading to underreporting in non-elite players. Prospective research that takes athletic exposures into account is needed to determine the extent of, and reasons for, potential differences in SRC prevalence in elite and non-elite LGF players.

The majority of previous research on SRC in female athletes has focused on elite collegiate or professional sport (101,102,112,116), and research on SRC in female community sport is very limited. Our findings suggest that SRC constitutes a significant problem at all levels in LGF, which is unsurprising considering that there may be frequent contact between players (4). While additional

research is needed to determine the direction of future SRC interventions in the sport, clinicians, coaches, and players should be aware of the potentially high risk of SRC in this population.

3.4.2 Clinical Profiles of Sport-Related Concussion

According to the CP Model, patients with SRC experience an initial phase of general fatigue and cognitive impairment, after which they may develop symptoms consistent with one or more clinical profiles: these include migraine, vestibular, ocular, cognitive and mood profiles, and neck and sleep modifiers (31). This model may be able to enhance SRC management through targeted treatment of signs and symptoms (31). In the current study we used the CP Screen to retrospectively identify trajectories in LGF players who had sustained an SRC during the previous season and found that participants scored highest in the ocular and migraine profiles, and lowest on the sleep modifier. However, the differences between all mean profile scores were small. The ocular profile involves a frontal headache, difficulty focusing one's eyes, blurred or double vision and may be aggravated by screens (131), while the migraine clinical profile is characterised by headache accompanied by nausea or photo- or phonophobia, visual aura and provocation by physical activity. Two other studies have classified athletes with SRC using the clinical profiles model. Female adolescents demonstrated highest mean scores on the cognitive and ocular profiles using the CP screen, while another study assigned athletes with SRC a primary and secondary profile on the basis of clinical assessments and self-reported symptoms, and reported that the most common primary profiles were migraine (26%) and mood (24%) (31). These differences in profile prevalence may reflect the low variability in profile scores (349). Clinicians working with LGF players should be aware of how to assess and treat the ocular and migraine profiles. However, as participants in our study scored similarly across multiple profiles, clinicians should also be aware of the symptoms of, and how to assess and manage all of the clinical profiles and modifiers. Traditional assessments such as the SCAT5 may be inadequate for diagnosing and managing SRC as they do not capture the full range of SRC symptoms. Therefore, our findings support the need for multi-domain SRC assessments in LGF players.

3.4.3 Management of Sport-Related Concussions

Our findings showed that a concerning number (10.4% to 61.7%) of LGF players did not adhere to specific recommended management guidelines following a diagnosed or suspected SRC. Among respondents with diagnosed SRCs, almost one-quarter of players returned to play on the day of the injury and almost half did not follow a graded RTP programme. Adherence to recommended management guidelines was even lower among respondents with suspected SRCs, with almost half returning to play on the same day as injury and only 14% following a graded RTP programme. Poor concussion management may have serious implications; delayed removal from play following a concussive incident has been associated with greater recovery times, symptom duration and symptom

severity in collegiate athletes (77,341). Therefore, our findings are concerning and should be addressed through actions such as increased medical support or player and coach education.

To our knowledge, our study is the first to examine SRC management in both elite and non-elite athletes. A greater proportion of elite LGF players received a medical diagnosis for their suspected SRC compared with non-elite players. Regardless of playing level, participants who were diagnosed more frequently informed their coach, followed a graded RTP programme, followed a medically supervised graded RTP programme and received medical clearance before RTP, and less frequently returned to play on the day of injury compared with participants who reported suspected concussions. However, while SRC management appeared to be more favourable in LGF players who had access to medical personnel and received a diagnosis (such as an athletic therapist, physiotherapist, or sports medicine physician) than those who did not, it was still not sufficient in this group. In particular, adherence to management guidelines beyond the initial phase of injury, such as following a graded RTP programme (51%) and receiving medical clearance prior to RTP (38%), was poor. While access to medical personnel in LGF is important for SRC management, it appears that many players do not fully adhere to management guidelines even after obtaining medical care. The reasons for this may include a lack of training in SRC management among medical personnel, poor communication of RTP guidelines to players, or a lack of follow-up or supervision of players with SRC by medical personnel. Further research should investigate reasons for poor SRC management in LGF players in order to guide future behavioural interventions.

3.4.4 Limitations

This study has several limitations. Firstly, convenience sampling was used, which may have resulted in a self-selection bias, with players with a history of SRC or more severe SRCs overrepresented. Secondly, participants reported both suspected and diagnosed SRCs. However, players who did not seek medical advice may not necessarily have sustained an SRC. We addressed this by providing a standardised definition of concussion (344). Thirdly, as the study was retrospective recall bias may have occurred. The CP Screen has only been validated in patients who are currently symptomatic and has not previously been used retrospectively. We attempted to minimise recall bias by only collecting detailed information on SRCs sustained in 2019. Fourthly, although we included a question on whether participants followed a return-to-school programme, we did not refer to a return-to-work programme. Therefore, we may not have captured information about return-to-occupation protocols in participants who had completed their education. Fifthly, we did not collect data on the number of players who were also involved with sports other than LGF. Players who played additional sports may have increased awareness of SRC management guidelines.

3.5 Conclusions

This is the first study to examine SRC prevalence, clinical profiles, and management behaviour in LGF. Our findings suggest that SRC is common at all levels of LGF. The highest scoring clinical profiles were the ocular and migraine profiles. However, as there were only small differences between all profile scores, it is important that clinicians are able to identify and manage all clinical profiles. Overall, SRC management was poor, with between 10.4% and 61.7% of players following specific recommended SRC management guidelines. While management was better among players with a diagnosed versus a suspected SRC, it remained poor beyond the initial phase of injury. This may be due to poor communication between medical personnel and players or to players not following medical advice. Further studies should investigate the underlying reasons for poor adherence to SRC management guidelines in LGF, which can guide the development of interventions. Overall, the findings from this study highlight the need to enhance concussion awareness and reporting among LGF players and ensure that they receive proper initial and follow-up clinical care.

3.6 Implications

The high prevalence of self-reported concussion identified in our study suggests that identifying and managing SRC should be a priority for the LGFA. Overall SRC management, even among diagnosed players, is poor and should be urgently addressed. As providing widespread medical coverage in a community sport may be challenging, this could alternatively be achieved by developing a formal SRC referral pathway for all LGF players. This would allow coaches to refer players or players to self-refer for an SRC assessment if required and should be widely advertised by the LGFA. Clinicians working with LGF players should be aware that SRCs are common in LGF, that poor SRC management behaviours are prevalent in the sport, and that players may present with symptoms across multiple profiles. Prospective research examining injury rates is needed to further establish SRC incidence in LGF. A prospective study design could also provide more detailed data on SRC clinical profiles in this population. Considering the poor management of suspected and diagnosed SRCs among participants in this study, qualitative research investigating the reasons for poor adherence to recommended management guidelines in LGF players is also required.

3.7 Link to Chapter 4

The results from this chapter suggest that SRC is a considerable problem in LGF. The key findings were (i) that many participants had previously experienced one or more SRCs arising from LGF, and (ii) that overall management of SRCs among LGF players was poor. Managing SRCs appropriately is essential as playing with symptoms or returning to play prematurely may increase the risk of a longer recovery (312,341). This is particularly pertinent for female athletes, who suffer disproportionately from SRCs lasting 28 days or longer compared with male athletes (21,94). As

LGF is a community sport with limited resources, medical personnel may not be present at training sessions and matches to identify and manage potential SRCs. Therefore, it is important that players seek medical care following potential SRCs. While we found that players with diagnosed SRCs more frequently followed SRC management guidelines than those with suspected, undiagnosed SRCs, a greater understanding of the factors driving post-SRC behaviour is needed in order to improve SRC management in LGF. This will enable the development of targeted SRC education and behavioural change interventions. Therefore, Chapter 4 will investigate demographic, sport-specific, and psychological factors that may modify management behaviour following an SRC in LGF players.

4 Factors associated with sport-related concussion management behaviour in Ladies Gaelic Football players

4.1 Introduction

SRC is a form of mild head injury that occurs when traumatic forces are rapidly applied to the brain during sport, resulting in temporary neurological dysfunction (18). This dysfunction may manifest in diverse clinical presentations involving the cognitive, vestibular, and ocular systems (337,350,351), as well as disturbances in mood (122) and sleep (352). The majority of adults with SRC recover symptomatically within fourteen days of injury (18), however a minority experience persistent symptoms and may have difficulty returning to their previous level of sport and academic activity (94,340). In Chapter 1.1.1, we identified that SRC is a problem in LGF; we reported that 17.5% of players in our cross-sectional survey had either been diagnosed with an SRC or experienced symptoms of an SRC while playing LGF during the previous season. A native Irish team sport, LGF is a form of women's football that is similar in style of play to Australian football and is one of Ireland's most popular female sports (353). It is an amateur sport, although an elite division exists (11). Although the LGFA endorses international recommended SRC management guidelines, a potential lack of access to medical personnel (28) and concussion education resources, especially at the non-elite level, may impair SRC management in players.

Appropriate management of SRC is essential to minimise recovery time and reduce the risk of further complications. SRC management guidelines recommend immediately removing players with a suspected SRC from play (18). Players should take cognitive and physical rest for 24-48 hours, before incrementally re-introducing activity by following a multi-stage standardised return-to-play (RTP) programme (18). A similar protocol exists for returning to academic activities (18). Non-adherence to recommended management guidelines may be associated with poorer outcomes (312). For example, players who are not immediately removed from play take an average of five days longer until cleared to return-to-play, experience more severe symptoms and are at a greater risk of taking 21 or more days to recover compared with players who do not continue to play following an SRC (312,341). In LGF, adherence to these protocols is poor; approximately half of players with a diagnosed SRC during the previous season reported following an RTP programme, with only 13.7% of those with a suspected SRC doing the same (see Chapter 3.3.5). While players who are diagnosed with SRC by a medical professional are likely supervised during the recovery period in sports with well-developed medical infrastructure, follow-up care may be lacking in LGF, and players may manage SRC poorly in spite of seeking initial medical assistance. Therefore, it is important to expand on current research from North American high school and collegiate sports, which primarily examines reporting behaviour (316,319,322,323), and investigate multiple aspects of SRC management behaviour in LGF. This may improve SRC care in LGF and the broader community sporting context.

The factors driving behaviour post-SRC are poorly understood. Concussion knowledge and attitude are theorised to influence reporting behaviour, with mixed findings (316,319,322). A history of SRC (319,323,327), age (319), and number of years playing a sport (325) have also been suggested to affect SRC reporting; of these factors, only SRC history has been associated with an increased risk of non-disclosure in high school and collegiate athletes (319,322). As medical follow-up may be poor in LGF, research should investigate the association between these factors and SRC management behaviours other than reporting (e.g., following a graded RTP programme). Being diagnosed by a medical professional (versus sustaining a suspected, undiagnosed SRC), previous use of SRC education resources, and level of play may also affect management behaviour among LGF players and should be investigated. Therefore, the aim of this study was to determine the extent to which these factors (age, number of years playing LGF, level of play, concussion history, diagnosis for the SRC, concussion knowledge, concussion attitudes, and engagement with LGFA concussion education resources) are associated with self-reported SRC management behaviours in adult LGF players.

4.2 Methods

4.2.1 Ethical Approval

DCU Research Ethics Committee approved this study in March 2019 (DCUREC/2019/010). Participants provided informed consent by selecting checkboxes agreeing to a number of statements at the beginning of the survey.

4.2.2 Participant Recruitment

The same sample of participants were analysed in this study as in Chapter 3.2.3. As previously described, a nationwide sample of adult LGF players were recruited. Players who (i) were aged eighteen or older, and (ii) had played LGF during the 2019 seasons, were eligible for inclusion. Recruitment was carried out through email advertisements and social media posts between July and December 2020.

4.2.3 Data Collection

The online survey that was described in Chapter 3.2.4 was used for data collection (see Appendix A). Screening questions were included at the beginning of the survey to ensure respondents had played LGF during 2019 and were over age 18. The survey components relevant to this study included:

- (i) Demographic characteristics
- (ii) SRC history
- (iii) Management behaviour following SRC
- (iv) Previous use of LGFA concussion education resources
- (v) RoCKAS

Concussion was defined using a standardised definition modified from a previous study (344), which is provided in full in Chapter 3.2.4.3. We modified the original definition, which described concussion as being caused by “a direct blow to the head” without acknowledging other mechanisms, to include other parts of the body. In our study, diagnosed SRCs refer to SRCs for which participants were diagnosed by a medical professional, while suspected SRCs refer to incidents that align with the concussion definition provided for which the participant did not receive a medical diagnosis. Respondents who reported a diagnosed LGF-related SRC that occurred during 2019 answered additional questions on whether they followed specific management recommendations.

4.2.4 Statistical Analysis

4.2.4.1 Data Cleaning and Processing

Raw data were exported from Google Forms (Google, California, US) as a CSV file, which was then imported into RStudio (RStudio, Boston, MA, US). We created a new dichotomous variable to

indicate concussion history (including both SRCs and non-SRCs) prior to 2019, with “Yes” or “No” responses. RoCKAS CKI, CAI, and the validity scale, were calculated as described by Rosenbaum (335).

As the Google Form had been pre-programmed to require a response to each question, there were no missing data in the original datasheet. However, the following responses were regarded as missing: (i) responses that did not make sense (e.g., where participants both reported having a history of “zero” concussions and sustaining a possible SRC in 2019 (n=2)), (ii) “Don’t remember” and “N/A” responses to concussion management behaviour questions due to their lack of usefulness as an outcome variable level (n=2-25), and (iii) RoCKAS data for participants with a validity score less than two (n=9), as suggested by the authors (335). Among participants who had sustained a possible SRC in 2019, missing data then accounted for 3.2% of the total data and 0.8-27.8% of values for individual variables. As only participants who had sustained an LGF-related SRC in 2019 were to be included in the analysis of SRC management behaviour, we performed multiple imputation via chained equations (MICE) in this group only. MICE is a data imputation technique that creates multiple datasets with plausible values for missing data based on an individual’s observed data and the associations between variables in the entire dataset (354).

4.2.4.2 Descriptive Statistics

Descriptive statistics were presented for demographic characteristics (level of play, age, number of years playing, region, playing position, previous concussion history and previous use of LGFA concussion education resources) for the total sample, as well as separately for participants who had sustained a possible SRC in 2019 (see

Table 46).

4.2.4.3 Explanatory Logistic Regression Analyses

We selected possible factors associated with SRC management behaviour based on the previous literature and clinical experience. Factors considered for inclusion included playing level, age, number of years played, diagnostic status, concussion history, CKI, CAI and previous use of LGFA concussion education material. For the purpose of the study, we considered time spent playing following a possible concussion, continuing to play following a possible concussion, and same day RTP as “immediate” behaviours; “medium-term” behaviours included symptomatic RTP, following a graded RTP, following a graded RTP with medical supervision, obtaining medical clearance prior to RTP, and following a RTS programme. We initially examined the univariate associations between these factors and SRC management behaviours using multinomial or binary logistic regression analyses with a significance level of $p < 0.25$ (355). We included significant factors in explanatory multinomial or binary logistic regression models with concussion management behaviours as the

outcome ($p < 0.05$). The number of independent variables allowed in each model was determined using the rule of ten-events-per-variable (356,357). When the number of significant independent variables exceeded this number, the factors considered the most relevant were selected for inclusion. Final models were assessed to ensure they met assumptions of linearity of the logit and multicollinearity and did not include outliers. Likelihood Ratio tests assessed goodness of fit by comparing final models with intercept-only models ($p < 0.05$) and McFadden's pseudo- R^2 expressed the proportion of difference in the outcome explained by the model. Odds ratios (ORs) with 95% confidence intervals were calculated to provide a measure of the effect of individual predictors on the outcomes.

4.3 Results

4.3.1 Participants

A total of 1049 players responded to the survey. Following the removal of participants who had not played LGF in 2019 (n=92), were under eighteen (n=156) and duplicate responses (n=144), 657 responses remained. Of the remaining participants, 17.5% (n=115) reported sustaining a possible SRC while playing LGF in 2019. Over half (54.8%, n=63) of these reported a diagnosed SRC, while 44.3% (n=51) reported a suspected SRC. One (0.9%) participant did not remember whether or not the SRC had been diagnosed. Demographic characteristics of participants are presented in

Table 46.

Table 46: Participant Demographic Characteristics

	No Concussion in 2019 Group (N=542)	Concussion in 2019 Group (N=115)	Total Sample (N=657)
Level of play, % (n)			
Elite	81.7% (443)	69.6% (80)	79.6% (523)
Non-Elite	18.3% (99)	30.4% (35)	20.4% (134)
Age, median (IQR)	23 (7.8)	22 (7.0)	22 (7.0)
Number of Years Playing Experience, median (IQR)	13 (6.0)	12 (7.5)	13 (6.0)
Playing Position, % (n)			
Back	42.8% (232)	40.0% (46)	42.3% (278)
Forward	38.2% (207)	38.3% (44)	38.2% (251)
Goalkeeper	6.8% (37)	7.8% (9)	7.0% (46)
Midfield	12.2% (66)	13.9% (16)	12.5% (82)
Region, % (n)			
Ulster	22.3% (121)	16.5% (19)	21.3% (140)
Leinster	49.1% (266)	46.1% (53)	48.6% (319)
Munster	16.2% (88)	22.6% (26)	17.4% (114)
Connaught	12.4% (67)	14.8% (17)	12.8% (84)
Previous Self-Reported Concussion, % (n)			
Yes	74.2% (402)	73.9% (85)	74.1% (487)
No	25.8% (140)	26.1% (30)	25.9% (170)
Previous Use of LGFA Concussion Education Resources			
Yes	4.2% (23)	14.8% (17)	6.1% (40)
No	95.8% (519)	85.2% (98)	93.9% (617)

IQR: Interquartile range; LGFA: Ladies Gaelic Football Association.

4.3.2 Factors Associated with Immediate Concussion Management

Time spent playing on following a possible SRC was best explained by a three-factor model, which included playing level, a history of concussion and CAI. CAI was the only factor that was significantly associated with time spent playing, with lower scores associated with playing for more than fifteen minutes compared with not playing (OR: 0.93; 95% CI: 0.87-0.99; p=0.028) (see Table 47). The model explained the data significantly better than an intercept-only model (p=0.049), accounting for 5.2% of the difference in the outcome. Immediate SRC management behaviours, such as informing a coach of a possible SRC and returning to play on the same day, were best explained by one-factor and four-factor models, respectively (see Table 47). A history of concussion was significantly associated with informing a coach of a possible SRC (OR: 2.86; 95% CI: 1.22-7.07; p=0.018), and this model fit the data significantly better than a model containing

only the intercept ($p=0.016$; McFadden's $R^2=3.7\%$). The model for returning to play on the same day included age, diagnosis for the concussion of interest, CKI and CAI as independent variables, however a diagnosis for the concussion of interest was the only significant variable (OR: 0.37; 95% CI: 0.16-0.84; $p=0.018$). This model fit the data better than the intercept-only model ($p=0.016$) and explained 8.1% of the difference in the outcome.

4.3.3 Factors Associated with Medium-Term Concussion Management

Medium-term SRC management behaviours included returning to play with symptoms, following a graded RTP programme, following a graded RTP programme with medical supervision, obtaining medical clearance prior to full RTP, and following a return-to-school programme (see Table 48). A one-factor model with CAI as the independent variable best explained returning to play with symptoms (OR: 0.95; 95% CI: 0.9-1.0; $p=0.078$), however it did not fit the data better than a model containing only the intercept ($p=0.07$; McFadden's $R^2: 2.1\%$). Following a graded RTP programme, following a graded RTP with medical supervision and receiving medical clearance before RTP were best explained by three-factor models. A diagnosis for the concussion of interest was the only significant factor for following a graded RTP programme (OR: 4.89; 95% CI: 1.99-13.09; $p=0.001$) and following a graded RTP programme with medical supervision (OR: 10.16; 95% CI: 3.41-38.53; $p<0.001$). Both models provided a significantly better goodness of fit than the intercept-only models ($p<0.001$; McFadden's $R^2: 13.3\%$ and 15.6% , respectively). Receiving medical clearance before full RTP was positively associated with a diagnosis for the concussion of interest (OR: 13.45; 95% CI: 3.62-74.81; $p=0.001$) and negatively associated with CKI (OR: 0.69; 95% CI: 0.54-0.86; $p=0.002$) in a model that provided a significantly better fit for the data than an intercept-only model ($p<0.001$; McFadden's $R^2: 14.9\%$). A model containing two independent variables best explained following a RTS programme, however it did not contain any significant factors and did not fit the data better than an intercept-only model ($p=0.07$; McFadden's $R^2: 6.2\%$).

Table 47: Factors associated with immediate concussion management behaviour

Variable	Beta	Standard Error	Odds Ratio (95% CI)	P-value	Likelihood Ratio Test	Pseudo-R ²
Model 1: Continued to play following a possible concussion					p=0.049	5.2%
<i>Played for less than 15 minutes</i>						
Elite level (yes)	0.27	0.63	1.32 (0.38-4.52)	0.664	-	-
Concussion history (yes)	-0.91	0.58	0.4 (0.13-1.25)	0.114	-	-
Concussion attitude	-0.02	0.04	0.98 (0.9-1.06)	0.571	-	-
<i>Played for more than 15 minutes</i>						
Elite level (yes)	0.99	0.51	2.68 (0.99-7.27)	0.052	-	-
Concussion history (yes)	-0.25	0.53	0.78 (0.28-2.22)	0.644	-	-
Concussion attitude	-0.08	0.03	0.93 (0.87-0.99)	0.028	-	-
Model 2: Told coach or manager about a possible concussion					p=0.016	3.7%
Concussion history (yes)	1.05	0.45	2.86 (1.22-7.07)	0.018	-	-
Model 3: Returned to play on the same day					p=0.016	8.1%
Age	0.04	0.04	1.04 (0.96-1.14)	0.335	-	-
Diagnosis (yes)	-1.00	0.42	0.37 (0.16-0.84)	0.018	-	-
Concussion knowledge	-0.05	0.10	0.95 (0.79-1.14)	0.581	-	-
Concussion attitude	-0.04	0.03	0.96 (0.9-1.02)	0.199	-	-

Table 48: Factors associated with medium-term concussion management

Variable	Beta	Standard Error	Odds Ratio (95% CI)	P-value	Likelihood Ratio Test	Pseudo-R ²
Model 4: Returned to play with symptoms					p=0.07	2.1%
Concussion attitude	-0.05	0.03	0.95 (0.9-1)	0.078	-	-
Model 5: Followed a Graded Return to Play Programme					p<0.001	13.3%
Elite level (yes)	0.31	0.45	1.36 (0.55-3.31)	0.500	-	-
Diagnosis	1.59	0.48	4.89 (1.99-13.09)	0.001	-	-
Concussion attitude	0.03	0.03	1.03 (0.97-1.1)	0.315	-	-
Model 6: Followed a Graded Return to Play with Medical Supervision					p<0.001	15.6%
Elite level	0.23	0.49	1.26 (0.48-3.27)	0.641	-	-
Number of Years Played	0.08	0.05	1.09 (0.99-1.2)	0.087	-	-
Diagnosis (yes)	2.32	0.61	10.16 (3.41-38.53)	0.000	-	-
Model 7: Received Medical Clearance					p<0.001	14.9%
Elite level (yes)	0.79	0.52	2.2 (0.78-6.22)	0.133	-	-
Diagnosis (yes)	2.60	0.75	13.45 (3.62-74.81)	0.001	-	-
Concussion knowledge	-0.37	0.12	0.69 (0.54-0.86)	0.002	-	-
Model 8: Followed a Return to School Programme					p=0.07	6.2%
Diagnosis (yes)	1.16	0.69	3.18 (0.91-14.8)	0.092	-	-
Concussion education (yes)	0.84	0.68	2.31 (0.55-8.32)	0.216	-	-

4.4 Discussion

This study aimed to identify factors associated with SRC management behaviours in LGF players. While factors influencing concussion reporting have been examined in previous studies of collegiate and high school athletes (315,316,319,322,323,327), little research has examined other aspects of management behaviour, particularly in the medium-term (e.g. not returning to play on the day of injury and following a graded RTP programme). Our study is the first to examine concussion management behaviours beyond reporting behaviour, as well as the first to focus on community sport. We found that being diagnosed with an SRC (versus sustaining a suspected, undiagnosed SRC) was associated with multiple safer behaviours. Players with a previous diagnosed or suspected concussion had increased odds of informing a coach of a possible SRC. However, concussion-related knowledge and attitudes had only a minimal influence on behaviour following an SRC, and demographic factors and previous engagement with LGFA concussion education resources were not associated with management behaviour in LGF players.

4.4.1 Receiving a diagnosis

Being diagnosed with SRC by a medical professional was the main factor influencing behaviour in the medium-term injury phase. Players with a diagnosis of SRC had an almost five-fold increased OR of following a graded RTP programme, ten times the OR of following a graded RTP with medical supervision, and thirteen times the OR of obtaining medical clearance before full RTP compared to players with a suspected, unconfirmed SRC. While previous research has not compared management behaviour among players with diagnosed and suspected SRCs in other sports, greater access to sports medicine professionals is associated with improved athlete outcomes (358). Limited access to medical personnel may impair SRC care-seeking in LGF players. Previous research has found that over 40% of Gaelic games players report that they do not “always” or “often” have access to medical personnel at matches and more than three-quarters do not “always” or “often” have access to medical personnel at training (28). LGF players who did not receive medical care may have been unaware of RTP guidelines and the potential negative consequences of early RTP. Therefore, an increased medical personnel presence at LGF training sessions and matches at all levels of play is highly recommended. This will ensure that players with possible SRCs are immediately removed from play and provided with follow-up care during the RTP process. However, as resources for non-elite LGF teams may be limited, there is also a need to develop a clear SRC referral path to ensure players and coaches can easily seek medical care for an SRC.

4.4.2 Concussion history

A suspected or diagnosed concussion history was associated with almost a three-fold increase in the OR of informing a coach or manager of a possible SRC in our study. This contradicts most of the existing literature which has shown a negative association between concussion history and reporting behaviour (315,319,327). However, the definition of concussion disclosure in these studies included

reporting to a coach or medical professional (315,319,327), whereas we only examined reporting to a coach or manager. LGF players with a previous concussion may be better able to recognise the signs and symptoms and may therefore be more likely to inform a coach if they think they have sustained an SRC. However, concussion history was not associated with other management behaviours in LGF players. This may reflect overall poor management behaviour in LGF players- e.g., players with a history of concussion may not have previously received appropriate care and therefore may not have been aware of recommended management guidelines, such as the graded RTP programme. While reporting a possible SRC to a coach is an important first step in the SRC management process, especially if medical personnel are not present, it is insufficient if additional management steps are not taken. Overall, concussion history does not appear to be an important factor in SRC management behaviour, especially beyond the immediate stage of injury. There is a need to educate players and coaches on how to manage SRCs beyond the immediate management stage, such as the importance of engaging with a clinician and RTP guidelines.

4.4.3 Previous use of concussion education resources

Previous engagement with LGFA concussion education resources did not affect management behaviour. While engagement with these resources is poor (359) among LGF players, this suggests that current concussion education resources provided by the LGFA are ineffective and require further development. Concussion education programmes are frequently recommended to improve concussion reporting and management among athletes, however their effectiveness is unclear (360). Most studies examining their effectiveness have used indirect outcome measures (e.g. knowledge, attitudes or reporting intention) (360) instead of directly measuring behaviour, and have only examined short-term effects (360). Concussion education resources, including the LGFA's resources, have traditionally used media such as information sheets, presentations and videos (360,361) to educate individuals and have been criticised for not considering the broader sociological context (362). Only one randomised control trial to date has directly examined reporting behaviour before and after an education intervention in collegiate athletes; this study found that while reporting intentions were increased following an online video module, reporting behaviour during the following year did not differ between intervention and control groups (363). Recently suggestions have been made to develop interventions that are based on behavioural theories (364,365), target multiple stakeholders (366), and address behaviour (362) instead of simply attempting to increase concussion knowledge (362). For example, scenario-based learning approaches that incorporate role-playing scenarios have been used effectively in substance use prevention programmes (367) and nursing training (368), and could be adapted to an SRC management situation.

4.4.4 Concussion-related knowledge and attitudes

Concussion knowledge and attitudes contributed minimally to management behaviour in this study. CKI was negatively associated with receiving medical clearance before RTP, although it was not associated with any other behaviours. It is possible that participants with increased SRC knowledge were more confident in judging when they were recovered and believed they did not need to seek medical care before RTP. Previous studies have also reported that concussion knowledge has minimal (319) or no effect (315,321,322) on concussion disclosure in collegiate and high school athletes. The Theory of Planned Behaviour suggests that behaviour is influenced by factors other than knowledge, such as attitudes, subjective norms, and perceived behavioural control (331). Therefore, consideration of other factors as well as knowledge is required. However, it is important to note that the RoCKAS focuses on knowledge of SRC symptoms, mechanisms, and consequences, and not on awareness of recommended management behaviour. Knowledge of these guidelines may still be important, although insufficient, for players to manage SRCs safely.

Higher CAI scores were associated with a small reduction in the OR of playing for more than fifteen minutes following a possible SRC compared with not continuing to play, but there was no association between CAI and other behaviours. According to the TPB, attitudes towards a behaviour are an important determinant of behaviour. Participants with safer attitudes in our study may have believed that playing with symptoms of SRC would result in negative outcomes, such as a prolonged recovery. However, safer attitudes in our sample did not translate into any other management behaviours. As mentioned above, this may be because participants may be lacking awareness of recommended SRC management guidelines, such as following a graded RTP. There is a need for research examining LGF players' knowledge of SRC management guidelines. A better understanding of the psychological factors that may influence SRC management behaviour is also required. This could be achieved through qualitative research of LGF players who have sustained an SRC and not followed recommended management guidelines. Factors identified from qualitative research could then be addressed through behavioural interventions.

4.4.5 Demographic characteristics

Finally, demographic characteristics (playing level, age, and number of years playing LGF), were not associated with significantly increased or decreased odds of following immediate or medium-term SRC management guidelines. This supports previous research that has found that concussion disclosure does not vary based on age (319,322) or number of years of college eligibility (325). It also expands on previous findings by demonstrating that these characteristics do not appear to influence other SRC management behaviours, such as avoiding same day RTP and following a graded RTP programme. Therefore, our findings suggest that it is not necessary to focus on modifying behaviour of specific groups of LGF players based on their demographic characteristics.

However, as our study did not include players under eighteen further research is required to determine whether differences exist between underage and adult players.

4.4.6 Limitations

Our study has several limitations. Firstly, we used convenience sampling to recruit participants. The survey was distributed via club secretaries and local administrative boards and promoted online, which meant some players may not have received it. There may have been a self-selection bias with players with a greater interest in or previous experience with SRC being more likely to participate in the survey. Secondly, participants self-reported information about SRC management behaviours in relation to both suspected and diagnosed SRCs. It is possible that not all suspected SRCs were actual SRCs. Thirdly, as the study was retrospective recall bias may have been present and information about behaviour following an SRC may not be fully accurate. Fourthly, we did not examine participants' involvement with sports other than LGF. Multi-sport players may have been more likely to have previously sustained an SRC and may have had differing levels of knowledge and awareness of SRC management guidelines compared with participants who only played LGF.

4.5 Conclusions

This is the first study to examine factors associated with SRC management behaviours in both LGF and female community sport. It also expands on the focus of previous research by including management behaviour outcomes beyond the immediate stage of injury (e.g., following a graded RTP programme). In community sport, disclosing a possible SRC does not always lead to a player receiving appropriate medical care as there may be limited access to medical personnel and a lack of follow up. Therefore, it is important to understand factors that contribute to management behaviour in both the immediate and medium-term stages. Being diagnosed with an SRC, versus sustaining a suspected, unconfirmed SRC, was associated with safer management behaviour (e.g., following a graded RTP programme, following a graded RTP programme with medical supervision, and receiving medical clearance before full RTP) among participants. Players with a previous concussion more often told a coach or manager if they thought they might have an SRC than those without a previous concussion, although there were no differences in any other management behaviours based on concussion history. Other factors (concussion-related knowledge and attitudes, age, playing level, number of years playing, use of concussion education) had minimal influence on SRC management behaviour. Greater access to medical personnel is required in LGF to ensure players receive adequate SRC care. Developing a clear concussion referral pathway and sport-specific education resources may also be helpful in case medical personnel are not available. Further research is also necessary to understand more about players' motivations for not following recommended management guidelines. Qualitative research may be useful in understanding barriers and facilitators of safe behaviour following an SRC and could inform education or behavioural interventions for improving SRC management in LGF.

4.6 Implications

The main finding from this study was that receiving a diagnosis of SRC was the primary factor influencing management behaviour in LGF players following a possible SRC. This emphasises the importance of strong medical infrastructure in improving care for players. Although it may not be possible for all LGF teams to have medical coverage at all times, the LGFA should strongly consider developing a formal SRC referral pathway. While factors such as education and knowledge appear to minimally influence SRC management behaviour, we also believe players would benefit from resources outlining RTP guidelines. The majority of participants had never used LGF concussion education resources, suggesting that many players may not be aware of recommended SRC management guidelines. SRC education is needed to highlight the importance of SRC assessment and management beyond immediate recognition and removal from play. Therefore, we recommend the introduction of mandatory SRC education for all LGF players. There is a need to further explore reasons for LGF players' poor management behaviour. Qualitative research methods, such as semi-structured interviews or focus groups, may help us to understand the psychosocial factors influencing SRC management behaviour in greater detail than quantitative research. In addition, future research should investigate the development and effectiveness of SRC education programmes that focus on factors other than knowledge, such as attitude or reporting intentions.

4.7 Link to Chapter 5

Poor SRC management is a problem in LGF. In this chapter we reported that being diagnosed with an SRC by a medical professional (as opposed to sustaining a suspected SRC) was the most influential factor in following SRC management guidelines. Other factors, such as age, level of play, number of years playing LGF, concussion knowledge, attitude, and prior engagement with SRC education materials, had little effect on whether or not participants adhered to SRC management guidelines. This demonstrates the essential role of clinicians in diagnosing, managing, and rehabilitating SRCs. Although LGF is a community sport and many teams may not have regular access to medical personnel at training sessions or matches, it is important that players seek medical attention if they think they may have sustained an SRC. SRCs have multiple clinical presentations, and some presentations (e.g., post-traumatic migraine) may have worse outcomes than others (120). Clinicians can diagnose and treat SRCs using multi-domain assessments that capture the full range of SRC signs and symptoms (31,32). Post-SRC results can be interpreted by comparison to individual baseline results or normative data. In community sport, the limited number of medical professionals means that there is reduced capacity to carry out baseline assessments. However, normative data, which consists of reference values from a specific population (167), may assist clinicians in diagnosing and rehabilitating SRCs in community sports such as LGF. Therefore, Chapter 5 will present normative data on a multi-domain SRC assessment in LGF players.

5 Normative data for a multi-domain concussion assessment in Ladies Gaelic Football players

5.1 Introduction

SRC is a condition involving cognitive, emotional, and somatic symptoms that occurs in response to head trauma (18). It presents with highly varied signs and symptoms, such as headaches (120), cognitive deficits (119), sensory disturbances (369), loss of balance and coordination (370), mood changes (122) and sleeping problems (336). These varying signs and symptoms may reflect different subtypes of SRC, each of which may require targeted screening tools and rehabilitation (117,130). Several conceptual models of SRC subtypes have been developed (31,117). The CP model hypothesizes that SRC symptoms develop along one or more of five (cognitive, migraine, mood, vestibular, ocular) trajectories following an acute period of general cognitive, fatigue and migraine-type symptoms; these trajectories may be modified by sleep and neck-related factors (31,129,130). In contrast, the Post-Concussion Disorder model suggests the existence of three types of SRC arising due to dysfunction in different neurological subsystems: physiological, vestibular/ocular, and cervicogenic (117). Both models acknowledge the heterogeneity of SRC and the need for an individualised approach to diagnosis and rehabilitation. In particular, they may be useful for guiding rehabilitation in players with persistent symptoms. While SRC symptoms typically resolve without treatment within one month, a minority of players experience symptoms that persist for longer (94,340). Being female, younger age, and various medical history characteristics (e.g., a previous concussion, ADHD, LDs, personal or family migraine or psychiatric diagnoses) may increase the risk of a player experiencing a longer recovery (33).

SRC may be challenging to diagnose and manage due to its highly individual presentation, non-specific symptoms, and lack of objective clinical signs (18). Therefore, multi-domain assessments, incorporating tests for cognitive, migraine, vestibular, ocular, mood, sleep, and neck-related dysfunction, have been recommended (31,32). Clinicians are often recommended to compare post-concussion test scores to pre-injury baseline scores when assessing players with a suspected SRC and when managing the RTP process (18,39). However, collecting baseline data is resource-intensive and may be challenging to implement in many community sports due to financial limitations. Comparing post-concussion test scores to normative data is an alternative approach which has been shown to have adequate diagnostic accuracy across a range of assessments (137,139). Normative data describes the range test scores in a healthy population with similar demographic characteristics and can be used to calculate diagnostic cut-off points (167). For example, using the normative approach the ImPACT PCSS had an AUC of 0.80 in detecting SRC in collegiate athletes (158). Normative data exists for several common SRC tests, such as the SCAT5 (191,371), ImPACT® (209,212,372), and VOMS (232). However, these datasets mainly feature North American youth (209,232,372), collegiate (212) or elite athletes (191), or international elite male athletes (371). As

baseline scores may be influenced by factors such as age, gender, and ethnicity (167). It is important that clinicians consult normative data drawn from a population with similar characteristics to the player. In addition, there is a lack of normative data on assessments for domains other than cognitive, vestibular and ocular domains, such as measures of neck strength (e.g., dynamometry) (299) and self-reported migraine, mood, neck, or sleep function (31,238).

LGF is one of the most popular team sports among females in Ireland (353). It is a fast-paced form of football resembling Australian football, and although it is officially a non-contact sport (4), impacts can still occur. Research among collegiate LGF players identified that 9% of injuries prospectively reported over two seasons were SRCs (101). LGF is primarily a community sport and lacks sophisticated medical infrastructure. Few teams have regular access to medical personnel other than at matches (28), meaning that there is limited capacity to carry out baseline testing. Sport-specific normative data on SRC assessments would therefore be extremely useful for clinicians working with LGF players with SRC. It would also be useful in female community sport internationally. While previous normative datasets for SRC assessments have included female athletes (209,212,232,372), normative data on community sport athletes is lacking. Therefore, this study aimed to (i) provide normative data on a multi-domain SRC assessment for LGF players, and (ii) to examine differences in baseline test outcomes based on age, level of play, and concussion history.

5.2 Methods

5.2.1 *Development of the Concussion Assessment*

Six researchers with expertise in SRC developed a multi-domain assessment based on the Clinical Profiles model of concussion. The group consisted of:

- The primary researcher (Róisín Leahy, BSc., Certified Athletic Therapist; two years' research experience)
- An Associate Professor in Athletic Therapy and Training (Dr. Siobhán O'Connor, PhD., Certified Athletic Therapist; 12 years' experience)
- An Assistant Professor in Athletic Therapy and Training (Dr. Enda Whyte, PhD., Certified Athletic Therapist and Chartered Physiotherapist; 23 years' experience)
- An Assistant Professor in Biomedical Sciences (Dr. Keith Rochfort, PhD.; 13 years' experience)
- A research director of the University of Pittsburgh Medical Center Sports Medicine Concussion Program and an Associate Professor in Sports Medicine (Dr. Anthony P. Kontos, PhD.; 16+ years' experience)
- A research director of the University of Pittsburgh Medical Center Sports Medicine Concussion Program and clinical neuropsychologist (Dr. Michael W. Collins, PhD.; 20+ years' experience)

An initial literature search was conducted to identify possible assessments for each clinical profile and modifier. The group met three times to establish the content validity of the suggested tests. They discussed the psychometric properties, time requirement, equipment needed, and cost of each of the tests. The tests (see Table 49) selected for inclusion in the assessment were:

- ImPACT® (133)
- SCAT5 (132)
- VOMS (121)
- Neck dynamometry (373,374)
- CP Screen (131)
- PHQ-9 (241)
- GAD-7 (240)
- NBQ (292)
- MIDAS (263)
- PSQI (286)

Table 49: Tests included in the concussion assessment and the reasons for inclusion

Functional Domain	Test	Reason for Inclusion
Cognitive	Immediate Post-Concussion Assessment and Cognitive Testing	• Demonstrated known-groups validity (197). • Sensitivity of 91.4% and specificity of 69.1% (375). • Validated in adolescent and adults (375). • Includes validity indices to identify invalid tests (133). • Content is randomised to lessen practice effects (133).
Cognitive, vestibular	Sport Concussion Assessment Tool 5 th Edition	• “Gold standard” assessment; recommended by Concussion in Sport Group (18).
Vestibular, ocular	Vestibular-Ocular Motor Screening	• Only concussion test that assesses dynamic (versus static) vestibular-ocular function (121). • Cut-off scores can accurately identify patients with and without SRC in 90% of cases (150).
Neck	Neck Dynamometry	• Neck strength may be associated with increased risk of concussion (376). • Cervicogenic symptoms may modify concussion symptoms (31).
All	Clinical Profiles Screen	• Assesses major symptoms of all clinical profiles and modifiers. • All profiles differ significantly between players with and without SRC, with medium to large effect sizes (131).
Mood	Patient Health Questionnaire-9	• Recommended in SRC common data elements. • Based on diagnostic criteria for depression. • High sensitivity (0.88) & specificity (0.78) (cut-off score of 10) for depressive disorder (241). • Validated in adolescents (377) and adults (241). • Freely available.
Mood	Generalised Anxiety Disorder-7	• Recommended in SRC common data elements. • Based on diagnostic criteria for generalised anxiety disorder. • High sensitivity (>0.8) & specificity (>0.8) (cut-off score of 10) for anxiety disorder (240). • Validated in adolescents (378) and adults (240). • Freely available.
Neck	Neck Bournemouth Questionnaire	• Assesses neck pain and dysfunction in the context of the biopsychosocial model (298). • High internal consistency (>0.87) (298).
Post-traumatic migraine	Migraine Disability Assessment	• Validated against a daily headache diary in adults (Spearman’s $r=0.63$) (266). • High reliability ($r=0.8$) (263).
Sleep	Pittsburgh Sleep Quality Index	• Strong evidence for known-group validity ($p<0.0001$, $I^2=93\%$) (273). • High convergent validity (>0.7) with other measures of sleep quality (273).

5.2.2 Ethical Approval

The Dublin City University Research Ethics Committee granted approval to carry out this study in March 2019 (DCUREC/2019/010). The study is fully compliant with the guidelines for conducting research involving human participants that are described in the Declaration of Helsinki (379). Prior to completing the concussion assessment, participants, or their parents (if under age 18) provided written informed consent using the forms in Appendix B and Appendix C.

5.2.3 Participant Recruitment

Participants were eligible for inclusion in the study if they were (i) at least 13 years old, and (ii) were currently playing with an LGF team. We excluded players who reported either (i) being diagnosed with a concussion by a medical professional in the 90 days prior to data collection, or (ii) sustaining a suspected concussion for which they did not seek medical attention in the 90 days preceding data

collection. Criteria for identifying participants with a suspected concussion are described in Chapter 5.2.4.

We used convenience sampling to recruit local collegiate and club LGF teams. The principal investigator contacted the coaches of four Dublin City University collegiate LGF teams. Four suitable local club teams were identified through the investigators' networks and with assistance of the LGFA, who advertised the study in an email sent to all LGF clubs in Ireland. The principal investigator visited all collegiate and club teams who expressed an interest in participating in the study and explained the aims, requirements, and benefits of participation to the players or their parents. Individual players or their parents from these teams who wished to participate in the study then provided contact details to the principal investigator. Participants were recruited from four collegiate teams, three adult club teams, and two underage club teams. All teams were located in Dublin, although the collegiate teams included players from multiple regions. While we did not include any elite teams, a number of elite players (29.7%) were involved with the recruited teams. Three participants playing with adult teams were aged 17 and are included in the adolescent group in this study (see Table 50). Participants were recruited continuously between June 2019 and February 2020. Sample sizes of 85 or more have been shown to produce stable means and standard deviations even when data are skewed, and are considered sufficient for normative data samples (380).

Table 50: Overview of teams recruited, setting, age group, and number of participants

Team	Region	Setting	Age Group	Number of Participants
O'Connor/Giles	Dublin	College	Adult	52
Moynihan/Donaghy	Dublin	College	Adult	29
Clontarf Senior/Junior	Dublin	Club	Adult	36
St. Vincent's Minor	Dublin	Club	Adolescent	12
St. Vincent's u/14	Dublin	Club	Adolescent	22

5.2.4 Data Collection

The full assessment took approximately 90 minutes per participant. Therefore, the majority (87.5%, $n=133$) of participants completed half of the assessment on one day and the remainder on another day due to time constraints. A median of 9 days (IQR: 7) separated the two assessments among these participants. Demographic and sport-specific characteristics, relevant medical history, and detailed information about previous diagnosed and suspected concussions were documented using self-report questionnaires (see Appendix D-Appendix G). The following standardised concussion definition was provided to participants to identify suspected concussions that may not have been medically diagnosed; this was modified from a previous definition to clarify that a concussion can occur due to indirect as well as direct impacts (344).

“Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. But, in reality, a concussion has occurred anytime

you have had a direct or indirect blow to the head that caused you to have symptoms for any amount of time. These include: blurred or double vision, seeing stars, sensitivity to light or noise, headache, dizziness or balance problems, nausea, vomiting, trouble sleeping, fatigue, confusion, difficulty remembering, difficulty concentrating, or loss of consciousness. Whenever anyone gets a ding or their bell rung, that too is a concussion.” (344)

Participants completed the ImPACT® and questionnaire (demographic and medical history questionnaire, CP Screen, PHQ-9, GAD-7, NBQ, MIDAS, and PSQI) components of the assessment in groups of up to twelve participants in a computer lab or tutorial room on DCU campus. A tester was present to ensure participants remained quiet and to answer questions or deal with technical issues. Participants were individually assessed for the clinical test (SCAT5, VOMS, and neck dynamometry) component of the assessment. The principal investigator (RL) and a trained assistant performed the clinical tests in either a biomechanics lab or an unused club changing room. The principal investigator carried out the SCAT5 neurological tests, mBESS, VOMS and neck dynamometry, while the assistant carried out the SCAT5 GSC and SAC. As a station format was used for testing, test order was not standardised. Assessments were carried out between August 2019 and March 2020.

5.2.5 Testing Protocol

5.2.5.1 Anthropometric Measurements

Participants’ height and body mass were measured using a combined stadiometer and weighing scales (Electric Column Scale, seca GmbH & Co. KG, Hamburg, Germany). Height was recorded in centimetres and rounded to the nearest millimetre, while body mass was recorded in kilograms and rounded to one decimal place.

5.2.5.2 Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®)

ImPACT® is a computerised neurocognitive test that aims to identify clinically important changes in cognitive function post-SRC. It includes six subtests that produce four composite scores: verbal memory, visual memory, visual motor processing speed, and reaction time. These tests are described in more detail in Table 51 and Figure 8. The Post-Concussion Symptom Scale (PCSS), a 22-item self-report measure of concussion symptoms, is also incorporated into the software. ImPACT® includes several validity indicators that identify unusually poor scores on several test components; “invalid” scores may suggest that participants were not paying attention or were deliberating underperforming. The test can usually be completed in 20 minutes (133).

Participants in our study completed the desktop version of ImPACT® (version 3.11.1; ImPACT® Applications, Pittsburgh, PA, US) using either a desktop computer or a laptop connected to an external mouse. The “baseline” test option was selected. Testing was carried out individually or in

groups of up to twelve participants in a quiet room. A tester supervised the assessment and in group settings participants were separated from each other by at least one metre.

Table 51: Description of tests included in Immediate Post-Concussion Assessment and Cognitive Testing

Test	Description of Test	Domain Assessed	Composite Score
Word Memory (Immediate)	At the start of the test, 12 “target” words are individually shown on-screen for 750 milliseconds. Words are shown twice. Twenty-four words (12 “target” words and 12 non-target words from the same semantic category) are then individually presented, and the participant has to correctly identify whether each word is one of the 12 “target” words by clicking a “yes” or “no” button. Five different word list options exist to reduce practice effects in case of serial administration. See Figure 8A for an example.	• Attention. • Verbal recognition memory.	• Verbal memory.
Design Memory (Immediate)	Twelve “target” designs appear individually on-screen for 750 milliseconds. Each “target” design appears twice. Participants are shown 24 designs (12 “target” designs and 12 non-target designs that are rotated versions of the “target” designs) and must identify whether a design is one of the “target” designs by clicking a “yes” or “no” button on-screen. Five different versions of the design lists exist to reduce practice effects. See Figure 8B for an example of the designs.	• Attention. • Visual recognition memory.	• Visual memory.
X’s and O’s	This test consists of a distractor and memory task. The distractor task is included to impede memory rehearsal. Distractor task (see Figure 8C): when a red circle appears on-screen participants should press “Q” on the keyboard as quickly as possible; when a blue square appears they should press “P”. Memory task: A random pattern of Xs and Os with three items highlighted is shown on-screen for 15 seconds. Participants repeat the distractor task and then the same pattern of Xs and Os without any items highlighted re-appears. They must click the Xs and Os that had previously been highlighted. The test consists of four trials.	• Visual working memory. • Visual processing/visual motor speed.	• Visual memory. • Visual motor speed. • Reaction time.
Symbol Match	A row of nine symbols is shown on-screen. Directly below it is a row of the numbers 1-9, displayed so that each symbol corresponds with a number. When a symbol that matches one of the nine symbols appears on-screen, participants must click on the associated number as quickly as possible. After completing 27 trials, the row of symbols disappears. Participants continue the task as before (a symbol appears and they must select the associated number), however this time they must remember the correct symbol/number pair. See Figure 8D.	• Visual processing speed. • Learning. • Memory.	• Verbal memory. • Reaction time.
Colour Match	Firstly, to ensure participants are not colourblind, they must click a red, green, or blue button on-screen as directed. Participants are then presented with the words “RED”, “BLUE” or “GREEN” in either the same or one of the other colours and must click the word as quickly as possible only if both the word and colour match. See Figure 8E.	• Choice reaction time. • Impulse control/response inhibition.	• Reaction time.
Three Letters	This test includes a distractor and memory tasks: Distractor task (see Figure 8F): Participants are presented with a 5x5 grid of the numbers 1-25 in a random order. They are required to click on the numbers in descending order as quickly as possible, beginning with the number 25. Three consonants then appear on-screen, which participants are asked to memorise. After the consonants disappear, participants are given 18 seconds to repeat as much of the distractor task as possible. Memory task: participants are asked to type the three consonants in the correct order. The test involves five trials.	• Working memory. • Visual motor response speed.	• Visual motor speed.
Word Memory (Delayed)	The twenty-four words presented for immediate word memory are shown again, and the participant has to correct identify whether each word is one of the 12 “target” words by clicking a “yes” or “no” button.	• Verbal recognition memory.	• Verbal memory.
Design Memory (Delayed)	The twenty-four designs shown in the delayed design memory are presented again. Participants must correctly identify whether each design is one of the 12 “target” designs by clicking a “yes” or “no” button.	• Visual recognition memory.	• Visual memory.

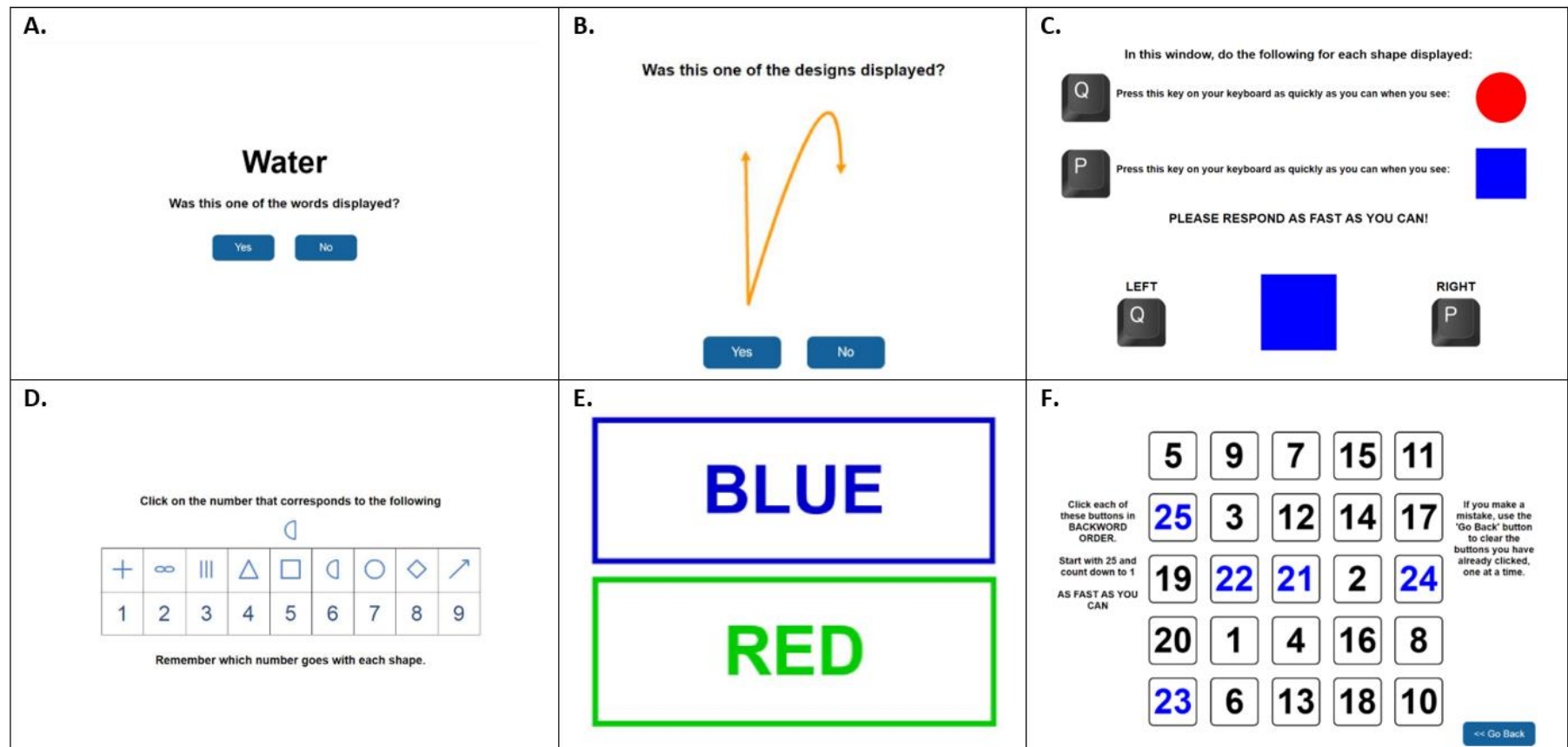


Figure 8: The six tests included in Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT®)

A: "Word Memory" uses a word discrimination task to examine immediate and delayed verbal memory; B: "Design Memory" examines immediate and delayed visual memory using a design discrimination task; C: "Xs and Os" includes a distractor (shown here) and memory task to assess visual memory, visual motor speed, and reaction time; D: "Symbol Match" evaluates verbal memory and reaction time; E: "Colour Match" is a choice-reaction time test assessing reaction time; F: "Three Letters" incorporates a distractor (shown here) and memory task to examine visual motor speed.

5.2.5.3 *Sport Concussion Assessment Tool 5th Edition (SCAT5)*

The Sport Concussion Assessment Tool 5th Edition (SCAT5) is a composite sideline assessment tool for SRC. It incorporates a graded symptom checklist (GSC), the standardized assessment of concussion (SAC), upper and lower limb coordination tests, and the modified Balance Error Scoring System (mBESS) (132). It requires minimal equipment and can be carried out in less than 15 minutes. The SCAT5 is described in detail in Table 52 and demonstrated in Figure 9 (finger-to-nose test), Figure 11 (tandem gait test), and Figure 10 (mBESS).

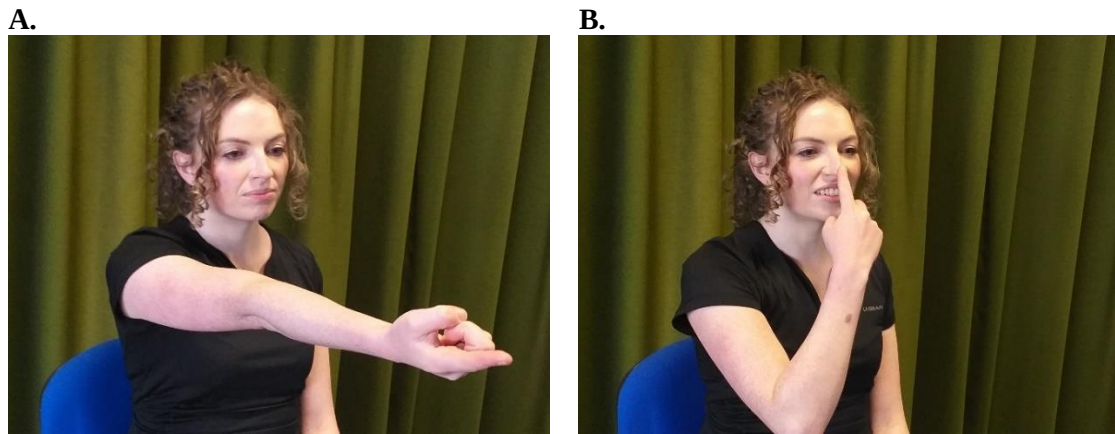


Figure 9: The finger-to-nose test.

The participant starts with her arm extended (A), touches her nose with her index finger (B) and returns to the starting position (A).

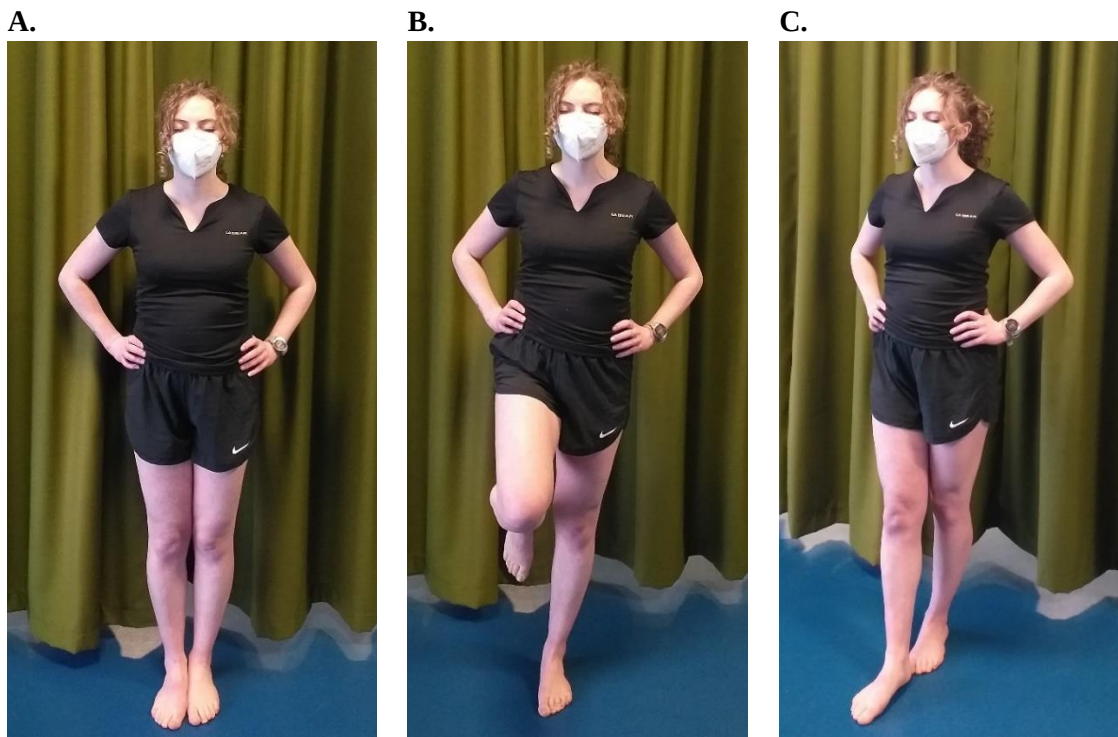
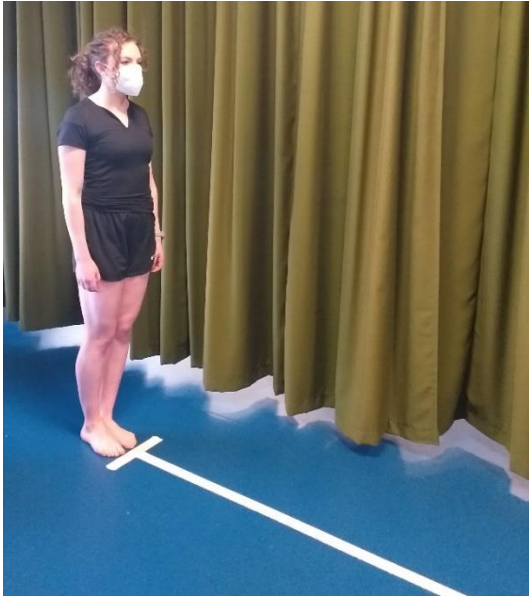


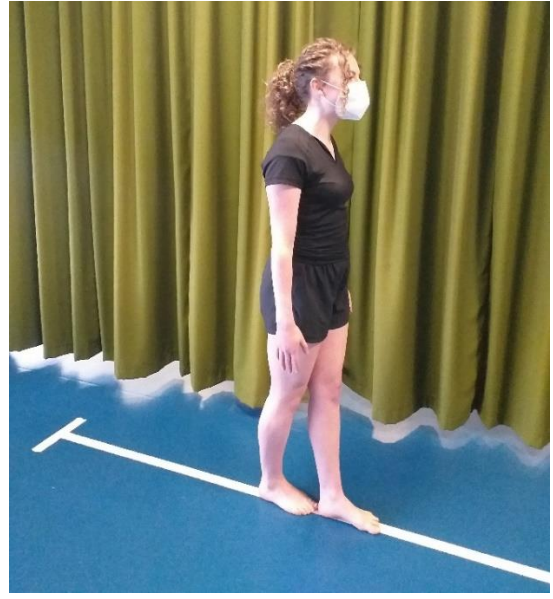
Figure 10: The modified Balance Error Scoring System.

A: Double-leg stance; B: Single-leg stance; C: Tandem gait stance.

A.



B.



C.



D.



Figure 11: The tandem gait test.

The participant begins standing at the end of the line (A), walks along the line using tandem gait (B), turns at the opposite end of the line (C), and returns to the starting position using tandem gait (D).

Table 52: Description of the Sport Concussion Assessment Tool 5th Edition (SCAT5)

<i>Test</i>	<i>Components</i>	<i>Description</i>	<i>Scoring</i>
<i>Graded Symptom Checklist</i>	-	The GSC includes 22 concussion symptoms, which are rated in severity on a seven-point scale (zero=not present, six=severe). Participants read the explanatory paragraph for the GSC aloud to ensure they understand the instructions and then answer a paper version of the form. They rate symptoms with regards to how they “typically feel”.	• Total Symptom Score: the number of symptoms the participant reports experiencing regardless of severity (range: 0-22). • Symptom Severity Score: sum of all 22 symptom scores (range: 0-132).
<i>Standardized Assessment of Concussion</i>	Orientation	The tester asks the participant five temporal questions (e.g., what month is it? What day is it?). Questions are marked as correct (score of one) or incorrect (score of zero).	• Orientation Score: sum of responses (range: 0-5).
	Immediate Memory	The tester reads a list of 10 words to the participant, who immediately repeats back as many as she can remember in any order. Three trials in total are performed using the same list of words. The SCAT5 includes three 10-word lists to reduce practice effects in participants who may undergo repeat testing; we chose to use the first 10-word list (list G) for participants in this assessment.	• Immediate Memory Score: sum of the total number of words correctly recalled across the three trials were counted (range: 0-30).
	Concentration	Concentration is assessed through a “Digits Backwards” and “Months in Reverse” test. • “Digits Backward” test: the tester reads out strings of digits of increasing length from a list and the participant repeats them in reverse order. Each list of digits includes two by three-, four-, five-, and six-digit strings. The tester begins by reading out the three-digit string. If the participant correctly repeats it, she is then tested on the four-digit string; alternatively, the tester reads out the other three-digit string. This process is repeated for each string length. A score of one is awarded for each string length correctly repeated backwards. Six different lists of digits are included in the SCAT5 to reduce practice effects; we used list A in this assessment. • “Months in Reverse” test: the participant is asked to repeat all of the months of the year in reverse order, beginning with December.	• Digits Backwards Score: sum of scores (range: 0-4). • Months in Reverse Score: a score of either one (if performed correctly) or zero (if performed incorrectly) is assigned. • Concentration Score: sum of “Digits Backwards” and “Months in Reverse” scores (range: 0-5).
	Delayed Memory	Delayed recall is assessed after all of the remaining SCAT5 sections had been completed (approximately 5 to 10 minutes after the immediate recall section). The participant is asked to repeat the words from the immediate recall section, this time without the tester reading the list.	• Delayed Memory Score: number of words correctly recalled (range: 0-10).
<i>Neurological Exam</i>	Finger-to-nose test	Participants sit in a chair and hold their non-dominant arm stretched out in front of them. They then tap their index finger to the tip of their nose and completely extended their arm at the elbow joint as quickly as possible; they perform five repetitions in total and pass the test if they are able to correctly complete all repetitions. Time taken to carry out the test is also recorded. See Figure 9.	• Time taken in seconds to complete five repetitions of the test.
	Tandem gait test	The TG test is performed along a three-metre line marked on a hard floor surface with Zinc Oxide tape. Participants perform the test barefooted. They begin the test with their feet together and their arms by their side at one end of the three-metre line. Using tandem gait (alternately placing one foot in front of the other so that the toes of the back foot touched the heel of the front foot), they attempt to walk along the line as quickly and accurately as possible. When they reach the opposite end of the line, they turn 180° and continue back to the starting point using tandem gait. A failed test occurs if the participant (i) steps off the line, (ii) allows a gap between the heel of the front foot and toes of the back foot, or (iii) grabs an object or the tester for support. While the SCAT5 uses a dichotomous version of the TG and FTN tests (“pass”/“fail”), we also timed these tests to provide additional quantitative information about neurological function. See Figure 11.	• Time taken in seconds to complete the test.
<i>Modified Balance Error Scoring System</i>	-	Participants hold three, 20-second static positions (double-leg, single-leg, and tandem stance) with their eyes closed while the tester records if they make any standardised errors. The participant stands on her non-dominant leg for the single-leg stance condition, and puts her non-dominant foot behind her dominant foot in the tandem stance condition. Possible errors include: (i) lifting their hands off their iliac crest, (ii) opening their eyes, (iii) stumbling or falling, (iv) abducting their hip more the 45°, (v) lifting their forefoot	• Total score: sum of scores from all three conditions (range:0-30)

<i>Test</i>	<i>Components</i>	<i>Description</i>	<i>Scoring</i>
		or heel, and (vi) remaining out of the test position for five or more seconds. A score of one is assigned for each error made, with a maximum of 10 errors permitted for each test condition. Multiple errors that occurred simultaneously were recorded as one error. If a participant is unable to hold the test position for the first five seconds, she is assigned a score of 10 for that position. Participants complete the test barefoot and standing on a hard floor surface. See Figure 10.	

GSC: Graded Symptom Checklist; SCAT5: Sport Concussion Assessment Tool 5th Edition; FTN: Finger-to-nose; TG: Tandem gait.

5.2.5.4 Vestibular-Ocular Motor Screening (VOMS)

The VOMS is a brief (five-minute) concussion assessment tool focusing on vestibular and oculomotor dysfunction (121). Participants performed seven different movements that aimed to stimulate the vestibular-ocular system. These included (i) smooth pursuits, (ii) horizontal saccades, (iii) vertical saccades, (iv) near point of convergence (NPC), (v) horizontal vestibular-ocular reflex (HVOR), (vi) vertical vestibular-ocular reflex (VVOR), and (vii) visual motion sensitivity (VMS). The movements and instructions given to participants are reported in detail in Table 53 and demonstrated in Figure 12, Figure 13, Figure 14, Figure 15, and Figure 16. We used a wooden lollipop stick taped with the number “14” in font size 14 as a target. At the beginning of the test (pre-test), and directly following each movement, participants rated four symptoms (headache, dizziness, nausea, and fogginess) on an 11-point numerical rating scale (0-10). A score of zero indicated that the symptom was not present, while a score of 10 signified the symptom was of the most severe intensity imaginable. Scores across the four symptoms were summed for the pre-test and each test item (0-40). Seven change scores were calculated by subtracting the pre-test score from each item score. In addition, the seven change scores were summed to produce a total symptom score (0-280). NPC distance (the distance in cm between the tip of the participant’s nose and the target) was measured if she experienced diplopia during the NPC test item. A score of ≥ 2 on any test item or an NPC distance ≥ 5 cm are typically regarded as positive cut-off thresholds (121). However, several studies have suggested alternative cut-off thresholds (150,224). One study suggested that a score ≥ 1 on the HVOR, VVOR or VMS items, an NPC distance of ≥ 3 cm, or a total symptom score ≥ 3 should be considered a “positive” result in adolescents,(224) while another study in collegiate athletes recommended using a score ≥ 1 on smooth pursuits, horizontal saccades, vertical saccades, NPC or VVOR items, a score ≥ 2 on the HVOR item, or a total symptom score ≥ 8 as cut-off points (150).

Table 53: Detailed description of vestibular-ocular motor screening (VOMS)

Test Item	Starting Position	Action	Instruction	Speed	Repetitions
<i>Smooth Pursuits</i>	Participant: seated in a chair. Tester: seated in a chair that is 3ft from the participant's chair and holding one of their fingertips 3ft from the participant.	The tester smoothly moves their finger horizontally and vertically while the participant focuses on their fingertip. For the horizontal component, the tester moves their finger from the participant's midline 1.5ft to the right, back to the midline, 1.5ft to the left, and back to the midline. For the vertical component, the tester moves their finger from the participant's midline 1.5ft up, back to the midline, 1.5ft down, and back to the midline. See Figure 12.	"Follow my finger with your eyes, without moving your head."	Two seconds right-left, two seconds up-down.	Two horizontal, two vertical
<i>Horizontal Saccades</i>	Participant: seated in a chair. Tester: seated in a chair that is 3ft from the participant's chair. They hold their right index finger 1.5ft to the right, and their left index finger 1.5ft to the left. Both fingertips are held 3ft from the participant.	The participant moves their eyes between the tester's fingertips as quickly as possible. This requires them to rotate their eyes 30° to the right and left. See Figure 13A.	"Look as quickly as you can between my fingers, 10 times, without moving your head."	As quickly as possible.	10
<i>Vertical Saccades</i>	Participant: seated in a chair. Tester: seated in a chair that is 3ft from the participant's chair. They hold their right index finger 1.5ft above the participant's midline, and their left index finger 1.5ft below the participant's midline. Both fingertips are held 3ft from the participant.	The participant moves their eyes between the tester's fingertips as quickly as possible. This requires them to rotate their eyes 30° up and down. See Figure 13B.	"Look as quickly as you can between my fingers, 10 times, without moving your head."	As quickly as possible.	10
<i>Near Point of Convergence</i>	Participant: seated in a chair, holding a target at eye level in their outstretched arm. Tester: seated or standing.	The participant focuses on the target as they slowly move it towards the tip of their nose. They stop moving the target if they experience double vision of the target or if the testers observe an outward deviation of their eye. See Figure 14.	"Focus on the target and bring it slowly toward your nose. Ignore any blurriness that occurs and stop when the target splits into two targets."	Slowly.	Three
<i>Horizontal Vestibular-Ocular Reflex</i>	Participant: seated in a chair. Tester: seated in a chair that is 3ft from the participant's chair. They hold a target at the participant's midline, 3ft from the participant.	The participant focuses on the target while horizontally rotating their head to the right and left in time to a metronome beat. This requires a head rotation of 20° to each side. The participant is given 10 seconds rest between performing the movement and rating the symptoms. See Figure 15A and B.	"Focus on the target while moving your head side to side, at the speed of this beat."	180 beats per minute.	10
<i>Vertical Vestibular-Ocular Reflex</i>	Participant: seated in a chair. Tester: seated in a chair that is 3ft from the participant's chair. They hold a target at the participant's midline, 3ft from the participant.	The participant focuses on the target as they flex and extend their neck in time to a metronome beat. This requires a head movement of 20° in both directions. Ten seconds rest are given between performing the movement and rating the symptoms. See Figure 15C and D.	"Focus on the target while moving your head up and down, at the speed of this beat."	180 beats per minute.	10
<i>Visual Motion Sensitivity</i>	Participant: standing with their feet shoulder-width apart facing a "busy" environment. Tester: standing next to and behind the participant.	The participant holds their arm stretched out in front of them with their thumb up and focuses on their thumb. While focusing on their thumb, they move their head, eyes, and trunk as one unit 80 degrees to the right and left, in time with the metronome. Ten seconds rest is given after performing the movement before the participant rates their symptoms. See Figure 16.	"Stand and hold your arm outstretched with your thumb up. Keep your head and eyes focused on your thumb, as you rotate your entire body side to side."	50 beats per minute.	Five

A.



B.



C.



D.



Figure 12: Vestibular-ocular motor screening smooth pursuits item.

Horizontal smooth pursuits: the participant follows the tester's fingertip with her eyes from the starting position (A) horizontally to the left (B) and back to the starting position (A). Vertical smooth pursuits: the participant follows the tester's fingertip with her eyes from the starting position (C), vertically down (D) and back to the starting position (C).

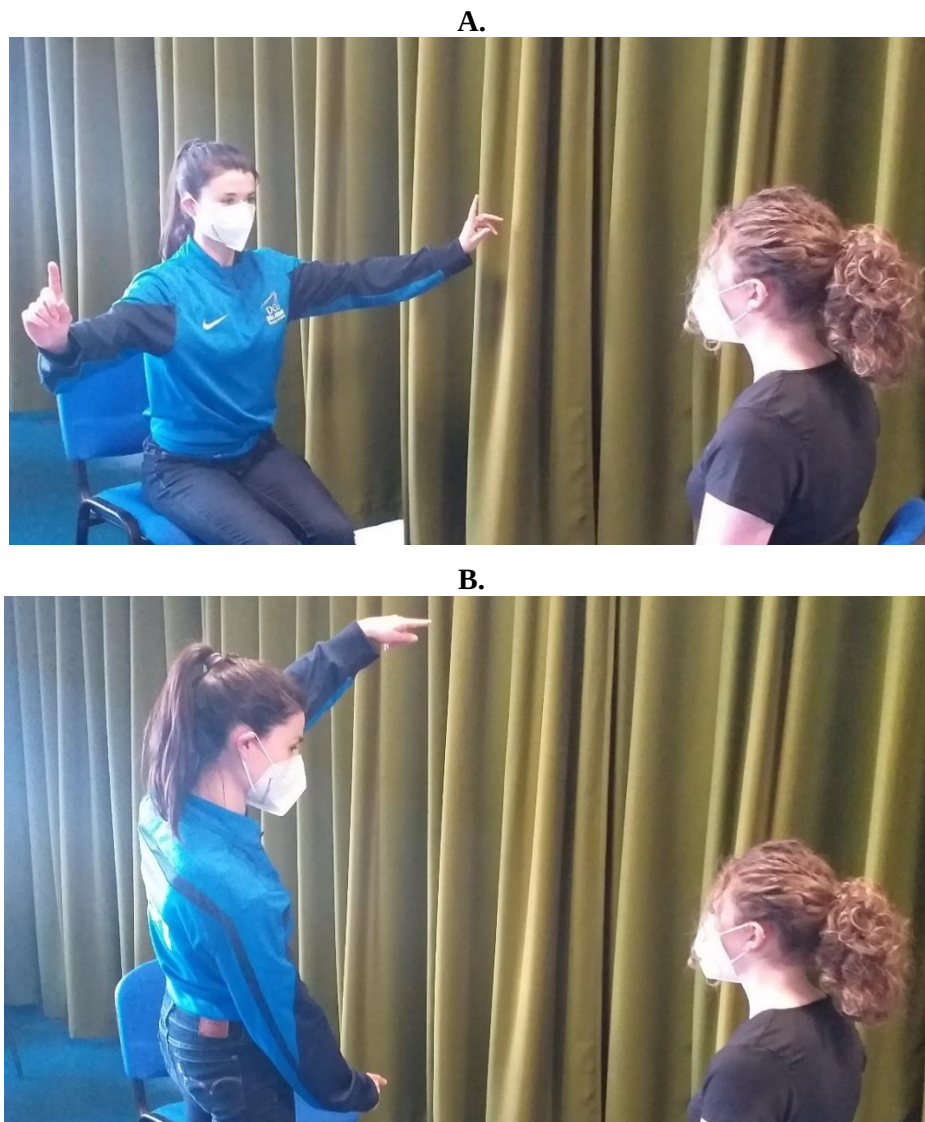


Figure 13: Vestibular-ocular motor screening saccades.

For horizontal saccades (A) the participant moves her eyes right and left between the tester's fingertips. For vertical saccades (B) the participant moves her eyes up and down between the tester's fingertips.

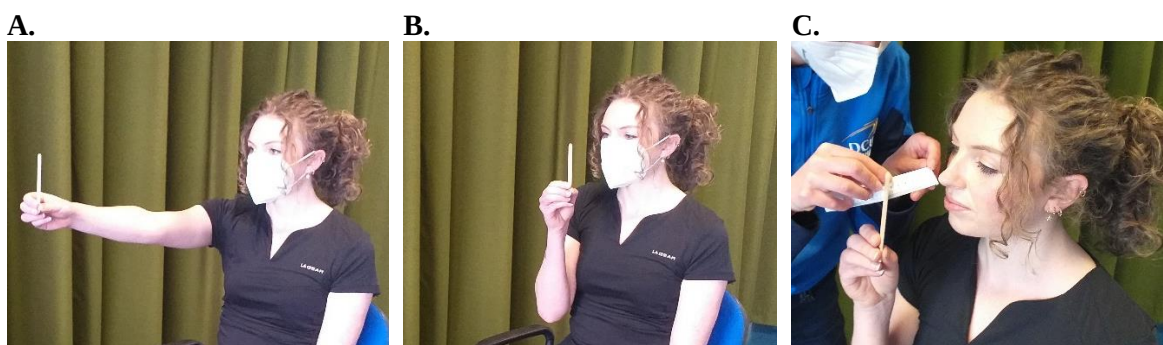


Figure 14: Vestibular-ocular motor screening near point of convergence (NPC) item.

The participants begins with her arm extended (A) and moves the target towards her nose until convergence (B). The distance between the tip of her nose and the target is measured (cm).

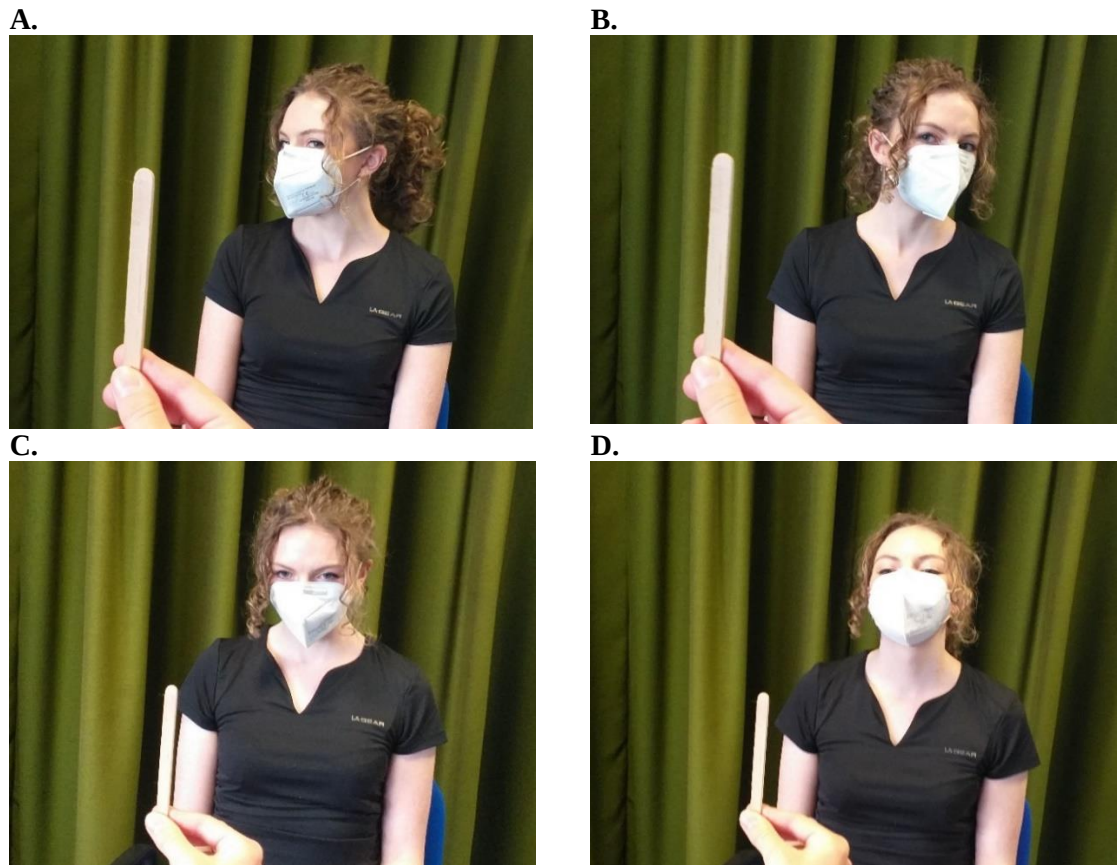


Figure 15: Vestibular-ocular motor screening vestibular-ocular reflex (VOR) items.

For the horizontal VOR item the participant rotates her head to the right (A) and left (B). For the vertical VOR item the participant flexes (C) and extends (D) her head.

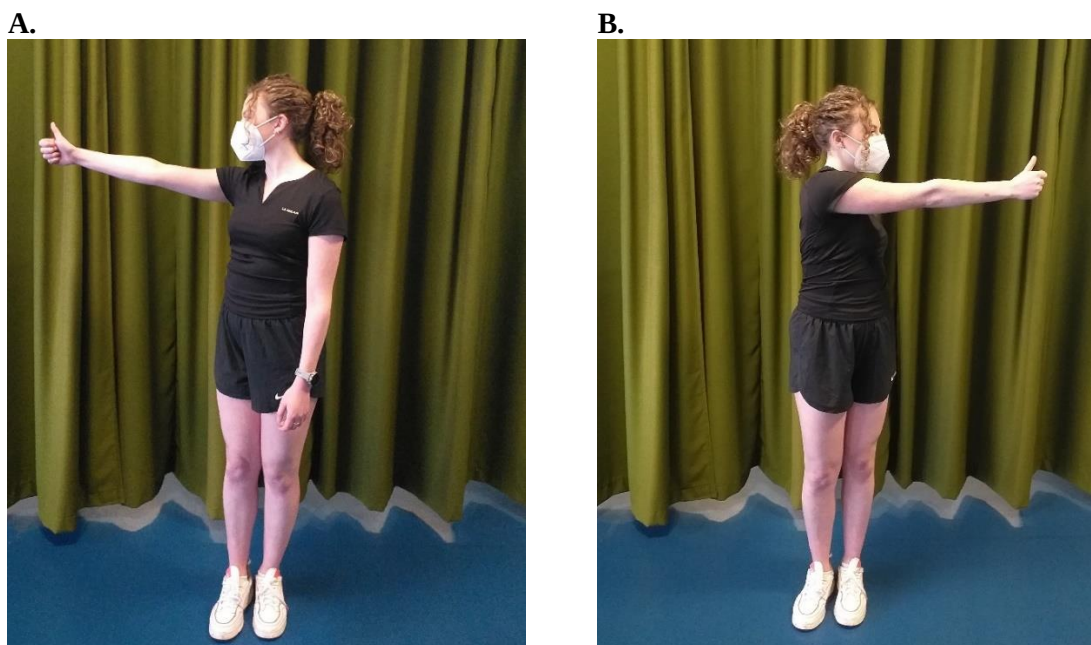


Figure 16: Vestibular-ocular motor screening visual motion sensitivity item.

The participant rotates her torso back and forth between the starting position (A) to the mid-position (B).

5.2.5.5 Neck Dynamometry

We assessed isometric neck flexion, extension, dominant and non-dominant side lateral flexion, and dominant and non-dominant side rotation (sternocleidomastoid) strength following HHD protocols from the literature (373,374). The HHD (JTECH Commander Echo Wireless Muscle Testing Starting Kit, JTECH Medical, Salt Lake City, UT, USA) was pre-programmed to perform six tests of three trials and was calibrated to detect minimal forces of 4.4 Newtons. Testing was carried out by the principal investigator and intra-rater reliability was high (ICC (2,k) of 0.81-0.98). Before commencing the test, we explained it to participants using the following standardised description: “I am going to test your neck strength. I’m going to do that by putting this device against your head in various positions. For each movement, I’ll get you to push against me as hard as you and I’ll resist the movement.” Detailed information about the test protocol is provided in Table 54 and the tests are shown in Figure 17. The three trials for each test were performed consecutively. Testing was halted if the participant complained of neck pain. Mean strength values were calculated for each of the six tests and were normalised to participants’ body mass by dividing force in Newtons by body mass in kilograms (N/kg).

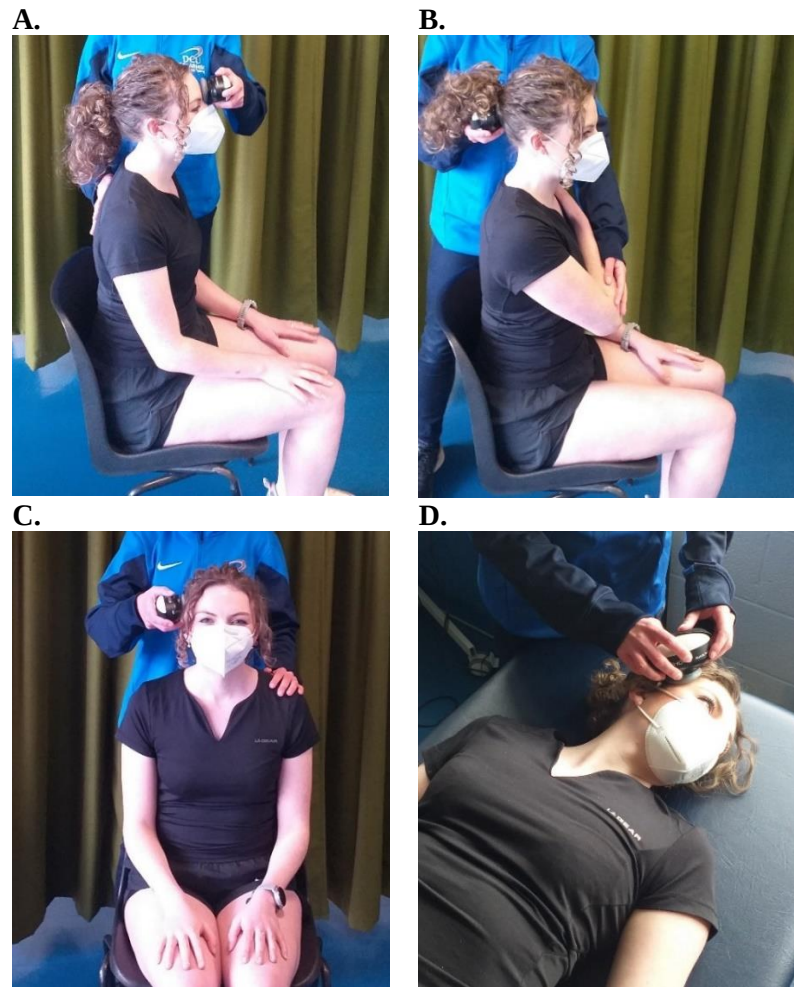


Figure 17: Neck dynamometry.

A: flexion; B: extension; C: lateral flexion; D: rotation.

Table 54: Detailed description of the neck dynamometry protocol

Test	Starting Position	Action	Instruction	Repetitions
Neck Flexion (373)	Participant: seated in a chair with their feet planted on the floor. Tester: standing beside the chair to the participant's right. They place their left hand on the participant's upper back and hold the HHD on the participant's forehead above their eyebrows with their right hand. See Figure 17A.	The participant performs a three second isometric neck flexion movement which the tester resists.	"I'm going to place the device on your forehead and place my hand on your upper back to stabilise. When you're ready, I'll get you to try to move your chin to your chest and I'll try to stop you. I want you to do this as hard as you can three times. Ready? Push, push, push, and relax."	Three
Neck Extension (373)	Participant: seated in chair with their feet planted on the floor and holding one of their hands in a fist across their chest. Tester: standing beside chair to the participant's left. Places their left hand over the participant's fist and places the HHD over back of participant's head (just above the external occipital protuberance) using their right hand. See Figure 17B.	The participant performs a three second isometric neck extension movement which the tester resists.	"I'm going to get you to make a fist using one of your hands and place it across your chest. I'll put my hand on your fist to stabilise and hold the device over the back of your head. When you're ready, I'll get you to try to look up at the ceiling using your neck only. I'll get you to do this as hard as you can, three times. Ready? Push, push, push, and relax."	Three
Neck Lateral Flexion (373)	Participant: seated in chair with their feet planted on floor. Tester: standing behind the participant with the HHD held above the participant's right/left ear in one hand. Their other hand is placed on the participant's opposite shoulder. See Figure 17C.	The participant performs a three second isometric right or left lateral neck flexion movement while the tester resists.	"I'm going to put the device over your ear and my hand on your opposite shoulder to stabilise. When you're ready, I want you to try to move your right/left ear towards your right/left shoulder without moving your shoulder. I'll get you to do this as hard as you can, three times. Ready? Push, push, push, and relax."	Three
Neck Rotation (Sternocleidomastoid) (374)	Participant: lying supine on a plinth with their head rotated to the left/right side. Tester: standing at the top of the plinth and holding the HHD over the participant's opposite temple. See Figure 17D.	The participant performs a three second isometric contraction of sternocleidomastoid which the tester resists.	"I'm going to put the device over your temple. Pick a point on the wall in front of you to focus on. When you're ready, I want you to attempt to lift your head off the plinth, while keeping focused on the same point on the wall the whole time. I'll try to stop you. I'll get you to do this as hard as you can, three times. Ready? Push, push, push, and relax."	Three

HHD: Hand-held dynamometer.

5.2.5.6 *Clinical Profile Screen (CP Screen)*

The CP Screen is a concussion symptom screening tool based on the Clinical Profiles model (131). It consists of 29 items, which capture symptoms associated with all five of the clinical profiles (cognitive: 3 items; migraine: 5 items; mood: 5 items; vestibular: 5 items; ocular: 5 items) and two modifiers (sleep: 4 items; neck: 2 items). Based on how they currently feel, participants rate each symptom as “none”, “mild”, “moderate”, or “severe”. Responses are assigned scores between zero (“none”) and three (“severe”). Scores for individual clinical profiles and modifiers are calculated by finding the mean score per profile (i.e., by summing all of a profile’s item scores and dividing by the total number of items in that profile). An overall total score is calculated by summing the 29 item scores (131).

5.2.5.7 *Health Questionnaires*

Participants answered five health questionnaires assessing depression (PHQ-9), anxiety (GAD-7), neck pain and dysfunction (NBQ), disability due to migraine (MIDAS), and sleep quality (PSQI). The PHQ-9 is a nine item self-report measure of depression symptoms. It is based on the diagnostic criteria for clinical depression. Participants rate the frequency with which they have experienced nine symptoms over the preceding two weeks: “not at all” is assigned a score of zero, “several days” is assigned a score of one, “more than half the days” is assigned a score of two, and “nearly every day” is assigned a score of three. The nine item scores are summed to produce a total score ranging from 0 to 27. A total score of 10 or greater is considered the clinical cut-off threshold for a depressive disorder (sensitivity: 70%-88%, specificity: 84%-93%).(381) Total scores are also used to grade depression severity (none: 0-4, mild: 5-9, moderate: 10-14, moderately severe: 15-19, severe: ≥ 20) (241).

The GAD-7 consists of seven items and is based on the diagnostic criteria for generalised anxiety disorder (GAD). Similar to the PHQ-9, participants report the frequency of their symptoms over the previous two weeks and are assigned scores based on their responses: “not at all” (score of 0), “several days” (score of 1), “more than half the days” (score of 2), or “nearly every day” (score of 3). The seven item scores are summed, resulting in total scores between 0 and 21. The clinical cut-off score of 10 has a sensitivity of 74% and a specificity of 83% for GAD (244). Scores can be further classified to describe severity (none: 0-4, mild: 5-9, moderate: 10-14, severe: ≥ 15) (240).

The NBQ is based on the biopsychosocial model of pain and assesses multiple dimensions of neck pain, including pain intensity, disability, mood, and cognitive-behavioural factors. It includes seven 11-point numerical rating scales ranging from 0 to 10, where 0 indicates no pain or dysfunction, and 10 represents extreme symptoms or an inability to carry out activities. Summing all seven item scores yields a total score with a possible range of 0 to 70 (292). As the NBQ is used to measure changes in neck pain-related outcomes rather than as a diagnostic tool, cut-off thresholds for classifying patients

(i.e., as positive or negative) have not been suggested. However, changes of ≥ 13 points or $\geq 36\%$ have been shown to identify patients with improvements in neck pain with high accuracy (100% and 94.4%, respectively) (296).

MIDAS quantifies disruption to daily activities caused by headaches. It includes five questions asking participants how many days over the previous three months they have experienced major disruption to activities (e.g., missing school or work, being unable to complete household tasks). The total number of days from the five questions are tallied and graded: 0-5 days= grade I (little or no disability), 6-10 days= grade II (mild disability), 11-20 days= grade III (moderate disability), and ≥ 21 days= grade IV (severe disability) (263).

The PSQI assesses overall sleep quality. It includes 19 questions that contribute to seven sleep component scores: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Component scores are calculated according to a complex scoring system and range from 0 to 3. A global PSQI score is computed by adding all seven component scores, giving a range of 0 to 21. A clinical cut-off threshold of 5 has been suggested to identify individuals with poor sleep quality (286).

5.2.6 Statistical Analysis

We exported data from ImPACT® into an Excel sheet (Microsoft Corporation, Redmond, WA, US) and manually entered raw data from the clinical test sheets and questionnaires into the same sheet. We imported this Excel sheet into RStudio (RStudio, Boston, MA, US), where we carried out data cleaning and analysis (version 4.1.0).

5.2.6.1 Data Cleaning and Processing

There were 68 complete cases in the dataset. Missing data accounted for 1.2% of the data, and for between 0.7% and 14.5% of values for individual variables. Missing data were caused by either unit (e.g., participants failing to return for the second part of the assessment, equipment or software malfunctions, or invalid ImPACT® results) or item (e.g., tester errors or failure of participants to answer all questionnaire items) non-responses. Available case analysis was used for unit non-responses (i.e., data were included only when the participant had completed the section). Item non-responses were imputed using median imputation. Median imputation replaces missing values in a variable with the variable's median value (382,383). We chose to use median imputation as the dataset contained too many variables relative to cases to perform multiple imputation. Furthermore, none of the variables of interest were normally distributed and most (45/60) contained outliers, making mean imputation unsuitable (383). Median imputation reduces the variability in the data, thereby increasing type I error rates (382,383). However, the variables we imputed contained only a small proportion of missing data (0.7% to 6.6%). Following imputation, we calculated scores for

clinical test and health questionnaire outcomes, as well as additional categorical variables for tests with recommended clinical cut-off thresholds and classification grades (VOMS, PHQ-9, GAD-7, MIDAS, PSQI) (see Table 55).

Table 55: Clinical Test and Health Questionnaire Scores

<i>Assessment</i>	<i>Outcome</i>	<i>Possible Range of Scores</i>
Immediate Post Concussion Assessment and Cognitive Testing¹	Verbal Memory Score	0-100
	Visual Memory Score	0-100
	Visual Motor Score	- ²
	Reaction Time	Time in seconds
	Post-Concussion Symptom Score	0-154
Sport Concussion Assessment Tool 5th Edition	Total Symptom Score	0-22
	Symptom Severity Score	0-132
	Orientation	0-5
	Immediate Memory	0-30
	Concentration	0-5
	<i>Digits Backwards</i>	0-4
	<i>Months Backwards</i>	0-1
	Delayed Memory	0-10
	Finger-to-nose Time	Time in seconds
	Tandem Gait Time	Time in seconds
	Modified BESS Total Score	0-30
	<i>Modified BESS Double-Leg Score</i>	0-10
	<i>Modified BESS Single-Leg Score</i>	0-10
	<i>Modified BESS Tandem Stance Score</i>	0-10
Vestibular-Ocular Motor Screening	Horizontal Saccades Score	0-40
	Vertical Saccades Score	0-40
	Convergence Score	0-40
	Near Point of Convergence	0-40
	Horizontal VOR Score	0-40
	Vertical VOR Score	0-40
	Visual Motion Sensitivity Score	0-40
	VOMS Cutoff	Positive, negative
Neck Dynamometry	Neck Flexion	0+ N/kg body mass
	Neck Extension	0+ N/kg body mass
	Dominant Side Lateral Neck Flexion	0+ N/kg body mass
	Non-Dominant Side Lateral Neck Flexion	0+ N/kg body mass
	Dominant Side Neck Rotation	0+ N/kg body mass
	Non-Dominant Side Neck Rotation	0+ N/kg body mass
Clinical Profiles Screen	CP Total Score	0-87
	CP Cognitive/Fatigue Score	0,0.33,0.67,1,1.33,1.67,2
	CP Migraine Score	0,0.2,0.4,0.6,0.8,1
	CP Vestibular Score	0,0.2,0.4,0.6,0.8,1,1.2
	CP Ocular Score	0,0.2,0.4,0.6,0.8,1,1.2,1.4,1.6,1.8
	CP Anxiety/Mood Score	0,0.2,0.4,0.6,0.8,1,1.2,1.4,1.6,1.8
	CP Sleep Score	0,0.25,0.5,0.75,1,1.25,1.5,2,2.5
	CP Neck Score	0,0.5,1,1.5,2,3
Patient Health Questionnaire-9	PHQ-9 Score	0-27
	PHQ-9 Clinical Cutoff	Positive, negative
	PHQ-9 Grades	None, mild, moderate, moderately severe, severe
Generalised Anxiety Disorder-7	GAD-7 Score	0-21
	GAD-7 Clinical Cutoff	Positive, negative
	GAD-7 Grades	None, mild, moderate, severe
Neck Bournemouth Questionnaire	Neck Bournemouth Score	0-70
Migraine Disability Assessment	MIDAS Score	0+ days
	MIDAS Grade	I, II, III, IV
Pittsburgh Sleep Quality Index	PSQI Global Score	0-21
	PSQI C1 Score	0-3
	PSQI C2 Score	0-3
	PSQI C3 Score	0-3
	PSQI C4 Score	0-3
	PSQI C5 Score	0-3
	PSQI C6 Score	0-3
	PSQI C7 Score	0-3
	PSQI Cutoff	Good sleep quality, poor sleep quality

1: ImPACT® scores are automatically calculated by the software; 2: Range not possible to determine.

5.2.6.2 *Normative Data*

We presented demographic and sport-related characteristics, as well as relevant medical history, for all participants, and separately for adolescent and adult participants, and elite and non-elite participants. Players were characterised as elite if they reported playing with a county team at the time of testing. All clinical test and health questionnaire outcomes were initially plotted and visually examined. Continuous outcomes were further assessed for normality using the Shapiro test and Q-Q plots, and for homogeneity of variance using Levene's test. Tables of descriptive data, including means and standard deviations, medians and IQRs, and the total range of sample scores, were generated for discrete and continuous clinical test and health questionnaire outcomes. Descriptive statistics were presented collectively for all participants and subsequently stratified by age group, level of play and history of diagnosed concussion. The proportion of participants meeting clinical cut-off thresholds (positive/negative) for the VOMS, PHQ-9, GAD-7, PSQI and MIDAS, as well as the proportion meeting various classification grades for the PHQ-9, GAD-7, and MIDAS, were presented for all participants, and by age group, level of play, and concussion history. When calculating proportions, we used the valid percentage (i.e., did not include participants with missing data in the calculation). We also calculated percentile ranks for the 1.9th (impaired), 9th (borderline impaired), 24th (low average), 75th (average), 90th (high average), 97th (superior) and $\geq 98^{\text{th}}$ (high superior) percentiles for all continuous outcomes, using classification ranges suggested by ImPACT® (384). Percentile ranks are presented in Appendix P-Appendix U.

5.2.6.3 *Between-Group Analyses*

Between-group analyses were performed to examine differences in clinical test and health questionnaire outcomes based on age (adolescent vs adult), level of play (elite versus non-elite), and concussion history (previously diagnosed with a concussion in any setting versus never previously diagnosed with a concussion). As few participants had been diagnosed with headache (n=21), migraine (n=13), ADHD (n=1), an LD (n=8), depression (n=3), or an anxiety disorder (n=2), between-group differences in outcomes based on other aspects of the medical history were not examined. Differences in normally distributed continuous outcomes were assessed using two-tailed independent t-tests with Welch corrections to account for unequal sample sizes and variances. Wilcoxon rank-sum tests were selected to examine differences in continuous outcomes when the assumption of normality was not met. Between-group differences in categorical outcomes were assessed using two-tailed Chi-square tests of independence if fewer than 20% of expected cell frequencies were less than five; otherwise, we used Fisher exact tests. Effect sizes were expressed as Glass's delta for t-tests (small: 0.2, moderate: 0.5, large: 0.8) (385), Glass rank biserial correlations for Wilcoxon rank-sum tests (with -1 indicating that all values in the second group are greater than all values in the first group, and +1 indicating that all values in the first group are greater than all values in the second group) (386), and Cramer's V for Chi-square and Fisher exact tests (small: 0.1;

moderate: 0.3; large: 0.5) (387). An a-priori alpha level of 0.05 was selected and Holm-Bonferroni procedures were applied to each between-group (age, level of play, and concussion history) set of analyses to minimise the family-wise error rate.

5.3 Results

5.3.1 Participant Characteristics

One hundred and fifty-two participants completed the initial assessment, however 14 were removed from the dataset due to a suspected or diagnosed concussion within the previous three months (n=8) or missing information about concussion history (n=6). The final sample contained 138 (101 adult, 37 adolescent) participants. Adolescent participants ranged in age from 13 to 17 (age 13: n=6, 16.2%; age 14: n=15, 40.5%; age 15: n=11, 29.7%; age 16: n=2, 5.4%; age 17: n=3, 8.1%).

Almost 30.0% of participants were playing at an elite level at the time of assessment and one-fifth reported a previous diagnosis of concussion by a medical professional. Elite players represented a greater proportion of adult (33.7%) than adolescent (18.9%) players. Multi-sport athletes comprised 58.7% of the sample. These participants most frequently played camogie (50.6%) or soccer (16.5%) as additional sports. While just over half (50.1%) of adult participants played another sport, four-fifths (81.1%) of adolescent participants did so. All adult participants had completed final school exams. The majority (81.1%) of adolescent participants had not completed their junior certificate exams, which are state examinations carried out at the end of third year in secondary school in Ireland. This reflects the young age profile of the adolescent participants. Additional demographic, sport-related, and medical history characteristics are presented for adult and adolescent participants in Table 56.

Table 56: Demographic characteristics of participants

	<i>Total Sample (N=138)</i>	<i>Adolescent (N=37)</i>	<i>Adult (N=101)</i>	<i>Elite (N=41)</i>	<i>Non-Elite (N=97)</i>
Age, median (IQR)	19.0 (3.0)	14.0 (1.0)	19.0 (2.0)	19.0 (1.0)	19.0 (6.0)
Height in cm, median (IQR)	166.5 (7.5)	166.6 (10.2)	166.5 (7.3)	169.5 (6.8)	165.8 (7.8)
Missing	12.3% (17)	18.9% (7)	9.9% (10)	7.3% (3)	14.4% (14)
Body mass in kg, median (IQR)	65.3 (12.3)	59.4 (12.0)	66.6 (9.6)	67.7 (10.4)	64.0 (11.1)
Missing	13.0% (18)	18.9% (7)	10.9% (11)	7.3% (3)	15.5% (15)
BMI, median (IQR)	23 (3.6)	21 (2.7)	24 (2.9)	24 (2.5)	23 (3.4)
Missing	18 (13.0%)	7 (18.9%)	11 (10.9%)	3 (7.3%)	15 (15.5%)
Current level of education, % (n)					
Completed undergraduate degree	8.8% (12)	0.0% (0)	12.1% (12)	2.4% (1)	11.6% (11)
Completed final school exams	66.2% (90)	8.1% (3)	87.9% (87)	87.8% (36)	56.8% (54)
Post-junior certificate	2.9% (4)	10.8% (4)	0.0% (0)	0.0% (0)	4.2% (4)
Pre-junior certificate	22.1% (30)	81.1% (30)	0.0% (0)	9.8% (4)	27.4% (26)
Other	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
Missing	1.4% (2)	0% (0)	2.0% (2)	0% (0)	2.1% (2)
Number of years playing, median (IQR)	12.0 (6.0)	8.00 (4.0)	13.0 (5.0)	12.0 (4.0)	11.0 (7.0)
Missing	1.4% (2)	0% (0)	2.0% (2)	0% (0)	2.1% (2)
Playing position, % (n)					
Forward	47.8% (65)	45.9% (17)	48.5% (48)	46.3% (19)	48.4% (46)
Midfield	15.4% (21)	13.5% (5)	16.2% (16)	31.7% (13)	8.4% (8)
Back	31.6% (43)	32.4% (12)	31.3% (31)	19.5% (8)	36.8% (35)
Goalkeeper	3.7% (5)	5.4% (2)	3.0% (3)	2.4% (1)	4.2% (4)
Multiple	1.5% (2)	2.7% (1)	1.0% (1)	0.0% (0)	2.1% (2)
Missing	1.4% (2)	0% (0)	2.0% (2)	0% (0)	2.1% (2)
Participates in another sport					
No	41.3% (57)	18.9% (7)	49.5% (50)	39.0% (16)	42.3% (41)
One other sport	44.2% (61)	62.2% (23)	37.6% (38)	46.3% (19)	43.3% (42)
Two other sports	11.6% (16)	16.2% (6)	9.9% (10)	14.6% (6)	10.3% (10)
Three other sports	2.9% (4)	2.7% (1)	3.0% (3)	0.0% (0)	4.1% (4)
History of suspected or diagnosed concussion, % (n)					
Yes	31.2% (43)	21.6% (8)	34.7% (35)	29.3% (12)	32.0% (31)
No	68.8% (95)	78.4% (29)	65.3% (66)	70.7% (29)	68.0% (66)

	<i>Total Sample (N=138)</i>	<i>Adolescent (N=37)</i>	<i>Adult (N=101)</i>	<i>Elite (N=41)</i>	<i>Non-Elite (N=97)</i>
History of diagnosed concussion, % (n)					
Yes	20.4% (28)	16.2% (6)	22.0% (22)	25.0% (10)	18.6% (18)
No	79.6% (109)	83.8% (31)	78.0% (78)	75.0% (30)	81.4% (79)
Missing	0.7% (1)	0% (0)	1.0% (1)	2.4% (1)	0% (0)
History of diagnosed headache, % (n)					
Yes	15.4% (21)	27.0% (10)	11.1% (11)	19.5% (8)	13.7% (13)
No	84.6% (115)	73.0% (27)	88.9% (88)	80.5% (33)	86.3% (82)
Missing	1.4% (2)	0% (0)	2.0% (2)	0% (0)	2.1% (2)
History of diagnosed migraine, % (n)					
Yes	9.6% (13)	18.9% (7)	6.1% (6)	9.8% (4)	9.5% (9)
No	90.4% (123)	81.1% (30)	93.9% (93)	90.2% (37)	90.5% (86)
Missing	1.4% (2)	0% (0)	2.0% (2)	0% (0)	2.1% (2)
History of diagnosed attention deficit hyperactivity disorder, % (n)					
Yes	0.7% (1)	0.0% (0)	1.0% (1)	2.5% (1)	0.0% (0)
No	99.3% (133)	100.0% (36)	99.0% (97)	97.5% (39)	100.0% (94)
Missing	2.9% (4)	2.7% (1)	3.0% (3)	2.4% (1)	3.1% (3)
History of diagnosed learning disorder, % (n)					
Yes	6.2% (8)	3.0% (1)	7.3% (7)	8.1% (3)	5.4% (5)
No	93.8% (121)	97.0% (32)	92.7% (89)	91.9% (34)	94.6% (87)
Missing	6.5% (9)	10.8% (4)	5.0% (5)	9.8% (4)	5.2% (5)
History of diagnosed mood disorder, % (n)					
Yes	2.2% (3)	2.8% (1)	2.0% (2)	0.0% (0)	3.2% (3)
No	97.8% (132)	97.2% (35)	98.0% (97)	100.0% (41)	96.8% (91)
Missing	2.2% (3)	2.7% (1)	2.0% (2)	0% (0)	3.1% (3)
History of diagnosed anxiety disorder, % (n)					
Yes	1.5% (2)	0.0% (0)	2.0% (2)	2.4% (1)	1.1% (1)
No	98.5% (132)	100.0% (36)	98.0% (96)	97.6% (40)	98.9% (92)
Missing	2.9% (4)	2.7% (1)	3.0% (3)	0% (0)	4.1% (4)
History of diagnosed sleep disorder, % (n)					
Yes	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
No	100.0% (133)	100.0% (35)	100.0% (98)	100.0% (40)	100.0% (93)
Missing	3.6% (5)	5.4% (2)	3.0% (3)	2.4% (1)	4.1% (4)

5.3.2 *Immediate Post-Concussion Assessment and Cognitive Testing*

Median ImPACT® composite scores of 87.5 (verbal memory), 73.0 (visual memory), 37.4 (visual motor speed), and 0.6 (reaction time) were recorded for all participants (see

Table 57). There were no statistically significant differences in any ImPACT® scores between elite and non-elite players, or between participants with and without a previous diagnosed concussion. Adolescent participants had significantly lower visual motor speed ($p < 0.001$, $d = 0.09$) and slower reaction time scores ($p < 0.001$, $r = 0.52$) than adult participants (see Figure 18).

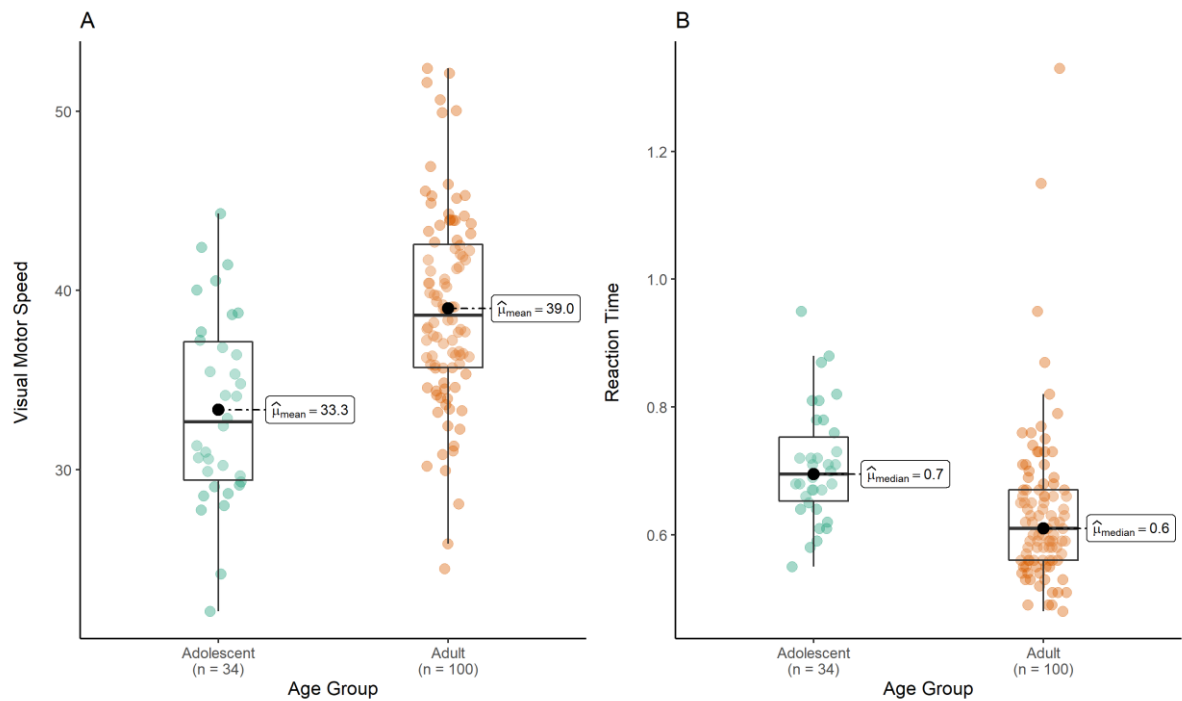


Figure 18: Adolescent and adult scores on A) visual motor speed, and B) reaction time

5.3.3 Sport Concussion Assessment Tool 5th Edition

Participants scored a median of four (out of 22) and five (out of 132) for the SCAT5 TSS and SSS, respectively (see Table 58). The majority (92.5%, n=124) of participants reported experiencing some concussion-like symptoms when asked how they “typically feel”; fatigue (66.4%, n=89), difficulty concentrating (47.8%, n=64), and feeling nervous or anxious (42.5%, n=57) were most frequently experienced (see Figure 19).

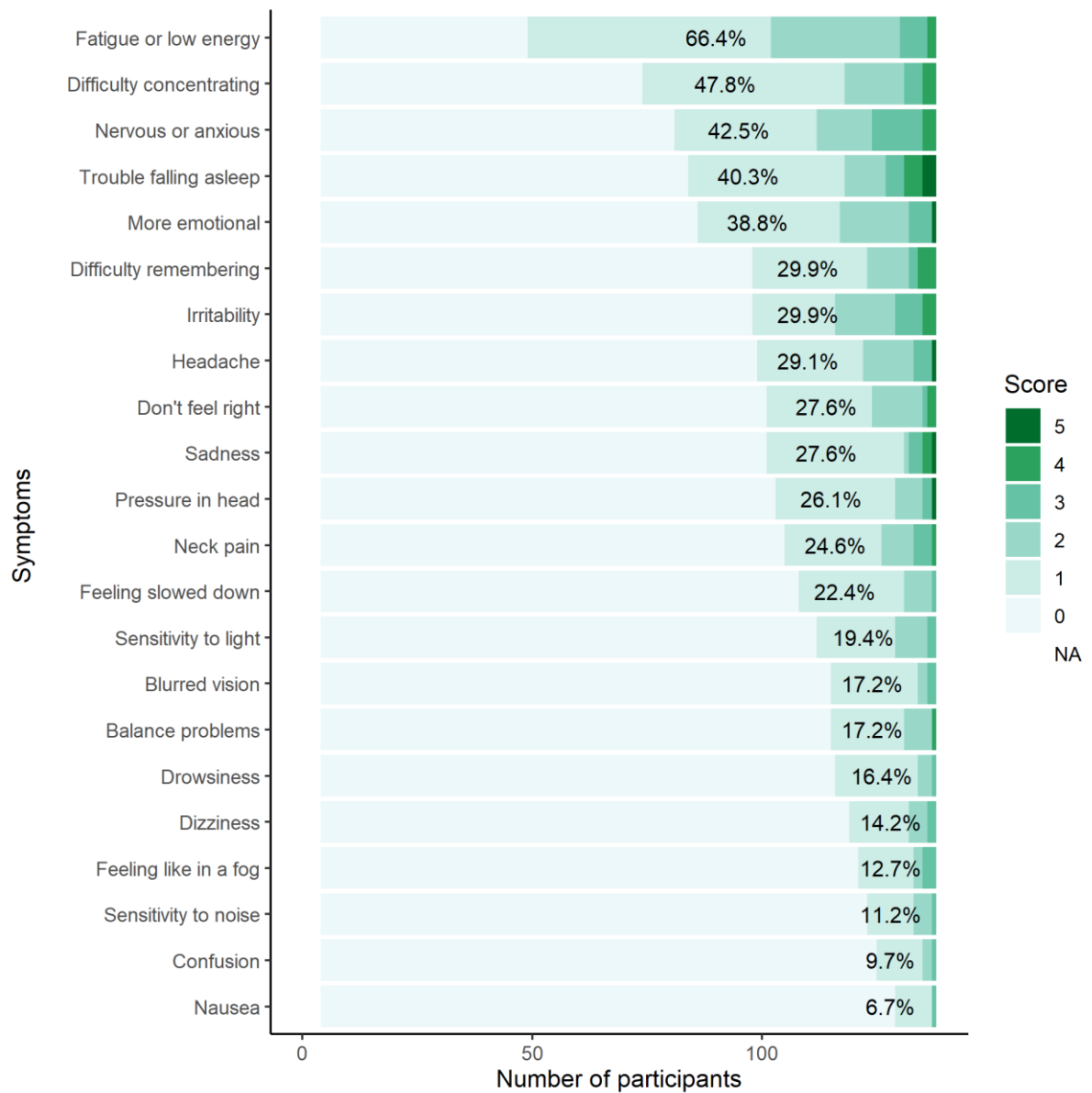


Figure 19: Percentage of participants reporting baseline symptoms

One-fifth (20.1%) of participants failed to correctly answer all five SCAT5 orientation questions; 19.4% correctly answered four questions and 0.7% correctly answered three questions. Participants recalled a median of 20 (IQR: 17-22) and 6 (IQR: 5-8) words in the immediate recall and delayed recall tests, respectively (see Table 58). A minority (7.5%) of participants were unable to correctly name all of the months backwards in the SCAT5 concentration component. Participants completed the FTN test in a mean time of 4.4 (± 0.9) seconds, and the TG test in a median time of 25.2 (IQR: 22.2-30.1) seconds. Two (1.5%) participants were unable to complete the TG test. The median mBESS score was 5 (IQR: 3-8), with participants scoring most poorly in the single-leg stance condition (median: 3.0, IQR: 2-6).

Between-group analyses did not show any significant differences in SCAT5 outcomes based on level of play or diagnosed concussion history. Adult participants scored significantly higher on the SAC “digits backwards” test ($p=0.037$, $V=0.36$) and total concentration ($p=0.015$, $V=0.38$), with moderate effect sizes (see Figure 20), and significantly lower on the mBESS tandem gait stance ($p=0.006$, $r=0.42$) and mBESS total ($p=0.009$, $r=0.42$) scores (see Figure 21).

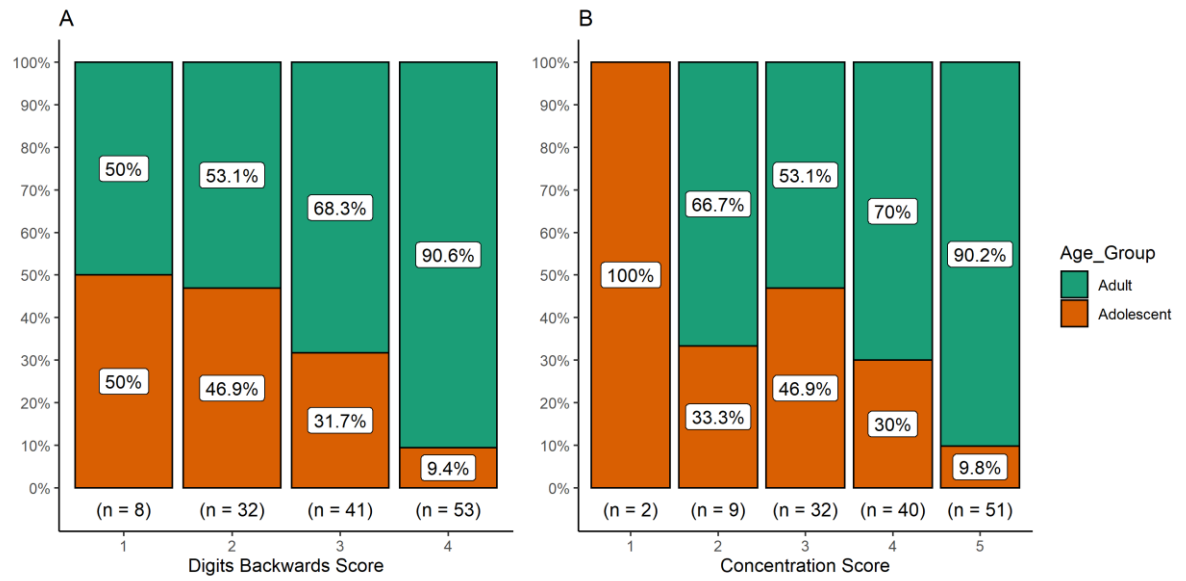


Figure 20: Differences between adults and adolescents on A) digits backwards score and B) overall concentration score

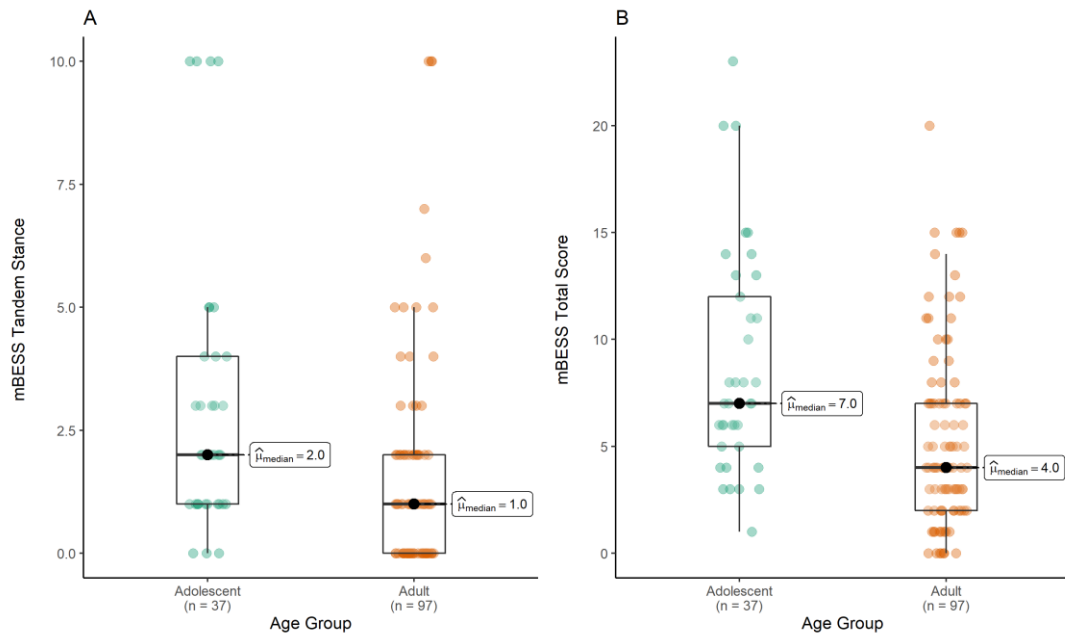


Figure 21: Differences between adolescents on adults on A) mBESS tandem stance score, and B) mBESS total score

Table 57: Descriptive statistics for Immediate Post-Concussion Assessment and Cognitive Testing

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
<i>Verbal Memory</i>	Total	-	134 (4)	86.9 (10.0)	87.5 (81.0-96.0)	56.0-100.0	-	-
	Age	Adolescent	34 (3)	83.8 (10.5)	85.0 (81.0-91.0)	56.0-99.0	1.000	-0.24 (-0.44--0.02) ¹
		Adult	100 (1)	88.0 (9.6)	88.5 (82.0-96.0)	63.0-100.0	-	-
	Level	Elite	40 (1)	87.8 (8.5)	87.5 (83.5-95.0)	63.0-100.0	1.000	0.04 (-0.17-0.25) ¹
		Non-Elite	94 (3)	86.5 (10.6)	87.5 (81.0-96.0)	56.0-100.0	-	-
	Concussion History	Yes	28 (0)	84.2 (11.2)	85.5 (79.5-93.0)	58.0-100.0	1.000	0.16 (-0.08-0.38) ¹
		No	105 (4)	87.5 (9.6)	88.0 (82.0-96.0)	56.0-100.0	-	-
<i>Visual Memory</i>	Total	-	134 (4)	70.9 (12.0)	73.0 (60.0-79.0)	44.0-97.0	-	-
	Age	Adolescent	34 (3)	67.2 (12.0)	68.0 (57.0-76.0)	44.0-91.0	1.000	-0.25 (-0.44--0.03) ¹
		Adult	100 (1)	72.2 (11.8)	74.0 (62.0-81.5)	48.0-97.0	-	-
	Level	Elite	40 (1)	71.0 (11.8)	72.5 (61.0-80.5)	51.0-97.0	1.000	-0.00 (-0.21-0.21) ¹
		Non-Elite	94 (3)	70.9 (12.2)	73.0 (60.0-79.0)	44.0-93.0	-	-
	Concussion History	Yes	28 (0)	70.3 (13.1)	73.0 (60.5-78.5)	44.0-92.0	1.000	0.01 (-0.23-0.25) ¹
		No	105 (4)	71.1 (11.8)	73.0 (60.0-80.0)	48.0-97.0	-	-
<i>Visual Motor Speed</i>	Total	-	134 (4)	37.6 (5.9)	37.4 (34.0-41.7)	22.1-52.4	-	-
	Age	Adolescent	34 (3)	33.4 (5.3)	32.7 (29.3-37.2)	22.1-44.3	<0.001	0.09 (-0.27-0.45) ²
		Adult	100 (1)	39.0 (5.4)	38.6 (35.7-42.6)	24.5-52.4	-	-
	Level	Elite	40 (1)	37.9 (5.8)	37.9 (34.7-41.2)	24.5-52.4	1.000	0.09 (-0.27-0.45) ²
		Non-Elite	94 (3)	37.4 (6.0)	37.1 (33.3-41.9)	22.1-52.1	-	-
	Concussion History	Yes	28 (0)	37.2 (6.4)	37.0 (31.9-42.2)	22.1-52.4	1.000	0.07 (-0.34-0.48) ²
		No	105 (4)	37.6 (5.8)	37.4 (34.2-41.5)	24.2-52.1	-	-
<i>Reaction Time</i>	Total	-	134 (4)	0.6 (0.1)	0.6 (0.6-0.7)	0.5-1.3	-	-
	Age	Adolescent	34 (3)	0.7 (0.1)	0.7 (0.6-0.8)	0.6-0.9	<0.001	0.52 (0.33-0.66) ¹
		Adult	100 (1)	0.6 (0.1)	0.6 (0.6-0.7)	0.5-1.3	-	-
	Level	Elite	40 (1)	0.6 (0.1)	0.6 (0.6-0.7)	0.5-1.3	1.000	-0.18 (-0.38-0.03) ¹
		Non-Elite	94 (3)	0.7 (0.1)	0.6 (0.6-0.7)	0.5-1.1	-	-
	Concussion History	Yes	28 (0)	0.6 (0.1)	0.6 (0.6-0.7)	0.5-0.8	1.000	0.19 (-0.05-0.41) ¹
		No	105 (4)	0.7 (0.1)	0.6 (0.6-0.7)	0.5-1.3	-	-
	Total	-	138 (0)	11.3 (12.2)	8.0 (3.0-17.0)	0.0-73.0	-	-

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
<i>Post-Concussion Symptom Score</i>	Age	Adolescent	37 (0)	16.5 (18.1)	9.0 (4.0-23.0)	0.0-73.0	1.000	0.19 (-0.03-0.39) ¹
		Adult	101 (0)	9.4 (8.6)	7.0 (3.0-15.0)	0.0-46.0	-	-
	Level	Elite	42 (0)	10.3 (9.2)	7.0 (3.0-17.0)	0.0-33.0	1.000	-0.01 (-0.22-0.20) ¹
		Non-Elite	97 (0)	11.7 (13.3)	8.0 (3.0-16.0)	0.0-73.0	-	-
	Concussion History	Yes	28 (0)	11.3 (10.4)	9.0 (2.5-15.0)	0.0-38.0	1.000	-0.05 (-0.28-0.19) ¹
		No	109 (0)	11.3 (12.8)	7.0 (3.0-17.0)	0.0-73.0	-	-

SD: Standard deviation; IQR: Interquartile range; 1: Rank-biserial correlation; 2: Glass' delta.

Table 58: Descriptive statistics for Sport Concussion Assessment Tool 5th Edition

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
Graded Symptom Checklist								
<i>Total Symptom Score</i>	Total	-	134 (4)	5.8 (4.7)	4.0 (2.0-9.0)	0.0-21.0	-	-
	Age	Adolescent	37 (0)	7.8 (5.9)	7.0 (3.0-12.0)	0.0-21.0	0.814	0.27 (0.05-0.46) ¹
		Adult	97 (4)	5.0 (3.9)	4.0 (2.0-8.0)	0.0-16.0	-	-
	Level	Elite	39 (2)	5.3 (4.7)	4.0 (2.0-6.5)	0.0-18.0	1.000	-0.09 (-0.29-0.13) ¹
		Non-Elite	95 (2)	6.0 (4.7)	5.0 (2.0-9.0)	0.0-21.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	6.4 (4.1)/5.7 (4.8)	6.0 (2.0-10.0)/4.0 (2.0-8.0)	1.0-15.0/0.0-21.0	1.000/-	-0.12 (-0.35-0.12) ¹ /-
<i>Symptom Severity Score</i>	Total	-	134 (4)	8.8 (9.5)	5.0 (3.0-12.0)	0.0-60.0	-	-
	Age	Adolescent	37 (0)	13.1 (13.4)	9.0 (3.0-18.0)	0.0-60.0	1.000	0.25 (0.04-0.45) ¹
		Adult	97 (4)	7.2 (6.8)	4.0 (2.0-11.0)	0.0-32.0	-	-
	Level	Elite	39 (2)	8.1 (8.6)	5.0 (2.0-12.5)	0.0-32.0	1.000	-0.07 (-0.28-0.14) ¹
		Non-Elite	95 (2)	9.1 (9.8)	6.0 (3.0-12.0)	0.0-60.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	10.0 (7.8)/8.6 (9.9)	6.0 (3.0-16.5)/5.0 (2.0-11.0)	2.0-27.0/0.0-60.0	1.000/-	-0.18 (-0.41-0.06) ¹ /-
Standardized Assessment of Concussion								
<i>Orientation</i>	Total	-	134 (4)	4.8 (0.4)	5.0 (5.0-5.0)	3.0-5.0	-	-
	Age	Adolescent	37 (0)	4.7 (0.5)	5.0 (5.0-5.0)	3.0-5.0	1.000	0.15 (0.00-0.30) ²
		Adult	97 (4)	4.8 (0.4)	5.0 (5.0-5.0)	4.0-5.0	-	-
	Level	Elite	35 (2)	4.7 (0.5)	5.0 (4.5-5.0)	3.0-5.0	1.000	0.15 (0.00- 0.30) ²
		Non-Elite	95 (2)	4.8 (0.4)	5.0 (5.0-5.0)	4.0-5.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	4.7 (0.4)/4.8 (0.4)	5.0 (4.5-5.0)/5.0 (5.0-5.0)	4.0-5.0/3.0-5.0	1.000/-	0.09 (0.00-0.23) ² /-
<i>Immediate Memory</i>	Total	-	134 (4)	19.8 (3.2)	20.0 (17.0-22.0)	11.0-27.0	-	-
	Age	Adolescent	37 (0)	18.8 (2.9)	19.0 (17.0-21.0)	12.0-25.0	0.826	-0.20 (-0.55-0.14) ³
		Adult	97 (4)	20.2 (3.3)	21.0 (18.0-23.0)	11.0-27.0	-	-
	Level	Elite	39 (2)	19.4 (2.9)	20.0 (17.0-22.0)	12.0-24.0	1.000	-0.11 (-0.32-0.11) ¹
		Non-Elite	95 (2)	20.0 (3.4)	20.0 (17.5-23.0)	11.0-27.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	19.9 (3.2)/19.8 (3.3)	20.0 (19.0-22.0)/20.0 (17.0-22.0)	11.0-25.0/12.0-27.0	1.000/-	-0.05 (-0.29-0.19) ¹ /-
<i>Concentration</i>	Total	-	134 (4)	4.0 (1.0)	4.0 (3.0-5.0)	1.0-5.0	-	-
	Age	Adolescent	37 (0)	3.4 (1.0)	3.0 (3.0-4.0)	1.0-5.0	0.016	0.38 (0.17-0.53) ²
		Adult	97 (4)	4.2 (0.9)	4.0 (4.0-5.0)	2.0-5.0	-	-
	Level	Elite	39 (2)	3.9 (0.8)	4.0 (3.0-4.5)	2.0-5.0	1.000	0.25 (0.00-0.38) ²
		Non-Elite	95 (2)	4.0 (1.1)	4.0 (3.0-5.0)	1.0-5.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	3.9 (1.0)/4.0 (1.0)	4.0 (3.0-5.0)/4.0 (3.0-5.0)	2.0-5.0/1.0-5.0	1.000/-	0.12 (0.00-0.22) ² /-
<i>Digits Backwards</i>	Total	-	134 (4)	3.0 (0.9)	3.0 (2.0-4.0)	1.0-4.0	-	-
	Age	Adolescent	37 (0)	2.5 (0.9)	2.0 (2.0-3.0)	1.0-4.0	0.038	0.36 (0.16-0.51) ²
		Adult	97 (4)	3.2 (0.9)	3.0 (3.0-4.0)	1.0-4.0	-	-
	Level	Elite	39 (2)	3.0 (0.8)	3.0 (2.5-3.5)	1.0-4.0	1.000	0.27 (0.03-0.42) ²
		Non-Elite	95 (2)	3.1 (1.0)	3.0 (2.0-4.0)	1.0-4.0	-	-
	Concussion History	Yes/No	27 (1)/106 (3)	3.0 (0.9)/3.1 (0.9)	3.0 (2.0-4.0)/3.0 (2.0-4.0)	1.0-4.0/1.0-4.0	1.000/-	0.10 (0.00-0.21) ² /-
<i>Months Backwards</i>	Total	-	134 (4)	0.9 (0.3)	1.0 (1.0-1.0)	0.0-1.0	-	-

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
Delayed Recall	Age	Adolescent	37 (0)	0.9 (0.3)	1.0 (1.0-1.0)	0.0-1.0	1.000	0.08 (0.00-0.24) ²
		Adult	97 (4)	0.9 (0.2)	1.0 (1.0-1.0)	0.0-1.0	-	-
	Level	Elite	39 (2)	0.9 (0.2)	1.0 (1.0-1.0)	0.0-1.0	1.000	0.06 (0.00-0.23) ²
		Non-Elite	95 (2)	0.9 (0.3)	1.0 (1.0-1.0)	0.0-1.0	-	-
	Concussion	Yes	27 (1)	0.9 (0.3)	1.0 (1.0-1.0)	0.0-1.0	1.000	0.00 (0.00-0.00) ²
	History	No	106 (3)	0.9 (0.3)	1.0 (1.0-1.0)	0.0-1.0	-	-
	Total	-	133 (5)	6.1 (1.9)	6.0 (5.0-8.0)	0.0-10.0	-	-
	Age	Adolescent	37 (0)	6.1 (1.6)	6.0 (5.0-7.0)	4.0-10.0	1.000	-0.01 (-0.23-0.20) ¹
		Adult	96 (5)	6.0 (2.0)	6.0 (5.0-8.0)	0.0-10.0	-	-
	Level	Elite	39 (2)	6.0 (2.0)	6.0 (5.0-7.0)	0.0-9.0	1.000	-0.01 (-0.23-0.20) ¹
Neurological Screen		Non-Elite	94 (3)	6.1 (1.8)	6.0 (5.0-8.0)	1.0-10.0	-	-
	Concussion	Yes	27 (1)	6.4 (1.9)	7.0 (5.0-7.5)	1.0-10.0	1.000	-0.15 (-0.38-0.09) ¹
	History	No	105 (4)	6.0 (1.9)	6.0 (5.0-8.0)	0.0-10.0	-	-
	Finger-to-Nose Test, time							
	-	Total	134 (4)	4.4 (0.9)	4.4 (3.8-5.0)	2.6-7.1	-	-
	Age	Adolescent	37 (0)	4.5 (0.8)	4.5 (3.9-5.0)	2.6-6.1	1.000	0.15 (-0.27-0.58) ³
		Adult	97 (4)	4.4 (1.0)	4.4 (3.6-5.1)	2.6-7.1	-	-
	Level	Elite	39 (2)	4.5 (1.1)	4.5 (3.6-5.1)	2.8-7.0	1.000	0.15 (-0.27-0.58) ³
		Non-Elite	95 (2)	4.4 (0.9)	4.3 (3.8-5.0)	2.6-7.1	-	-
	Concussion	Yes	27 (1)	4.5 (0.8)	4.6 (4.0-5.0)	3.2-5.9	1.000	-0.09 (-0.54-0.37) ³
Tandem Gait, time	History	No	106 (3)	4.4 (1.0)	4.4 (3.8-5.1)	2.6-7.1	-	-
	-	Total	132 (6)	26.4 (5.2)	25.2 (22.2-30.1)	16.2-42.0	-	-
	Age	Adolescent	36 (1)	28.4 (5.8)	28.3 (23.6-32.8)	19.7-40.0	0.783	0.27 (0.06-0.46) ¹
		Adult	96 (5)	25.6 (4.8)	25.0 (22.0-28.7)	16.2-42.0	-	-
	Level	Elite	39 (2)	25.5 (4.7)	25.0 (22.1-28.9)	16.2-34.9	1.000	-0.11 (-0.32-0.10) ¹
		Non-Elite	93 (4)	26.8 (5.4)	25.7 (22.4-30.6)	18.9-42.0	-	-
	Concussion	Yes	27 (1)	27.2 (6.8)	26.1 (21.4-32.4)	19.0-42.0	1.000	-0.03 (-0.27-0.21) ¹
	History	No	104 (5)	26.2 (4.7)	25.2 (22.5-29.6)	16.2-37.9	-	-
	Modified Balance Error Scoring System Total							
	-	Total	134 (4)	6.2 (4.7)	5.0 (3.0-8.0)	0.0-23.0	-	-
Double-Leg Stance	Age	Adolescent	37 (0)	8.7 (5.3)	7.0 (5.0-12.0)	1.0-23.0	0.009	0.42 (0.23-0.58) ¹
		Adult	97 (4)	5.3 (4.2)	4.0 (2.0-7.0)	0.0-20.0	-	-
	Level	Elite	39 (2)	5.1 (4.0)	4.0 (2.5-7.0)	0.0-20.0	1.000	-0.20 (-0.39-0.01) ¹
		Non-Elite	95 (2)	6.7 (4.9)	6.0 (3.0-8.5)	0.0-23.0	-	-
	Concussion	Yes	27 (1)	6.5 (4.6)	6.0 (3.0-8.5)	1.0-20.0	1.000	-0.05 (-0.29-0.19) ¹
	History	No	106 (3)	6.2 (4.8)	5.0 (3.0-8.0)	0.0-23.0	-	-
	-	Total	134 (4)	0.0 (0.3)	0.0 (0.0-0.0)	0.0-3.0	-	-
	Age	Adolescent	37 (0)	0.1 (0.5)	0.0 (0.0-0.0)	0.0-3.0	1.000	0.20 (0.00-0.35) ²
		Adult	97 (4)	0.0 (0.0)	0.0 (0.0-0.0)	0.0-0.0	-	-
	Level	Elite	39 (2)	0.0 (0.0)	0.0 (0.0-0.0)	0.0-0.0	1.000	0.08 (0.00-0.22) ²
Single-Leg Stance		Non-Elite	95 (2)	0.0 (0.3)	0.0 (0.0-0.0)	0.0-3.0	-	-
	Concussion	Yes	27 (1)	0.0 (0.2)	0.0 (0.0-0.0)	0.0-1.0	1.000	0.18 (0.00-0.33) ²
	History	No	106 (3)	0.0 (0.3)	0.0 (0.0-0.0)	0.0-3.0	-	-
	-	Total	134 (4)	4.3 (3.2)	3.0 (2.0-6.0)	0.0-10.0	-	-
	Age	Adolescent	37 (0)	5.6 (3.2)	5.0 (3.0-10.0)	1.0-10.0	0.131	0.34 (0.13-0.51) ¹
		Adult	97 (4)	3.8 (3.1)	3.0 (2.0-6.0)	0.0-10.0	-	-
	Level	Elite	39 (2)	3.7 (2.9)	3.0 (2.0-5.0)	0.0-10.0	1.000	-0.15 (-0.35-0.07) ¹
		Non-Elite	95 (2)	4.6 (3.3)	4.0 (2.0-6.0)	0.0-10.0	-	-
	Yes	27 (1)	4.3 (3.0)	4.0 (2.0-6.0)	0.0-10.0	1.000	-0.02 (-0.26-0.22) ¹	

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
<i>Tandem Gait Stance</i>	Concussion History	No	106 (3)	4.3 (3.3)	3.0 (2.0-6.0)	0.0-10.0	-	-
	-	Total	134 (4)	1.9 (2.4)	1.0 (0.0-2.0)	0.0-10.0	-	-
	Age	Adolescent	37 (0)	3.0 (2.8)	2.0 (1.0-4.0)	0.0-10.0	0.006	0.42 (0.23-0.59) ¹
		Adult	97 (4)	1.5 (2.2)	1.0 (0.0-2.0)	0.0-10.0	-	-
	Level	Elite	39 (2)	1.4 (2.3)	1.0 (0.0-1.5)	0.0-10.0	1.000	-0.22 (-0.42--0.01) ¹
		Non-Elite	95 (2)	2.1 (2.5)	1.0 (0.0-2.5)	0.0-10.0	-	-
	Concussion History	Yes	27 (1)	2.1 (3.0)	1.0 (0.0-3.0)	0.0-10.0	1.000	0.04 (-0.21-0.27) ¹
		No	106 (3)	1.8 (2.3)	1.0 (0.0-2.0)	0.0-10.0	-	-

SD: Standard deviation; IQR: Interquartile range; 1: Rank-biserial correlation; 2: Cramer's V; 3: Glass' delta.

5.3.4 Vestibular-Ocular Motor Screening

The median change score for all VOMS items was 0 (see

Table 60). Using clinical cut-off thresholds of symptom provocation ≥ 2 and NPC distance $\geq 5\text{cm}$, 30.6% (n=41) of participants attained a positive score on at least one VOMS item. Change scores of ≥ 2 were most frequently reported for vertical saccades (17.2%, n=23), horizontal vestibular-ocular reflex (13.4%, n=18), vertical vestibular-ocular reflex (11.9%, n=16), and visual motion sensitivity (11.9%, n=16). Using the alternative cut-off points, either 46.3% (n=62) or 53.7% (n=72) of participants scored positively on at least one VOMS item. The proportion of participants who were classified as positive on each item using the three classification methods are presented in Table 59.

Table 59: Percentage of participants meeting the clinical cut-off thresholds for vestibular-ocular motor screening (VOMS) using the original and alternative cut-off points

Test Item	Mucha, 2014 (121)		Elbin, 2020 (224)		Kontos, 2021 (150)	
	Positive Score	% (n) of Participants	Positive Score	% (n) of Participants	Positive Score	% (n) of Participants
Smooth Pursuits	≥ 2	2.2 (3)	≥ 1	19.4 (26) ¹	≥ 1	19.4 (26)
Horizontal Saccades	≥ 2	9.7 (13)	≥ 1	31.3 (42) ¹	≥ 1	31.3 (42)
Vertical Saccades	≥ 2	17.2 (23)	≥ 1	37.3 (50) ¹	≥ 1	37.3 (50)
Near Point of Convergence (NPC)	≥ 2	9.0 (12)	≥ 1	23.1 (31) ¹	≥ 1	23.1 (31)
Horizontal Vestibular-Ocular Reflex (HVOR)	≥ 2	13.4 (18)	≥ 1	28.4 (38)	≥ 2	13.4 (18)
Vertical Vestibular-Ocular Reflex (VVOR)	≥ 2	11.9 (16)	≥ 1	29.1 (39)	≥ 1	29.1 (39)
Visual Motion Sensitivity (VMS)	≥ 2	11.9 (16)	≥ 1	27.6 (37)	≥ 1	27.6 (37)
Total Symptom Score	-	-	≥ 3	36.6 (49)	≥ 8	12.7 (17)
NPC Distance	$\geq 5\text{cm}$	2.2 (3)	$\geq 3\text{cm}$	8.2 (11)	$\geq 4.5\text{cm}$	3.7 (5)
Any	-	30.6 (41)	-	46.3 (62) ²	-	53.7 (72) ³

1: Assessed in validation study but did not distinguish between concussed and control participants; 2: Calculated using HVOR, VVOR, VMS, NPC distance, and total symptom score only (224); 3: Calculated from all items excluding NPC distance (150).

The proportion of participants reporting change scores of 0, 1, 2, 3, 4, 5, and 6 (note: no participant had a change score greater than 6 on any item) for each individual VOMS item are shown in Figure 22. Individual VOMS item scores, total symptom score, or the proportion of participants with a positive VOMS score as determined using the original cut-off points, did not differ between adolescents and adults, elite and non-elite players, or players with and without a previous diagnosed concussion ($p>0.05$).

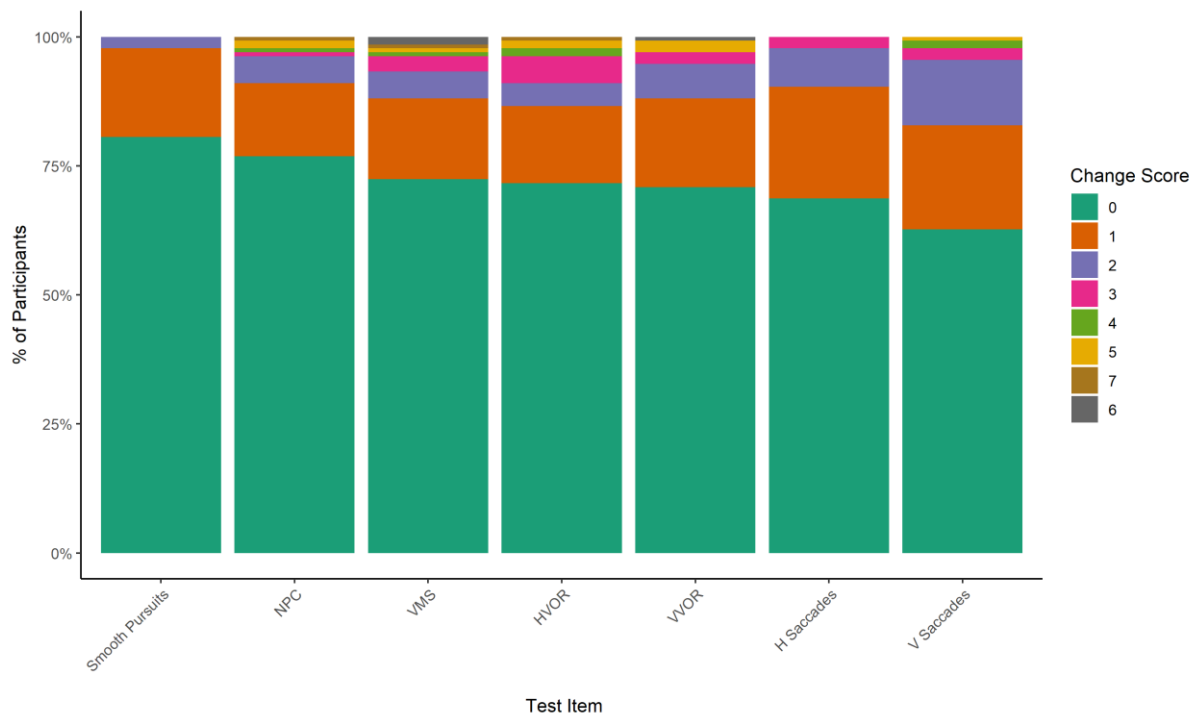


Figure 22: Proportion of participants reporting change scores of 0, 1, 2, 3, 4, 5, and 6 on individual vestibular-ocular motor screening (VOMS) items.

NPC=near point of convergence; VMS=visual motion sensitivity; HVOR=horizontal vestibular-ocular reflex; VVOR=vertical vestibular-ocular reflex; H Saccades=horizontal saccades; V Saccades=vertical saccades.

5.3.5 Neck Dynamometry

Participants recorded mean neck dynamometry values of 1.2 (± 0.3) N/kg body mass for flexion, 1.3 (± 0.3) N/kg for extension, 1.0 (± 0.2) N/kg for dominant-side lateral flexion, 1.0 (± 0.2) N/kg for non-dominant side lateral flexion, and 0.7 (± 0.2) N/kg for non-dominant side rotation. The median value for dominant side rotation was 0.7 (IQR: 0.6-0.8) (see Table 61). Normalised neck strength did not differ between participants based on level of play, age, or history of diagnosed concussion ($p > 0.05$).

Table 60: Descriptive statistics for vestibular-ocular motor screening

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect size	N (%) Meeting Clinical Cut-off (≥2)
<i>Total Score</i>	Total	-	134 (4)	3.4 (5.4)	1.0 (0.0-4.0)	0.0-28.0	-	-	41 (30.6)
	Age	Adolescent	37 (0)	3.7 (6.9)	0.0 (0.0-4.0)	0.0-28.0	1.000	-0.13 (-0.34-0.09) ¹	10 (27.0)
		Adult	97 (4)	3.2 (4.8)	1.0 (0.0-4.0)	0.0-25.0	-	-	31 (32.)
	Level	Elite	39 (2)	3.5 (6.3)	0.0 (0.0-5.0)	0.0-25.0	1.000	-0.05 (-0.26-0.17) ¹	11 (28.2)
		Non-Elite	95 (2)	3.3 (5.0)	1.0 (0.0-4.0)	0.0-28.0	-	-	30 (31.6)
	Concussion History	Yes	27 (1)	5.4 (6.5)	3.0 (0.0-7.5)	0.0-23.0	0.840	0.29 (0.06-0.50) ¹	14 (51.9)
		No	106 (3)	2.8 (5.0)	1.0 (0.0-4.0)	0.0-28.0	-	-	26 (24.5)
<i>Smooth Pursuits</i>	Total	-	134 (4)	0.2 (0.5)	0.0 (0.0-0.0)	0.0-2.0	-	-	3 (2.2)
	Age	Adolescent	37 (0)	0.3 (0.5)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.02 (0.00-0.17) ²	1 (2.7)
		Adult	97 (4)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-2.0	-	-	2 (2.1)
	Level	Elite	39 (2)	0.2 (0.5)	0.0 (0.0-0.0)	0.0-2.0	1.000	0.01 (0.00-0.16) ²	1 (2.6)
		Non-Elite	95 (2)	0.2 (0.5)	0.0 (0.0-0.0)	0.0-2.0	-	-	2 (2.1)
	Concussion History	Yes	27 (1)	0.3 (0.5)	0.0 (0.0-0.5)	0.0-2.0	1.000	0.05 (0.00-0.22) ²	1 (3.7)
		No	106 (3)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-2.0	-	-	2 (1.9)
<i>Horizontal Saccades</i>	Total	-	134 (4)	0.4 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	13 (9.7)
	Age	Adolescent	37 (0)	0.3 (0.7)	0.0 (0.0-0.0)	0.0-3.0	1.000	0.03 (0.00-0.20) ²	3 (8.1)
		Adult	97 (4)	0.5 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	10 (10.3)
	Level	Elite	39 (2)	0.4 (0.8)	0.0 (0.0-1.0)	0.0-3.0	1.000	0.01 (0.00-0.15) ²	4 (10.3)
		Non-Elite	95 (2)	0.4 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	9 (9.5)
	Concussion History	Yes	27 (1)	0.7 (0.8)	0.0 (0.0-1.0)	0.0-3.0	1.000	0.09 (0.00-0.26) ²	4 (14.8)
		No	106 (3)	0.4 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	9 (8.5)
<i>Vertical Saccades</i>	Total	-	134 (4)	0.6 (1.0)	0.0 (0.0-1.0)	0.0-5.0	-	-	23 (17.2)
	Age	Adolescent	37 (0)	0.5 (0.8)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.02 (0.00-0.16) ²	6 (6.2)
		Adult	97 (4)	0.7 (1.0)	0.0 (0.0-1.0)	0.0-5.0	-	-	17 (17.5)
	Level	Elite	39 (2)	0.5 (1.0)	0.0 (0.0-1.0)	0.0-4.0	1.000	0.07 (0.00-0.24) ²	5 (12.8)
		Non-Elite	95 (2)	0.7 (1.0)	0.0 (0.0-1.0)	0.0-5.0	-	-	18 (18.9)
	Concussion History	Yes	27 (1)	1.0 (1.3)	1.0 (0.0-1.0)	0.0-5.0	1.000	0.07 (0.00-0.23) ²	6 (22.2)
		No	106 (3)	0.5 (0.9)	0.0 (0.0-1.0)	0.0-4.0	-	-	17 (16.0)
<i>Near Point of Convergence</i>	Total	-	134 (4)	0.4 (1.0)	0.0 (0.0-0.0)	0.0-7.0	-	-	12 (9.0)
	Age	Adolescent	37 (0)	0.7 (1.6)	0.0 (0.0-1.0)	0.0-7.0	1.000	0.04 (0.00-0.21) ²	4 (10.8)
		Adult	97 (4)	0.3 (0.8)	0.0 (0.0-0.0)	0.0-5.0	-	-	8 (8.2)
	Level	Elite	39 (2)	0.6 (1.5)	0.0 (0.0-0.0)	0.0-7.0	1.000	0.09 (0.00-0.26) ²	5 (12.8)
		Non-Elite	95 (2)	0.3 (0.8)	0.0 (0.0-0.0)	0.0-5.0	-	-	7 (7.4)
	Concussion History	Yes	27 (1)	0.7 (1.6)	0.0 (0.0-1.0)	0.0-7.0	1.000	0.04 (0.00-0.20) ²	3 (11.1)
		No	106 (3)	0.3 (0.8)	0.0 (0.0-0.0)	0.0-5.0	-	-	9 (8.5)
<i>Horizontal Vestibulo-Ocular Reflex</i>	Total	-	134 (4)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-7.0	-	-	18 (13.4)
	Age	Adolescent	37 (0)	0.7 (1.6)	0.0 (0.0-1.0)	0.0-7.0	1.000	0.00 (0.00-0.00) ²	5 (13.5)
		Adult	97 (4)	0.5 (1.0)	0.0 (0.0-1.0)	0.0-5.0	-	-	13 (13.4)
	Level	Elite	39 (2)	0.6 (1.2)	0.0 (0.0-0.5)	0.0-5.0	1.000	0.04 (0.00-0.20) ²	6 (15.4)
		Non-Elite	95 (2)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-7.0	-	-	12 (12.6)

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect size	N (%) Meeting Clinical Cut-off (≥2)
<i>Vertical Vestibulo-Ocular Reflex</i>	Concussion	Yes	27 (1)	1.1 (1.4)	0.0 (0.0-2.0)	0.0-5.0	0.435	0.25 (0.08-0.42) ²	8 (29.6)
	History	No	106 (3)	0.4 (1.1)	0.0 (0.0-0.0)	0.0-7.0	-	-	9 (8.6)
	Total	-	134 (4)	0.5 (1.1)	0.0 (0.0-1.0)	0.0-6.0	-	-	16 (11.9)
	Age	Adolescent	37 (0)	0.7 (1.5)	0.0 (0.0-1.0)	0.0-6.0	1.000	0.03 (0.00-0.19) ²	5 (13.5)
		Adult	97 (4)	0.5 (0.9)	0.0 (0.0-1.0)	0.0-5.0	-	-	11 (11.3)
	Level	Elite	39 (2)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-5.0	1.000	0.02 (0.00-0.17) ²	5 (12.8)
<i>Visual Motion Sensitivity</i>		Non-Elite	95 (2)	0.5 (1.0)	0.0 (0.0-1.0)	0.0-6.0	-	-	11 (11.6)
	Concussion	Yes	27 (1)	0.9 (1.2)	0.0 (0.0-2.0)	0.0-5.0	0.272	0.27 (0.10-0.44) ²	8 (29.6)
	History	No	106 (3)	0.4 (1.0)	0.0 (0.0-0.0)	0.0-6.0	-	-	8 (7.5)
	Total	-	134 (4)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-7.0	-	-	16 (11.9)
	Age	Adolescent	37 (0)	0.5 (1.3)	0.0 (0.0-0.0)	0.0-6.0	1.000	0.03 (0.00-0.19) ²	5 (13.5)
		Adult	97 (4)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-7.0	-	-	11 (11.3)
<i>Near Point of Convergence (cm)</i>	Level	Elite	39 (2)	0.6 (1.3)	0.0 (0.0-1.0)	0.0-7.0	1.000	0.03 (0.00-0.20) ²	4 (10.3)
		Non-Elite	95 (2)	0.6 (1.2)	0.0 (0.0-1.0)	0.0-6.0	-	-	12 (12.6)
	Concussion	Yes	27 (1)	0.8 (1.2)	0.0 (0.0-1.0)	0.0-5.0	1.000	0.16 (0.00-0.33) ²	6 (22.2)
	History	No	106 (3)	0.5 (1.2)	0.0 (0.0-0.0)	0.0-7.0	-	-	10 (9.4)
	Total	-	134 (4)	0.6 (1.6)	0.0 (0.0-0.0)	0.0-10.2	-	-	3 (2.2)
	Age	Adolescent	37 (0)	0.8 (1.9)	0.0 (0.0-0.9)	0.0-10.2	1.000	0.02 (0.00-0.17) ²	1 (2.7)
		Adult	97 (4)	0.6 (1.5)	0.0 (0.0-0.0)	0.0-8.1	-	-	2 (2.1)
	Level	Elite	39 (2)	0.7 (1.9)	0.0 (0.0-0.0)	0.0-10.2	1.000	0.01 (0.00-0.16) ²	1 (2.6)
		Non-Elite	95 (2)	0.6 (1.5)	0.0 (0.0-0.0)	0.0-8.1	-	-	2 (2.1)
	Concussion	Yes	27 (1)	1.2 (2.8)	0.0 (0.0-0.3)	0.0-10.2	0.450	0.30 (0.13-0.47) ²	3 (11.1)
	History	No	106 (3)	0.5 (1.1)	0.0 (0.0-0.0)	0.0-4.6	-	-	0 (0.0)

SD: Standard deviation; IQR: Interquartile range; 1: Rank-biserial correlation; 2: Cramer's V.

Table 61: Descriptive statistics for neck strength normalised to body mass

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect size
<i>Neck Flexion (N/kg)</i>	Total	-	118 (20)	1.2 (0.3)	1.1 (1.0-1.4)	0.4-1.9	-	-
	Age	Adolescent	30 (7)	1.2 (0.4)	1.1 (0.9-1.5)	0.4-1.9	1.000	0.09 (-0.44-0.62) ¹
		Adult	88 (13)	1.1 (0.3)	1.1 (1.0-1.4)	0.5-1.8	-	-
	Level	Elite	37 (4)	1.2 (0.3)	1.3 (1.0-1.5)	0.7-1.8	1.000	0.37 (0.01-0.73) ¹
		Non-Elite	81 (16)	1.1 (0.3)	1.1 (0.9-1.3)	0.4-1.9	-	-
	Concussion History	Yes	23 (5)	1.2 (0.3)	1.1 (1.0-1.4)	0.5-1.8	1.000	0.11 (-0.34-0.56) ¹
		No	94 (15)	1.1 (0.3)	1.1 (1.0-1.4)	0.4-1.9	-	-
<i>Neck Extension (N/kg)</i>	Total	-	118 (20)	1.3 (0.3)	1.3 (1.0-1.5)	0.3-2.2	-	-
	Age	Adolescent	30 (7)	1.3 (0.4)	1.3 (1.0-1.6)	0.3-2.2	1.000	0.13 (-0.35-0.61) ¹
		Adult	88 (13)	1.3 (0.3)	1.2 (1.0-1.5)	0.6-2.1	-	-
	Level	Elite	37 (4)	1.3 (0.3)	1.3 (1.1-1.5)	0.6-2.2	1.000	0.16 (-0.18-0.51) ¹
		Non-Elite	81 (16)	1.3 (0.4)	1.2 (1.0-1.5)	0.3-2.1	-	-
	Concussion History	Yes	23 (5)	1.3 (0.3)	1.4 (1.1-1.5)	0.6-1.7	1.000	0.03 (-0.38-0.43) ¹
		No	94 (15)	1.3 (0.4)	1.2 (1.0-1.5)	0.3-2.2	-	-
<i>Dominant Side Lateral Flexion (N/kg)</i>	Total	-	118 (20)	1.0 (0.2)	1.0 (0.9-1.2)	0.4-1.5	-	-
	Age	Adolescent	30 (7)	1.0 (0.2)	1.1 (0.9-1.2)	0.4-1.5	1.000	0.03 (-0.20-0.27) ²
		Adult	88 (13)	1.0 (0.2)	1.0 (0.9-1.2)	0.5-1.5	-	-
	Level	Elite	37 (4)	1.0 (0.2)	1.0 (0.8-1.2)	0.5-1.5	1.000	-0.05 (-0.44-0.35) ¹
		Non-Elite	81 (16)	1.0 (0.2)	1.1 (0.9-1.2)	0.4-1.5	-	-
	Concussion History	Yes	23 (5)	1.0 (0.2)	1.1 (0.9-1.2)	0.6-1.4	1.000	-0.00 (-0.46-0.45) ¹
		No	94 (15)	1.0 (0.2)	1.0 (0.9-1.2)	0.4-1.5	-	-
<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	Total	-	118 (20)	1.0 (0.2)	1.0 (0.8-1.2)	0.3-1.5	-	-
	Age	Adolescent	30 (7)	0.9 (0.2)	0.9 (0.8-1.1)	0.3-1.4	1.000	-0.29 (-0.71-0.14) ¹
		Adult	88 (13)	1.0 (0.2)	1.0 (0.8-1.2)	0.4-1.5	-	-
	Level	Elite	37 (4)	1.0 (0.2)	1.1 (0.9-1.2)	0.6-1.4	1.000	0.23 (-0.12-0.58) ¹
		Non-Elite	81 (16)	1.0 (0.3)	1.0 (0.8-1.1)	0.3-1.5	-	-
	Concussion History	Yes	23 (5)	1.0 (0.2)	1.1 (0.8-1.2)	0.6-1.5	1.000	0.12 (-0.32-0.55) ¹
		No	94 (15)	1.0 (0.2)	1.0 (0.8-1.2)	0.3-1.5	-	-
	Total	-	118 (20)	0.7 (0.2)	0.7 (0.6-0.8)	0.3-1.2	-	-

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect size
Dominant Side Rotation (N/kg)	Age	Adolescent	30 (7)	0.7 (0.2)	0.7 (0.5-0.8)	0.3-1.2	1.000	-0.04 (-0.27-0.20) ²
		Adult	88 (13)	0.7 (0.2)	0.7 (0.6-0.8)	0.3-1.2	-	-
	Level	Elite	37 (4)	0.7 (0.2)	0.7 (0.6-0.8)	0.4-1.2	1.000	0.23 (0.01-0.43) ²
		Non-Elite	81 (16)	0.7 (0.2)	0.6 (0.6-0.7)	0.3-1.2	-	-
	Concussion History	Yes	23 (5)	0.7 (0.1)	0.7 (0.7-0.8)	0.4-1.1	1.000	0.28 (0.02-0.50) ²
		No	94 (15)	0.7 (0.2)	0.6 (0.5-0.8)	0.3-1.2	-	-
Non-Dominant Side Rotation (N/kg)	Total	-	118 (20)	0.7 (0.2)	0.6 (0.5-0.8)	0.2-1.3	-	-
	Age	Adolescent	30 (7)	0.7 (0.2)	0.6 (0.5-0.8)	0.2-1.3	1.000	0.09 (-0.44-0.62) ¹
		Adult	88 (13)	0.6 (0.2)	0.6 (0.6-0.8)	0.3-1.1	-	-
	Level	Elite	37 (4)	0.7 (0.2)	0.7 (0.6-0.8)	0.4-1.1	1.000	0.28 (-0.09-0.65) ¹
		Non-Elite	81 (16)	0.6 (0.2)	0.6 (0.5-0.7)	0.2-1.3	-	-
	Concussion History	Yes	23 (5)	0.7 (0.2)	0.7 (0.6-0.8)	0.3-1.0	1.000	0.23 (-0.18-0.65) ¹
		No	94 (15)	0.6 (0.2)	0.6 (0.5-0.8)	0.2-1.3	-	-

SD: Standard deviation; IQR: Interquartile range; 1: Glass' delta; 2: Rank-biserial correlation.

5.3.6 Clinical Profiles Screen

Participants reported a median of 6.0 (IQR: 3.0-10.0) on the CP Screen total score. Highest scores were reported for the cognitive profile (median: 0.3, IQR: 0.0-0.7), followed by the ocular (median: 0.2, IQR: 0.0-0.6) and anxiety/mood (median: 0.2, IQR: 0.0-0.6) profiles and sleep modifier (median: 0.2, IQR: 0.0-0.5). The median migraine profile, vestibular profile, and neck modifier score was 0 (see

Table 62).

CP Screen total or individual profile scores did not differ between elite and non-elite players, or between players with a previous diagnosed concussion and those without a previous diagnosed concussion ($p>0.05$). Adolescents scored significantly higher on the vestibular profile than adults ($p=0.006$; $r=0.38$) (see Figure 23). No other significant differences were observed between age groups ($p>0.05$).

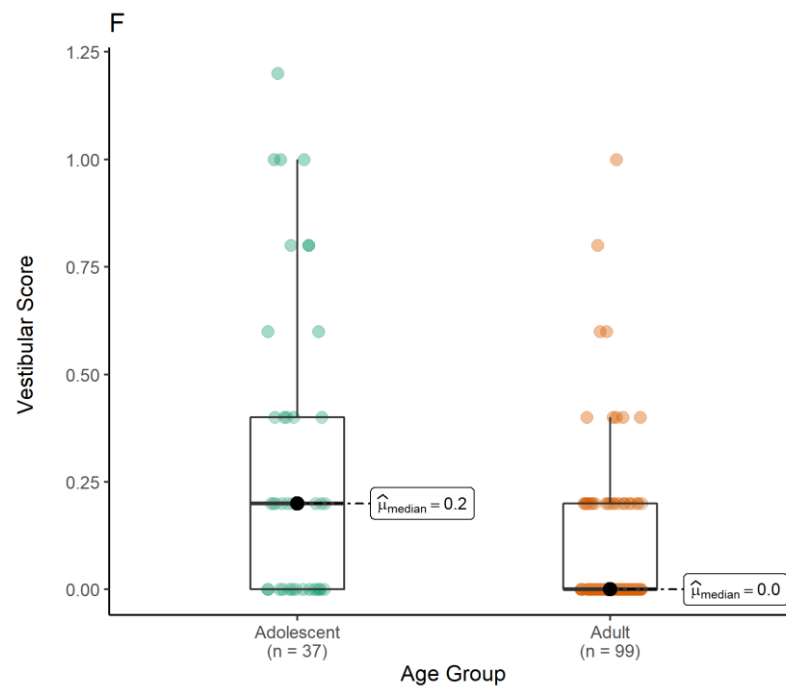


Figure 23: Differences between adolescents and adults on Clinical Profile Screen vestibular score

5.3.7 Health Questionnaires

The median scores for the PHQ-9 and GAD-7 were 3.0 (IQR: 1.0-5.0) and 1.5 (IQR: 0.0-4.0), respectively. Most participants were graded as “none” (72.1%, n=98) or “mild” (21.3%, n=29) on the PHQ-9, with 5.1% (n=7) graded as moderate and 1.5% (n=1) graded as moderately severe. No participants met the criteria for the “severe” grade. Just over three-quarters (75.7%, n=103) of participants were classified “none” on the GAD-7, followed by 14.0% (n=19) as “mild”, 7.4% (n=10) as “moderate”, and 2.9% (n=4) as “severe”. Overall, 6.6% (n=9) of participants met the recommended clinical cut-off threshold (score of ≥ 10 , i.e., “moderate” depression) for the PHQ-9, and 10.3% (n=14) of all participants met the recommended clinical cut-off threshold (score of ≥ 10 , i.e., “moderate” anxiety) for the GAD-7 (see Table 63). The proportion of participants meeting the criteria for each grade of the PHQ-9 and GAD-7 based on age, level of play and concussion history are shown in Figure 24 and Figure 25. There were no significant differences in any PHQ-9 or GAD-7 outcomes between groups ($p > 0.05$).

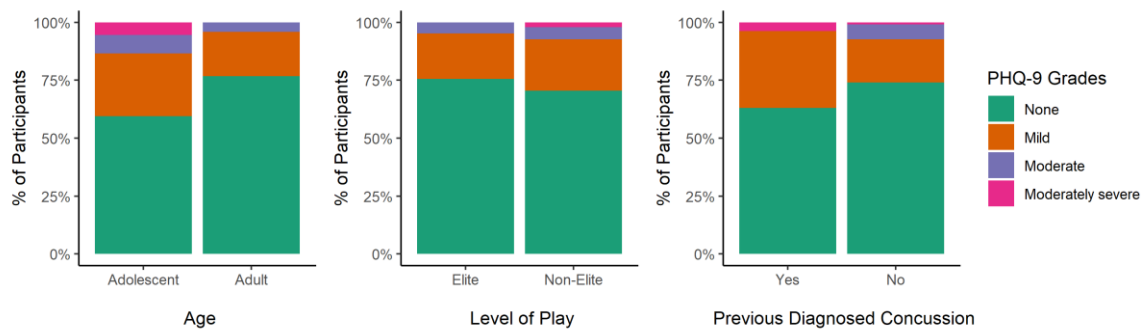


Figure 24: Patient Health Questionnaire-9 (PHQ-9) grades by age, level of play, and previous diagnosed concussion

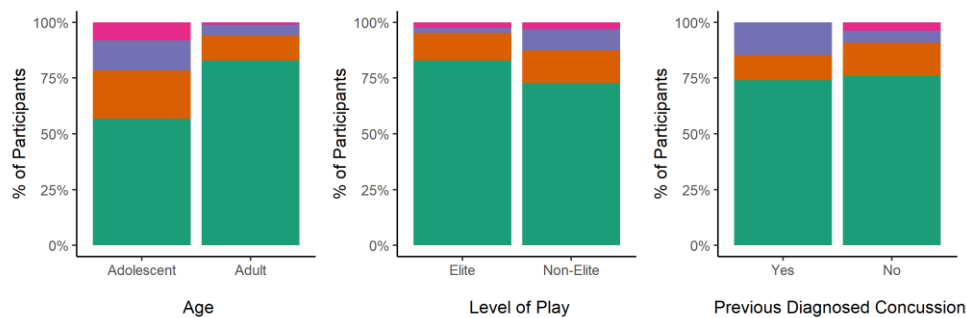


Figure 25: Generalised Anxiety Disorder-7 (GAD-7) grades by age, level of play, and previous diagnosed concussion

The median NBQ score was 3.0 (IQR: 0.5-7.5). Participants reported a median number of 0 days (IQR: 0-2 days) disability due to migraine over the previous three months on the MIDAS. Most participants (83.8%, n=114) met the criteria for a MIDAS grade I (little or no disability); 11.8% (n=16) were classified as grade II (mild disability), 2.2% (n=3) as grade III (moderate disability), and 2.2% (n=3) as grade IV (severe disability) (see Figure 26). The median global PSQI score for all participants was 5 (IQR: 3-7). PSQI components with the highest median scores were subjective sleep quality (1), sleep latency (1), sleep disturbance (1), and daytime dysfunction (1). Over half (56.3%, n=76) of participants were classified as having poor quality sleep (global score of ≥ 5). Between-group analyses did not find any statistically significant differences in any NBQ, MIDAS, or PSQI outcomes based on age, level of play, or history of diagnosed concussion ($p>0.05$).

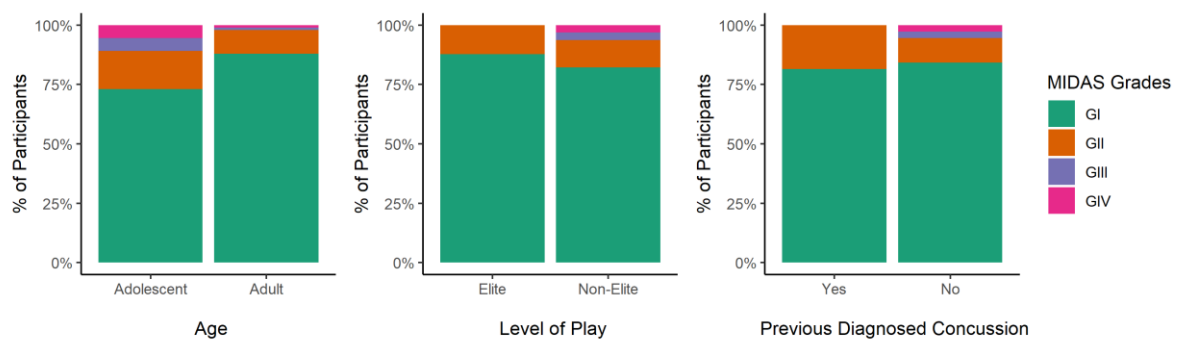


Figure 26: Migraine Disability Assessment (MIDAS) grades by age, level of play, and previous diagnosed concussion

Table 62: Descriptive statistics for clinical profile screen

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
Clinical Profiles Screen Total	Total	-	136 (2)	8.1 (7.7)	6.0 (3.0-10.0)	0.0-40.0	-	-
	Age	Adolescent	37 (0)	11.3 (10.0)	8.0 (3.0-17.0)	0.0-40.0	1.000	0.26 (0.04-0.45) ¹
		Adult	99 (2)	6.9 (6.3)	5.0 (3.0-9.0)	0.0-30.0	-	-
	Level	Elite	41 (0)	8.0 (8.1)	6.0 (3.0-10.0)	0.0-32.0	1.000	-0.05 (-0.26-0.16) ¹
		Non-Elite	95 (2)	8.2 (7.5)	7.0 (3.0-10.0)	0.0-40.0	-	-
	Concussion History	Yes	27 (1)	8.8 (7.8)	7.0 (3.0-13.5)	0.0-32.0	1.000	-0.08 (-0.31-0.16) ¹
		No	108 (1)	8.0 (7.7)	6.0 (3.0-10.0)	0.0-40.0	-	-
Cognitive/Fatigue	Total	-	136 (2)	0.5 (0.4)	0.3 (0.0-0.7)	0.0-2.0	-	-
	Age	Adolescent	37 (0)	0.6 (0.5)	0.7 (0.3-0.7)	0.0-2.0	1.000	0.22 (0.01-0.42) ¹
		Adult	99 (2)	0.4 (0.4)	0.3 (0.0-0.7)	0.0-2.0	-	-
	Level	Elite	41 (0)	0.5 (0.5)	0.3 (0.0-0.7)	0.0-2.0	1.000	-0.10 (-0.30-0.11) ¹
		Non-Elite	95 (2)	0.5 (0.4)	0.3 (0.3-0.7)	0.0-2.0	-	-
	Concussion History	Yes	27 (1)	0.7 (0.6)	0.7 (0.3-1.0)	0.0-2.0	1.000	-0.20 (-0.42-0.05) ¹
		No	108 (1)	0.5 (0.4)	0.3 (0.0-0.7)	0.0-1.7	-	-
Ocular	Total	-	136 (2)	0.3 (0.4)	0.2 (0.0-0.6)	0.0-1.8	-	-
	Age	Adolescent	37 (0)	0.4 (0.4)	0.4 (0.0-0.6)	0.0-1.6	1.000	0.19 (-0.03-0.39) ¹
		Adult	99 (2)	0.3 (0.4)	0.2 (0.0-0.5)	0.0-1.8	-	-
	Level	Elite	41 (0)	0.4 (0.5)	0.2 (0.0-0.6)	0.0-1.8	1.000	0.09 (-0.12-0.30) ¹
		Non-Elite	95 (2)	0.3 (0.4)	0.2 (0.0-0.4)	0.0-1.6	-	-
	Concussion History	Yes	27 (1)	0.4 (0.5)	0.2 (0.0-0.6)	0.0-1.6	1.000	-0.11 (-0.34-0.14) ¹
		No	108 (1)	0.3 (0.4)	0.2 (0.0-0.6)	0.0-1.8	-	-
Anxiety/Mood	Total	-	136 (2)	0.4 (0.4)	0.2 (0.0-0.6)	0.0-1.8	-	-
	Age	Adolescent	37 (0)	0.6 (0.5)	0.4 (0.2-1.0)	0.0-1.8	0.121	0.33 (0.12-0.51) ¹
		Adult	99 (2)	0.3 (0.4)	0.2 (0.0-0.4)	0.0-1.8	-	-
	Level	Elite	41 (0)	0.3 (0.4)	0.2 (0.0-0.4)	0.0-1.8	1.000	-0.07 (-0.28-0.14) ¹
		Non-Elite	95 (2)	0.4 (0.4)	0.2 (0.0-0.7)	0.0-1.8	-	-
	Concussion History	Yes	27 (1)	0.3 (0.4)	0.2 (0.0-0.6)	0.0-1.2	1.000	0.02 (-0.22-0.26) ¹
		No	108 (1)	0.4 (0.5)	0.2 (0.0-0.6)	0.0-1.8	-	-
Migraine	Total	-	136 (2)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-1.0	-	-
	Age	Adolescent	37 (0)	0.2 (0.3)	0.0 (0.0-0.2)	0.0-1.0	1.000	0.17 (-0.05-0.37) ¹
		Adult	99 (2)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-0.8	-	-
	Level	Elite	41 (0)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-0.8	1.000	-0.05 (-0.25-0.16) ¹
		Non-Elite	95 (2)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-1.0	-	-
	Concussion History	Yes	27 (1)	0.1 (0.2)	0.0 (0.0-0.1)	0.0-0.8	1.000	0.06 (-0.18-0.30) ¹
		No	108 (1)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-1.0	-	-
Vestibular	Total	-	136 (2)	0.1 (0.3)	0.0 (0.0-0.2)	0.0-1.2	-	-
	Age	Adolescent	37 (0)	0.3 (0.4)	0.2 (0.0-0.4)	0.0-1.2	0.006	0.38 (0.18-0.55) ¹
		Adult	99 (2)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-1.0	-	-
	Level	Elite	41 (0)	0.2 (0.3)	0.0 (0.0-0.2)	0.0-1.2	1.000	-0.03 (-0.24-0.18) ¹
		Non-Elite	95 (2)	0.1 (0.2)	0.0 (0.0-0.2)	0.0-1.0	-	-
	Concussion History	Yes	27 (1)	0.2 (0.3)	0.0 (0.0-0.2)	0.0-1.2	1.000	-0.04 (-0.27-0.20) ¹
		No	108 (1)	0.1 (0.3)	0.0 (0.0-0.2)	0.0-1.0	-	-
Sleep	Total	-	136 (2)	0.4 (0.4)	0.2 (0.0-0.5)	0.0-2.2	-	-
	Age	Adolescent	37 (0)	0.4 (0.5)	0.2 (0.0-0.5)	0.0-2.2	1.000	-0.02 (-0.23-0.20) ¹

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size
Neck	Level	Adult	99 (2)	0.3 (0.4)	0.2 (0.0-0.5)	0.0-1.5	-	-
		Elite	41 (0)	0.3 (0.4)	0.2 (0.0-0.5)	0.0-1.5	1.000	-0.07 (-0.27-0.14) ¹
		Non-Elite	95 (2)	0.4 (0.4)	0.2 (0.0-0.5)	0.0-2.2	-	-
	Concussion History	Yes	27 (1)	0.4 (0.4)	0.2 (0.0-0.8)	0.0-1.2	1.000	-0.07 (-0.31-0.17) ¹
		No	108 (1)	0.3 (0.4)	0.2 (0.0-0.5)	0.0-2.2	-	-
	Total	-	136 (2)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-3.0	-	-
	Age	Adolescent	37 (0)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-1.5	1.000	0.03 (-0.19-0.24) ¹
		Adult	99 (2)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-3.0	-	-
	Level	Elite	41 (0)	0.2 (0.6)	0.0 (0.0-0.0)	0.0-3.0	1.000	-0.00 (-0.21-0.21) ¹
		Non-Elite	95 (2)	0.2 (0.4)	0.0 (0.0-0.0)	0.0-2.0	-	-
	Concussion History	Yes	27 (1)	0.2 (0.3)	0.0 (0.0-0.2)	0.0-1.0	1.000	-0.07 (-0.31-0.17) ¹
		No	108 (1)	0.2 (0.5)	0.0 (0.0-0.0)	0.0-3.0	-	-

SD: Standard deviation; IQR: Interquartile range; 1. Rank-biserial correlation.

Table 63: Descriptive statistics for health questionnaires

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size	N (%) Meeting Clinical Cut-off
Patient Health Questionnaire-9	Total	-	136 (2)	3.5 (3.4)	3.0 (1.0-5.0)	0.0-19.0	-	-	9 (6.6)
	Age	Adolescent	37 (0)	4.7 (4.8)	3.0 (2.0-7.0)	0.0-19.0	1.000	0.14 (-0.07-0.35) ¹	5 (13.5)
		Adult	99 (2)	3.1 (2.7)	3.0 (1.0-4.0)	0.0-11.0	-	-	4 (4.0)
	Level of play	Elite	41 (0)	3.3 (3.0)	3.0 (1.0-4.0)	0.0-11.0	1.000	-0.03 (-0.23-0.18) ¹	2 (4.9)
		Non-Elite	95 (2)	3.6 (3.6)	3.0 (1.0-5.0)	0.0-19.0	-	-	7 (7.4)
	Concussion History	Yes	27 (1)	3.8 (3.8)	3.0 (1.5-5.5)	0.0-17.0	1.000	-0.05 (-0.28-0.19) ¹	1 (3.7)
		No	108 (1)	3.4 (3.3)	2.5 (1.0-5.0)	0.0-19.0	-	-	8 (7.4)
Generalised Anxiety Disorder-7	Total	-	136 (2)	3.2 (4.2)	1.5 (0.0-4.0)	0.0-21.0	-	-	14 (10.3)
	Age	Adolescent	37 (0)	5.5 (5.5)	4.0 (1.0-9.0)	0.0-21.0	0.066	0.35 (0.15-0.53) ¹	8 (21.6)
		Adult	99 (2)	2.4 (3.3)	1.0 (0.0-3.5)	0.0-15.0	-	-	6 (6.1)
	Level of play	Elite	41 (0)	2.4 (3.4)	1.0 (0.0-3.0)	0.0-15.0	1.000	-0.18 (-0.37-0.03) ¹	2 (4.9)
		Non-Elite	95 (2)	3.6 (4.5)	2.0 (0.0-5.5)	0.0-21.0	-	-	12 (12.4)
	Concussion History	Yes	27 (1)	3.3 (3.9)	2.0 (0.0-5.0)	0.0-12.0	1.000	-0.02 (-0.26-0.22) ¹	4 (14.8)
		No	108 (1)	3.2 (4.3)	1.0 (0.0-4.0)	0.0-21.0	-	-	10 (9.3)
Neck Bournemouth Questionnaire	Total	-	136 (2)	6.0 (8.4)	3.0 (0.5-7.5)	0.0-55.0	-	-	-
	Age	Adolescent	37 (0)	7.9 (9.2)	5.0 (1.0-12.0)	0.0-29.0	1.000	0.15 (-0.06-0.36) ¹	-
		Adult	99 (2)	5.2 (8.0)	3.0 (0.0-6.0)	0.0-55.0	-	-	-
	Level of play	Elite	41 (0)	5.8 (10.1)	2.0 (0.0-6.0)	0.0-55.0	1.000	-0.13 (-0.33-0.09) ¹	-
		Non-Elite	95 (2)	6.0 (7.6)	4.0 (1.0-7.5)	0.0-35.0	-	-	-
	Concussion History	Yes	27 (1)	6.3 (7.7)	3.0 (1.8-9.0)	0.0-29.0	1.000	-0.07 (-0.31-0.17) ¹	-
		No	108 (1)	5.8 (8.6)	3.0 (0.0-7.0)	0.0-55.0	-	-	-
Migraine Disability Assessment	Total	-	136 (2)	2.3 (4.9)	0.0 (0.0-2.0)	0.0-27.0	-	-	-
	Age	Adolescent	37 (0)	4.0 (6.8)	0.0 (0.0-6.0)	0.0-25.0	1.000	0.14 (-0.08-0.34) ¹	-
		Adult	99 (2)	1.6 (3.8)	0.0 (0.0-1.5)	0.0-27.0	-	-	-
	Level of play	Elite	41 (0)	1.4 (2.6)	0.0 (0.0-1.0)	0.0-9.0	1.000	-0.07 (-0.27-0.14) ¹	-
		Non-Elite	95 (2)	2.7 (5.6)	0.0 (0.0-2.5)	0.0-27.0	-	-	-
	Concussion History	Yes	27 (1)	1.8 (3.0)	0.0 (0.0-2.8)	0.0-8.5	1.000	0.01 (-0.23-0.25) ¹	-
		No	108 (1)	2.4 (5.3)	0.0 (0.0-2.0)	0.0-27.0	-	-	-
Pittsburgh Sleep Quality Index	Total	-	135 (3)	5.1 (2.5)	5.0 (3.0-7.0)	0.0-15.0	-	-	76 (56.3)
	Age	Adolescent	37 (0)	5.5 (2.9)	5.0 (3.0-7.0)	1.0-15.0	1.000	0.08 (-0.14-0.29) ¹	23 (62.2)
		Adult	98 (3)	5.0 (2.4)	5.0 (3.0-7.0)	0.0-11.0	-	-	53 (54.1)
	Level of play	Elite	40 (1)	5.0 (2.5)	5.0 (3.0-7.0)	1.0-9.0	1.000	0.01 (-0.20-0.22) ¹	23 (57.5)
		Non-Elite	95 (2)	5.1 (2.6)	5.0 (3.0-7.0)	0.0-15.0	-	-	53 (55.8)
	Concussion History	Yes	27 (1)	5.6 (2.4)	5.0 (3.5-7.5)	1.0-10.0	1.000	-0.16 (-0.38-0.09) ¹	18 (66.7)
		No	107 (2)	5.0 (2.6)	5.0 (3.0-7.0)	0.0-15.0	-	-	57 (53.3)
Component 1: Subjective Sleep Quality	Total	-	136 (2)	1.1 (0.6)	1.0 (1.0-1.0)	0.0-3.0	-	-	-
	Age	Adolescent	37 (0)	1.1 (0.6)	1.0 (1.0-1.0)	0.0-2.0	1.000	0.07 (0.00-0.17) ²	-
		Adult	99 (2)	1.1 (0.6)	1.0 (1.0-1.0)	0.0-3.0	-	-	-

Outcome	Demographic	Group	N (m/)	Mean (SD)	Median (IQR)	Range	P-value	Effect Size	N (%) Meeting Clinical Cut-off
<i>Component 2: Sleep Latency</i>	Level of play	Elite	41 (0)	1.1 (0.6)	1.0 (1.0-1.0)	0.0-2.0	1.000	0.07 (0.00-0.15) ²	-
		Non-Elite	95 (2)	1.1 (0.6)	1.0 (1.0-1.0)	0.0-3.0	-	-	-
	Concussion	Yes	27 (1)	1.3 (0.7)	1.0 (1.0-2.0)	0.0-3.0	1.000	0.22 (0.00-0.36) ²	-
	History	No	108 (1)	1.0 (0.6)	1.0 (1.0-1.0)	0.0-2.0	-	-	-
	Total	-	135 (3)	1.3 (1.0)	1.0 (1.0-2.0)	0.0-3.0	-	-	-
	Age	Adolescent	37 (0)	1.6 (1.1)	2.0 (1.0-3.0)	0.0-3.0	1.000	0.24 (0.00-0.38) ²	-
		Adult	98 (3)	1.2 (0.9)	1.0 (1.0-2.0)	0.0-3.0	-	-	-
	Level of play	Elite	40 (1)	1.2 (1.0)	1.0 (0.0-2.0)	0.0-3.0	1.000	0.13 (0.00-0.25) ²	-
<i>Component 3: Sleep Duration</i>		Non-Elite	95 (2)	1.4 (1.0)	1.0 (1.0-2.0)	0.0-3.0	-	-	-
	Concussion	Yes	27 (1)	1.4 (1.1)	1.0 (0.5-2.0)	0.0-3.0	1.000	0.14 (0.00-0.27) ²	-
	History	No	107 (2)	1.3 (0.9)	1.0 (1.0-2.0)	0.0-3.0	-	-	-
	Total	-	136 (2)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	-	-	-
	Age	Adolescent	37 (0)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.08 (0.00-0.21) ²	-
		Adult	99 (2)	0.5 (0.6)	0.0 (0.0-1.0)	0.0-2.0	-	-	-
	Level of play	Elite	41 (0)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.02 (0.00-0.05) ²	-
		Non-Elite	95 (2)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	-	-	-
<i>Component 4: Sleep Efficiency</i>	Concussion	Yes	27 (1)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.05 (0.00-0.17) ²	-
	History	No	108 (1)	0.4 (0.6)	0.0 (0.0-1.0)	0.0-2.0	-	-	-
	Total	-	136 (2)	0.6 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	-
	Age	Adolescent	37 (0)	0.6 (0.8)	0.0 (0.0-1.0)	0.0-3.0	1.000	0.03 (0.00-0.00) ²	-
		Adult	99 (2)	0.6 (0.7)	0.0 (0.0-1.0)	0.0-3.0	-	-	-
	Level of play	Elite	41 (0)	0.6 (0.7)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.10 (0.00-0.22) ²	-
		Non-Elite	95 (2)	0.6 (0.8)	0.0 (0.0-1.0)	0.0-3.0	-	-	-
	Concussion	Yes	27 (1)	0.5 (0.6)	0.0 (0.0-1.0)	0.0-2.0	1.000	0.08 (0.00-0.18) ²	-
<i>Component 5: Sleep Disturbance</i>	History	No	108 (1)	0.6 (0.8)	0.0 (0.0-1.0)	0.0-3.0	-	-	-
	Total	-	136 (2)	0.9 (0.5)	1.0 (1.0-1.0)	0.0-3.0	-	-	-
	Age	Adolescent	37 (0)	1.0 (0.7)	1.0 (1.0-1.0)	0.0-3.0	1.000	0.23 (0.00-0.37) ²	-
		Adult	99 (2)	0.9 (0.4)	1.0 (1.0-1.0)	0.0-2.0	-	-	-
	Level of play	Elite	41 (0)	1.0 (0.3)	1.0 (1.0-1.0)	0.0-2.0	1.000	0.21 (0.00-0.35) ²	-
		Non-Elite	95 (2)	0.9 (0.5)	1.0 (1.0-1.0)	0.0-3.0	-	-	-
	Concussion	Yes	27 (1)	1.0 (0.2)	1.0 (1.0-1.0)	0.0-1.0	1.000	0.21 (0.00-0.35) ²	-
	History	No	108 (1)	0.9 (0.5)	1.0 (1.0-1.0)	0.0-3.0	-	-	-
<i>Component 6: Use of Sleep Medication</i>	Total	-	136 (2)	0.0 (0.1)	0.0 (0.0-0.0)	0.0-1.0	-	-	-
	Age	Adolescent	37 (0)	0.0 (0.0)	0.0 (0.0-0.0)	0.0-0.0	1.000	0.05 (0.00-0.22) ²	-
		Adult	99 (2)	0.0 (0.1)	0.0 (0.0-0.0)	0.0-1.0	-	-	-
	Level of play	Elite	41 (0)	0.0 (0.0)	0.0 (0.0-0.0)	0.0-0.0	1.000	0.06 (0.00-0.22) ²	-
		Non-Elite	95 (2)	0.0 (0.1)	0.0 (0.0-0.0)	0.0-1.0	-	-	-
	Concussion	Yes	27 (1)	0.0 (0.0)	0.0 (0.0-0.0)	0.0-0.0	1.000	0.04 (0.00-0.21) ²	-
	History	No	108 (1)	0.0 (0.1)	0.0 (0.0-0.0)	0.0-1.0	-	-	-
	Total	-	136 (2)	0.7 (0.6)	1.0 (0.0-1.0)	0.0-3.0	-	-	-
<i>Component 7: Daytime Dysfunction</i>	Age	Adolescent	37 (0)	0.8 (0.8)	1.0 (0.0-1.0)	0.0-3.0	1.000	0.15 (0.00-0.29) ²	-
		Adult	99 (2)	0.7 (0.6)	1.0 (0.0-1.0)	0.0-2.0	-	-	-
	Level of play	Elite	41 (0)	0.7 (0.6)	1.0 (0.0-1.0)	0.0-2.0	1.000	0.07 (0.00-0.16) ²	-
		Non-Elite	95 (2)	0.7 (0.7)	1.0 (0.0-1.0)	0.0-3.0	-	-	-
	Concussion	Yes	27 (1)	1.0 (0.7)	1.0 (0.5-1.0)	0.0-2.0	1.000	0.25 (0.00-0.40) ²	-
	History	No	108 (1)	0.6 (0.6)	1.0 (0.0-1.0)	0.0-3.0	-	-	-

SD: Standard deviation; IQR: Interquartile range; 1. Rank-biserial correlation; 2. Cramer's V.

5.4 Discussion

The aims of this study were (i) to report normative data on a multi-domain SRC assessment in a cohort of LGF players, and (ii) to examine differences in baseline test scores across age, level of play, and concussion history in these players. This is the first study to describe normative data on a comprehensive SRC assessment in female, community sport athletes. While it is best practice to use random sampling when collecting normative data, this was not feasible in our study due to limited resources. However, we attempted to make our sample as representative of the LGF community as possible by including adolescent and adult players participating at elite and non-elite levels. Normative data is particularly important in community sport where there may be a lack of medical professionals. Unlike most previous studies of normative data, we included both adolescent and adult players. We presented normative data on core aspects of an SRC assessment including ImPACT®, SCAT5, and VOMS, as well as on a variety of secondary measures, such as neck dynamometry and the CP Screen, PHQ-9, GAD-7, NBQ, MIDAS, and PSQI questionnaires. There were no significant differences in any of these outcomes between elite and non-elite players, or between players with and without a previous diagnosed concussion. Adolescent and adult participants did not significantly differ on the majority of measures. However, adolescent participants performed worse than adult participants on ImPACT® visual motor speed and reaction time, SCAT5 concentration, mBESS, and CP Screen vestibular profile scores.

5.4.1 *Immediate Post-Concussion Assessment and Cognitive Testing*

Previous studies have reported broad ranges of mean ImPACT® composite scores in adolescent and adult female players: 82.5-99.1 (verbal memory), 70.8-80.6 (visual memory), 29.0-44.0 (visual motor speed), and 0.55-0.62 (reaction time) (169,170,174,209,210,212). Similarly, we reported overall median ImPACT® scores of 87.5 for verbal memory, 73.0 for visual memory, 37.4 for visual motor speed, and 0.6 seconds for reaction time. Many factors are thought to influence neurocognitive assessment results, such as gender (174,350,351), age (174,211,216), history of concussion (170,210), diagnoses of LDs or ADHD (169), sleep (270,388), and testing environment (i.e. group versus individual assessment) (174). Therefore, establishing normative values is difficult. Clinicians consulting normative data should be aware of the vast array of factors that may influence results and ensure that they select appropriate normative data if it is available.

Adolescent participants in our study demonstrated significantly poorer scores on the “speed” components, but not the memory components, of ImPACT® compared with adult participants. Visual motor speed and reaction time composite scores may represent an underlying “speed” factor on ImPACT®, while verbal memory and visual memory may constitute a “memory” factor (389). Similar to our study, previous studies have found improved visual motor speed (174,211) and reaction time (174,211) scores in older adolescents compared with younger adolescents, as well as

significantly better visual motor speed scores among collegiate athletes compared with adolescent athletes (45.8 versus 39.4) (216). Age-related differences in processing speed and reaction time may be because white matter development, which is associated with processing speed (390), continues throughout adolescence and into adulthood (390,391). However, findings on memory differences between age groups have been mixed; with one study finding higher scores in verbal memory but not visual memory in older versus younger adolescents (211), and another reporting no differences between adolescent and collegiate athletes (216). The small number of adolescent participants in our study likely increased the risk of Type II errors, and it is possible that the study was underpowered to identify some between-group differences. While our findings suggest that separate norms for adolescent and adult LGF players on ImPACT® composite scores may be needed, further research should first attempt to reproduce our findings in a sample with a larger number of adolescent players. In addition, as considerable neurocognitive maturation takes place during adolescence (390), future studies should consider further stratifying adolescent participants into younger (e.g., 13-15) and older (e.g., 16-17) adolescents when presenting normative data for LGF players.

It has been suggested that repeated head impacts or SRCs may lead to long-term neurocognitive dysfunction (218,392). An athlete's concussion history is therefore frequently of interest to clinicians when carrying out baseline or post-SRC neurocognitive assessments. There were no significant differences in any ImPACT® composite scores in participants with and without a previous diagnosed concussion in our study. Previous research has identified minimal differences in ImPACT® neurocognitive outcomes based on concussion history (170,393,394), with results from a meta-analysis reporting slightly lower verbal memory scores in players with one previous concussion compared with players without a previous concussion (395). Considering that a similar effect was not found for players with a history of two or more concussions, the meta-analysis authors concluded that this was likely a spurious finding (395). Our findings suggest that separate norms for LGF players based on SRC may not be necessary. However, we only examined differences based on previous diagnosed concussions; as LGF is a community sport with limited access to medical personnel, some players with a concussion may not have been diagnosed and would therefore have been analysed in the "no concussion history" group. We also dichotomised concussion history ("yes" or "no"); this may have obscured the cumulative effect of concussion on neurocognitive measures. Future research is needed to determine whether differences in ImPACT® outcomes based on the number of previous suspected and diagnosed concussions exist in this population.

5.4.2 Sport Concussion Assessment Tool 5th Edition

Participants in our study reported a median of four symptoms on the SCAT5 GSC, with a median SSS of five. The most common symptoms were fatigue (66.4%), difficulty concentrating (47.8%), and feeling nervous or anxious (42.5%). Baseline reporting of concussion-like symptoms is common,

particularly in female athletes (336). Concussion symptoms are non-specific and may present in players without concussion due to multiple reasons; these include underlying medical conditions (e.g., migraine (396) and mood disorders (397,398), which are more prevalent in females), lifestyle factors (318), or hormonal fluctuations (399). However, the SCAT5 GSC scores in our study were considerably higher than the ranges reported in female collegiate and professional athletes in other studies (TSS: 0-1, SSS: 0-2) (145,190,191). This may reflect lifestyle or training differences between LGF players and other athletes. LGF players, including elite players, typically study or work full-time and could experience greater amounts of stress and have less recovery time than collegiate or professional athletes. Unlike previous studies, we did not find differences in baseline concussion symptoms based on previous concussion history (170,393) or age (398). Due to low rates of relevant medical conditions (e.g., LDs, ADHD) among participants in our sample, we were unable to examine baseline symptom differences between players with and without these conditions. While participants with these conditions represented a small percentage (0.0-15.4%) of the overall sample, high TSSs and SSSs among these participants may nevertheless have skewed GSC scores. Future studies should expand on our research and present normative data for LGF players with a history of migraine, ADHD, LDs, depression, anxiety, and sleep disorders. This information is important for clinicians as players who experience high baseline symptom scores may not need to be completely symptom-free when returning-to-play following an SRC.

We reported similar median scores for the SAC as previous studies of adolescent (186,192), collegiate (400), and elite adult (191) female athletes: five for orientation, 20 for immediate recall, four for concentration, and six for delayed recall. We opted for the 10-word list over the five-word list in the immediate and delayed recall components of the SAC as a ceiling effect has been observed when using the five-word list (180). Ceiling effects occur when a large proportion of individuals attain high scores on a test, potentially making it difficult to detect changes post-SRC (180,400). As we did not observe signs of a ceiling effect when using the ten-word list, we therefore recommend that clinicians use the 10-word list when carrying out SCAT5 assessments. However, the high proportion of participants with maximum orientation (79.9%) and concentration (38.1%) scores in our study suggests that ceiling effects may also be present for other components of the SAC. Clinicians should be aware that these components of the SAC may be of limited utility in LGF players.

Adolescent participants in our study scored significantly lower than adult participants on the digits backwards test, contributing to significantly lower concentration scores with a moderate effect size. Due to the small number of adolescents in our study, this finding should be examined in further studies of LGF players. Very few previous studies have examined the effect of age on SAC scores (186,401). One study compared older (aged 16-19) and younger (aged 13-15) female adolescents and reported lower concentration scores (means of 3.0 vs 3.6) in the younger athletes (401). Another

study found no age effects in high school players' concentrations scores, however 75% of participants were male and separate analyses for male and female players were not performed (186). Differences in concentration abilities between adolescents and adults may reflect natural neurocognitive development processes (391). As neurodevelopment rates differ between males and females (402), it is essential that clinicians consult normative data from the appropriate population when assessing players with the SAC.

Our participants recorded median total mBESS scores of five out of a maximum of 30, which is higher than the median scores of two to three that have been previously reported in female youth (168), high school (168), collegiate (168,190), and elite rugby (191) players. This suggests that our participants may have had poorer static postural stability abilities than other female sporting populations. However, previous studies did not provide detailed information about how the mBESS was carried out. As the SCAT5 is intended for sideline usage, variation in some aspects of the protocol is permitted (403). Unsurprisingly, most errors committed occurred during the single-leg (median: 3) and tandem gait (median: 1) stances in our study; compared with the double-leg stance, it is more difficult to maintain postural stability in these stances due to the reduced base of support and altered their centre of gravity (404). We assessed participants standing barefooted on a firm surface; for the single-leg stance participants stood on their non-dominant leg, while for the tandem gait stance they placed their non-dominant foot behind their dominant foot. Clinicians consulting our normative data should follow the same protocol. While we found no significant differences in mBESS scores between elite and non-elite players or between players with and without a previous diagnosed concussion, adolescent players had worse total and tandem gait stance scores than adult players. Improved mBESS scores have been reported with increasing age in adolescents (168,405). The sensorimotor systems, which are responsible for balance, develop throughout adolescence, (406) possibly explaining the differences in mBESS scores between adolescents and adults.

5.4.3 Vestibular-Ocular Motor Screening

We reported median provocation scores of zero for all VOMS items, as well as a median NPC distance of zero centimetres, with no differences found based on age, level of play, or concussion history. However, between 19.4% and 37.3% of participants experienced some symptom provocation (score ≥ 1) on individual VOMS items. Individual item scores ≥ 2 or an NPC distance ≥ 5 cm have been suggested as clinical cut-off points for VOMS. These cut-off points have demonstrated positive likelihood ratios of 5.8 to 42.8, with HVOR, VMS, and NPC distance best distinguishing players with SRC from controls (121). While this classification method has been widely adopted (231,234,337), it has several limitations: the validation study focused on young adolescents, included a greater proportion of female participants in the concussion group than the control group, and assessed participants up to 21 days post-SRC (121). Additional analyses have found that a score ≥ 1

on the HVOR, VVOR or VMS items, an NPC distance $\geq 3\text{cm}$, or a total symptom score ≥ 3 , may best identify adolescent players with an SRC (224), while a score of ≥ 2 on the HVOR, ≥ 1 on any other individual item other than the VMS, or a TSS score ≥ 8 were suggested as alternative cut-off points in collegiate players (150). However, further research is needed before changes to cut-off points can be recommended.

Regardless of classification method, a high proportion of our participants scored positively on the VOMS; using the initial, recommended method, 30.6% of participants scored positively on at least one VOMS item (2.2%-17.2% per item, 2.2% for NPC distance), while 46.3% and 53.7% met the criteria for a positive result when the alternative classification methods were used. Other studies have similar reported false positive rates (i.e., the proportion of participants without an SRC who are classified as positive) of between 4.8% and 15.8% for individual VOMS items (227,230,231,234), and between 11.0% and 24.8% for NPC distance (227,230,231,234) when using the initial classification method. The high rates of false positives in our sample may be a result of using a female-only sample; females have been reported to experience more baseline VOMS symptoms than males (230,231). This may be due to biological reasons, such as an increased prevalence of certain medical conditions in females (e.g., females are more likely to suffer from migraine (236), motion sickness (237), and anxiety (407), all of which are associated with vestibular dysfunction (408,409)), or hormonal fluctuations (399). However, it may also be due to psychosocial factors- i.e., it is possible that females are more likely to admit to experiencing symptoms than males. Due to the small proportion of participants who had been diagnosed with migraine ($n=13$) or anxiety ($n=2$), we were unable to examine differences in VOMS results based on medical history. However, these conditions may be underdiagnosed and there is a need for more extensive normative data on the VOMS in female athletes that takes relevant medical history into account. Clinicians working with LGF teams should recognise that existing cut-off points for the VOMS may result in high false positive rates in this population, and therefore may be of limited utility. Further research on developing clinical cut-off points for the VOMS based on demographic characteristics and medical history is required.

5.4.4 Neck Dynamometry

This is the first study to present normative data on neck strength in female athletes, regardless of age, sport, or playing level. No differences were observed in normalised neck flexion, extension, bilateral flexion, or bilateral rotation strength based on age group, level of play, or diagnosed concussion history. Cervical spine injuries may co-occur with SRC, resulting in headaches, neck pain, and muscle weakness (117,410). Increased neck strength may also help to reduce the risk of SRCs by counter-acting forces that are exerted on the brain during head impacts (411). Therefore, incorporating neck dynamometry into SRC assessments may assist clinicians in managing the RTP

and rehabilitation processes, as well as in identifying players who may be at an increased risk of SRC.

The lack of between-group (age, level of play, concussion history) differences in neck strength values after accounting for body mass was surprising. Adults typically demonstrate increased muscle strength relative to adolescents (412), while elite athletes may be more likely to partake in strength training than non-elite athletes. It is possible that normalising force to body mass concealed strength differences between adolescents and adults. The finding that neck strength did not differ based on participants' concussion history contradicts previous research observing a 5% reduction in the odds of sustaining an SRC per every increase in neck strength of one pound (57). This may be due to participants with a previous concussion undertaking a neck strengthening programme as part of their rehabilitation; alternatively, it is possible that factors other than neck strength were more influential in concussion risk among participants who had previously sustained a concussion. SRC is a complex injury with multiple risk factors (18). There is currently insufficient evidence to recommend the inclusion of neck strengthening in players' training as a form of injury prevention. However, several neck strengthening protocols aimed at reducing the risk of SRC have been developed (413), and may be useful for clinicians who wish to incorporate neck strengthening in rehabilitation programmes.

5.4.5 Clinical Profiles Screen

The CP Screen was developed to assess self-reported SRC symptoms based on the clinical profiles model of concussion (31,131). Unlike other concussion symptom report scales (e.g. the SCAT5 GSC (132) and the PCSS (133)) which produce an overall symptom score, the CP Screen also produces a score for each of the five clinical profiles and two modifiers. Normative data on the CP Screen has not been previously collected in any population. Our participants scored highest on the cognitive (median: 0.3), ocular (median: 0.2), and anxiety/mood profiles (median: 0.2). These profiles include non-specific symptoms (e.g., memory difficulties, headaches, eye strain, rumination, and feeling anxious), which may be explained by psychological stress (397), environmental factors (e.g., frequent use of screens) (414) or underlying medical conditions (such as LDs or mood disorders) (396,415) in players without concussion. Our results support a considerable body of literature reporting that female players frequently experience mild concussion-like symptoms even when not suffering from a concussion (170,336,416). It is important for clinicians to be aware of this as it may not be possible for some female athletes to be completely symptom-free when returning-to-play following an SRC. SRC diagnosis and RTP decisions should be made taking a range of factors and assessment findings into consideration.

Higher scores for the vestibular component of the CP Screen were found for adolescent participants compared with adult participants, with a moderate effect size. The vestibular component of the CP Screen assesses symptoms including dizziness, motion sickness, and discomfort in busy

environments (131). There is little data available on the prevalence of symptoms relating to vestibular dysfunction in adolescents (417), and none to our knowledge that compares symptoms in adolescents and adults. It is possible that adolescents experience greater vestibular dysfunction relative to adults due to ongoing development of the vestibular system throughout adolescence (406). Alternatively, differences in vestibular scores between adolescent and adult participants may be due to a confounding factor, such as a history of migraine or motion sickness, which have been associated with vestibular dysfunction (230,235,417). A greater proportion of adolescent (18.9%, n=7) than adult (6.1%, n=6) participants self-reported a history of migraine, however our sample size was insufficient to analyse differences in outcomes based on medical history. Furthermore, we did not assess participants for motion sickness susceptibility. Additional research is required to understand differences in self-reported vestibular function in adolescent players compared with adult players before recommendations can be made to clinicians.

5.4.6 Health Questionnaires

SRC tests, such as ImPACT® (133) or the SCAT5 (132), do not provide detailed information on subjective symptoms that may present following an SRC. Incorporating general measures of health into an SRC assessment may therefore be useful in guiding rehabilitation. We included measures of mood (PHQ-9), anxiety (GAD-7), sleep quality (PSQI), neck pain (NBQ), and disability due to migraine (MIDAS), all of which may occur following an SRC (117,120,122,418), in our assessment. These measures may be useful in or beyond the sub-acute phase of injury in players who are suffering from persistent symptoms. Although a wealth of normative data on these measures exists for various clinical populations, few studies have reported baseline scores in athletes (253–255,276,279,280,419).

5.4.6.1 Patient Health Questionnaire-9

Participants scored a median of three (maximum of 27) on the PHQ-9, indicating that the majority were experiencing low levels of depression symptoms at the time of testing. Baseline data for the PHQ-9 in athletes is very limited. Median scores of zero have been reported in several cohorts of male and female athletes (253–255,419), with all but one of these studies reporting results for males and females collectively (253,254,419). Depression is more common in females, which may explain why we reported slightly higher median scores than previous studies (420). Females may also be more likely to report mood-related symptoms than males. In addition, depression may be influenced by sociocultural factors (421), emphasising the need for population-specific normative data. LGF players and other community sport athletes represent a unique population; while they may train and compete at a high level, unlike collegiate or professional athletes they are also subject to work and study-related stresses. Therefore this study, which is the first to report normative data for the PHQ-

9 in a sample of female, community sport athletes, contributes important data to the literature and will greatly assist clinicians in managing the RTP process from SRC in these players.

The proportion (6.6%) of participants who met the clinical cut-off threshold (≥ 10) for depression in our study was considerably higher than the proportion (2.2%) who reported previously being diagnosed with a mood disorder. Using a cut-off score of 10, the PHQ-9 has a sensitivity of 70%-88% and a specificity of 84%-93% for detecting depression (241,381). While mood disorders can only be diagnosed by a mental health professional, including self-report measures of depression symptoms alongside a medical history in SRC assessments may be beneficial. Mood disorders are thought to be underdiagnosed, and symptom reports may provide a more accurate measure of a player's mental health than medical history. Pre-existing mood disorders or self-reported depressive symptoms may increase the risk of mood-related symptoms post-SRC (422). As an understanding of players' pre-injury emotional function may help clinicians to identify players at risk of post-SRC mood disturbances and develop suitable interventions, we believe that the PHQ-9 should be included in baseline assessments. However, because the PHQ-9 captures symptoms from the two weeks prior to assessment, it may be most useful in SRC patients with prolonged symptoms, rather than during the acute injury phase.

5.4.6.2 *Generalised Anxiety Disorder-7*

Participants experienced low levels of baseline anxiety, with a median GAD-7 score of 1.5 (maximum of 21) reported. Little normative data is available for the GAD-7 in athletes, however medians of 0-1 have been reported in male and female high school and collegiate athletes.(253,254) Our data will enhance clinicians' understanding of baseline anxiety symptoms in female players participating in community sport. A history of a mental health condition may predispose a player to mood-related symptoms or a prolonged recovery following an SRC (33). Similar to our findings regarding mood disorders, a far greater proportion of participants met the clinical cut-off threshold of ≥ 10 (14.0%) for the GAD-7 than those who reported a diagnosed anxiety disorder (1.5%). The GAD-7 has a sensitivity of 74% and a specificity of 83% at a cut-off score of 10 (244). Anxiety disorders may be underdiagnosed, and baseline screening using the GAD-7 may detect players with undiagnosed anxiety disorders. Like the PHQ-9, the GAD-7 focuses on symptoms experienced over the previous two weeks. Therefore, we recommend it for use at baseline and in players with prolonged symptoms in the chronic stage of injury.

5.4.6.3 *Neck Bournemouth Questionnaire*

We reported median NBQ scores of three (maximum of 70), with no differences observed between adults and adolescents, elite and non-elite players, or participants with and without a concussion history. Our study is the first to use the NBQ in a sporting context. The NBQ was originally developed to assess neck pain and dysfunction in clinical populations and has mostly been used in

patients with chronic neck pain (308) and conditions associated with neck dysfunction.(307) There are no suggested cut-off points for the NBQ, although changes of ≥ 13 have been suggested to denote a clinically significant change in function (296). As expected, our participants reported low NBQ scores, suggesting that they experienced minimal neck pain and dysfunction. Neck injuries may occur alongside SRCs due to a shared mechanism of injury (423). As there may be an overlap of some symptoms between neck injuries and SRCs (e.g., dizziness, poor balance and visual problems) (18,289), assessing neck function is an important part of the SRC assessment. Our data shows that self-reported neck impairment is uncommon in LGF players without SRC. The NBQ may be useful in tracking symptoms in players who present with persistent neck pain and associated symptoms following an SRC. Including it in baseline assessments may assist clinicians in the rehabilitation process.

5.4.6.4 *Migraine Disability Assessment*

The majority (83.8%) of participants were classified as having “little or no disability” (≤ 5 days disruption in activities due to headaches in the previous 90 days) on the MIDAS, however 11.8% experienced “some disability” (6-10 days disruption) and the remainder experienced “moderate disability” (2.2%; 11-20 days disruption) or “severe disability” (2.2%; ≥ 21 days disruption). While players with SRC often present with post-traumatic migraine (120,259), specific migraine measures are rarely included in SRC assessments. No other studies have provided normative data on any measure of migraine symptoms in athletes. Our finding that 16.2% of participants had experienced at least “some” headache-related disability in the three months prior to the assessment is concerning. Pre-existing migraine may be a risk factor for a prolonged recovery from SRC (120). As migraine may be underdiagnosed, incorporating a measure such as the MIDAS into baseline SRC assessments may be useful in identifying players who may be at an increased risk of SRC complications. However, as the MIDAS focuses on the 90 days prior to assessment, incorporating it into post-SRC assessments may have limited usefulness. Alternative measures of migraine symptoms (e.g., CP Screen or the MS-Q (261)) may be more appropriate for post-SRC assessments.

5.4.6.5 *Pittsburgh Sleep Quality Index*

Participants scored a median of five on the global PSQI score. More than half (56.3%) of participants were considered to have poor sleep quality (global score ≥ 5). High rates of poor sleep quality have also been reported in high school, collegiate and elite athletes, with 40.4%-67.0% scoring ≥ 5 on the PSQI in previous studies (276,279–281). Our study is the first to present normative PSQI data for female athletes participating in a community sport. LGF players often train and compete at a high level in addition to attending school, college or work full-time, which may have contributed to poor sleep among our participants. In spite of the higher training load in elite LGF players, we did not find any differences in PSQI scores based on playing level. This may have been because our study

contained an insufficient number of elite athletes to detect differences between groups. It is also possible that elite LGF players place a higher priority on recovery than non-elite players, and that this compensates for the potential increased training load and stress in elite players. Sleeping difficulties (such as difficulty falling asleep, sleeping more or less than usual, or drowsiness) also commonly occur following an SRC (191,336,418). In addition, pre-existing sleeping difficulties have been associated with a greater symptom burden and neurocognitive impairments both at baseline (270,424) and following an SRC (157). Therefore, an awareness of players' baseline sleep quality is important for monitoring RTP. However, as the PSQI assesses sleep quality over the previous month, it may be more useful at baseline or in players with prolonged symptoms rather than in the acute period of SRC. Alternative measures of sleep that do rely on a particular timeframe (e.g., Epworth Sleepiness Scales) (274) may be more suitable post-SRC.

Participants demonstrated worse scores on the subjective sleep quality, sleep latency (time taken to fall asleep), sleep disturbance, and daytime dysfunction components of the PSQI compared with the sleep duration, sleep efficiency, and sleep medication components, echoing findings from elite female athletes (276). This suggests that poor sleep quality in our participants may have been due to factors such as difficulty falling asleep and interruptions during sleep, as opposed to not sleeping for long enough. Sleep is important for injury recovery (425,426) and poor sleep may exacerbate other SRC symptoms (31). Poor sleep is also associated with multiple detrimental effects, including mood dysfunction and cognitive impairment (270,388). However, it is also a modifiable factor. Clinicians may be able to suggest ways to target poor sleep quality in LGF players by improving sleep hygiene, such as reducing screen usage prior to sleeping and avoiding caffeine.

5.4.7 *Interpreting Normative Data*

Normative data can be used to identify cut-off points for abnormal scores that may assist clinicians in making a diagnosis of SRC. This can be achieved through calculating percentiles, which are usually interpreted thus: 1st- impaired; 9th- borderline; 24th- low average; 75th- average; 90th- high average; 97th- superior; $\geq 98^{\text{th}}$ - very superior (212). However, interpretation can vary slightly. This approach to normative data has previously been used in SRC assessments, such as the ImPACT and SCAT (212,371,427). These studies have regarded scores in approximately 10th percentile as cut-off points for SRC assessments (371,427). Our percentile tables are presented in Appendix P- Appendix U and may be useful for clinicians working with LGF players with SRC. Clinicians should be aware that “high performers” on clinical tests may not demonstrate abnormal scores post-SRC.

5.4.8 *Limitations*

This study has a number of limitations relating to (i) the development of the SRC assessment, (ii) participant recruitment, (iii) testing, and (iv) analysis.

Firstly, the development of the SRC assessment was guided by the University of Pittsburgh Medical Center Clinical Profiles model of concussion (31). This model describes five different symptom profiles of SRC, which may be modified by sleep or neck-related symptoms. However, it was developed based on clinical expertise and lacks empirical validity. It is possible that the suggested clinical profiles do not represent distinct entities.

Secondly, participants were recruited from local LGF teams using convenience sampling. Participants with a greater interest in SRC or who had previously suffered from an SRC may have been more likely to participate in the study. This may have resulted in participants with a history of SRC being overrepresented in the sample. In addition, there were differences in the number of participants for each group in our between-group analyses, with adult participants greatly outnumbering adolescent participants (101 vs 37), non-elite players outnumbering elite players (97 vs 41), and participants without a history of concussion outnumbering those with a history of concussion (109 vs 28). Samples of 85 or more participants have been suggested to ensure accurate normative data (380). The study may therefore have been underpowered to detect small effect sizes between groups and may have an increased risk of Type II errors.

Thirdly, most participants completed part of the assessment on one day and the remainder on another day due to time constraints. A median of nine days elapsed between testing sessions. As we used a “station” format for testing, the order of tests was not standardised. We also carried out the testing in several different locations to best facilitate participants (e.g., collegiate participants were assessed in the university biomechanics lab, while local club players were assessed in an empty club changing room).

Fourthly, a low proportion of participants reported a history of relevant medical conditions (e.g., ADHD, LDs, migraine, mood disorders, anxiety, and sleep disorders), preventing us from analysing differences in test outcomes between players with and without these conditions. These conditions have been associated with worse outcomes following an SRC and may also ImpACT® baseline test results. While we compared outcomes based on concussion history, we did not take the number of previous concussions into account; some research suggests that there may be a dose-dependent relationship between concussion and neurocognitive impairment (428). We compared outcomes between players with and without a diagnosed concussion, excluding players who may have sustained a suspected concussion for which they did not seek medical care. Both diagnosed and suspected concussions were self-reported by participants, which may have led to inaccuracies in concussion history.

5.5 Conclusions

This study described normative data from a multi-domain SRC assessment in a sample of LGF players. In addition to being the only such study to focus on female athletes participating in a

community sport, it also captured baseline data on multiple measures of SRC symptoms. SRC is a complex neurological injury with divergent clinical pathways, and it is recommended that a multi-domain assessment is used to assess for and monitor recovery of SRC (31,32). While significant between-group differences were not reported based on level of play or diagnosed concussion history, we found significantly worse scores in ImPACT® visual-motor speed, ImPACT® reaction time, SCAT5 concentration, mBESS, and CP Screen vestibular item scores in adolescent compared with adult participants. This highlights the need for clinicians to consult population-specific normative data when individual baseline data is not available. However, due to the low number of adolescents, elite players, and participants with a previous diagnosed SRC in our study, further normative data in these groups is required. Although additional work is needed, we have presented percentiles based on our normative data that may assist clinicians working with LGF players with SRC. However, some measures may not be suitable for use in the post-SRC assessment- e.g., self-report measures, such as the PHQ-9 assess symptoms over a defined time period and therefore would not be suitable in acute post-SRC assessments. These measures may still be beneficial in players with prolonged SRC symptoms.

5.6 Implications

This is the first study to generate normative data for a multi-domain SRC assessment in LGF players, or any comparable cohort of female, community sport athletes. Clinicians working with LGF players will now have a sport-specific database of clinical test results for post-SRC comparison. This has the potential to assist clinicians in diagnosing SRC, monitoring recovery, and guiding targeted treatments in LGF players. We recommend that the LGFA ensure that clinicians working in the sport have access to this normative data, in particular the percentile tables with suggested cut-off points. However, clinicians should be aware that this normative data included low number of adolescents, elite players, and participants with a previous diagnosed SRC, and that the findings may not accurately represent these groups. Future research should focus on generating more normative data in adolescent LGF players. Due to ongoing maturation in this age group, detailed normative data by age is required in adolescents (e.g., 13-15 years, 16-18 years). Similarly, there is also a need to develop more normative data for elite LGF players, players with a previous concussion, and players with medical conditions that may modify SRC risk or recovery (e.g., ADHD, LDs, or depression).

5.7 Link to Chapter 6

This chapter presented normative data on a multi-domain SRC assessment in LGF players, stratifying data by age, level of play, and concussion history. Normative data from a suitable population is useful for clinicians carrying out clinical assessments as it describes the range of test scores in healthy individuals. To be most useful, normative data should reflect the gender, age, and relevant medical

history of the population of interest (167). Comparing post-SRC assessment results to pre-injury baseline results, if available, is another approach for diagnosing and managing SRC. Comparison to individual baseline results may be more sensitive than using normative data in identifying deficits relating to SRC (137). However, in order for this method to be accurate, it is important that assessments produce consistent results over time. While pre-injury baseline assessments may not be frequently carried out in community sports, such as LGF, it is nevertheless important to examine the test-retest reliability of SRC assessments. Tests that demonstrate inadequate test-retest reliability may not be appropriate for inclusion in a baseline assessment, especially if a long period of time has elapsed between the baseline and post-SRC assessment. Therefore, Chapter 6 will examine the test-retest reliability of a multi-domain SRC assessment in healthy LGF players at six- and twelve-months post-baseline.

6 Test-retest reliability of a multi-domain assessment for sport-related concussion

6.1 Introduction

SRC is a trauma-induced neurological disorder that may lead to generalised cognitive impairment, as well as emotional, somatic and sleep dysregulation (18). While this impairment does not typically correspond with physical brain damage (18), symptoms may nevertheless be debilitating and result in considerable time-loss from sporting (23), educational (94) and occupational (429) activities for some players. Research suggests that the majority of SRCs are self-limiting and that symptoms usually resolve within one month of injury (94,340). Resting for the initial 24 hours post-injury, asymptomatic RTP, and following a graded RTP programme may reduce the likelihood of experiencing a prolonged recovery (18,312,341). Players who do not recover within the expected timeframe of one month may require additional rehabilitation. SRC rehabilitation is usually tailored to the signs and symptoms the player is experiencing (e.g., a player with ongoing balance and visual problems may be referred for vestibular therapy) (31,430). SRC researchers and clinicians have developed several frameworks which may explain the different clinical manifestations of SRC. One of these is the CP model, which describes five clinical profiles (cognitive, post-traumatic migraine, mood, vestibular, and ocular), as well as two modifiers (sleep and neck). Each profile is characterised by a distinct pattern of risk factors, symptoms, and clinical assessment findings, and may be useful in guiding SRC rehabilitation (31).

SRC assessments are vitally important for diagnosing, managing, and rehabilitating SRC. Multi-domain assessments that examine the full range of SRC signs and symptoms are recommended (31,32). They may incorporate computerised neurocognitive testing (158,254,431), symptom checklists (338,432), basic sideline screening tools (158,254), tests of postural or vestibular function (158,431), or general self-report measures of mood (254) or sleep (418). Following a potential SRC, a player's test results can then either be compared to an individual pre-injury baseline result or to normative data from a population with similar characteristics (137,433–435). SRC assessments may also be repeated to monitor recovery (18). Due to the serialised nature of SRC testing, it is imperative that these assessments demonstrate high test-retest reliability. Test-retest reliability refers to the degree to which a test produces consistent results across multiple assessments; it is generally lower when there is more time between assessments (159). Large amounts of measurement error (i.e., variation in a test score arising from factors that are unrelated to the construct being measured) obscure “true” test results and lead to lower reliability (159). Sources of measurement error may be random (e.g., due to a measure's inherent variability or alterations in the assessment protocol) or systematic (e.g., practice effects) (436).

The test-retest reliability of several popular SRC assessments has been evaluated over a variety of timeframes. Short- (less than one week) (161,216), medium- (two weeks to 45 days) (173,199–201),

and long-term (six months to two years) (185,203–207) ImPACT® reliability has been extensively examined. Overall, meta-analytic procedures found the test-retest reliability of ImPACT to be poor to moderate (437,438). Reliability research on The SCAT and VOMS is limited. The SCAT has demonstrated low to good test-retest reliability at intervals of one (184)- and two-weeks (439), 196 days (184), and one- and two-years (185), with the symptom report section showing higher reliability than the cognitive and balance components. Test-retest reliability of the VOMS has been shown to be high when measured between the pre-season and mid-season (228), but low after one and two years (185). Variations in timeframes between assessments, as well as in procedures for determining reliability, makes it difficult to compare studies. While these three tests comprise core SRC assessment domains, clinicians are increasingly recommended to incorporate measures that also examine other symptom domains (e.g., mood, sleep, and neck pain) into SRC assessments. However, the test-retest reliability of these measures in a sporting population is not known (276). There is a need to examine the test-retest reliability of the full battery of assessments that are recommended to be used when assessing and managing players with a suspected SRC.

LGF is a high-energy team sport in which SRCs may occur (101), and is played extensively by female athletes in Ireland (353). It is predominantly a community sport, although there is also an elite division (4). There are no reliability data available for SRC assessments in LGF players or any comparable (i.e., female, community-level) population. This is concerning as female athletes may be at an increased risk of sustaining an SRC (22,440) and may be more susceptible to a longer recovery (33) than male athletes. An understanding of the test-retest reliability of SRC assessments in this population may help to inform clinical practice in both LGF and other female, community sports. As baseline SRC testing may be performed annually (185), and as the club LGF season lasts less than eight months (personal communication, June 2022), we believe that examining the test-retest reliability of an SRC assessment both within the timeframe of the season and after twelve months would be useful to clinicians working with LGF players. Therefore, the aim of this study was to examine the test-retest reliability of a multi-domain concussion assessment (i) six- and (ii) twelve-months post-baseline in a cohort of LGF players.

6.2 Methods

6.2.1 Ethical Approval

This study was approved by the Dublin City University Research Ethics Committee in March 2019 (DCUREC/2019/010). A protocol of protective measures for in-person testing during the pandemic was also approved by the Dublin City University Biosafety Committee in October 2020.

6.2.2 Participant Recruitment

We recruited LGF players from local college and club teams. As described in Chapter 5.2.3, the eligibility criteria for inclusion were: (i) a minimum age of 13 years, and (ii) current participation in LGF. Exclusion criteria included a diagnosis of concussion by a medical professional in the 90 days preceding the initial assessment, or a suspected concussion for which the player did not seek or receive a medical assessment in the 90 days preceding the initial assessment. Participants were recruited using convenience sampling from June 2019 to February 2020.

6.2.3 Data Collection

We used a test-retest study design with three timepoints: (i) an initial assessment, (ii) a six-month re-assessment, and (iii) a twelve-month re-assessment. As outlined in Chapter 5.2.5, participants completed an in-person baseline assessment comprising computerised neurocognitive testing (ImPACT), clinical tests (SCAT5, VOMS, neck dynamometry), and symptom-report questionnaires (CP Screen, PHQ-9, GAD-7, NBQ, MIDAS, and PSQI). Due to the COVID-19 pandemic, the six-month re-assessment was carried out using an online format; therefore, only the ImPACT and questionnaire components were included in the six-month re-assessment. The twelve-month re-assessment included all tests, however ImPACT and questionnaires were carried out online to minimise the risk of COVID-19 transmission. An outline of the tests included in the analysis at each timepoint is shown in Figure 27.

Baseline Assessment (n=121)	Six-Month Assessment (n=51)	Twelve-Month Assessment (n=81)
• ImPACT • SCAT5 • VOMS • Neck Dynamometry • Questionnaires	• ImPACT • Questionnaires	• ImPACT • SCAT5 • VOMS • Neck Dynamometry • Questionnaires

Figure 27: Concussion tests carried out at baseline, six-months, and twelve-months. ImPACT: Immediate Post-Concussion Assessment and Cognitive Testing; SCAT5: Sport Concussion Assessment Tool 5th Edition; VOMS: Vestibular-Ocular Motor Screening.

6.2.4 Testing Protocol

6.2.4.1 Initial Assessment

The initial, ninety-minute assessment involved anthropometric measurements, ImPACT® (133), the SCAT5 (132), VOMS (121), neck dynamometry (373), the CP Screen (131), the PHQ-9 (241), the GAD-7 (240), the NBQ (292), the MIDAS (263), and the PSQI (286). Most participants completed the assessment split across two separate days, with a median of 9 (IQR: 7) days between the two parts of the assessment. Written, informed consent was provided by participants before data collection. Chapter 5.2.5 contains an in-depth description of the initial assessment.

6.2.4.2 Online Re-Assessment

The principal investigator organised a Zoom call with each participant who was available for the online re-assessment. Before the Zoom call, participants received an email containing: (i) a link to an online version of ImPACT®, (ii) an ImPACT® test code, (iii) their ImPACT® passport ID, (iv) a link to an online version of the questionnaires, and (v) an ID number assigned to them by the principal investigator at the initial assessment. The online re-assessment took approximately 50 minutes.

6.2.4.2.1 Immediate Post-Concussion Assessment and Cognitive Testing

Participants completed the online version of ImPACT® (version 3.11.1; ImPACT Applications, Pittsburgh, PA, US) from their own homes. Whilst on the Zoom call, the principal investigator instructed participants on how to launch the test, assisted with technical issues, and remotely supervised the entire duration of the test. Remote supervision enabled the principal investigator to ensure that tests were carried out in a quiet, distraction-free environment. As participants used their own laptops, the majority performed the test using a laptop trackpad instead of an external mouse.

6.2.4.2.2 Questionnaires

We created an online version of the questionnaires using a Google form (Google, Mountain View, CA, US). To prevent participants from accidentally or intentionally skipping questions, the questionnaires were programmed to require a response to each question. Participants answered these questionnaires while the principal investigator was online on the Zoom call.

6.2.4.3 In-Person Re-Assessment

In-person re-assessments included the SCAT5, VOMS, and neck dynamometry. We followed the protocols used for the baseline assessment, however as testing took place during the COVID-19 pandemic the following additional infection control measures were taken:

- a) Before attending DCU campus, participants were required to submit a health declaration form confirming that they had not experienced any COVID-19 symptoms, been a close contact of a COVID-19 case or travelled internationally to a non-green list country during the previous 14 days, and that they were not currently being advised to self-isolate. The principal investigator

contacted participants on the morning of testing to ensure that they had not since developed symptoms.

- b) Individual testing times for participants were organised to prevent contact between participants. Time slots were spaced with at least two-and-a-half hours between starting times to provide sufficient time to disinfect all equipment and surface areas with which either the principal investigator or participant came into contact.
- c) To minimise time spent indoors, the principal investigator arranged to meet participants at a designated point outside and then escorted them to the biomechanics lab, where testing took place.
- d) The exact time the participant arrived in and departed from the building were recorded in case this information was subsequently required for contact tracing.
- e) The principal investigator and participant sanitised their hands before and after testing.
- f) Both the principal investigator and participant wore masks for the duration of testing. The principal investigator also wore a disposable gown and face shield, which she put on once the participant had been escorted to the biomechanics lab. Immediately after testing, gowns were disposed of in a general waste bin and the face shield was disinfected.
- g) The door to the biomechanics lab was left open for the duration of testing.
- h) Where possible, a distance of at least two metres was maintained between the principal investigator and the participant.
- i) Immediately following the participant's departure, all equipment and surface areas with which either the principal investigator or the participant came into contact were disinfected.

6.2.4.3.1 Sport Concussion Assessment Tool 5th Edition

Several hours before testing, the principal investigator sent participants an online version of the GSC and asked them to complete it prior to attending DCU to minimise in-person testing time. As the GSC asks participants to rate symptoms based on how they “typically feel”, the time lag between completing the GSC and the rest of the SCAT5 should not have affected results. Before commencing the SCAT5, the principal investigator checked that the participant had already answered the GSC, and if they had not, gave them the opportunity to complete it on their phone before continuing with the testing.

The SAC and FTN tests were performed with the principal investigator and participant seated three metres apart. The 10-word list “H” was used in the immediate memory component of the SAC, while list “B” was used in the “digits backward” test. When assessing the TG and mBESS, the principal investigator stood at least two metres away from the participant.

6.2.4.3.2 Vestibular-Ocular Motor Screening

The VOMS was carried out as described in Chapter 5.2.5.4. A new target was provided for each participant and was immediately disposed of following the completion of the VOMS. NPC distance was measured using a paper ruler, which was disposed of following the completion of the NPC component.

6.2.4.3.3 Neck Dynamometry

We followed the neck dynamometry protocol from Chapter 1.1.1.1. The HHD, chair and plinth were sanitised after each participant had been tested.

6.2.5 *Statistical Analysis*

6.2.5.1 *Data Cleaning and Processing*

Raw data were initially manually entered (i.e., from paper questionnaires and clinical test results recorded on paper) or imported (i.e., from ImPACT® results and online questionnaires) into an Excel spreadsheet (Microsoft Corporation, Redmond, WA, US). This spreadsheet was imported into RStudio (RStudio, Boston, MA, US) for cleaning and analysis.

Overall, 9.9% of data were missing across the three time-points. Between 0.8% and 29.8% of data were missing for each variable. Data were missing due to (i) some participants only completing partial re-assessments due to the COVID-19 pandemic (unit non-response), (ii) the HHD not working or software malfunctions (unit non-response), (iii) invalid ImPACT results (unit non-response), (iv) errors made by the tester during data collection (item non-response) or (v) participants skipping questions on paper versions of questionnaires (item non-response). Multiple imputation was considered inappropriate for dealing with missing data due to the large number of variables compared to cases in the dataset. We instead used available case analysis for unit non-responses (i.e., only participants who had completed a particular test at both timepoints were included in the analysis for that test). We imputed item non-responses using median imputation, which substitutes missing values with the variable's median value (382,383). A limitation of median imputation is that it reduces the variability of data, however we only applied it to variables with a small amount of missing data (0.8% to 7.4%). We calculated scores for the SCAT5 components, individual VOMS items and total symptoms, normalised neck strength, CP Screen, PHQ-9, GAD-7, NBQ, MIDAS, and PSQI as described in Chapter 5.2.5 for each timepoint.

6.2.5.2 *Test-Retest Reliability*

Demographic and sport-related characteristics were reported for adolescent and adult participants collectively and separately. We calculated descriptive statistics (means, standard deviations, medians, and interquartile ranges) for all outcomes at each timepoint. Baseline descriptive statistics for ImPACT® and questionnaire variables were presented separately for participants who did a repeat assessment at six-months and twelve-months. We were unable to carry out separate reliability analyses for adolescent and adult participants due to the low number of participants in each group when participants were separated by age.

Prior to conducting reliability analyses, we assessed the distribution of all outcomes at each timepoint using a combination of histograms with density curves, Q-Q plots, and Shapiro-Wilk tests. Variables displaying a very limited range of values (e.g., orientation, concentration, and delayed memory scores, and VOMS and CP screen items) were converted to categorical variables. Categorical variables containing levels with a small number of participants ($n \leq 4$) were collapsed into fewer levels. VOMS item scores were categorised as 0, 1 or ≥ 2 . CP screen items were categorised into levels of 0, 1 or ≥ 2 (migraine, vestibular and neck items), levels of 0, 1, 2 or ≥ 3 (cognitive and sleep items), or levels of 0, 1, 2, 3 or ≥ 4 (ocular or anxiety items). Weighted Cohen's Kappa using linear weights were used to assess the test-retest reliability of categorical variables. Kappa coefficients range from 0-1 (no agreement: ≤ 0 ; none to slight agreement: 0.01-0.20; fair agreement: 0.21-0.40; moderate agreement: 0.41-0.60; substantial agreement: 0.61-0.80; almost perfect agreement: 0.81-1.00) A Kappa coefficient of 0.40 was considered to represent adequate reliability (229). The test-retest reliability of normally distributed continuous outcomes was examined using intraclass correlation coefficients (ICCs). We selected two-way random-effects ICC models for agreement between timepoints and used either average (ICC (2,k)) or single (ICC (2,1)) measures. ICCs range from 0-1 (low: <0.60 ; marginal: 0.60-0.69; adequate: 0.70-0.79; high: 0.80-0.89; very high: ≥ 0.90) An ICC ≥ 0.70 was considered to show adequate reliability (164). Lin's concordance correlation coefficients (LCCCs) were used to analyse the test-retest reliability of continuous outcomes that were not normally distributed. LCCCs also range from 0-1 and can be interpreted similarly to Pearson's correlation coefficients (very weak: <0.20 ; weak: ≥ 0.20 -0.40; moderate: ≥ 0.40 -0.60; strong: ≥ 0.60 -0.80; very strong: >0.80). LCCCs ≥ 0.40 were regarded as representing sufficient reliability (163,208). Similar to ICCs, LCCCs are a measure of agreement between variables however they do not assume a normal distribution.(441) 95% CIs were computed for all reliability coefficients. We also calculated Cohen's D effect sizes to measure the amount of change in measures between assessment timepoints (negligible: <0.20 ; small: 0.20- <0.50 ; medium: 0.50- <0.80 ; large: ≥ 0.80) (442). The reliability analyses used for each outcome are shown in Table 64.

Table 64: Analyses selected for concussion outcomes

Assessment	Outcome	Reliability Analysis	
		Baseline to 6-months	Baseline to 12-months
Immediate Post Concussion Assessment and Cognitive Testing	Verbal Memory Score	LCCC	LCCC
	Visual Memory Score	ICC (2,1)	ICC (2,1)
	Visual Motor Score	ICC (2,1)	ICC (2,1)
	Reaction Time	LCCC	LCCC
	Post-Concussion Symptom Score	LCCC	LCCC
Sport Concussion Assessment Tool 5th Edition	Total Symptom Score	-	LCCC
	Symptom Severity Score	-	LCCC
	Orientation	-	Weighted κ
	Immediate Memory	-	ICC (2,1)
	Concentration	-	Weighted κ
	Delayed Memory	-	Weighted κ
	Finger-to-nose Time	-	ICC (2,1)
	Tandem Gait Time	-	ICC (2,1)
	Modified BESS Total Score	-	LCCC
	Smooth Pursuits Score	-	Weighted κ (0, 1, ≥ 2)
	Horizontal Saccades Score	-	Weighted κ (0, 1, ≥ 2)
	Vertical Saccades Score	-	Weighted κ (0, 1, ≥ 2)
Vestibular-Ocular Motor Screening	Convergence Score	-	Weighted κ (0, 1, ≥ 2)
	Near Point of Convergence	-	LCCC
	Horizontal VOR Score	-	Weighted κ (0, 1, ≥ 2)
	Vertical VOR Score	-	Weighted κ (0, 1, ≥ 2)
	Visual Motion Sensitivity Score	-	Weighted κ (0, 1, ≥ 2)
	Total symptom score	-	LCCC
Neck Dynamometry	Neck Flexion	-	ICC (2,k)
	Neck Extension	-	ICC (2,k)
	Dominant Side Lateral Neck Flexion	-	ICC (2,k)
	Non-Dominant Side Lateral Neck Flexion	-	ICC (2,k)
	Dominant Side Neck Rotation	-	ICC (2,k)
	Non-Dominant Side Neck Rotation	-	ICC (2,k)
Clinical Profiles Screen	CP Total Score	LCCC	LCCC
	CP Cognitive/Fatigue Score	Weighted κ (0, 1, 2, ≥ 3)	Weighted κ (0, 1, 2, ≥ 3)
	CP Migraine Score	Weighted κ (0, 1, ≥ 2)	Weighted κ (0, 1, ≥ 2)
	CP Vestibular Score	Weighted κ (0, 1, ≥ 2)	Weighted κ (0, 1, ≥ 2)
	CP Ocular Score	Weighted κ (0, 1, 2, 3, ≥ 4)	Weighted κ (0, 1, 2, 3, ≥ 4)
	CP Anxiety/Mood Score	Weighted κ (0, 1, 2, 3, ≥ 4)	Weighted κ (0, 1, 2, 3, ≥ 4)
	CP Sleep Score	Weighted κ (0, 1, 2, ≥ 3)	Weighted κ (0, 1, 2, ≥ 3)
	CP Neck Score	Weighted κ (0, 1, ≥ 2)	Weighted κ (0, 1, ≥ 2)
Patient Health Questionnaire-9	Total Score	LCCC	LCCC
Generalised Anxiety Disorder-7	Total Score	LCCC	LCCC
Neck Bournemouth Questionnaire	Total Score	LCCC	LCCC
Migraine Disability Assessment	Total Score	LCCC	LCCC
Pittsburgh Sleep Quality Index	Total Global Score	ICC (2,1)	ICC (2,1)

6.2.5.3 *Reliable Change Indices*

We calculated reliable change indices (RCIs) for all normally distributed variables using the method outlined by Iverson (161). RCIs quantify how much change is required on a test score to demonstrate a “reliable change”- i.e., a change that is not due to measurement error. Confidence intervals are constructed around a mean change score to reflect the amount of variation that may be expected between assessments, and change scores that exceed these limits are regarded as having demonstrated a reliable change at a given confidence level (443). RCIs are advantageous to clinicians as they provide an objective measure of reliability. However, they are not appropriate for non-normally distributed data as they are calculated using standard errors of measurement (SEMs), which assume a normal distribution. To calculate RCIs, standard errors of the difference between means (SDiff) were first derived using the following formulae, where SD_1 refers to the variable's standard deviation at the baseline, SD_2 refers to the variable's standard deviation at the re-assessment, and $r_{1,2}$ refers to the reliability coefficient of the variable (e.g., the ICC) between the two assessments:

$$SEM_1 = SD_1 \sqrt{1 - r_{1,2}}$$

$$SEM_2 = SD_2 \sqrt{1 - r_{1,2}}$$

$$SDiff = \sqrt{SEM_1^2 + SEM_2^2}$$

SDiffs were multiplied by ± 1.282 (80% CI), ± 1.645 (90% CI), and ± 1.960 (95% CI). The resulting scores represented the magnitude of change that may occur between assessments due to measurement error at various confidence levels; change scores exceeding these thresholds can therefore be interpreted as representing significant, reliable change. We presented SEMs for normally distributed variables at baseline and re-assessment, SDiffs, and RCIs at 80%, 90%, and 95% CIs. We subsequently calculated the proportion of participants who exceeded RCI cut-off points at each confidence level. It was expected that approximately 20%, 10% and 5% of participants would exceed RCIs at the 80%, 90%, and 95% confidence levels in normally distributed variables, respectively. Results were presented for 80% and 90% CIs, in addition to the 95% CI, to provide clinicians with a greater understanding of the amount of measurement error associated with assessments.

6.3 Results

6.3.1 Participants

An initial 121 participants took part in the study. Fifty-one participants completed a baseline assessment and re-assessment at six-months, while 81 completed a re-assessment at twelve-months. There were 11 participants who completed both a six-month and twelve-month re-assessment; due to the potential practice effects associated with repeat testing, we assessed the test-retest reliability of participants' first and second assessments only for a given test (i.e., participants who were assessed at the three time-points were included in the six-month group for the ImPACT and questionnaires, and in the twelve-month group for the clinical tests). In addition, 13 participants were excluded from the dataset due having to a history of a suspected or diagnosed concussion in the three months prior to the baseline assessment (n=5), missing information about their concussion history (n=4) or sustaining a concussion between the baseline and re-assessment (n=4). The final dataset included 108 participants (70.4% adult, 29.6% adolescent).

Elite players comprised over a quarter of the sample (26.9%), although a greater proportion of adult than adolescent players were elite (31.6% vs 15.6%). An overall 29.6% of participants reported a previous suspected or diagnosed concussion; less than half (43.8%) of these believed they had previously sustained two or more concussions. Similar proportions of participants played one (46.8% vs 43.1%), two (10.6% vs 9.7%), or three (0.0% vs 2.8%) sports other than LGF in both the six-month and the twelve-month re-assessment groups. These characteristics are presented by timepoint group in detail in Table 65.

Table 65: Participant demographic characteristics by re-assessment group. Eleven participants completed re-assessments at both the six- and twelve-months timepoints and are included in both groups here.

	Overall (N=108)	Six-month group (N=47)	Twelve-month group (N=72)
Days since baseline assessment, median (IQR)	-	168 (54)	367 (82)
Age, median (IQR)	19 (5.0)	19 (1.0)	18 (6.3)
Age Group			
Adolescent	29.6 (32)	0.0 (0)	44.4 (32)
Adult	70.4 (76)	100.0 (47)	55.6 (40)
Height in cm, median (IQR)	170 (6.0)	170 (5.5)	170 (7.4)
Missing	10.2 (11)	-	15.3 (11)
Body mass in kg, median (IQR)	65.0 (11)	66 (7.9)	63 (11)
Missing	11.1 (12)	-	16.7 (12)
County			
Elite	26.9 (29)	46.8 (22)	16.7 (12)
Non-Elite	73.1 (79)	53.2 (25)	83.3 (60)
Number of years playing, median (IQR)	11 (6.3)	12 (5.0)	10 (7.0)
Playing position, % (n)			
Forward	45.4 (49)	40.4 (19)	44.4 (32)
Midfield	16.7 (18)	25.5 (12)	15.3 (11)
Back	33.3 (36)	27.7 (13)	36.1 (26)
Goalkeeper	2.8 (3)	4.3 (2)	2.8 (2)
Multiple	1.9 (2)	2.1 (1)	1.4 (1)
Participates in another sport			
No	43.5% (47)	42.6% (20)	44.4% (32)
One other sport	44.4% (48)	46.8% (22)	43.1% (31)
Two other sports	10.2% (11)	10.6% (5)	9.7% (7)
Three other sports	1.9% (2)	0.0% (0)	2.8% (2)
History of diagnosed concussion, % (n)			
Yes	17.8 (19)	26.1 (12)	15.3 (11)
No	82.2 (88)	73.9 (34)	84.7 (61)
Missing	0.9 (1)	2.1 (1)	-
History of suspected or diagnosed concussion, % (n)			
Yes	29.6 (32)	36.2 (17)	29.2 (21)
No	70.4 (76)	63.8 (30)	70.8 (51)
Number of suspected and diagnosed concussion, % (n)			
None	70.4 (76)	63.8 (30)	70.8 (51)
1	16.7 (18)	19.1 (9)	16.7 (12)
2	9.3 (10)	10.6 (5)	9.7 (7)
3+	3.7 (4)	6.4 (3)	2.8 (2)

IQR: Interquartile range.

6.3.2 Immediate Post-Concussion Assessment and Cognitive Testing

We assessed ImPACT® test-retest reliability in both the six- and twelve-month re-assessment groups (see Table 67). The reliability of ImPACT® composite scores ranged from low (ICC=0.28, LCCC=0.30) to adequate (ICC=0.78, LCCC=0.58). Verbal and visual memory reliability coefficients were mostly low, with the exception of verbal memory at twelve months (adequate; LCCC=0.48) (see Figure 28). Visual-motor speed score was adequate at the six-month assessment (ICC=0.78) but low at the twelve-month assessment (ICC=0.56), while reaction time score was low at the six-month assessment (LCCC=0.30) and adequate at the twelve-month assessment (LCCC=0.58) (see Figure 29). The reliability of PCSS scores ranged from adequate (LCCC=0.46, six-month assessment) to strong (LCCC=0.68, twelve-month assessment). ImPACT® scores, other than visual-motor speed score, demonstrated higher reliability at the twelve-month re-assessment than at the six-month re-assessment. Cohen's D effect sizes indicated that there were small changes in visual memory (increase; $d=0.20$) and visual-motor speed (decrease; $d=0.25$) score between the baseline and twelve-month assessment, and in PCSS scores (decrease; $d=0.30$) between the baseline and six-month assessment. In addition, there was a medium increase in visual-motor speed score ($d=0.53$) between the baseline and six-month assessments. RCI clinical cut-off points of 26.1 (six-month group) and 28.2 (twelve-month group) for visual memory score, and 7.7 (six-month group) and 10.4 (twelve-month group) for visual-motor speed score, were reported at the 95% CI (see Table 68). 95.6% ($n=2$) of participants fell within the expected range of scores at the six-month assessment, while 96.5% ($n=2$) were within the expected range at the twelve-month assessment (see Table 69,

Figure 33 and Figure 34).

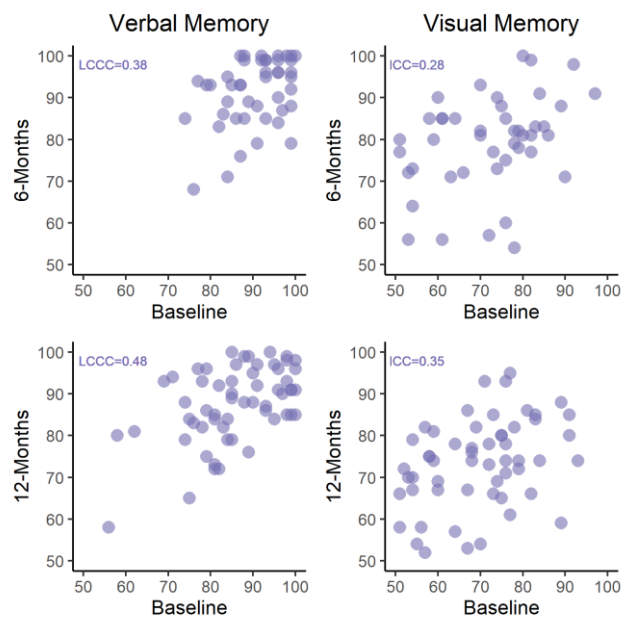


Figure 28: Test-retest reliability scatterplots for ImPACT® Verbal Memory and Visual Memory composite scores at the (i) baseline to six-month (above), and (ii) baseline to twelve-month (below) timepoints.

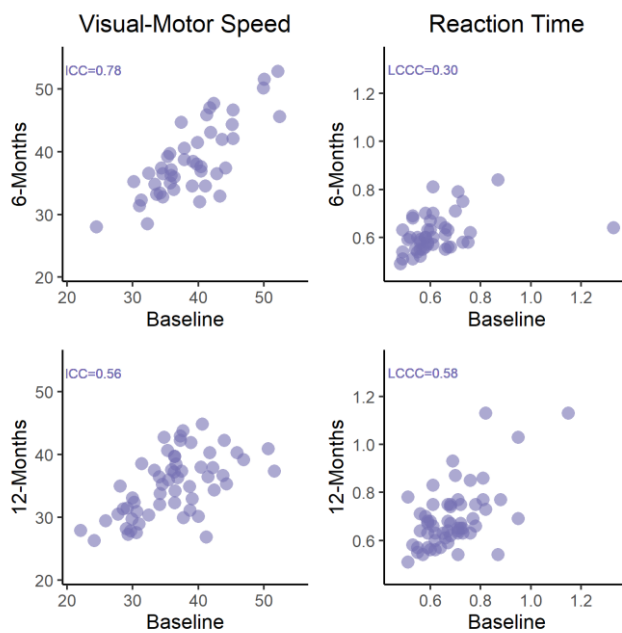


Figure 29: Test-retest reliability scatterplots for ImPACT® Visual-Motor Speed and Reaction Time composite scores at the (i) baseline to six-month (above), and (ii) baseline to twelve-month (below) timepoints.

6.3.3 *Sport Concussion Assessment Tool 5th Edition*

Test-retest reliability of SCAT5 components was assessed from baseline to twelve-months and is reported in detail in

Table 66. The highest test-retest reliability coefficients for the SCAT5 were reported for the TSS and SSS, which displayed strong (LCCC=0.69, 0.79) reliability (see Figure 30). Reliability for both the SAC (orientation, immediate memory, concentration, and delayed memory) and neurological (FTN, TG, and mBESS) components of the SCAT5 was low (ICCs=0.40-0.47; LCCCs=0.22; κ =0.00-0.21) (see Figure 31). Small improvements were found for orientation ($d=0.48$), immediate memory ($d=0.47$), and concentration ($d=0.22$) scores at the twelve-month assessment. Delayed memory ($d=0.59$) and TG time ($d=0.50$) demonstrated moderate improvements at the twelve-month assessment, while mBESS total score showed a moderate deterioration ($d=0.59$). Change scores exceeding 6.17 for immediate memory, 1.97 seconds for FTN time, and 10 seconds for TG time were considered to signify reliable change with a 95% CI (see Table 68). Between 4.7% ($n=2$) and 9.3% ($n=4$) of participants scored outside of this range at the twelve-month assessment (see Table 69 and Figure 34).

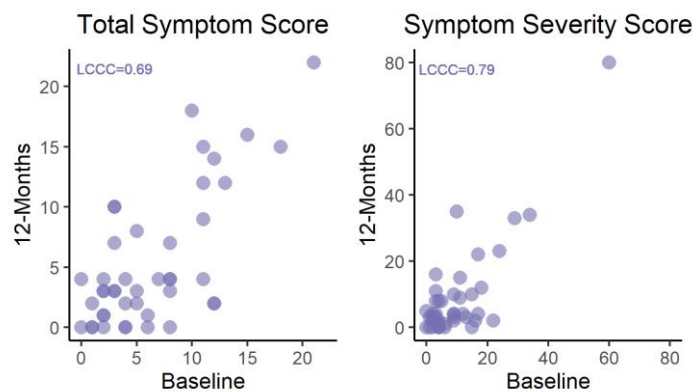


Figure 30: Test-retest reliability scatterplots for the SCAT5 Total Symptom Score (left) and Symptom Severity Score (right)

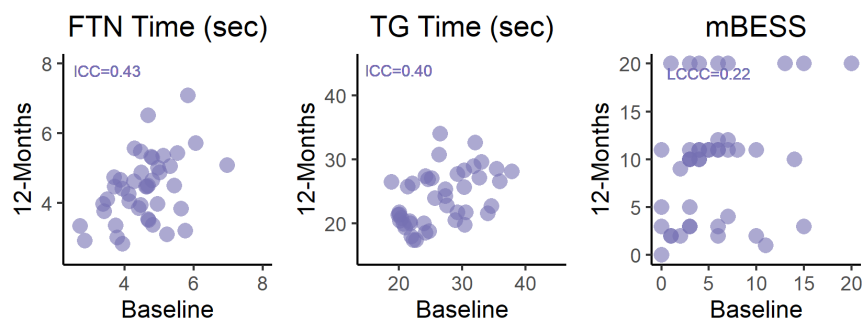


Figure 31: Test-retest reliability scatterplots for the SCAT5 Finger-to-Nose (FTN) time in seconds, Tandem Gait (TG) time in seconds, and modified Balance Error Scoring System (mBESS) tests

6.3.4 Vestibular-Ocular Motor Screening

VOMS test-retest reliability was examined between baseline and twelve months (see

Table 66). Weighted Kappa coefficients for individual VOMS items ranged from 0.08-0.34. Horizontal saccades ($\kappa=0.34$), horizontal VOR ($\kappa=0.31$), and convergence ($\kappa=0.23$) items demonstrated fair reliability between the baseline and twelve-month assessment, although the CI for the convergence item included zero. Smooth pursuits ($\kappa=0.15$), vertical saccades ($\kappa=0.19$), vertical VOR ($\kappa=0.16$), and VMS ($\kappa=0.08$) displayed no or fair reliability between assessments, and all had CIs crossing zero. Similarly, test-retest reliability for NPC distance (LCCC=0.09) and TSS (LCCC=0.25) was low. Small decreases ($d=0.30$) and increases ($d=0.20$) were reported for the vertical saccades and convergence item scores between the baseline and twelve-month assessments, respectively. NPC distance increased at the twelve-month assessment, with a medium effect size ($d=0.65$).

6.3.5 Neck Dynamometry

The test-retest reliability of neck strength was evaluated between the baseline and twelve-month timepoints (see

Table 66). Neck strength ICCs for the baseline to twelve-month assessment ranged from 0.54-0.76. The highest ICCs were reported for neck flexion (ICC=0.75), and dominant (ICC=0.76) and non-dominant (ICC=0.76) side rotation, representing good test-retest reliability. Neck extension (ICC=0.54) and dominant (ICC=0.58) and non-dominant (ICC=0.62) side lateral flexion showed moderate reliability, although the neck extension ICC CI included zero. Neck flexion ($d=0.54$) and non-dominant side lateral flexion strength ($d=0.63$) demonstrated a medium reduction at the twelve-month assessment, while a large reduction in strength was found for neck extension ($d=0.91$) at the twelve-month assessment.

RCI cut-off scores of between 0.28 and 0.68 N/kg were reported at the 95% CI (see Table 68). The proportion of participants exceeding these thresholds ranged from 10.3% to 23.1% (see Table 69 and Figure 35). Most participants exceeding the cut-off values for neck flexion (20.5%), extension (12.8%) and lateral flexion (7.7% and 12.8%) demonstrated decreases, rather than improvements, in neck strength at the twelve-month assessment.

6.3.6 Clinical Profiles Screen

Six-month and twelve-month test-retest reliability of the CP Screen was evaluated in separate groups and is reported in Table 67. The total CP Screen score demonstrated strong test-retest reliability (LCCC: 0.68) in six-month group, and weak test-retest reliability (LCCC: 0.34) in the twelve-month group. Weighted kappa coefficients of 0.25-0.46 (representing fair to moderate reliability) were reported for CP Screen items between the baseline and six-month assessments, while coefficients of 0.03-0.42 (representing no to moderate reliability) were reported between the baseline and twelve-month assessments. The migraine ($\kappa=0.46$) and mood ($\kappa=0.37$) items had the highest reliability at the six-month assessment, while the ocular ($\kappa=0.42$) and mood ($\kappa=0.28$) items had the highest reliability at the twelve-month assessment. The cognitive ($\kappa=0.12$), migraine ($\kappa=0.05$), sleep ($\kappa=0.10$), and neck ($\kappa=0.03$) items displayed no to slight test-retest reliability at the twelve-month assessment. Medium increases in ocular ($d=0.26$), migraine ($d=0.23$), and neck ($d=0.25$) scores, signifying worsened symptoms, were found between the baseline and twelve-month assessment. Negligible changes were found for all CP Screen items between the baseline and six-month timepoints.

6.3.7 Health Questionnaires

Health questionnaire test-retest reliability was examined between the baseline and six-month, and baseline and twelve-month timepoints (see Table 67). The PHQ-9 and GAD-7 showed moderate to strong test-retest reliability (LCCCs of 0.40-0.68), with higher reliability reported at the twelve-month re-assessment than the six-month re-assessment (see Figure 32). The test-retest reliability of the NBQ was weak (LCCC=0.38) at the six-month and moderate (LCCC=0.44) at the twelve-month assessment, while the MIDAS demonstrated weak reliability (LCCCs=0.33, 0.29) at both timepoints.

ICCs for the PSQI ranged from 0.57 (six-month re-assessment) to 0.48 (twelve-month re-assessment), indicating moderate and poor test-retest reliability, respectively. Overall, the GAD-7 showed the highest test-retest reliability of all health questionnaires at both timepoints, while the MIDAS showed the lowest reliability. Negligible changes in health questionnaire scores were reported between assessment timepoints with the exception of the PHQ-9, for which a small decrease in score was found between the baseline and six-month assessments. RCI cut-off values of 4.5 and 4.8 were determined for the PSQI for the six- and twelve-month assessments at 95% CIs, respectively (see Table 68). The proportion of participants who fell outside these values was 6.7% (n=3) at the six-month assessment, and 8.2% (n=5) at the twelve-month assessment (see Table 69 and Figure 34).

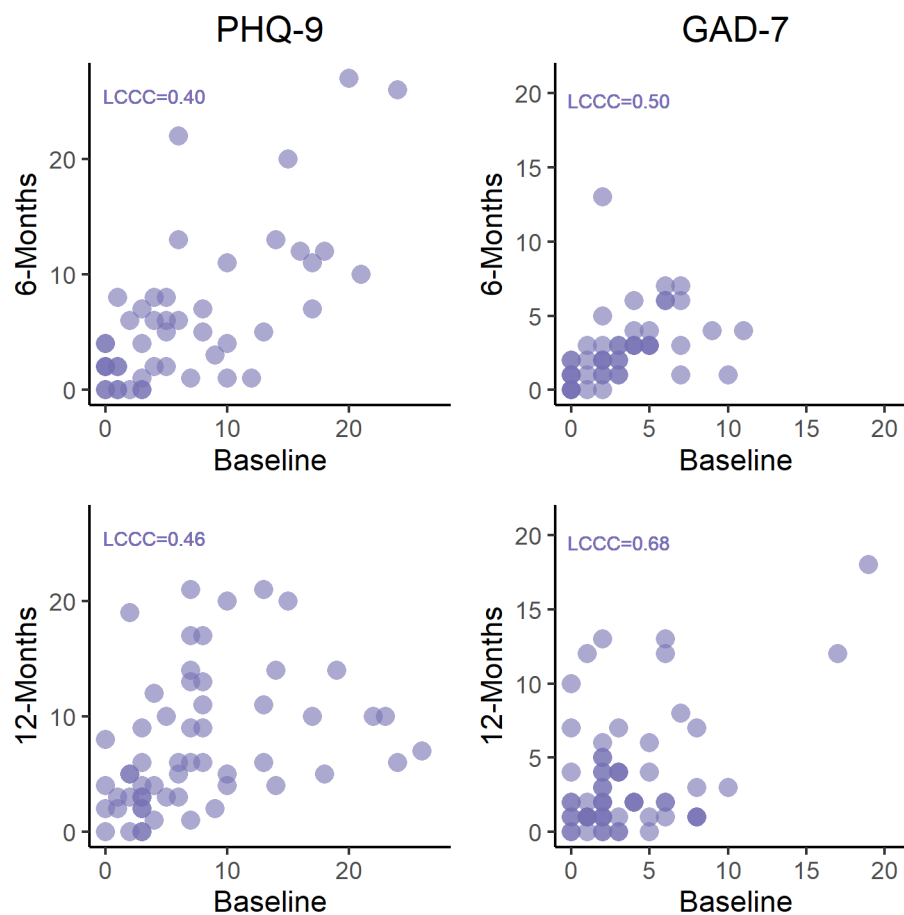


Figure 32: Test-retest reliability scatterplots for the Patient Health Questionnaire-9 (PHQ-9) and Generalised Anxiety Disorder-7 (GAD-7) questionnaires at the (i) six-month (above) and (ii) twelve-month (below) timepoints

Table 66: Descriptive statistics and reliability analyses for clinical tests

<i>Sport Concussion Assessment Tool 5th Edition</i>		N	Missing	Mean (SD)	Median (IQR)	ICC (2,1)/LCCC	Weighted κ (95% CI)	Cohen's D
<i>Graded Symptom Checklist</i>								
Total symptom score	Baseline	43	0	6.4 (5.0)	5.0 (2.5-10.5)	0.69 (0.51, 0.82) ¹	-	0.11
	12-months	43	0	5.4 (5.7)	3.0 (1.5-8.5)	-	-	-
Symptom severity score	Baseline	43	0	10.1 (11.1)	6 (3-14)	0.79 (0.67, 0.88) ¹	-	-0.01
	12-months	43	0	9.1 (14.4)	4 (2-10)	-	-	-
<i>Standardized Assessment of Concussion</i>								
Orientation	Baseline	43	0	4.9 (0.4)	5 (5-5)	-	0 (0, 0)	-0.48
	12-months	43	0	5.0 (0.0)	5 (5-5)	-	-	-
Immediate memory	Baseline	43	0	19.7 (3.4)	20 (18-22)	0.47 (0.19, 0.68) ²	-	-0.47
	12-months	43	0	21.2 (2.9)	21 (19-22.5)	-	-	-
Concentration	Baseline	43	0	4.0 (1.1)	4 (3-5)	-	0.03 (-0.12, 0.19)	-0.22
	12-months	43	0	4.2 (1.0)	4 (4-5)	-	-	-
Delayed memory	Baseline	43	0	6.3 (1.7)	6 (5-8)	-	0.21 (-0.01-0.43)	-0.59
	12-months	43	0	7.3 (1.7)	8 (6-9)	-	-	-
<i>Neurological Tests</i>		43	0					
Finger-to-nose time	Baseline	43	0	4.6 (0.9)	4.7 (3.9-5.0)	0.43 (0.16, 0.65) ²	-	0.14
	12-months	43	0	4.4 (0.9)	4.5 (3.8-5.0)	-	-	-
Tandem gait time	Baseline	43	0	26.5 (5.2)	25.7 (21.9-30.4)	0.40 (0.10, 0.63) ²	-	0.50
	12-months	43	0	23.9 (4.3)	22.8 (20.4-27.1)	-	-	-
mBESS	Baseline	43	0	5.6 (4.6)	4 (3-7)	0.22 (0.00, 0.43) ¹	-	-0.59
	12-months	43	0	9.6 (6.3)	10 (3-11)	-	-	-
<i>Vestibular-Ocular Motor Screening</i>		N	Missing	Mean (SD)	Median (IQR)	LCCC	Weighted κ (95% CI)	Cohen's D
Smooth pursuits	Baseline	43	0	0.2 (0.4)	0 (0-0)	-	0.15 (-0.31, 0.62)	0.05
	12-months	43	0	0.2 (0.4)	0 (0-0)	-	-	-
Horizontal saccades	Baseline	43	0	0.3 (0.6)	0 (0-1)	-	0.34 (0.08, 0.60)	0.11
	12-months	43	0	0.3 (0.7)	0 (0-0)	-	-	-
Vertical saccades	Baseline	43	0	0.7 (0.8)	0 (0-1)	-	0.19 (-0.05, 0.43)	0.30
	12-months	43	0	0.4 (0.8)	0 (0-1)	-	-	-
Near point of convergence	Baseline	43	0	0.3 (0.7)	0 (0-0)	-	0.23 (-0.06, 0.53)	-0.20
	12-months	43	0	0.5 (1.1)	0 (0-0)	-	-	-
Horizontal vestibular-ocular reflex	Baseline	43	0	0.4 (1.0)	0 (0-0.5)	-	0.31 (0.11, 0.52)	-0.07
	12-months	43	0	0.5 (0.9)	0 (0-1)	-	-	-
Vertical vestibular-ocular reflex	Baseline	43	0	0.5 (1.0)	0 (0-1)	-	0.16 (-0.05, 0.37)	0.10

	12-months	43	0	0.4 (0.8)	0 (0-1)	-	-	-
Visual motion sensitivity	Baseline	43	0	0.4 (1.1)	0 (0-0)	-	0.08 (-0.18, 0.34)	-0.11
	12-months	43	0	0.6 (1.1)	0 (0-1)	-	-	-
Near point of convergence, cm	Baseline	43	0	0.7 (1.6)	0.0 (0.0-0.3)	0.09 (-0.14, 0.31)	-	-0.65
	12-months	43	0	2.0 (2.7)	1.7 (0.0-2.7)	-	-	-
Total symptom score	Baseline	43	0	2.9 (4.5)	1 (0-4.5)	0.25 (0.05, 0.51)	-	-0.02
	12-months	43	0	2.9 (4.5)	1 (0-4)	-	-	-
Neck Dynamometry		N	Missing	Mean (SD)	Median (IQR)	ICC (2,k)	Weighted κ (95% CI)	Cohen's D
Neck flexion	Baseline	39	4	1.2 (0.3)	1.2 (1.0-1.4)	0.75 (0.37, 0.89)	-	0.54
	12-months	39	4	1.0 (0.4)	0.9 (0.8-1.1)	-	-	-
Neck extension	Baseline	39	4	1.3 (0.3)	1.3 (1.1-1.5)	0.54 (-0.07, 0.79)	-	0.91
	12-months	39	4	1.2 (0.4)	1.1 (0.9-1.3)	-	-	-
Dominant side neck lateral flexion	Baseline	39	4	1.0 (0.2)	1.0 (0.9-1.1)	0.58 (0.21, 0.78)	-	0.44
	12-months	39	4	0.9 (0.3)	0.9 (0.7-1.1)	-	-	-
Non-dominant side neck lateral flexion	Baseline	39	4	1.0 (0.2)	1.0 (0.9-1.1)	0.62 (0.19, 0.81)	-	0.63
	12-months	39	4	0.8 (0.3)	0.8 (0.6-1.0)	-	-	-
Dominant side neck rotation	Baseline	39	4	0.7 (0.2)	0.7 (0.6-0.7)	0.76 (0.54, 0.87)	-	0.15
	12-months	39	4	0.6 (0.2)	0.6 (0.5-0.8)	-	-	-
Non-dominant side neck rotation	Baseline	39	4	0.6 (0.2)	0.6 (0.5-0.7)	0.76 (0.53, 0.87)	-	0.08
	12-months	39	4	0.6 (0.3)	0.6 (0.4-0.7)	-	-	-

SD: Standard deviation; IQR: Interquartile range; LCCC: Lin's concordance correlation coefficient; ICC (2,1) /ICC (2,k): Intraclass correlation coefficient two-way model random effects for single/average measurements; Weighted κ : Weighted Kappa; 1: LCCC used; 2: ICC (2,1) used.

Table 67: Descriptive statistics and reliability analyses for Immediate Post-Concussion Assessment and Cognitive Testing and questionnaires

ImPACT®¹	Timepoint	N	Missing	Mean (SD)	Median (IQR)	ICC (2,1) (95% CI)	LCCC (95% CI)	Cohen's D
Verbal memory score	Baseline	45	2	90.4 (7.1)	92 (86-96)	-	0.38 (0.10, 0.60)	-0.12
	6-months	45	2	91.4 (8.1)	93 (86-99)	-	-	-
	Baseline	58	3	85.8 (10.7)	85 (79-95)	-	0.48 (0.27, 0.65)	-0.09
	12-months	58	3	87.6 (9.0)	88.5 (83-95)	-	-	-
Visual memory score	Baseline	45	2	72.3 (12.0)	75 (61-80)	0.28 (0.01, 0.52)	-	-0.53
	6-months	45	2	78.6 (12.0)	81 (73-85)	-	-	-
	Baseline	58	3	69.1 (12.1)	70.5 (58-77)	0.35 (0.11, 0.55)	-	-0.20
	12-months	58	3	72.6 (11.1)	74 (66-80)	-	-	-
Visual-motor score	Baseline	45	2	38.9 (5.9)	39.1 (34.6-42.3)	0.78 (0.64, 0.88)	-	0.04
	6-months	45	2	38.7 (5.9)	37.4 (34.5-42)	-	-	-
	Baseline	58	3	36.0 (6.2)	36.4 (30.7-40)	0.56 (0.36, 0.71)	-	0.25
	12-months	58	3	35.1 (5.0)	35.3 (30.9-38.6)	-	-	-
Reaction time	Baseline	45	2	0.6 (0.1)	0.6 (0.6-0.7)	-	0.30 (0.06, 0.51)	0.06
	6-months	45	2	0.6 (0.1)	0.6 (0.6-0.6)	-	-	-
	Baseline	58	3	0.7 (0.1)	0.7 (0.6-0.7)	-	0.58 (0.38, 0.72)	-0.15
	12-months	58	3	0.7 (0.1)	0.7 (0.6-0.8)	-	-	-
Post-concussion symptom scale	Baseline	46	1	10.1 (8.6)	8.5 (3-17)	-	0.46 (0.21, 0.65)	0.31
	6-months	46	1	7.6 (7.8)	6 (2-11)	-	-	-
	Baseline	61	0	10.8 (11.2)	7.0 (3-15)	-	0.68 (0.52, 0.80)	-0.00
	12-months	61	0	10.7 (11.1)	9.0 (3-14)	-	-	-
Clinical Profiles Screen		N	Missing	Mean (SD)	Median (IQR)	LCCC (95% CI)	Kappa (95% CI)	Cohen's D
Total score	Baseline	47	0	6.9 (6.5)	5 (1.5-10)	0.68 (0.49, 0.81)	-	0.08
	6-months	47	0	6.3 (6.6)	5 (2-8)	-	-	-
	Baseline	61	0	8.0 (6.9)	7 (3-10)	0.34 (0.11, 0.53)	-	-0.19
	12-months	61	0	9.3 (9.0)	6 (3-13)	-	-	-
Cognitive score	Baseline	47	0	1.4 (1.4)	1 (0-2)	-	0.32 (0.13, 0.52)	0.09
	6-months	47	0	1.3 (1.3)	1 (0-2)	-	-	-
	Baseline	61	0	1.5 (1.1)	2 (1-2)	-	0.12 (-0.08, 0.31)	0.06
	12-months	61	0	1.5 (1.1)	1 (1-2)	-	-	-
Ocular score	Baseline	47	0	1.5 (2.1)	1 (0-3)	-	0.33 (0.11, 0.55)	0.17
	6-months	47	0	1.2 (1.6)	1 (0-2)	-	-	-
	Baseline	61	0	1.5 (1.8)	1 (0-3)	-	0.42 (0.26, 0.58)	-0.26
	12-months	61	0	2.0 (2.2)	1 (0-3)	-	-	-
Anxiety/Mood score	Baseline	47	0	1.6 (1.9)	1 (0-3)	-	0.37 (0.16, 0.58)	-0.01

	6-months	47	0	1.7 (2.3)	1 (0-2)	-	-	-
	Baseline	61	0	2.0 (2.3)	1 (0-3)	-	0.28 (0.11, 0.44)	-0.20
	12-months	61	0	2.4 (2.3)	2 (1-3)	-	-	-
Migraine score	Baseline	47	0	0.3 (0.8)	0 (0-0)	-	0.46 (0.17, 0.75)	-0.03
	6-months	47	0	0.4 (0.8)	0 (0-0)	-	-	-
	Baseline	61	0	0.5 (1.0)	0 (0-1)	-	0.05 (-0.17, 0.26)	-0.23
	12-months	61	0	0.9 (2.0)	0 (0-1)	-	-	-
Vestibular score	Baseline	47	0	0.4 (0.8)	0 (0-1)	-	0.25 (-0.04, 0.54)	0.05
	6-months	47	0	0.4 (0.8)	0 (0-0.5)	-	-	-
	Baseline	61	0	0.9 (1.4)	0 (0-1)	-	0.26 (0.05, 0.46)	-0.05
	12-months	61	0	1.0 (1.8)	0 (0-1)	-	-	-
Sleep score	Baseline	47	0	1.3 (1.5)	1 (0-2)	-	0.33 (0.13, 0.54)	0.01
	6-months	47	0	1.3 (1.5)	1 (0-2)	-	-	-
	Baseline	61	0	1.3 (1.3)	1 (0-2)	-	0.10 (-0.08, 0.27)	0.14
	12-months	61	0	1.1 (1.5)	1 (0-2)	-	-	-
Neck score	Baseline	47	0	0.3 (0.7)	0 (0-0)	-	0.32 (-0.01, 0.64)	0.09
	6-months	47	0	0.2 (0.6)	0 (0-0)	-	-	-
	Baseline	61	0	0.2 (0.7)	0 (0-0)	-	0.03 (-0.21, 0.27)	-0.25
	12-months	61	0	0.4 (0.8)	0 (0-1)	-	-	-
Health Questionnaires		N	Missing	Mean (SD)	Median (IQR)	ICC (2,1) (95% CI)	LCCC	Cohen's D
Patient Health Questionnaire-9	Baseline	47	0	3.3 (2.8)	3 (1-5)	-	0.40 (0.14, 0.61)	0.20
	6-months	47	0	2.8 (2.4)	2 (1-3.5)	-	-	-
	Baseline	61	0	3.5 (3.7)	2 (1-5)	-	0.46 (0.23, 0.63)	-0.00
	12-months	61	0	3.6 (4.0)	2 (1-4)	-	-	-
Generalised Anxiety Disorder	Baseline	47	0	2.2 (2.8)	1 (0-3.5)	-	0.50 (0.25, 0.69)	0.03
	6-months	47	0	2.1 (2.8)	1 (0-3)	-	-	-
	Baseline	61	0	3.8 (4.4)	2 (1-6)	-	0.68 (0.52, 0.80)	-0.00
	12-months	61	0	3.5 (4.2)	2 (0-5)	-	-	-
Neck Bournemouth Questionnaire	Baseline	47	0	4.8 (6.7)	3 (0-6)	-	0.38 (0.11, 0.60)	0.02
	6-months	47	0	4.7 (6.5)	3 (0-6)	-	-	-
	Baseline	61	0	5.6 (6.8)	4 (1-7)	-	0.44 (0.22, 0.62)	-0.19
	12-months	61	0	7.0 (8.0)	4 (2-11)	-	-	-
Migraine Disability Assessment	Baseline	47	0	1.7 (3.2)	0 (0-2)	-	0.33 (0.07, 0.55)	-0.06
	6-months	47	0	1.9 (4.6)	0 (0-2)	-	-	-
	Baseline	61	0	2.4 (5.7)	0 (0-2)	-	0.29 (0.07, 0.47)	0.18
	12-months	61	0	1.7 (3.4)	0 (0-2)	-	-	-
Pittsburgh Sleep Quality Index	Baseline	45	2	5.0 (2.4)	5 (3-7)	0.57 (0.34, 0.74)	-	-0.10

6-months	45	2	5.3 (2.5)	5 (3-7)	-	-	-
Baseline	61	0	4.9 (2.5)	5 (3-6)	0.48 (0.26, 0.65)	-	-0.07
12-months	61	0	5.1 (2.3)	5 (4-7)	-	-	-

SD: Standard deviation; IQR: Interquartile range; LCCC: Lin's concordance correlation coefficient; ICC (2,1): Intraclass correlation coefficient two-way model random effects for single measurements; Weighted κ : Weighted Kappa.

Table 68: Standard errors of measurement (SEMs), standard errors of the difference (SDiff), and reliable change indices at 80%, 90% and 95% confidence intervals for normally distributed variables

ImPACT® and Questionnaires	Timepoint	SEM	SDiff	80% CI	90% CI	95% CI
Visual memory score	Baseline	10.15	14.4	18.5	23.7	28.2
	6-months	10.22	-	-	-	-
	Baseline	9.85	13.3	17.1	21.9	26.1
	12-months	8.95	-	-	-	-
Visual-motor speed score	Baseline	2.76	3.90	5.00	6.42	7.65
	6-months	2.76	-	-	-	-
	Baseline	4.18	5.32	6.82	8.75	10.4
	12-months	3.29	-	-	-	-
Pittsburgh Sleep Quality Index	Baseline	1.60	2.31	2.96	3.79	4.52
	6-months	1.66	-	-	-	-
	Baseline	1.77	2.44	3.13	4.01	4.78
	12-months	1.68	-	-	-	-
SCAT5						
Immediate Memory	Baseline	2.36	3.15	4.03	5.17	6.17
	12-months	2.08	-	-	-	-
Finger-to-nose time	Baseline	0.71	1.00	1.29	1.65	1.97
	12-months	0.71	-	-	-	-
Tandem gait time	Baseline	3.91	5.12	6.56	8.42	10.0
	12-months	3.30	-	-	-	-
Neck Dynamometry						
Neck flexion	Baseline	0.16	0.25	0.32	0.41	0.49
	12-months	0.19	-	-	-	-
Neck extension	Baseline	0.22	0.35	0.45	0.57	0.68
	12-months	0.27	-	-	-	-
Dominant side neck lateral flexion	Baseline	0.12	0.24	0.31	0.40	0.47
	12-months	0.21	-	-	-	-
Non-dominant side neck lateral flexion	Baseline	0.13	0.22	0.29	0.37	0.44
	12-months	0.18	-	-	-	-
Dominant side neck rotation	Baseline	0.09	0.14	0.18	0.23	0.28
	12-months	0.11	-	-	-	-
Non-dominant side neck rotation	Baseline	0.10	0.16	0.21	0.27	0.32
	12-months	0.13	-	-	-	-

SEM: Standard error of measurement; SDiff: Standard error of the difference; CI: Confidence interval; SCAT5: Sport Concussion Assessment Tool 5th Edition.

Table 69: The proportion of participants classified as demonstrating a reliable change between assessments based on 80%, 90%, and 95% confidence intervals

Baseline to 6-months	80% CI			90% CI			95% CI		
	Impr (%)	Decl (%)	Tot (%)	Impr (%)	Decl (%)	Tot (%)	Impr (%)	Decl (%)	Tot (%)
<i>ImPACT® and Questionnaires</i>									
Visual memory score	26.7	6.7	33.3	13.3	4.4	17.8	4.4	0.0	4.4
Visual-motor speed score	8.9	13.3	22.2	2.2	11.1	13.3	0.0	4.4	4.4
Pittsburgh Sleep Quality Index	13.3	11.1	24.4	6.7	4.4	11.1	2.2	4.4	6.7
<i>Baseline to 12-months</i>									
<i>ImPACT® and Questionnaires</i>									
Visual memory score	13.8	5.2	19.0	6.9	3.5	10.3	0.0	3.5	3.5
Visual-motor speed score	5.2	17.2	22.4	0.0	8.62	8.62	0.0	3.5	3.5
Pittsburgh Sleep Quality Index	9.8	6.6	16.4	3.3	4.9	8.2	4.9	3.3	8.2
<i>SCAT5</i>									
Immediate Memory	16.3	2.3	18.6	11.6	2.3	14.0	9.3	0.0	9.3
Finger-to-nose time	2.3	11.6	14.0	2.3	9.3	11.6	4.7	0.0	4.7
Tandem gait time	4.7	20.9	25.6	0.0	16.3	16.3	7.0	0.0	7.0
<i>Neck Dynamometry</i>									
Neck flexion	2.6	33.3	35.9	2.6	23.1	24.6	2.6	20.5	23.1
Neck extension	10.3	28.2	38.5	2.6	20.5	23.1	2.6	12.8	15.4
Dominant side neck lateral flexion	7.7	12.8	20.5	2.6	10.3	12.8	2.6	7.7	10.3
Non-dominant side neck lateral flexion	5.1	33.3	38.5	2.6	12.8	15.4	0.0	12.8	12.8
Dominant side neck rotation	15.4	18.0	33.3	7.7	10.3	18.0	7.7	5.1	12.8
Non-dominant side neck rotation	10.3	12.8	23.1	5.1	5.1	10.3	5.1	5.1	10.3

CI: Confidence interval; Impr: Proportion showing a reliable improvement; Decl: Proportion showing a reliable decline; Tot: Proportion showing a reliable improvement or decline; SCAT5: Sport Concussion Assessment Tool 5th Edition.

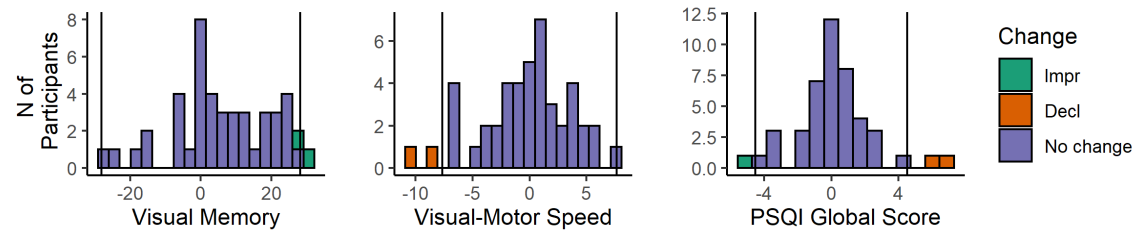


Figure 33: Histograms of change scores between baseline and six-month assessments for ImPACT® visual memory and visual-motor speed scores, and PSQI global score. Impr: statistically reliable improvement in scores; Decl: statistically reliable decline in scores. PSQI Global Score is reverse scored so that a decrease signifies an improvement.

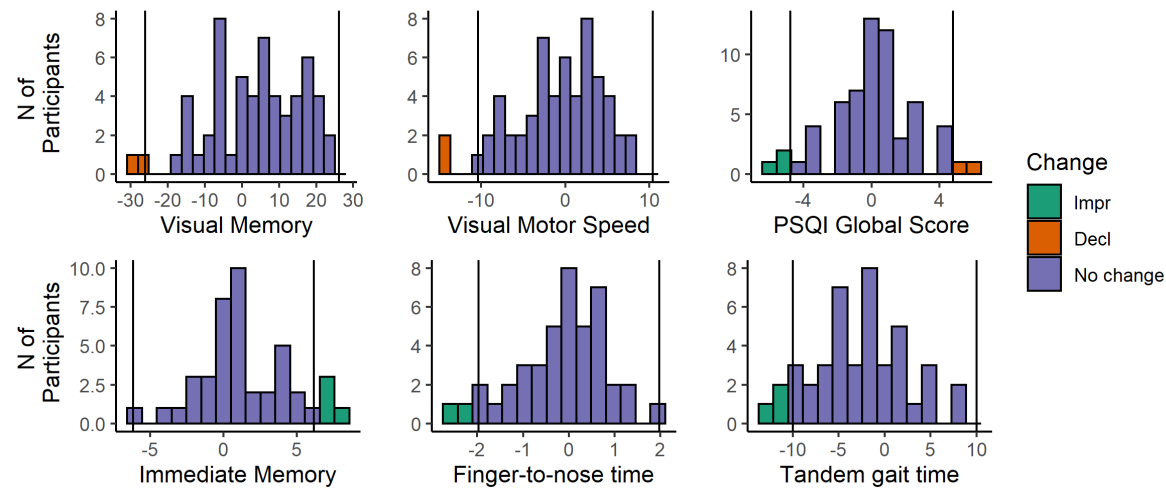


Figure 34: Histograms of change scores between baseline and twelve-month assessments for ImPACT® visual memory and visual-motor speed scores, PSQI global score, SCAT5 immediate memory, finger-to-nose time, and tandem gait time.

Impr: statistically reliable improvement in scores; Decl: statistically reliable decline in scores. PSQI Global Score, finger-to-nose time, and tandem gait time are reverse scored so that a decrease signifies an improvement.

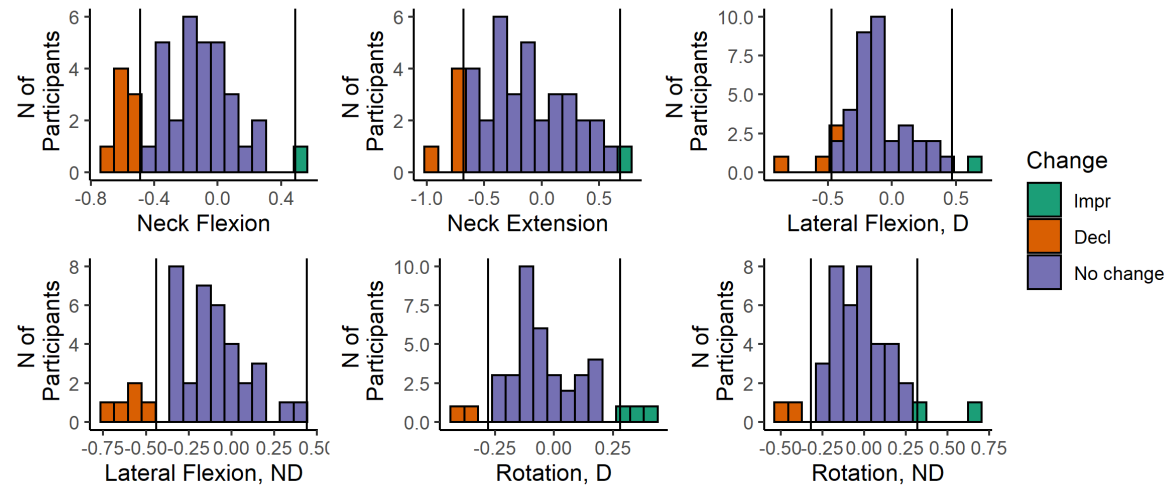


Figure 35: Histograms of change scores between baseline and twelve-month assessments for neck flexion, extension, dominant side lateral flexion, non-dominant side lateral flexion, dominant side rotation, and non-dominant side rotation.

Impr: statistically reliable improvement in scores; *Decl*: statistically reliable decline in scores.

6.4 Discussion

This study aimed to examine the test-retest reliability of a multi-domain SRC assessment in LGF players at six- and twelve-month timepoints. It is currently the only study examining test-retest reliability of SRC assessments that has focused on a female, community sport population. In addition, it is one of the few studies that has assessed the reliability of the full battery of tests recommended for inclusion in a multi-domain SRC assessment (158,185), as opposed to individual tests. We included recommended SRC tests (e.g., ImPACT® and the SCAT5) (18,19,31), as well as general symptom report measures (e.g., PHQ-9 and GAD-7) in our assessment. Overall, the tests in our assessment exhibited minimal to adequate test-retest reliability, with only the SCAT5 GSC, PHQ-9, and GAD-7 demonstrating moderate reliability. Measures that were assessed in both the six- and twelve-month re-assessment groups generally displayed higher reliability at the twelve-month timepoint, although this may have been influenced by differences in group demographics. Our sample size was not sufficient to conduct separate reliability analyses based on age or other demographic characteristics.

6.4.1 *Immediate Post-Concussion Assessment and Cognitive Testing*

We reported low to adequate test-retest reliability for the four ImPACT® composite scores in both the six- (ICCs=0.28-0.78; LCCCs=0.30-0.38) and twelve-month (ICCs=0.35-0.56; LCCCs=0.48-0.68) re-assessment groups, supporting previous research over similar timeframes (ICCs=0.38-0.87) (203,205–207). Similar to existing findings in male and female youth (203), high school (205,207) and professional athletes (206), the reliability of verbal (LCCC=0.38-0.48) and visual (ICC=0.28-0.35) memory composite scores in our sample tended to be lower than the reliability of visual-motor speed (ICC=0.56-0.78) and reaction time (LCCC=0.30-0.58) scores. The high variability in the measurements across assessments is also reflected in the large RCI scores reported (e.g., at the 95% confidence level, a participant would need to experience a change exceeding 28.2 on visual memory between assessments to be considered to have reliably changed). This variation in reliability across scores may be explained, at least partially, by the fact that some aspects of cognition may be more amenable to influence from external or internal factors, such as testing environment (174), sleep (270), and exercise (444). Clinicians should be aware of the limitations of ImPACT even when a standardised testing protocol is followed.

While test-retest reliability typically declines over time (159), all scores apart from visual-motor score exhibited higher reliability in the twelve-month assessment group than the six-month assessment group in this study. This may be due to differences in participant characteristics between the two groups. The twelve-month assessment group contained a lower proportion of participants who played at an elite level (16.7% vs 46.8%) and who reported a diagnosed history of concussion (15.3% vs 26.1%) than the six-month assessment group. In addition, the twelve-month group

contained adolescent (44.4%) as well as adult participants, while the six-month group contained only adult participants. Reliability may be influenced by participant demographics (159). Overall, ImPACT demonstrated inadequate test-retest reliability in our study. Due to the large amount of variability in all composite scores over six and twelve months, it appears that ImPACT® may not be useful in baseline SRC assessments. However, no previous test-retest reliability studies have included adolescent and adult participants even though ongoing neurological development processes in adolescents may mean that they demonstrate greater variability than adults. Further research is needed to separately examine the test-retest reliability of ImPACT® scores in adolescent and adult participants.

6.4.2 *Sport Concussion Assessment Tool 5th Edition*

Our finding that most of the SCAT5 components displayed low test-retest reliability at the twelve-month interval supports previous research in male and female high school and collegiate players and male professional athletes (184,185,445). Like several previous studies (185,445), we found that the GSC was the only SCAT5 component that showed adequate test-retest reliability. High levels of baseline symptom reporting may be influenced by a variety of individual factors (e.g., age (170), gender (170,336), and medical history (396,397,415)). While some players, in particular female players, may report high levels of concussion-type symptoms when uninjured (336,446), it appears that the number and severity of these symptoms is relatively stable over time. Moreover, the GSC has higher sensitivity to detecting SRC than the SAC and mBESS components of the SCAT5 (184,187). The SCAT5 is considered the “gold-standard” sideline SRC assessment and is endorsed by multiple international sporting governing bodies, including the LGFA (30,36). However, clinicians should be aware that due to the low test-retest reliability of some of its components, the utility of the SCAT5 may be limited as a baseline test. We recommend that clinicians prioritise the GSC, which was the only SCAT5 component that demonstrated adequate test-retest reliability, over other components of the SCAT5 when comparing post-SRC and baseline assessments results.

Participants in this study scored better on all SAC items and neurological tests (e.g., FTN, TG, mBESS) at the twelve-month assessment compared with baseline, with small to medium effect sizes. This may be due to practice effects, which have been documented in cognitive (199,216) and neurological (447) assessments. Practice effects refer to improvements in a test score that occur due to participants becoming more familiar with the format and content of a test on repeat assessments (249). While using alternate form tests (i.e., different content that measures the same construct) are a way to potentially mitigate practice effects, practice effects cannot be completely eliminated (159,448). It is notable that improvements among our participants were found with a relatively long time interval between assessments even though we utilised the alternate content where available (e.g., recall and digits backwards sections). This suggests that the SCAT5 SAC and neurological

components may be of limited benefit to clinicians when post-SRC results are compared to a pre-injury baseline. However, they may still be useful in other contexts, such as when acutely compared with normative data. Alternatively, participants may have experienced true improvements in the SAC and neurological test scores over time. Unlike the six-month re-assessment group, the twelve-month re-assessment group included adolescent participants as well as adults. As adolescents continually develop, they may have improved on measures such as concentration and motor control over the twelve-month timeframe between assessments. While our study did not include sufficient adolescent participants to perform reliability analyses by age group, future research examining the test-retest reliability of the SCAT5 in adolescent LGF players is needed.

6.4.3 Vestibular-Ocular Motor Screening

The test-retest reliability of individual VOMS items ranged from minimal to fair (Weighted $\kappa=0.08-0.34$) at the twelve-month timepoint in our study, which is lower than previously reported in male and female collegiate athletes over a similar timeframe ($\kappa=0.28-0.38$) (185). While the previous study assessed reliability using unweighted Kappa coefficients, we used Weighted Kappa coefficients, which are more appropriate when analysing ordinal data (449). It is possible that female players are more prone to fluctuations in vestibular-ocular measures than male players due to natural hormonal variations (399) or the higher prevalence of vestibular conditions such as migraine (236) and motion sickness (237) in females. Females also report more symptoms of vestibular dysfunction than males when uninjured (e.g., headaches (336,450), dizziness (450,451), balance problems (450,451), and anxiety (336)). These factors may partially explain why our study found lower reliability of the VOMS than those that included male and female athletes (185). In addition, 44.4% of participants who completed the retest of the VOMS at the twelve-month timepoint in our study were adolescents. Adolescents commonly experience vestibular symptoms (260,451) and the adolescents in our study scored significantly higher on the CP Screen vestibular item than adults (median of 0.2 vs 0.0) at the initial assessment (see Chapter 5.3.6). Ongoing development of the vestibular system throughout adolescence (406) may influence the reliability of the VOMS in this age group. More research is needed that evaluates the effects of age and gender on test-retest reliability of individual VOMS items.

In addition to evaluating the reliability of individual VOMS items, we also examined the stability of the TSS. The VOMS TSS has shown greater discriminative validity for identifying concussion than any of the individual items (150,224). However, we reported an LCCC of 0.25 for the TSS between baseline and the twelve-month timepoint, indicating poor test-retest reliability. One other study examined the test-retest reliability of the VOMS TSS over one year in collegiate athletes, and also reported low reliability (ICC=0.36) (158). As described above, it is possible that female and adolescent players demonstrate a high degree of variability on measures of vestibular function, and

that this may have contributed to the poor reliability of the VOMS in this study. Overall, our finding of low test-retest reliability suggests that the VOMS may not be useful as a baseline measure against which post-SRC results are compared. However, it may still be useful as a post-SRC assessment.

6.4.4 Neck Dynamometry

Adequate test-retest reliability of neck flexion strength and rotation strength on both sides was reported between baseline and twelve months in our study, however reliability for neck extension and lateral flexion was poor to marginal. This study is the first to report the test-retest reliability of a neck dynamometry protocol in either male or female athletes of any age. Stronger neck muscles have been suggested to reduce the risk of SRC by providing a resistance against external forces applied during head impacts (57), and interventions aiming to improve neck strength have been suggested as possible injury prevention programmes for SRC (57). However, existing interventions have had limited results (302,303). It is essential that neck dynamometry protocols are reliable over time so that clinicians can effectively determine whether real changes in strength have occurred following an intervention. In particular, community sports may benefit from introducing neck strengthening programmes, should they be found effective at reducing the risk of SRC, as they are cost-effective and can be easily integrated into training sessions (302,303). Although several aspects of neck strength demonstrated ICCs greater than 0.70 in our study, more participants than expected exceeded RCI cut-off values at the 95% CI for every outcome. This suggests that a large amount of variability exists in neck strength values in LGF players. Between 5.1% and 20.1% of participants (versus the expected 2.5%) (161) demonstrated reliable declines between the baseline and twelve-month assessment. It is unclear why participants experienced reductions in strength over this timeframe, however as the twelve-month assessment was conducted during the Covid-19 pandemic it is possible that disruption to participants' regular training schedules resulted in a genuine reduction in strength. Follow-up research on the test-retest reliability of neck dynamometry values is necessary before recommendations on its inclusion into pre-season assessments to clinicians can be made. While neck dynamometry demonstrated adequate test-retest reliability for some movements, the test-retest reliability was low for other movements. As suggested neck strengthening programmes aim to increase multi-directional neck strength (413), test-retest reliability for all neck movements important. Therefore, we do not currently recommend using neck dynamometry for serial assessments.

6.4.5 Clinical Profiles Screen

The CP Screen is a new instrument that was developed based on the UPMC clinical profiles model to examine self-reported symptoms of the clinical profiles of SRC (131). Our study is the first to examine the test-retest reliability of the CP Screen in any population. Unlike other SRC symptom report scales (e.g., the SCAT5 GSC and PCSS) which produce an overall symptom score (132,133),

the CP Screen also generates scores for individual clinical profiles (31,131). We reported strong test-retest reliability of the total score in the six-month group, but low test-retest reliability in the twelve-month group. The greatest differences were observed in the ocular, mood, migraine, and neck scores, with higher scores, indicating worsening symptoms, reported at the twelve-month re-assessment. The Covid-19 pandemic, which resulted in widespread sleep (452) and mood (453) impairments may partially explain the higher symptom burden on re-assessment. However, test-retest reliability is also expected to decrease over time, and this decrease is more pronounced for fluctuating variables, such as mood (159). The CP Screen captures symptoms that participants experience at the time of testing (131). These symptoms are non-specific to concussion (e.g., mood and sleep disturbances) and may occur due to lifestyle factors (318,454) or various medical conditions (255,388,396). The development of the CP Screen was informed by the Clinical Profiles theory of concussion (31,131), however this theory is primarily based on clinical expertise and is not supported by empirical research (129). It is possible that the items on the CP Screen do not represent distinct symptom constructs and that the total score provides a better measure of SRC symptoms than the individual items. The low test-retest reliability in the twelve-month group may reflect the inherent variability of these symptoms. It is also possible that between-group differences in participant demographics affected test-retest reliability. While the six-month group in our study included only adult participants, 44.4% of the twelve-month group were adolescents. Adolescents frequently report elevated levels of concussion-like symptoms (450,451) and may exhibit greater variability in symptom measures than adults. Our study contained a small number of adolescent participants, preventing us from carrying out separate analyses based on age. However, research analysing the test-retest reliability of the CP Screen in adolescent and adult players is needed. Currently, the test-retest reliability of CP Screen is inadequate to suggest its inclusion in a baseline assessment.

6.4.6 Health Questionnaires

Moderate test-retest reliability was found for the PHQ-9 and GAD-7 in the six-month group, while reliability in the twelve-month group was moderate (PHQ-9) to strong (GAD-7). The PHQ-9 and GAD-7 have been extensively used to screen for depression and anxiety symptoms in multiple clinical populations (244,455), and have also been incorporated into SRC assessments (253,254,419). However, existing research has only examined the test-retest reliability of the PHQ-9 and GAD-7 over short (i.e., two weeks) timeframes (250,252) and no studies have assessed reliability in a sporting population. Our findings suggest that PHQ-9 and GAD-7 scores remain relatively stable in female LGF players over at least a six- to twelve-month timeframe. While mood dysregulation is common post-concussion (122), especially in female players (129,396), SRC assessments have traditionally focused more on assessing cognitive and physical signs of SRC (132,133). Mood disturbances may arise due to neurometabolic changes that occur during a concussion (83), however a player's pre-existing mental health status and emotional response to injury may also affect mood

(238). Including measures of mood in SRC assessments is vital to ensure players receive appropriate treatment. Brief, self-report measures such as the PHQ-9 and GAD-7 are a quick and cost-effective way of monitoring mood-related symptoms and may be particularly useful in community sports where resources to carry out a more extensive psychological examination are limited. The PHQ-9 and GAD-7 demonstrated adequate test-retest reliability at both six- and twelve-month re-assessments. They could be incorporated into baseline assessments to identify players who may be at risk of mood dysfunction if they sustain an SRC, or alternatively used to monitor players with chronic SRC symptoms.

Overall, the NBQ and MIDAS demonstrated poor test-retest reliability in both the six- and twelve-month assessment groups. Other than initial validation studies examining short term (same day (292) or after 21 days (263)) test-retest reliability, no studies have examined the test-retest reliability of the NBQ or MIDAS in any population. Although many players with SRC experience symptoms of migraine (e.g., headache and photophobia) (120,129) and neck pain (410), specific measures of migraine and neck function are not typically included in SRC assessments. This is concerning as post-traumatic migraine may be predictive of a longer SRC recovery time (33). Based on the low test-retest reliability, it appears that there may little clinical utility in including the NBQ or MIDAS in baseline SRC assessments for LGF players. It is possible that participants' low levels of baseline neck and migraine-related disability artificially reduced the test-retest reliability of these assessments by reducing the inter-individual variability. In addition, we recommend further study is carried out on other measures of neck and migraine symptoms in LGF players to determine whether more reliable alternatives to the NBQ and MIDAS exist.

The PSQI demonstrated poor test-retest reliability in both the six-month and twelve-month assessment groups, supporting previous research in male and female athletes (276). Overall, participants in our study experienced worse sleep quality at the re-assessment than the baseline assessment. The variability in sleep quality in our study may have been due to the effects of the Covid-19 pandemic. While baseline assessments were carried out prior to the pandemic, both the six-month and twelve-month re-assessments took place during the pandemic. Research has reported that lockdowns resulted in disruption to sleep patterns across the general population (452). Therefore, further research on the test-retest reliability of sleep measures in LGF players may be needed. Sleep disturbances (e.g., insomnia and drowsiness) may occur following a concussion due to circadian rhythm disruptions (127,128,418). These disturbances may subsequently worsen cognitive, mood and migraine symptoms of concussion (31). Clinicians should assess sleep quality in players post-SRC in case intervention is required. While concussion-related sleep problems are well-documented (128,418), sleep-specific measures are rarely included in SRC assessments. The low test-retest reliability of the PSQI in our study suggests that it may be of limited benefit when included in

baseline assessments in this population. The low reliability of the PSQI may reflect the fact that perceived sleep quality is highly subjective and amenable to influence from multiple factors. While we recommend including a measure of sleep quality into SRC assessments, more research is needed to determine whether the PSQI is the most appropriate measure for use in female athletes.

6.4.7 Limitations

Apart from the limitations discussed in Chapter 5.4.8, this study has several additional weaknesses. Firstly, while we attempted to perform all re-assessments at the appropriate timepoints, there was considerable variation in the number of days between the baseline and re-assessment in both groups. As test-retest reliability declines over time, this may have either positively or negatively affected reliability. Secondly, as the six- and twelve-month re-assessments took place during the Covid-19 pandemic, we carried out the ImPACT and questionnaire re-assessments online. Participants completed the baseline ImPACT using an external mouse, however most only had access to a laptop trackpad during the re-assessment. This may have affected visual-motor speed and reaction time composite scores. Thirdly, emotional and sleep-related disturbances throughout the Covid-19 pandemic have been well documented in the general public (452,453). It is possible that this introduced a systematic bias into our study at the six- and twelve-month re-assessments. Fourthly, participants who completed the six- and twelve-month re-assessments differed on several demographic factors. The six-month group consisted entirely of adults, of which almost half (46.8%) were elite players and 26.1% reported a previous diagnosed concussion. The twelve-month group included adolescents (44.4%) and adults and had lower proportions playing at the elite level (16.7%) and with a history of diagnosed concussion (15.3%). As some outcomes may be more variable in certain populations, these differences may have influenced test-retest reliability. For example, adolescents experience neurological changes as they mature (406). As sample sizes per timepoint groups were relatively small, we were unable to perform separate reliability analyses for participants based on demographic characteristics, such as age. We were unable to calculate RCI cut-off values for variables that were not normally distributed due to small sample sizes. RCI cut-off values may be more useful than reliability coefficients in a clinical setting as they quantify measurement error and provide a more objective way to interpret reliability.

6.5 Conclusions

This study examined the six- to twelve-month test-retest reliability of a multi-domain SRC assessment in LGF players. It is the first study to examine the reliability of SRC tests in a female only sample of community sport athletes. We found that the majority of tests displayed inadequate test-retest reliability at both six- and twelve-month timepoints. The highest reliability was reported for symptom-based assessments, including the SCAT5 GSC, CP Screen, PHQ-9, and GAD-7. These measures are quick, cost-effective, and easy to implement. Clinicians should be aware that other,

more objective measures used to assess for SRC (e.g., ImPACT® or VOMS) may lack test-retest reliability in the female, community sport population over periods of six months or longer. The high degree of measurement error demonstrated means that they may not be suitable for inclusion in a baseline assessment that may be later compared to post-injury results in players who sustain an SRC. However, it still may be useful to carry out these tests at baseline to identify players at risk of post-SRC complications.

The normative data approach may be more appropriate than the baseline-retest approach for clinicians working with LGF players. Many factors may cause an individual's test result to change over time, including the presence of medical conditions, environmental conditions, maturation, practice effects, and regression to the mean (159,249). This may result in inadequate test-retest reliability over time when assessed within individuals; in particular, test-retest reliability decreases with longer test-retest intervals (159). Comparing test results to normative data may be more accurate as healthy individuals who experience changes in scores over time may still score within the expected range. In addition, consulting normative data would enable the clinician to control for variables that may have changed over time (e.g., baseline test results for an adolescent player who completes a baseline assessment may not be valid as she matures, however age-specific normative data may be available). Therefore, it is essential that the normative data is drawn from a population with similar characteristics to the player (e.g., age and medical history). However, further research on the sensitivity and specificity of multi-domain SRC assessments in LGF players and other female, community sport athletes is needed.

Test-retest reliability is reported to decrease over time, especially in populations with a high degree of variability (e.g., adolescents) (159). Therefore, the normative data approach may be more appropriate for clinicians working with LGF players. However, research on the sensitivity and specificity of the multi-domain SRC assessment is also needed in LGF players and other female, community sport athletes (see Table 70 for more details). In addition, further research that examines the test-retest reliability of SRC assessments separately in adolescent and adult participants is required before recommendations to clinicians can be made.

Table 70: Clinical utility of a multi-domain sport-related concussion assessment for Ladies Gaelic Football

Test	Baseline	Post-SRC
Immediate Post Concussion Assessment and Cognitive Testing	Inadequate test-retest reliability means it may be of limited use in baseline assessment	May be of use post-SRC, however data on diagnostic accuracy in LGF players is required
Sport Concussion Assessment Tool 5th Edition	- The GSC has moderate test-retest reliability and may be useful in a baseline assessment - The SAC, FTN test, TG test, and mBESS have inadequate test-retest reliability and may be of limited use in baseline assessments	- Post-injury GSC can be compared to baseline results - The SAC, FTN test, TG test, and mBESS may be of use post-SRC, however data on diagnostic accuracy in LGF players is required
Vestibular-Ocular Motor Screening	Inadequate test-retest reliability means it may be of limited use in baseline assessment	May be of use post-SRC, however data on diagnostic accuracy in LGF players is required
Neck Dynamometry	May identify players with poor neck strength who may be at increased risk of SRC, however more research is needed	Not recommended for use post-SRC
Clinical Profiles Screen	- Total score has moderate test-retest reliability and may be useful in a baseline assessment - Individual profile scores have inadequate test-retest reliability and may be of limited use in baseline assessments	- Post-injury total score can be compared to baseline results - Individual profile scores may be useful in guiding post-SRC management
Patient Health Questionnaire-9	- May identify players with mood dysfunction - Can be compared to post-SRC results in players with prolonged symptoms	- Not suitable for acute post-SRC period at it examines symptoms over the previous two weeks - Can be compared to baseline results in players with prolonged symptoms
Generalised Anxiety Disorder-7	- May identify players with mood dysfunction - Can be compared to post-SRC results in players with prolonged symptoms	- Not suitable for acute post-SRC period at it examines symptoms over the previous two weeks - Can be compared to baseline results in players with prolonged symptoms
Neck Bournemouth Questionnaire	Inadequate test-retest reliability means it may be of limited use in baseline assessment	Not suitable for acute post-SRC period at it examines symptoms over the week
Migraine Disability Assessment	- May identify players with pre-existing migraine - Inadequate test-retest reliability means it may be of limited use in baseline assessment	Not suitable for acute post-SRC period at it examines symptoms over the previous three months
Pittsburgh Sleep Quality Index	- May identify players with pre-existing sleep difficulties - Inadequate test-retest reliability means it may be of limited use in baseline assessment	Not suitable for acute post-SRC period at it examines symptoms over the previous four weeks

6.6 Implications

As most tests included in the multi-domain SRC assessment had inadequate test-retest reliability over six- and twelve-months, we do not recommend the use of a pre-injury, baseline SRC assessment in LGF. The baseline-retest approach is also time and resource-intensive, and ideally baseline assessments should be completed at the start of each season. This makes it impractical to carry out in community sports, such as LGF. Therefore, the normative data approach may be a more useful alternative approach for clinicians when evaluating post-SRC results in LGF players. SRC tests, including the SAC and BESS, have previously demonstrated sufficient diagnostic accuracy in identifying SRC (137,433). Due to the low number of adolescents in this study, as well as the variable nature of this age group, there is also a need for research examining test-retest reliability of the multi-domain SRC assessment in adolescent LGF players.

7 Thesis Summary, Conclusions, and Directions for Future Research

7.1 Thesis Summary

SRC is a mild, trauma-induced brain injury that may result in dysfunction across multiple neurological domains. Although SRC is believed to be a concern in LGF, little previous research has examined SRC prevalence or management behaviour in the sport. There is also little normative and test-retest reliability data available on multi-domain SRC assessments in female, community sport athletes.

In Study 1, we aimed to establish SRC prevalence, injury characteristics, and management behaviours in LGF players. An online survey of adult LGF players found that 17.5% of participants believed they had sustained an SRC during the previous year (2019). Elite players demonstrated almost double the odds of having sustained a possible SRC during the previous year than non-elite players (OR=1.96). These injuries most often occurred while playing a match (85.8%) and resulted from impacts to the head or neck (96.5%) that involved contact with another player (62.6%). Overall SRC management was poor, although participants with diagnosed SRCs followed the recommended guidelines more often than those who believed they had sustained an SRC for which they had not sought medical care. The majority of participants did not RTP on the day of injury (61.7%) and did not RTP while experiencing symptoms (59.1%). However, only a minority followed a medically supervised graded RTP programme (27.8%) and a RTS programme (10.4%).

Study 2 aimed to explore the factors associated with SRC management behaviours. Possible factors associated with behaviour included level of play, age, a history of concussion, CKI, CAI, previous exposure to SRC education materials, and where relevant, being diagnosed with SRC by a medical professional. Immediate management behaviour included playing for more or less than 15 minutes following a suspected SRC, informing a coach of a suspected SRC, and RTP on the day of injury. Lower CAI scores were associated with playing for more than 15 minutes following a suspected SRC (OR=0.93). A history of concussion was associated with reporting a suspected SRC to a coach (OR=2.86), while being diagnosed with a SRC by a medical professional was negatively associated with same day RTP (OR=0.37). Medium-term management behaviour consisted of symptomatic RTP, following a graded RTP programme, following a graded RTP with medical supervision, obtaining medical clearance prior to full contact RTP, and completing a RTS programme. Completing a graded RTP programme (OR=4.89) and completing a graded RTP programme while medically supervised (OR=10.16) were both associated with being diagnosed with SRC by a medical professional. Obtaining medical clearance before full RTP was associated with being diagnosed with an SRC (OR=13.45) and lower CKI scores (OR=0.69). No factors were significantly associated with symptomatic RTP or following an RTS programme. Therefore, this study highlighted the essential role of medical professionals in diagnosing and managing SRCs.

It is recommended that medical professionals use multi-domain assessments to identify and manage SRCs. The results from such assessments can be compared against normative data or an individual baseline assessment. In Study 3, we presented normative data on a multi-domain SRC assessment in a cohort of LGF players. This assessment included tests that captured the full range of SRC dysfunction, including CNT, tests of vestibular and oculomotor impairments, neck dynamometry, and self-reported mood, migraine symptoms, neck pain, and sleep quality. Normative data on these tests were described collectively for 138 participants, and subsequently stratified by level of play (elite and non-elite), age (adults and adolescents), and concussion history (previously sustained a diagnosed concussion and did not previously sustain a diagnosed concussion). Adult participants performed significantly better than adolescent participants on several measures, including ImPACT® visual-motor speed score ($d=0.09$), ImPACT® reaction time ($r=0.52$), SCAT5 SAC concentration score ($V=0.38$), SCAT5 mBESS ($r=0.42$) score, and the CP Screen vestibular profile score ($r=0.38$). No significant differences were reported between elite and non-elite players, or based on concussion history, on any tests. Between 2.2% and 13.4% of participants met the threshold for symptom provocation on the individual VOMS items. Overall, 6.6% of participants exceeded the clinical cut-off point for depression on the PHQ-9 and 10.3% exceeded the clinical cut-off point for anxiety on the GAD-7. More than half (56.3%) of participants experienced poor sleep quality, as measured by the PSQI.

Although comparing post-SRC results to normative data may be more feasible than carrying out baseline assessments in LGF due to limited resources, the clinical utility of baseline SRC assessments should also be investigated. Tests included in baseline assessments should demonstrate adequate test-retest reliability. The aim of Study 4 was to evaluate the test-retest reliability of a multi-domain SRC assessment at six- and twelve-month intervals in LGF players. Separate groups of participants were re-assessed at the six- and twelve-month timepoints. The SCAT5 GSC, CP Screen total score, PHQ-9, and GAD-7 all demonstrated moderate test-retest reliability in both the six- and twelve-month groups. However, ImPACT®, the SCAT5 SAC and neurological components, neck dynamometry, individual CP Screen items, MIDAS, NBQ, and PSQI displayed inadequate test-retest reliability at both re-assessment timepoints. Similarly, 95% RCIs derived for elements of ImPACT®, the SCAT5, and neck dynamometry indicated that there was a large degree of measurement error between assessments.

7.2 Conclusion

The literature review revealed a lack of high-quality data on SRC prevalence and management behaviour in LGF and other female, community sports. Furthermore, there was limited normative data and test-retest reliability data available on the tests recommended for inclusion in multi-domain SRC assessments in comparable populations. Few previous studies had provided normative or test-

retest reliability data on multi-domain SRC assessments in any population, and instead tended to focus on individual tests (e.g., ImPACT®) in isolation.

Our research showed that although SRC occurs in LGF and appears to be a concern, many participants did not adhere to the recommended management guidelines following a suspected SRC. Being diagnosed with SRC by a medical professional (as opposed to sustaining a suspected SRC) was the main factor that was associated with safe management behaviour following a possible SRC. Other factors, including level of play, age, concussion history, knowledge, attitude, and previous exposure to SRC education materials contributed minimally to SRC management behaviour. This emphasises the importance of medical professionals in diagnosing, managing and rehabilitating SRC in LGF. Players with suspected SRCs should initially be assessed by a medical professional using a multi-domain SRC assessment. Medical professionals should then guide them through SRC management and RTP protocols. There is a clear need to improve medical cover and improve referral pathways for SRC in LGF at all levels. We presented normative data on a multi-domain SRC assessment from a cohort of LGF players, which may assist clinicians in diagnosing SRC. Adolescent participants demonstrated worse scores on several cognitive and vestibular measures, however no differences were observed based on level of play or history of concussion. Clinicians working with LGF players should therefore consult normative data for the appropriate age group. Finally, the test-retest reliability of the SCAT5 GSC, CP Screen, PHQ-9, and GAD-7 was moderate over six- and twelve-month intervals. However, the remaining measures showed inadequate reliability. Normative data will assist clinicians working with LGF players in diagnosing and managing SRC. It appears that many of the measures included in the multi-domain assessment may have poor reliability over time and may be more useful when compared with suitable normative data than pre-injury baseline results.

It is important to acknowledge that this thesis draws on the work of the CISG, who guide the development of international SRC recommendations- e.g., questions about management behaviours in Studies 1 and 2 were based on the most recent SRC consensus statement (37). In April 2022, the chairperson of the CISG resigned after reports that he had committed multiple accounts of plagiarism over the past two decades. This has cast doubt over the group's work, in particular over the SRC management and RTP guidelines. The CISG RTP guidelines have been accused of not reflecting physiological recovery time from SRC (456). Although the LGFA Medical and Scientific Committee developed LGF-specific SRC management guidelines, these were adapted from CISG recommendations (30). The LGFA recommend a longer recovery period and more time spent on the graded RTP programme than the CISG (30). The CISG have acknowledged that the SRC literature is continually evolving, and have reported their methods for the upcoming international meeting in October 2022 (457). This meeting will be the first in six years and will update current

SRC management recommendations. It is likely that these updates will affect the LGFA, and changes to the LGF management guidelines will be made.

7.3 Directions for future research and recommendations

This is the first study to examine SRC prevalence and management behaviour in LGF. It is also the only study to present normative data on and examine the test-retest reliability of a multi-domain SRC assessment in female athletes participating in a community sport. Therefore, future research that builds on our findings is necessary.

- Study 1 involved an online survey that recruited participants using convenience sampling. Prospective research of SRC in LGF is required to follow-up on our preliminary findings, which may have overestimated the prevalence of SRC. In addition, future epidemiological research on SRC in LGF should include adolescent participants.
- We noted differences in SRC prevalence between elite and non-elite LGF players in Study 1. Both elite and non-elite players should be included in future prospective SRC research. This will help to determine whether the increased SRC prevalence in elite players is related to differences in athletic exposures, playing style, player attributes, or other factors.
- Further research is needed to understand the reasons for poor adherence to recommended SRC management guidelines among participants. This could be addressed quantitatively using a theory-driven approach, or through qualitative research methods, such as focus groups or semi-structured interviews. This would enable us to gain greater insight to the barriers to and facilitators of managing SRCs appropriately. Targeted interventions aimed at changing behaviour based on findings from qualitative research could then be developed.
- Study 2 examined the association between multiple factors and SRC management behaviours, however its retrospective design means that it is not possible to determine whether modifiable factors (e.g., CAI) had changed since the time of injury. Follow-up prospective research using random sampling is therefore needed to confirm our findings. This research should also be expanded to include adolescent players.
- Psychosocial factors other than knowledge and attitudes may affect how players behave following a suspected SRC. Further research examining the effect of constructs such as subjective norms, perceived behavioural control, and reporting intention on SRC management behaviour using validated measures should be conducted.
- Being diagnosed with SRC by a medical professional was the most influential factor in multiple SRC management behaviours in Study 2. However, it is not known whether players were diagnosed by on-site medical personnel or whether they later sought medical care. Future research should explore when and how medical attention was sought, and how we can further encourage LGF players to engage with medical professionals following an SRC.

- Developing behavioural change interventions may help to improve SRC management among LGF players. Although purely didactic education interventions appear to have limited benefit in improving SRC management behaviour, interventions that use methods such as scenario-based learning have been successful in other areas and could be adapted to SRC.
- In Study 3, worse scores on several cognitive and vestibular measures were reported for adolescent participants compared with adult participants. However, as the study contained a small number of adolescent participants, more research on differences based on age is needed. Ideally, these differences should be examined for various age groups (e.g., 13-15 years, 16-18 years, 19+ years). In addition, our study included low numbers of participants who played at the elite level and who had previously been diagnosed with an SRC. Research on larger sample sizes is necessary to accurately examine whether differences in baseline SRC measures differ between these groups.
- Pre-existing medical conditions, such as depression, anxiety, ADHD, LD, and migraine, may influence baseline SRC assessment results. Our sample size was insufficient to stratify data based on these conditions, however future, more comprehensive normative databases of SRC assessments are required to assist in the diagnosis and management of SRC in LGF.
- Large proportions of participants met the clinical cut-off thresholds on the VOMS at baseline, regardless of the scoring method used. There is disagreement in the literature regarding the most appropriate cut-off points for the VOMS. Additional research is required to establish the most useful cut-off points in female athletes.
- More participants exceeded the clinical cut-off points for the PHQ-9 and GAD-7 than reported being diagnosed with depression or anxiety. Future research should examine the prevalence of mental health disorders in LGF players, which may increase the risk of prolonged SRC recovery.
- Due to low sample sizes, we were unable to examine the test-retest reliability of the multi-domain SRC assessment separately in adolescent and adult participants in Study 4. Adolescents may exhibit greater variability in neurological measures than adults due to maturational processes. Therefore, further research that examines the test-retest reliability of the multi-domain SRC assessment in different age groups is needed.
- Although many aspects of the multi-domain SRC assessment demonstrated inadequate test-retest reliability over long (>six months) timeframes, they may still be useful in the short-term. Research that assesses the acute sensitivity and specificity of the multi-domain SRC assessment in LGF players is required.

7.4 Recommendations for the LGFA

The LGFA should recognise that SRC is a prevalent injury with potentially serious consequences for LGF players. Therefore, we recommend the following:

- As resources to provide medical support to LGF teams throughout Ireland is limited, the LGFA should consider developing a formal SRC referral pathway to assist in SRC diagnosis and management. This pathway could include referral to an LGFA-associated clinician who could then comprehensively assess and treat players with SRC. The LGFA should also ensure players receive written clearance by a clinician before RTP. This could be completed by either a team clinician or another clinician the player attends.
- Although SRC education has not been proven to improve management behaviour, it is still important the players and coaches are educated on current LGFA management guidelines. We recommend the introduction of mandatory SRC education for all players and coaches. In particular, this education should include up-to-date guidance on RTP and the graded RTP programme.
- Although further development is required on our normative database, we recommend that clinicians working the LGF players use a multi-domain SRC assessment when diagnosing and managing SRC. This may enable a more comprehensive, individualised assessment than relying on only one or two clinical tests. Currently, we recommended a normative approach as there is insufficient evidence to support individualised baseline assessments in LGF players.

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Appendices

Appendix A

Online Survey

Plain Language Statement

Development of a novel, multi-level strategy to enhance concussion identification and appropriate management in the community sport of Ladies Gaelic Football

School of Health and Human Performance, Dublin City University

Principal Investigator: Ms Róisín Leahy

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Other Investigators: Dr Siobhán O' Connor, Dr Keith Rochfort, Dr Enda Whyte

Purpose of the research:

Concussion is a type of mild head injury that causes a wide range of signs and symptoms. In community sports, such as Ladies Gaelic Football, a lack of access to medical personnel may mean that players do not receive appropriate medical advice. Therefore, there is a need for concussion education programmes that aim to improve concussion reporting among players. However, currently information needed to develop these programmes in Ladies Gaelic Football is lacking. This includes information about how Ladies Gaelic Football players experience concussion, how players respond to suspected concussions, their knowledge of and attitude towards concussion, and their experience with using concussion education resources.

This study aims to examine players' concussion history, concussion-related knowledge and attitudes and views on future concussion education, with the ultimate aim of contributing towards the development of a concussion education programme for Ladies Gaelic Football players.

What does participation in this research involve?

If you choose to participate in this study, you will be asked to answer a questionnaire that takes approximately 20 minutes to complete. This questionnaire includes sections on your medical history, your concussion history and how you managed previous concussions, your experience with and views of concussion education and your knowledge of and attitudes towards concussion.

Confidentiality and Use of Data:

All data collected for this study will be anonymous and cannot be used to identify participants. Data will be deleted from the online server after one year. Downloaded data will be stored anonymously in an encrypted file on the principal investigator's laptop and will be retained in the case it is required for publication. The data will only be used for the research purposes outlined in this document and will only be shared with named researchers working on the study. Results from this study will be published in scientific journals and promoted by the Ladies Gaelic Football Association. If you have any queries, you may contact the DCU Data Protection Officer, Mr Martin Ward (data.protection@dcu.ie; Ph: 7005118 / 7008257).

Benefits (Direct or Indirect) to Participants:

There are no direct benefits to participating in this study. However, by taking part

participants will provide valuable information on concussion in Ladies Gaelic Football, contributing to increased safety and improved player welfare in the sport.

Potential Risks to Participants:

The study poses a very low risk to participants.

Freedom of Withdrawal:

Participation in this study is entirely voluntary. If you volunteer to be in this study, you can withdraw at any time. You do not have to give reasons for your withdrawal.

Funding Source:

This study is jointly funded by the Ladies Gaelic Football Association and the Irish Research Council under the Enterprise Partnership Scheme.

If participants have concerns about this study and wish to contact an independent person please contact:

The Secretary,
Dublin City University Research Ethics Committee,
c/o Research and Innovation Support,
Dublin City University, Dublin 9.
Tel 01-7008000,
E-mail: rec@dcu.ie

*Required

Informed Consent Form

1. I have read the Plain Language Statement. *

Mark only one oval.

☐ Yes

2. I understand the information that has been provided. *

Mark only one oval.

☐ Yes

-
3. I understand the information that has been provided in relation to data protection. *

Mark only one oval.

☐ Yes

4. I understand that I may withdraw from this study at any time. *

Mark only one oval.

☐ Yes

5. I have had an opportunity to ask questions and discuss the study. *

Mark only one oval.

☐ Yes

6. I have received satisfactory answers to all of my questions. *

Mark only one oval.

☐ Yes

7. I consent to take part in this study. *

Mark only one oval.

☐ Yes

8. Did you play Ladies Gaelic Football during the 2019 season? *

Mark only one oval.

☐ Yes

☐ No *Skip to section 18 (null)*

Background Information

9. 1. Did you play Ladies Gaelic Football with your county team during 2019? *

Mark only one oval.

☐ Yes

☐ No

10. 2. What age are you? *

11. 3. Where is your club located? *

Mark only one oval.

☐ Antrim

☐ Armagh

☐ Carlow

☐ Cavan

☐ Clare

☐ Cork

☐ Derry

☐ Donegal

☐ Down

☐ Dublin

☐ Fermanagh

☐ Galway

☐ Kerry

☐ Kildare

☐ Kilkenny

☐ Laois

☐ Leitrim

☐ Limerick

☐ Longford

☐ Louth

☐ Mayo

☐ Meath

☐ Monaghan

☐ Offaly

☐ Roscommon

☐ Sligo

☐ Tipperary

☐ Tyrone

☐ Waterford

☐ Westmeath

☐ Wexford

☐ Wicklow

12. 4. In what Championship division did your club team play during the 2019 season? If you play on several teams, please answer in relation to the team you played with most frequently. *

Mark only one oval.

- ☐ Senior
- ☐ Intermediate
- ☐ Junior

13. 5. How many years have you played Ladies Gaelic Football? *

14. 6. What position do you most often play (more than half the time)? *

Mark only one oval.

- ☐ Forward
- ☐ Midfield
- ☐ Back
- ☐ Goalkeeper

Medical History

15. 1. Do you experience any of the following? *

Mark only one oval per row.

	Yes, but I HAVE NOT been diagnosed by a doctor or medical professional	Yes, and I HAVE been diagnosed by a doctor or medical professional	No
Headache (Non-Migraine)	☐	☐	☐
Attention Deficit Hyperactivity Disorder (ADHD)/Attention Deficit Disorder (ADD)	☐	☐	☐
Learning disorder (e.g., Dyslexia, Language Processing Disorder, Visual Perceptual/Visual Motor Deficit)	☐	☐	☐
Migraine	☐	☐	☐

Mood Disorder/Depression	☐	☐	☐
Anxiety Disorder	☐	☐	☐
Other Mental Illness	☐	☐	☐
Motion Sickness	☐	☐	☐
Vestibular Disorder (e.g. benign paroxysmal positional vertigo (BPPV), labyrinthitis, vestibular neuritis, Ménière's disease or secondary endolymphatic hydrops)	☐	☐	☐
Vision Problems (Other than need for glasses/contacts)	☐	☐	☐
Sleep Disorder	☐	☐	☐
Neck problems	☐	☐	☐

16. 2. Have you received treatment for any of the following? *

Mark only one oval per row.

	Yes	No
Mood Disorder/Depression	☐	☐
Anxiety Disorder	☐	☐
Other Mental Illness	☐	☐

Concussion
History and
Management:
Part 1

Please read the following before answering the questions below:

"Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. But, in reality, a concussion has occurred anytime you have had a direct blow to the head or other part of the body that caused you to have symptoms for any amount of time. These include: blurred or double vision, seeing stars, sensitivity to light or noise, headache, dizziness or balance problems, nausea, vomiting, trouble sleeping, fatigue, confusion, difficulty remembering, difficulty concentrating, or loss of consciousness."

17. 1. How many concussions do you think you have EVER sustained? Please select the total number of concussions you think you have had in BOTH sport and non sports-related situations. *

Mark only one oval.

- ☐ None
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10 or more

18. 2. How many concussions do you think you have EVER sustained when playing Ladies Gaelic Football? Please DO NOT count concussions sustained playing other sports or during non sports-related situations. *

Mark only one oval.

- ☐ None
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10 or more

19. 3. Do you think you sustained a concussion when playing Ladies Gaelic Football in 2019? *

Mark only one oval.

☐ Yes

☐ No *Skip to question 31*

**Concussion
History and
Management:
Part 2**

Please answer the following questions in relation to the concussion you sustained when playing Ladies Gaelic Football in 2019. If you sustained more than one concussion when playing Ladies Gaelic Football in 2019, please answer in relation to the MOST RECENT concussion in 2019.

20. 1. Please select the option that best describes your immediate response to the concussion you sustained playing Ladies Gaelic Football in 2019. *

Mark only one oval.

☐ I played on for less than fifteen minutes during the same training session or match

☐ I played on for more than fifteen minutes during the same training session or match

☐ I did not play for the rest of the training session or match

☐ Don't remember

☐ Other: _____

21. 2. How many days did you experience symptoms related to the injury? *

22. 3. How many days was it until you returned to full contact training? *

23. 4. Please answer the following questions in relation to the concussion you sustained when playing Ladies Gaelic Football in 2019. If you sustained more than one concussion when playing Ladies Gaelic Football in 2019, please answer in relation to the MOST RECENT concussion in 2019. *

Mark only one oval per row.

	Yes	No	Don't remember	N/A
Did you tell your coach or manager that you thought you had a concussion?	☐	☐	☐	☐
Was your concussion diagnosed by medical personnel (i.e. doctor, athletic therapist or physiotherapist)?	☐	☐	☐	☐
Did you return to play on the same day?	☐	☐	☐	☐
Did you return to play when you were still experiencing symptoms?	☐	☐	☐	☐
Did you follow a return-to-play programme that required you to gradually increase your levels of activity from rest to full contact training in a standardised manner?	☐	☐	☐	☐
If you followed a return-to-play programme, did you do this under the guidance of a doctor or registered healthcare practitioner?	☐	☐	☐	☐
Did you get medical clearance from a doctor or registered healthcare practitioner before returning to play?	☐	☐	☐	☐
If relevant, did you follow a graded return-to-school programme that required you to gradually increase your level of mental activity, prescribed by a registered healthcare professional?	☐	☐	☐	☐

**Concussion
History and
Management:
Part 3**

Please answer the following questions in relation to the concussion you sustained when playing Ladies Gaelic Football in 2019. If you sustained more than one concussion when playing Ladies Gaelic Football in 2019, please answer in relation to the MOST RECENT concussion in 2019.

24. 1. When during the season did you sustain this concussion? *

Mark only one oval.

- ☐ Pre-season
- ☐ During the season
- ☐ Don't remember
- ☐ Other: _____

25. 2. During what activity did you sustain this concussion? *

Mark only one oval.

- ☐ Match
- ☐ Team training session
- ☐ Training on your own
- ☐ Don't remember
- ☐ Other: _____

26. 3. How did this concussion occur? *

Mark only one oval.

- ☐ I hit against another player(s)
- ☐ I hit against the ground
- ☐ I hit against a fence, railing or goalpost
- ☐ I hit against the ball
- ☐ Don't remember
- ☐ Other: _____

27. 4. What part of your body was impacted during this concussion? *

Mark only one oval.

- ☐ Head or neck
- ☐ Torso
- ☐ Shoulder or arm
- ☐ Leg
- ☐ Don't remember
- ☐ Other: _____

Concussion Signs and Symptoms

Think back to the concussion you sustained playing Ladies Gaelic Football in 2019 (if you sustained more than one concussion in 2019, please answer in relation to the most recent concussion in 2019).

28. 1. Please indicate your symptom severity for each symptom for the concussion you sustained when playing Ladies Gaelic Football in 2019. *

Mark only one oval per row.

	None	Mild	Moderate	Severe
1. Feeling sad	☐	☐	☐	☐
2. Headache when you wake up	☐	☐	☐	☐
3. Difficulty or headache when looking at phone or computer screen	☐	☐	☐	☐
4. Dizziness when you move your head	☐	☐	☐	☐
5. Difficulty turning off your thoughts (e.g., rumination)	☐	☐	☐	☐
6. Headache with nausea or upset stomach	☐	☐	☐	☐
7. Trouble focusing your eyes while reading	☐	☐	☐	☐
8. Frontal headache	☐	☐	☐	☐
9. Difficulty or discomfort in busy environments	☐	☐	☐	☐
10. Constantly thinking about your symptoms	☐	☐	☐	☐

11. Headache with sensitivity to light or noise	☐	☐	☐	☐
12. Feeling motion sick ("sea or car sick")	☐	☐	☐	☐
13. Feeling more tired at the end of the day	☐	☐	☐	☐
14. Blurry or double vision	☐	☐	☐	☐
15. Feeling or sensation of slow wavy dizziness (i.e., lightheadedness)	☐	☐	☐	☐
16. Neck pain or stiffness	☐	☐	☐	☐
17. Sleeping more than usual	☐	☐	☐	☐
18. Sleeping less than usual	☐	☐	☐	☐
19. Eye strain (eyes feel tired) during visual activities	☐	☐	☐	☐
20. Visual aura (e.g., flashes, stars, spots, flickering light) with or without headache	☐	☐	☐	☐
21. Feeling or sensation of fast spinning dizziness (i.e., vertigo)	☐	☐	☐	☐
22. Difficulty falling asleep	☐	☐	☐	☐
23. Difficulty staying asleep	☐	☐	☐	☐
24. Trouble remembering things (e.g., what you completed today or having to re-read information)	☐	☐	☐	☐
25. Difficulty moving your neck	☐	☐	☐	☐
26. Feeling nervous or anxious	☐	☐	☐	☐
27. Increased headache following physical activity	☐	☐	☐	☐
28. Increased headache following cognitive activity	☐	☐	☐	☐
29. Feeling more stressed than usual	☐	☐	☐	☐

29. 2. Please indicate how long you experienced the following symptoms for the concussion you sustained playing Ladies Gaelic Football in 2019. *

Mark only one oval per row.

	I didn't experience this symptom	Up to 3 days	3-7 days	More than one week
1. Feeling sad	☐	☐	☐	☐
2. Headache when you wake up	☐	☐	☐	☐
3. Difficulty or headache when looking at phone or computer screen	☐	☐	☐	☐
4. Dizziness when you move your head	☐	☐	☐	☐
5. Difficulty turning off your thoughts (e.g., rumination)	☐	☐	☐	☐
6. Headache with nausea or upset stomach	☐	☐	☐	☐
7. Trouble focusing your eyes while reading	☐	☐	☐	☐
8. Frontal headache	☐	☐	☐	☐
9. Difficulty or discomfort in busy environments	☐	☐	☐	☐
10. Constantly thinking about your symptoms	☐	☐	☐	☐
11. Headache with sensitivity to light or noise	☐	☐	☐	☐
12. Feeling motion sick ("sea or car sick")	☐	☐	☐	☐
13. Feeling more tired at the end of the day	☐	☐	☐	☐
14. Blurry or double vision	☐	☐	☐	☐
15. Feeling or sensation of slow wavy dizziness (i.e., lightheadedness)	☐	☐	☐	☐

16. Neck pain or stiffness	☐	☐	☐	☐
17. Sleeping more than usual	☐	☐	☐	☐
18. Sleeping less than usual	☐	☐	☐	☐
19. Eye strain (eyes feel tired) during visual activities	☐	☐	☐	☐
20. Visual aura (e.g., flashes, stars, spots, flickering light) with or without headache	☐	☐	☐	☐
21. Feeling or sensation of fast spinning dizziness (i.e., vertigo)	☐	☐	☐	☐
22. Difficulty falling asleep	☐	☐	☐	☐
23. Difficulty staying asleep	☐	☐	☐	☐
24. Trouble remembering things (e.g., what you completed today or having to re-read information)	☐	☐	☐	☐
25. Difficulty moving your neck	☐	☐	☐	☐
26. Feeling nervous or anxious	☐	☐	☐	☐
27. Increased headache following physical activity	☐	☐	☐	☐
28. Increased headache following cognitive activity	☐	☐	☐	☐
29. Feeling more stressed than usual	☐	☐	☐	☐

30. 3. Which of these signs or symptoms did you experience straightaway (on-field) at the time of injury? *

Mark only one oval per row.

	Yes	No	Don't Remember
Knocked out/blacked out	☐	☐	☐
Difficulty remembering events occurring before the injury	☐	☐	☐
Difficulty remembering events occurring after the injury	☐	☐	☐
Confusion	☐	☐	☐
Poor balance	☐	☐	☐
Headache	☐	☐	☐
Nausea or vomiting	☐	☐	☐
Fogginess	☐	☐	☐
Sensitivity to light or noise	☐	☐	☐
Blurred/double vision	☐	☐	☐
Dizziness	☐	☐	☐

Concussion Education

31. 1. Are you aware of any concussion resources provided by the LGFA? *

Mark only one oval.

- ☐ Yes
- ☐ No *Skip to question 37*
- ☐ Don't know

Concussion Education: Part 1

32. 2. If yes, where would you access LGFA concussion resources? *

33. 3. If yes, what LGFA concussion resources are you aware of? *

34. 4. If yes, have you previously used LGFA concussion education resources? *

Mark only one oval per row.

	Yes	No	Don't know
I used LGFA concussion education resources in 2019	☐	☐	☐
I used LGFA concussion education resources before 2019	☐	☐	☐

35. 5. If yes, have you used any of the following LGFA concussion resources? *

Mark only one oval per row.

	Yes	No	Don't know
Concussion Information Sheets for Female Players	☐	☐	☐
Concussion Information Sheets for Coaches and Parents	☐	☐	☐
Concussion Information Sheets for Referees	☐	☐	☐
Concussion Management Guidelines for Gaelic Games 2018 document	☐	☐	☐
Concussion awareness posters to hang in clubhouse (available on GAA website)	☐	☐	☐
E-learning module	☐	☐	☐
Pocket Concussion Recognition Tool 5 (available on GAA website)	☐	☐	☐

36. 6. After using LGFA concussion education resources, what level of understanding did you think you had of:

Mark only one oval per row.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I understand what a concussion is	☐	☐	☐	☐	☐
I can recognise the main signs and symptoms of a concussion	☐	☐	☐	☐	☐
I know what to do if I think I have a concussion	☐	☐	☐	☐	☐
I understand return-to-play guidelines	☐	☐	☐	☐	☐
I understand the possible long-term effects of concussion	☐	☐	☐	☐	☐
I understand the effects of poor concussion management	☐	☐	☐	☐	☐
I know the main risk factors for concussion	☐	☐	☐	☐	☐

Concussion Education: Part 2

37. 1. Which of the following do the LGFA and GAA recommend to female players following a concussion? Please select all that apply. *

Mark only one oval per row.

	True	False
There are no official LGFA recommendations for players following a concussion.	☐	☐
Female players with a concussion are recommended to follow the same guidelines as male players.	☐	☐
Players should take physical and mental rest for at least 48 hours following a concussion.	☐	☐
Players should take physical and mental rest for at least 24 hours following a concussion.	☐	☐
Players are advised to follow a six step return-to-play programme which involves gradually increasing activity in a standardised manner and takes at least 15 days to complete.	☐	☐
Players are advised to follow a six step return-to-play programme which involves gradually increasing activity in a standardised manner and takes at least 7 days to complete.	☐	☐
Players should receive written medical clearance from a doctor or registered healthcare practitioner before returning to full contact play.	☐	☐
Players with a suspected concussion should be removed from play and immediately assessed by a doctor or registered healthcare practitioner.	☐	☐
Players with a suspected concussion should be urgently referred to a doctor if a doctor or registered healthcare practitioner is not present.	☐	☐
It is not always necessary for players with a suspected concussion to be assessed by a doctor or registered healthcare practitioner.	☐	☐
	☐	☐

Players should not return to play if they are experiencing symptoms.

— —

Players in school or college should follow a return-to-learn programme, which involves gradually increasing mental activity in a standardised manner.

☐ ☐

38. 2. How interested are you in the following types of concussion education resources? *

Mark only one oval per row.

	Extremely Interested	Very Interested	Somewhat Interested	Not very Interested	Not At All Interested
Interactive workshops with group discussions	☐	☐	☐	☐	☐
Presentations	☐	☐	☐	☐	☐
Online modules with quizzes	☐	☐	☐	☐	☐
Personal testimonies from players who have had a concussion	☐	☐	☐	☐	☐
Role-playing of concussion scenarios	☐	☐	☐	☐	☐
Concussion information sheets	☐	☐	☐	☐	☐

Coach-delivered education	☐	☐	☐	☐	☐
Peer-delivered education	☐	☐	☐	☐	☐
Once off concussion education during the pre-season	☐	☐	☐	☐	☐
Once during the pre-season and once during the season	☐	☐	☐	☐	☐
Monthly concussion education for 3 months	☐	☐	☐	☐	☐
Weekly concussion education for 12 weeks	☐	☐	☐	☐	☐

39. 3. How interested are you in learning about the following? *

Mark only one oval per row.

	Extremely interested	Very interested	Somewhat interested	Not very interested	Not At All Interested
Causes of concussion	☐	☐	☐	☐	☐
Signs and symptoms of concussion	☐	☐	☐	☐	☐
Immediate concussion management	☐	☐	☐	☐	☐
Return-to-play guidelines	☐	☐	☐	☐	☐
Concussion reporting and underreporting	☐	☐	☐	☐	☐
Long-term effects of concussion	☐	☐	☐	☐	☐
Effects of poor concussion management	☐	☐	☐	☐	☐

Risk factors for concussion	☐	☐	☐	☐	☐
Psychological aspects of concussion	☐	☐	☐	☐	☐
Creating a healthier sporting environment for managing concussion	☐	☐	☐	☐	☐

Concussion Knowledge and Attitudes: Part 1

40. Please read the following statements and answer TRUE or FALSE for each question. *

Mark only one oval per row.

	True	False
There is a possible risk of death if a second concussion occurs before the first one has healed.	☐	☐
Running everyday does little to improve cardiovascular health.	☐	☐
People who had one concussion are more likely to have another concussion.	☐	☐
Studs help players' feet grip the playing surface.	☐	☐
In order to be diagnosed with a concussion, you have to be knocked out.	☐	☐
A concussion can only occur if there is a direct hit to the head.	☐	☐
Being knocked unconscious always causes permanent damage to the brain.	☐	☐
Symptoms of a concussion can last several weeks.	☐	☐

Sometimes a second concussion can help a person remember things that were forgotten after the first.	☐	☐
Weightlifting helps to tone and/or build muscle.	☐	☐
After a concussion occurs, brain imaging (e.g., CAT Scan, MRI, X-Ray, etc.) typically shows visible physical damage (e.g., bruise, blood clot) to the brain.	☐	☐
If you receive one concussion and you have never had a concussion before, you will become less intelligent.	☐	☐
After 10 days, symptoms of a concussion are usually completely gone.	☐	☐
After a concussion, people can forget who they are and not recognise others but be perfect in every other way.	☐	☐
Secondary school first-years and college first-years tend to be the same age.	☐	☐
Concussions can sometimes lead to emotional disruptions.	☐	☐
A player who gets knocked out after getting a concussion is experiencing a coma.	☐	☐
There is rarely a risk to long-term health and well-being from multiple concussions.	☐	☐

Concussion
Knowledge and
Attitudes: Part 2

DIRECTIONS: Please read each of the following scenarios and select TRUE or FALSE for each question that follows the scenarios.

41. SCENARIO 1: While playing in a game, Player Q and Player X collide with each other and each suffers a concussion. Player Q has never had a concussion in the past. Player X has had 4 concussions in the past. *

Mark only one oval per row.

	True	False
It is likely that Player Q's concussion will affect his long-term health and well-being.	☐	☐
It is likely that Player X's concussion will affect his long-term health and well-being.	☐	☐

42. SCENARIO 2: Player F suffered a concussion in a game. She continued to play in the same game despite the fact that she continued to feel the effects of the concussion. *

Mark only one oval per row.

	True	False
Even though Player F is still experiencing the effects of the concussion, her performance will be the same as it would be had she not suffered a concussion.	☐	☐

Concussion Knowledge and Attitudes: Part 3

43. For each question, select the answer that best describes how you feel about each statement. *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I would continue playing a sport while also having a headache that resulted from a minor concussion.	☐	☐	☐	☐	☐
2. I feel that coaches need to be extremely cautious when determining whether a player should return to play.	☐	☐	☐	☐	☐
3. I feel that mouthguards protect teeth from being damaged or knocked out.	☐	☐	☐	☐	☐
4. I feel that professional players are more skilled at their sport than secondary school players	☐	☐	☐	☐	☐
5. I feel that concussions are less important than other injuries.	☐	☐	☐	☐	☐
6. I feel that a player has a responsibility to return to a game even if it means playing while still experiencing symptoms of a concussion.	☐	☐	☐	☐	☐
7. I feel that a player who is knocked unconscious should be taken to the emergency room.	☐	☐	☐	☐	☐
8. I feel that most secondary school players will play professional sports in the future.	☐	☐	☐	☐	☐

Concussion
Knowledge
and
Attitudes:
Part 4

For each question, read the scenarios and select the answer that best describes your view. (For the questions that ask you what most players feel, base your answers on how you think MOST players would feel.)

44. SCENARIO 1: Player R suffers a concussion during a game. Coach A decides to keep Player R out of the game. Player R's team loses the games. *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel that Coach A made the right decision to keep Player R out of the game.	☐	☐	☐	☐	☐
2. Most players would feel that Coach A made the right decision to keep Player R out of the game.	☐	☐	☐	☐	☐

45. SCENARIO 2: Player M suffered a concussion during the first game of the season. Player O suffered a concussion of the same severity during the semi-final playoff game. Both players had persisting symptoms. *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel that Player M should have returned to play during the first game of the season.	☐	☐	☐	☐	☐
2. Most players would feel that Player M should have returned to play during the first game of the season.	☐	☐	☐	☐	☐
3. I feel that Player O should have returned to play during the semi-final playoff game.	☐	☐	☐	☐	☐
4. Most players feel that Player O should have returned to play during the semi-final playoff game.	☐	☐	☐	☐	☐

46. SCENARIO 3: Player R suffered a concussion. Player R's team has a physiotherapist/athletic therapist on the staff. *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel that the physiotherapist/athletic therapist, rather than Player R, should make the decision about returning Player R to play.	☐	☐	☐	☐	☐
2. Most players would feel that the physiotherapist/athletic therapist, rather than Player R, should make the decision about returning Player R to play.	☐	☐	☐	☐	☐

47. SCENARIO 4: Player H suffered a concussion and he has a game in two hours. He is still experiencing symptoms of concussion. However, Player H knows that if he tells his coach about the symptoms, his coach will keep him out of the game. *

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel that Player H should tell his coach about the symptoms.	☐	☐	☐	☐	☐
2. Most players would feel that Player H should tell his coach about the symptoms.	☐	☐	☐	☐	☐

Concussion Knowledge and Attitudes: Part 5

48. DIRECTIONS: Think about someone who has had a concussion. Check off the following signs and symptoms that you believe someone may be likely to experience AFTER a concussion. *

Tick all that apply.

- ☐ Hives
- ☐ Headache
- ☐ Difficulty Speaking
- ☐ Arthritis
- ☐ Sensitivity to Light
- ☐ Difficulty Remembering
- ☐ Panic Attacks
- ☐ Drowsiness
- ☐ Feeling in a "Fog"
- ☐ Weight Gain
- ☐ Feeling Slowed Down
- ☐ Reduced Breathing Rate
- ☐ Excessive Studying
- ☐ Difficulty Concentrating
- ☐ Dizziness
- ☐ Hair Loss

Appendix B

Plain Language Statement (Adult Participants)

DUBLIN CITY UNIVERSITY Plain Language Statement Adult

Introduction to the Research Study:

Development of a novel, multi-level strategy to enhance concussion identification and appropriate management in the community sport of Ladies Gaelic Football

DCU School of Health and Human Performance

Principal Investigator: Ms Róisín Leahy

Contact details: roisin.leahy6@mail.dcu.ie

Other Investigators: Dr. Siobhán O Connor, Dr Keith Rochfort, Dr Enda Whyte, Dr Phil Cummins

Study Details:

Concussion is a form of traumatic brain injury that may occur during contact sports. Diagnosing concussion presents considerable challenges due to its non-specific symptoms and lack of definitive diagnostic test. While many tests have been developed for concussion, it is not known how well they measure symptoms and whether they produce consistent results over time. This is especially true in community sports such as Ladies Gaelic Football (LGF) where there has been little research carried out. This study aims to assess the repeatability of a comprehensive concussion assessment over time in LGF players without a concussion.

If you are being asked to participate in this study, then you have already completed an initial baseline testing session consisting of tests for memory, balance, vision, mood and neck movement and function. If you choose to continue your participation, you will be asked to (i) complete an online computer test for memory and reaction time and online questionnaires (taking approximately 60 minutes), and (ii) attend an in-person testing session in DCU (taking approximately 60 minutes). This session includes tests for balance, vision and neck strength. At this session, you will also be asked to give a 5ml saliva sample and two 10ml blood samples. The in-person session will be done in full compliance with Covid-19 guidelines. Before you arrive, you will be asked to answer a Covid-19 health questionnaire. Both you and the tester will wear a face mask and keep a distance of at least two metres from each other when possible during the tests.

Personal Data/GDPR Compliance:

A Personal Data Security Schedule (PDSS) is in place to ensure GDPR compliance. The principal investigator is the data controller. Personal data collected for this study will include name, date of birth, medical history and health data. This data will only be used for the research purposes outlined in this document and will only be shared with named researchers working on the study. All identifying data will be retained for 12 months following the completion of the study and then they will be destroyed by the principal investigator. You may withdraw from the study at any time. If you have any queries, you may contact the DCU Data Protection Officer, Mr Martin Ward (data.protection@dcu.ie; Ph: 7005118 / 7008257).

Confidentiality and Use of Data:

All data and samples collected throughout the course of this study will remain confidential and will be disclosed only with your permission or as required by the law. Confidentiality will be ensured by assigning each participant an ID number which will allow the investigators to know who you are. Your name will not be used in any of the information received from this study or in any of the research reports. Information that can identify you individually will not be released to anyone outside the study. All hard copy data will be stored in a locked cabinet in the principal investigators office and electronic data will be stored in an encrypted file on the principal investigator's laptop. De-identified blood samples will be stored in a dedicated stored facility.

Identifying information will be destroyed 12 months after completion of the research project by the principal investigator. Anonymous data will be retained in the case it is required for publication and de-identified blood samples will be retained and may be used in future studies. In the event of an emergency or illness, your information may be passed on to medical staff. Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some profession.

Benefits (Direct or Indirect) to Participants

There are no direct benefits to participants. However, results from this study may contribute to increased safety and improved player welfare in Ladies Gaelic Football and thereby indirectly benefit you and all Ladies Gaelic football players.

Potential Risks to Participants

The study poses minimal risk to participants. A comprehensive protocol that fully adheres to Covid-19 regulations has been developed. To reduce person-to-person contact, half of the testing will be carried out online prior to you attending the in-person session. Before you attend the in-person testing session you will be required to answer a Covid-19 health questionnaire. Both you and the tester will be required to wear a face mask for the duration of the testing and a distance of two metres will be kept between you and the tester when possible.

Freedom of Withdrawal:

Participation in this study is entirely voluntary. If you volunteer to be in this study, you can withdraw at any time by approaching the investigator and informing them of your withdrawal. You do not have to give reasons for your withdrawal.

Funding Source:

This study is jointly funded by the Ladies Gaelic Football Association and the Irish Research Council under the Enterprise Partnership Scheme.

Other Relevant Information:

Participation in this research project will have no effect on any on-going relationship with Dublin City University.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

DUBLIN CITY UNIVERSITY Informed Consent Form Adult

Development of a novel, multi-level strategy to enhance concussion identification and appropriate management in the community sport of Ladies Gaelic Football

School of Health and Human Performance, Dublin City University

Principal Investigator: Ms Róisín Leahy

Contact details: roisin.leahy6@mail.dcu.ie

Other Investigators: Dr Siobhán O' Connor, Dr Keith Rochfort, Dr Phil Cummins

Clarification of the purpose of the research

Concussion is a form of traumatic brain injury that may occur during contact sports. Diagnosing concussion presents considerable challenges due to its non-specific symptoms and lack of definitive diagnostic test. This is especially true in community sports such as Ladies Gaelic Football where players have limited access to medical personnel. This study aims to (i) develop a clinical tool for concussion diagnosis specific to female athletes and (ii) investigate how many concussions occur, previous concussion history, knowledge and attitudes in Ladies Gaelic Football players. I am aware that the data collected will only be used for the purposes outlined here and that the principal investigator is the data controller.

Confirmation of particular requirements as highlighted in the Plain Language Statement

I will be required to attend an initial screening session lasting between 60 and 90 minutes in the School of Health and Human Performance in DCU. I will be asked to provide information about my age, training schedule and medical history. I will do tests to examine my symptoms, memory, concentration, balance, mood, and neck movement and function. I will also give two 10ml blood samples and answer a questionnaire about my concussion history, knowledge of and attitude to concussion. If I sustain a concussion in the following 2 years I will inform the researchers and return to DCU with 72 hours of injury to provide details about the injury and be retested on the same clinical and blood tests. I may also be asked to return for additional testing if my symptoms persist. If I do not sustain a concussion during this time frame, I may be asked to return at the end of the season for the same tests to enable comparisons between players with and without

concussion. In addition I may be asked about other non-concussion injuries sustained during the 2 year period at the end of the study.

Participant – please complete the following (Circle Yes or No for each question)

<i>I have read the Plain Language Statement (or had it read to me)</i>	Yes/No
<i>I understand the information provided</i>	Yes/No
<i>I have had an opportunity to ask questions and discuss this study</i>	Yes/No
<i>I have received satisfactory answers to all my questions</i>	Yes/No

Confirmation that involvement in the Research Study is voluntary

I understand that involvement within this research project is purely voluntary. Should I wish to withdraw from the study at any stage throughout, I am entitled to do so. There will be no penalty enforced on me if I wish to quit the Research Study prior to all stages being completed.

Confirmation of arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

I understand that confidentiality is an important issue during data collection. My identity, or other personal information will not be revealed or published. I will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The investigators alone will have access to my data. However, I understand that confidentiality of information provided can only be protected within the limitations of the law. I am aware that it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some profession.

Confirmation of arrangements regarding retention/disposal of data

I understand that identifying data (e.g. name, date of birth) will be destroyed 12 months following the completion of this study. I am aware that the principal investigator will shred hard copies of identifying data in a secure bin and delete all electronic identifying data.

Confirmations relating to any other relevant information as indicated in the PLS

I understand that if I share a relationship of any kind with any of the researchers, relevant to this study, this will not be affected in any way with regard to their ongoing studies throughout the entire duration of this study.

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project.

Participants Signature: _____

Name in Block Capitals: _____

Date: _____

Appendix C

Plain Language Statement (Adolescent Participants)

DUBLIN CITY UNIVERSITY Plain Language Statement Minor

Introduction to the Research Study:

Development of a novel, multi-level strategy to enhance concussion identification and appropriate management in the community sport of Ladies Gaelic Football

DCU School of Health and Human Performance

Principal Investigator: Ms Róisín Leahy

Contact details: roisin.leahy6@mail.dcu.ie

Other Investigators: Dr. Siobhán O Connor, Dr Keith Rochfort, Dr Phil Cummins

Study Details:

Concussion is a type of head injury you may get when playing football. However, it can be difficult to tell if you have a concussion as there are currently no accurate tests for concussion. While many tests have been developed for concussion, it is not known how well they measure symptoms and whether they produce similar results over time. This is especially true in sports such as Ladies Gaelic Football (LGF) where there has been little research carried out. This study aims to assess whether a baseline concussion assessment produces similar results over time in LGF players without a concussion.

If you are being asked to participate in this study, then you have already completed an initial baseline testing session involving tests for memory, balance, vision, mood and neck movement and function. If you choose to continue your participation, you will be asked to (i) complete an online computer test for memory and reaction time and online questionnaires (taking approximately 60 minutes), and (ii) attend an in-person testing session in DCU (taking approximately 60 minutes). This session includes tests for balance, vision and neck strength. At this session, you will also be asked to give a 5ml saliva sample and two 10ml blood samples. The in-person session will be done in full compliance with Covid-19 guidelines. Before you arrive, you will be asked to answer a Covid-19 health questionnaire. Both you and the tester will wear a face mask and keep a distance of at least two metres from each other when possible during the tests.

Personal Data/GDPR Compliance:

A Personal Data Security Schedule (PDSS) is in place to ensure GDPR compliance. The principal investigator is the data controller. Personal data collected for this study will include name, date of birth, medical history and health data. This data will only be used for the research purposes outlined in this document and will only be shared with named researchers working on the study. All identifying data will be retained for 12 months following the completion of the study and then they will be destroyed by the principal investigator. You may withdraw from the study at any time. If you have any queries, you may contact the DCU Data Protection Officer, Mr Martin Ward (data.protection@dcu.ie; Ph: 7005118 / 7008257).

Confidentiality and Use of Data:

All data and samples collected throughout the course of this study will remain confidential and will be disclosed only with your permission or as required by the law. Confidentiality will be ensured by assigning each participant an ID number which will allow the investigators to know who you are. Your name will not be used in any of the information received from this study or in any of the research reports. Information that can identify you individually will not be released to anyone outside the study. All hard copy data will be stored in a locked cabinet in the principal investigators office and electronic data will be stored in an encrypted file on the principal investigator's laptop. De-identified blood samples will be stored in a dedicated stored facility.

Identifying information will be destroyed 12 months after completion of the research project by the principal investigator. Anonymous data will be retained in the case it is required for publication and de-identified blood samples will be retained and may be used in future studies. In the event of an emergency or illness, your information may be passed on to medical staff. Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

Benefits (Direct or Indirect) to Participants

There are no direct benefits to participants. However, results from this study may contribute to increased safety and improved player welfare in Ladies Gaelic Football and thereby indirectly benefit you and all Ladies Gaelic football players.

Potential Risks to Participants

The study poses minimal risk to participants. A comprehensive protocol that fully adheres to Covid-19 regulations has been developed. To reduce person-to-person contact, half of the testing will be carried out online prior to you attending the in-person session. Before you attend the in-person testing session you will be required to answer a Covid-19 health questionnaire. Both you and the tester will be required to wear a face mask for the duration of the testing and a distance of two metres will be kept before you and the tester when possible.

Freedom of Withdrawal:

Participation in this study is entirely voluntary. If you volunteer to be in this study, you can withdraw at any time by approaching the investigator and informing them of your withdrawal. You do not have to give reasons for your withdrawal.

Funding Source:

This study is jointly funded by the Ladies Gaelic Football Association and the Irish Research Council under the Enterprise Partnership Scheme.

Other Relevant Information:

Participation in this research project will have no effect on any on-going relationship with Dublin City University.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie.

DUBLIN CITY UNIVERSITY Informed Consent Form Minor

Development of a novel, multi-level strategy to enhance concussion identification and appropriate management in the community sport of Ladies Gaelic Football

School of Health and Human Performance, Dublin City University

Principal Investigator: Ms Róisín Leahy

Contact details: roisin.leahy6@mail.dcu.ie

Other Investigators: Dr Siobhán O' Connor, Dr Keith Rochfort, Dr Phil Cummins

Clarification of the purpose of the research

Concussion is a type of head injury you may get when playing football. However, it can be difficult to tell if you have a concussion as there are currently no accurate tests for concussion. In amateur sports like Ladies Gaelic Football a doctor, physiotherapist or athletic therapist is often not at training or matches. This means that if players do not recognise concussion symptoms or do not want to tell anyone that they have symptoms, they may not receive proper medical care. This study aims to improve concussion management in Ladies Gaelic Football by (i) developing a test for concussion and (ii) examining how many concussions occur, previous concussion history, knowledge and attitudes in Ladies Gaelic Football players. I am aware that the data collected will only be used for the purposes outlined here and that the principal investigator is the data controller.

Confirmation of particular requirements as highlighted in the Plain Language Statement

My daughter will be required to attend an initial screening session lasting between 60 and 90 minutes in the School of Health and Human Performance in DCU. She will be asked to provide information about her age, training schedule and medical history. She will take part in tests examining my symptoms, memory, concentration, balance, mood, and neck movement and function. She will also give two 10ml blood samples and answer a questionnaire about her concussion history, knowledge of and attitude to concussion. If she sustains a concussion in the following 2 years she will inform the researchers and return to DCU with 72 hours of injury to provide details about the injury and be retested on the same clinical and blood tests. She may also be asked to return for additional testing if her symptoms do not resolve quickly. If my daughter does not sustain a concussion during this time frame, she may be asked to return at the end of the

season for the same tests to enable comparisons between players with and without concussion. In addition, she may be asked about other non-concussion injuries sustained during the 2 year period at the end of the study.

Participant – please complete the following (Circle Yes or No for each question)

<i>I have read the Plain Language Statement (or had it read to me)</i>	Yes/No
<i>I understand the information provided</i>	Yes/No
<i>I have had an opportunity to ask questions and discuss this study</i>	Yes/No
<i>I have received satisfactory answers to all my questions</i>	Yes/No

Confirmation that involvement in the Research Study is voluntary

I understand that involvement within this research project is purely voluntary. Should I wish to withdraw my daughter from the study at any stage throughout, I am entitled to do so. There will be no penalty enforced on if she wishes to quit the Research Study prior to all stages being completed.

Confirmation of arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

I understand that confidentiality is an important issue during data collection. My daughter's identity, or other personal information will not be revealed or published. She will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The investigators alone will have access to her data. However, I understand that confidentiality of information provided can only be protected within the limitations of the law. I am aware that it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some profession.

Confirmation of arrangements regarding retention/disposal of data

I understand that identifying data (e.g. name, date of birth) will be destroyed 12 months following the completion of this study. I am aware that the principal investigator will shred hard copies of identifying data in a secure bin and delete all electronic identifying data.

Confirmations relating to any other relevant information as indicated in the PLS

I understand that if I or my daughter share a relationship of any kind with any of the researchers relevant to this study, this will not be affected in any way with regard to their ongoing studies throughout the entire duration of this study.

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I give consent for my daughter to take part in this research project.

Signature: _____

Name in Block Capitals: _____

Date: _____

Assent by Minor

I understand what is involved in this project. It has been explained to me by the research team and by my parents. I agree to take part.

Name of Minor in Block Letters _____ Witness _____

Signed: _____ Date _____

Appendix D

Demographic Characteristics Questionnaire (Adult Participants)

DEMOGRAPHIC & TRAINING INFORMATION

1. What is the **highest level** of education you have attained?

Junior Certificate	☐	Higher Diploma	☐
Leaving Certificate	☐	Masters Degree	☐
Level 4 Certificate	☐	Post-Graduate Diploma	☐
Level 5 Certificate	☐	Doctoral Degree	☐
Advanced Certificate	☐	Higher Doctorate	☐
Higher Certificate	☐	Other (Please Specify)	☐
Ordinary Bachelor Degree	☐	_____	
Honours Bachelor Degree	☐		

2. Do you play with your **county** team?

Yes ☐ No ☐

3. How many years have you played Ladies Gaelic Football at **club** level?

Less than 1 year	☐	11-12 years	☐
1-2 years	☐	12-13 years	☐
2-3 years	☐	13-14 years	☐
3-4 years	☐	14-15 years	☐
4-5 years	☐	15-16 years	☐
5-6 years	☐	16-17 years	☐
6-7 years	☐	17-18 years	☐
7-8 years	☐	18-19 years	☐
8-9 years	☐	19-20 years	☐
9-10 years	☐	More than 20 years	☐
10-11 years	☐	Other (Please Specify)	☐

4. How many years have you played Ladies Gaelic Football at **county** level?

Less than 1 year	☐	12-13 years	☐
1-2 years	☐	13-14 years	☐
2-3 years	☐	14-15 years	☐
3-4 years	☐	15-16 years	☐
4-5 years	☐	16-17 years	☐
5-6 years	☐	17-18 years	☐
6-7 years	☐	18-19 years	☐
7-8 years	☐	19-20 years	☐
8-9 years	☐	More than 20 years	☐
9-10 years	☐	N/A	☐
10-11 years	☐	Other (Please Specify)	☐
11-12 years	☐	_____	

5. What position do you most often play (more than half the time) with your **club** team?

Full Forward	☐	Full-Back	☐	Midfield	☐
Left Corner-Forward	☐	Left Corner-Back	☐	Goalkeeper	☐
Right Corner-Forward	☐	Right Corner-Back	☐	Other (Please Specify)	☐
Half-Forward	☐	Centre Half-Back	☐	_____	
Left Half-Forward	☐	Left Half-Back	☐		
Right Half-Forward	☐	Right Half-Back	☐		

6. What position do you most often play (more than half the time) with your **county** team?

Full Forward	☐	Full-Back	☐	Midfield	☐
Left Corner-Forward	☐	Left Corner-Back	☐	Goalkeeper	☐
Right Corner-Forward	☐	Right Corner-Back	☐	Other (Please Specify)	☐
Half-Forward	☐	Centre Half-Back	☐	_____	
Left Half-Forward	☐	Left Half-Back	☐		
Right Half-Forward	☐	Right Half-Back	☐		

7. Do you play any sports **other than** Ladies Gaelic Football (not including personal exercise activities such as the gym, jogging or pilates)?

Yes ☐ No ☐

8. If yes, please select all the other sports you play below:

Athletics	☐	Golf	☐	Swimming	☐
Badminton	☐	Gymnastics	☐	Tae Kwon Do	☐
Basketball	☐	Handball	☐	Tennis	☐
Boxing	☐	Hockey	☐	N/A	☐
Camogie	☐	Karate	☐	Other (Please Specify)	☐
Cricket	☐	Netball	☐	_____	☐
Cycling	☐	Rowing	☐		
Equestrian	☐	Rugby	☐		
Frisbee	☐	Soccer	☐		

Appendix E

Demographic Characteristics Questionnaire (Adolescent Participants)

DEMOGRAPHIC & TRAINING INFORMATION

1. What year are you in in school?

1 st Year	☐	4 th Year	☐
2 nd Year	☐	5 th Year	☐
3 rd Year	☐	6 th Year	☐

2. Do you play with your **county** team?

Yes	☐	No	☐

3. How many years have you played Ladies Gaelic Football at **club** level?

Less than 1 year	☐	11-12 years	☐
1-2 years	☐	12-13 years	☐
2-3 years	☐	13-14 years	☐
3-4 years	☐	14-15 years	☐
4-5 years	☐	15-16 years	☐
5-6 years	☐	16-17 years	☐
6-7 years	☐	17-18 years	☐
7-8 years	☐	18-19 years	☐
8-9 years	☐	19-20 years	☐
9-10 years	☐	More than 20 years	☐
10-11 years	☐	Other (Please Specify)	☐

4. How many years have you played Ladies Gaelic Football at **county** level?

Less than 1 year	☐	12-13 years	☐
1-2 years	☐	13-14 years	☐
2-3 years	☐	14-15 years	☐
3-4 years	☐	15-16 years	☐
4-5 years	☐	16-17 years	☐
5-6 years	☐	17-18 years	☐
6-7 years	☐	18-19 years	☐
7-8 years	☐	19-20 years	☐
8-9 years	☐	More than 20 years	☐
9-10 years	☐	N/A	☐
10-11 years	☐	Other (Please Specify)	☐
11-12 years	☐		☐

5. What position do you most often play (more than half the time) with your **club** team?

Centre Forward	☐	Full-Back	☐	Midfield	☐
Left Corner-Forward	☐	Left Corner-Back	☐	Goalkeeper	☐
Right Corner-Forward	☐	Right Corner-Back	☐	Other (Please Specify)	☐
Centre Half-Forward	☐	Centre Half-Back	☐		☐

Left Half-Forward	☐	Left Half-Back	☐
Right Half-Forward	☐	Right Half-Back	☐

6. What position do you most often play (more than half the time) with your **county** team?

Centre Forward	☐	Full-Back	☐	Midfield	☐
Left Corner-Forward	☐	Left Corner-Back	☐	Goalkeeper	☐
Right Corner-Forward	☐	Right Corner-Back	☐	Other (Please Specify)	☐
Centre Half-Forward	☐	Centre Half-Back	☐		
Left Half-Forward	☐	Left Half-Back	☐		
Right Half-Forward	☐	Right Half-Back	☐		

7. Do you play any sports **other than** Ladies Gaelic Football (not including personal exercise activities such as the gym, jogging or pilates)?

Yes ☐ No ☐

8. If yes, please select all the other sports you play below:

Athletics	☐	Golf	☐	Swimming	☐
Badminton	☐	Gymnastics	☐	Tae Kwon Do	☐
Basketball	☐	Handball	☐	Tennis	☐
Boxing	☐	Hockey	☐	N/A	☐
Camogie	☐	Karate	☐	Other (Please Specify)	☐
Cricket	☐	Netball	☐		
Cycling	☐	Rowing	☐		
Equestrian	☐	Rugby	☐		
Frisbee	☐	Soccer	☐		

Appendix F

Medical History Questionnaire

MEDICAL HISTORY

Please answer 'YES' or 'NO' to whether you have ever been DIAGNOSED BY A DOCTOR OR MEDICAL PROFESSIONAL with any of the following medical conditions.

	YES	NO
1. Headache (Non-Migraine)	☐	☐
a. If yes, was your ability to work, study, or do what you wanted to do was limited?	☐	☐
b. If yes, did light bother you (more than when you don't have a headache)?	☐	☐
c. If yes, did you get nauseous or sick to your stomach?	☐	☐
d. If yes, have you had one or more headaches (unrelated to alcohol/substance use) in the past 3 months?	☐	☐
2. Migraine	☐	☐
3. Motion Sickness	☐	☐
4. ADHD/ADD	☐	☐
a. If yes, are you currently prescribed ADHD medication?	☐	☐
5. Learning disorder (e.g., Dyslexia, Language Processing Disorder, Visual Perceptual/Visual Motor Deficit)	☐	☐
a. If yes, please specify: _____		
6. Mood Disorder/Depression/Bipolar	☐	☐
7. Anxiety Disorder	☐	☐
8. Sleep Disorder	☐	☐
a. If yes, please specify: _____		
9. Epilepsy/Seizure Disorder	☐	☐
10. Confusion	☐	☐
11. Memory Difficulties	☐	☐
12. Vision Problems (Other than need for glasses/contacts)	☐	☐
a. If yes, please specify: _____		
13. Hearing Problems	☐	☐
a. If yes, please specify: _____		
14. Balance Disorder	☐	☐
a. If yes, please specify: _____		
15. If yes, please specify: _____	☐	☐
16. Diabetes	☐	☐
17. Arthritis	☐	☐
18. Stroke	☐	☐

19.	Major Cardiovascular Risk	☐	☐
	a. High Blood Pressure	☐	☐
	b. Coronary Artery Disease	☐	☐
	c. Heart Attack	☐	☐
	d. Peripheral Vascular Disease	☐	☐
	e. Other (Please Specify)	☐	☐
20.	Moderate/Severe Traumatic Brain Injury (NOT including concussion)	☐	☐
21.	Brain Tumour	☐	☐
22.	Meningitis	☐	☐
23.	Other Neurological Disorder	☐	☐
	a. If yes, please specify: _____		
24.	Other Psychological Disorder (e.g. substance abuse, somatoform disorder, OCD, eating disorder, personality disorder or psychotic disorder/schizophrenia)	☐	☐
	a. If yes, please specify: _____		

Appendix G

Concussion History Questionnaire

Please read the following before answering the questions below:

“Some people have the misconception that concussions only happen when you black out after a hit to the head or when the symptoms last for a while. But, in reality, a concussion has occurred anytime you have had a direct or indirect blow to the head that caused you to have symptoms for any amount of time. These include: blurred or double vision, seeing stars, sensitivity to light or noise, headache, dizziness or balance problems, nausea, vomiting, trouble sleeping, fatigue, confusion, difficulty remembering, difficulty concentrating, or loss of consciousness. Whenever anyone gets a ding or their bell rung, that too is a concussion”.

1. How many suspected concussions have you sustained in the past?

None	☐	5	☐	10 or more	☐
1	☐	6	☐	Don't Remember	☐
2	☐	7	☐	Other (Please Specify)	☐
3	☐	8	☐	_____	
4	☐	9	☐		

Please answer the following questions in relation to any concussions you have sustained in the past, beginning with your MOST RECENT concussion.

1. How did the injury occur?	Injury 1 ☐ Sport/recreation ☐ Motor vehicle crash-occupant ☐ Motor vehicle crash-pedestrian/bicyclist ☐ Fall ☐ Blow to head or neck ☐ Fight or being hit ☐ Explosion/Blast ☐ Don't Remember ☐ Other (Please Specify) 	Injury 2 ☐ Sport/recreation ☐ Motor vehicle crash-occupant ☐ Motor vehicle crash-pedestrian/bicyclist ☐ Fall ☐ Blow to head or neck ☐ Fight or being hit ☐ Explosion/Blast ☐ Don't Remember ☐ Other (Please Specify) 	Injury 3 ☐ Sport/recreation ☐ Motor vehicle crash-occupant ☐ Motor vehicle crash-pedestrian/bicyclist ☐ Fall ☐ Blow to head or neck ☐ Fight or being hit ☐ Explosion/Blast ☐ Don't Remember ☐ Other (Please Specify) 	Injury 4 ☐ Sport/recreation ☐ Motor vehicle crash-occupant ☐ Motor vehicle crash-pedestrian/bicyclist ☐ Fall ☐ Blow to head or neck ☐ Fight or being hit ☐ Explosion/Blast ☐ Don't Remember ☐ Other (Please Specify)
2. Was the injury diagnosed by a medical professional?	☐ Yes ☐ No ☐ Don't Remember ☐ Other (Please Specify) 	☐ Yes ☐ No ☐ Don't Remember ☐ Other (Please Specify) 	☐ Yes ☐ No ☐ Don't Remember ☐ Other (Please Specify) 	☐ Yes ☐ No ☐ Don't Remember ☐ Other (Please Specify)
3. If the injury was diagnosed by a medical professional, who diagnosed it?	☐ Physiotherapist/Athletic Therapist(Training/Match) ☐ Physiotherapist/ Athletic Therapist (Clinic)	☐ Physiotherapist/Athletic Therapist(Training/Match) ☐ Physiotherapist/ Athletic Therapist (Clinic)	☐ Physiotherapist/Athletic Therapist(Training/Match) ☐ Physiotherapist/ Athletic Therapist (Clinic)	☐ Physiotherapist/Athletic Therapist(Training/Match) ☐ Physiotherapist/ Athletic Therapist (Clinic)

4. What was the approximate date of injury?

☐ G.P.
☐ Doctor in A&E
☐ Don't Remember
☐ Other (Please Specify)

____ (month) ____ (year)

☐ Don't Remember
☐ Other (please specify)

5. Did you lose consciousness (i.e. knocked out/blacked out)?

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

6. How long were you unconscious (seconds)?

____ (sec)
☐ Unknown
☐ Other (Please Specify)

7. Did/do you have difficulty remembering things before or after the injury?

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

☐ G.P.
☐ Doctor in A&E
☐ Don't Remember
☐ Other (Please Specify)

____ (month) ____ (year)

☐ Don't Remember
☐ Other (please specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

____ (sec)
☐ Unknown
☐ Other (Please Specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

☐ G.P.
☐ Doctor in A&E
☐ Don't Remember
☐ Other (Please Specify)

____ (month) ____ (year)

☐ Don't Remember
☐ Other (please specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

____ (sec)
☐ Unknown
☐ Other (Please Specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

☐ G.P.
☐ Doctor in A&E
☐ Don't Remember
☐ Other (Please Specify)

____ (month) ____ (year)

☐ Don't Remember
☐ Other (please specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

____ (sec)
☐ Unknown
☐ Other (Please Specify)

☐ Yes
☐ No
☐ Unknown
☐ Other (Please Specify)

**8. How many minutes
do you not remember
(minutes)?**

_____ (min)
☐ Unknown
☐ Other (Please Specify)

_____ (min)
☐ Unknown
☐ Other (Please Specify)

_____ (min)
☐ Unknown
☐ Other (Please Specify)

_____ (min)
☐ Unknown
☐ Other (Please Specify)

**9. How many days did
you experience
symptoms related to
the injury?**

_____ (days)
☐ Unknown
☐ Other (Please Specify)

_____ (days)
☐ Unknown
☐ Other (Please Specify)

_____ (days)
☐ Unknown
☐ Other (Please Specify)

_____ (days)
☐ Unknown
☐ Other (Please Specify)

If you sustained a concussion during sports or recreation (Q1), please answer Q10-15.

	Injury 1	Injury 2	Injury 3	Injury 4
10. What sport were you participating in?	☐ Ladies Gaelic Football ☐ Camogie ☐ Soccer ☐ Rugby ☐ Basketball ☐ Don't Remember ☐ Other (Please Specify)	☐ Ladies Gaelic Football ☐ Camogie ☐ Soccer ☐ Rugby ☐ Basketball ☐ Don't Remember ☐ Other (Please Specify)	☐ Ladies Gaelic Football ☐ Camogie ☐ Soccer ☐ Rugby ☐ Basketball ☐ Don't Remember ☐ Other (Please Specify)	☐ Ladies Gaelic Football ☐ Camogie ☐ Soccer ☐ Rugby ☐ Basketball ☐ Don't Remember ☐ Other (Please Specify)
11. Where did you get hit?	☐ Head or neck ☐ Torso ☐ Shoulder or arm ☐ Leg ☐ Other (Please Specify)	☐ Head or neck ☐ Torso ☐ Shoulder or arm ☐ Leg ☐ Other (Please Specify)	☐ Head or neck ☐ Torso ☐ Shoulder or arm ☐ Leg ☐ Other (Please Specify)	☐ Head or neck ☐ Torso ☐ Shoulder or arm ☐ Leg ☐ Other (Please Specify)
12. When did you sustain this injury?	☐ Training Session ☐ Match ☐ Don't Remember ☐ Other (Please Specify)	☐ Training Session ☐ Match ☐ Don't Remember ☐ Other (Please Specify)	☐ Training Session ☐ Match ☐ Don't Remember ☐ Other (Please Specify)	☐ Training Session ☐ Match ☐ Don't Remember ☐ Other (Please Specify)
13. How did the injury occur?	☐ I hit against another player ☐ I hit against the ground	☐ I hit against another player ☐ I hit against the ground	☐ I hit against another player ☐ I hit against the ground	☐ I hit against another player ☐ I hit against the ground

14. Did you continue playing while experiencing symptoms?

☐ I hit against a fence, railing or goalpost
☐ I hit against the ball
☐ Don't Remember
☐ Other (Please Specify)

☐ Yes, I played on in the same match/training session

☐ I did not play on in the same match/training session, but I went back playing before my symptoms had fully resolved

☐ No, I did not play on in the same match/training session and I did not go back playing until my symptoms had fully resolved

☐ Don't Remember
☐ Other (Please Specify)

☐ I hit against a fence, railing or goalpost
☐ I hit against the ball
☐ Don't Remember
☐ Other (Please Specify)

☐ Yes, I played on in the same match/training session

☐ I did not play on in the same match/training session, but I went back playing before my symptoms had fully resolved

☐ No, I did not play on in the same match/training session and I did not go back playing until my symptoms had fully resolved

☐ Don't Remember
☐ Other (Please Specify)

☐ I hit against a fence, railing or goalpost
☐ I hit against the ball
☐ Don't Remember
☐ Other (Please Specify)

☐ Yes, I played on in the same match/training session

☐ I did not play on in the same match/training session, but I went back playing before my symptoms had fully resolved

☐ No, I did not play on in the same match/training session and I did not go back playing until my symptoms had fully resolved

☐ Don't Remember
☐ Other (Please Specify)

☐ I hit against a fence, railing or goalpost
☐ I hit against the ball
☐ Don't Remember
☐ Other (Please Specify)

☐ Yes, I played on in the same match/training session

☐ I did not play on in the same match/training session, but I went back playing before my symptoms had fully resolved

☐ No, I did not play on in the same match/training session and I did not go back playing until my symptoms had fully resolved

☐ Don't Remember
☐ Other (Please Specify)

15. How many days was
it until you returned
fully to play?

_____ (days)

☐ Don't Remember

☐ Other (Please Specify)

_____ (days)

☐ Don't Remember

☐ Other (Please Specify)

_____ (days)

☐ Don't Remember

☐ Other (Please Specify)

_____ (days)

☐ Don't Remember

☐ Other (Please Specify)

Appendix H.

Sport Concussion Assessment Tool 5th Edition

ID Number: _____

Height: _____

Dominant Arm: Right Left

Weight: _____

Dominant Leg: Right Left

2

STEP 2: SYMPTOM EVALUATION

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

Please Check: ☐ Baseline ☐ Post-Injury

Please hand the form to the athlete

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

Total number of symptoms: _____ of 22

Symptom severity score: _____ of 132

Do your symptoms get worse with physical activity? Y N

Do your symptoms get worse with mental activity? Y N

If 100% is feeling perfectly normal, what percent of normal do you feel?

If not 100%, why?

Please hand form back to examiner

STEP 3: COGNITIVE SCREENING
Standardised Assessment of Concussion (SAC)⁴

ORIENTATION

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score	of 5	

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List						Score (of 5)		
Alternate 5 wordlists						Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
Immediate Memory Score						of 15		
Time that last trial was completed								

List						Score (of 10)		
Alternate 10 word lists						Trial 1	Trial 2	Trial 3
G	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
H	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
I	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
Immediate Memory Score						of 30		
Time that last trial was completed								

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

CONCENTRATION
DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
Digits Score:			of 4		

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0	1
Months Score	of 1	
Concentration Total Score (Digits + Months)	of 5	

STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient perform the finger nose coordination test normally?	Y	N
Time taken to complete FTN test:	_____ sec	
Can the patient perform tandem gait normally?	Y	N
Time taken to complete tandem gait test:	_____ sec	

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing⁵

Which foot was tested ☐ Left
(i.e. which is the non-dominant foot) ☐ Right

Testing surface (hard floor, field, etc.) _____

Footwear (shoes, barefoot, braces, tape, etc.) _____

Errors:	Double Leg Stance:	Single Leg Stance:	Tandem Stance:	
:				
Hands lifted off iliac crest				
Opening eyes				
Step, stumble or fall				
Moving hip in >30 abduction				
Lifting forefoot or heel				
Remaining out of test position >5 seconds				
Total Errors:	_____ of 10	_____ of 10	_____ of 10	_____ of 30

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started _____

Please record each word correctly recalled. Total score equals number of words recalled.

Total number of words recalled accurately: _____

of 5 or

of 10

Appendix H

Vestibular-Ocular Motor Screening Testing Sheet

UPMC Vestibular/Ocular Motor Screening (VOMS) for Concussion

VOMS Test Item:	N T	Headache 0-10	Dizziness 0-10	Nausea 0-10	Fogginess 0-10	Total	Comments
BASELINE SYMPTOMS	X						
1. Smooth Pursuits							
2. Saccades – Horizontal							
3. Saccades – Vertical							
4. Convergence (Near Point in cm)							NPC 1:____ NPC 2:____ NPC 3:____ Avg NPC: _____
5. VOR – Horizontal							
6. VOR – Vertical							
7. Visual Motion Sensitivity							
Tester:					Date:		

Appendix I

Neck Dynamometry Testing Sheet

NECK STRENGTH & NECK FLEXOR ENDURANCE TEST:

	Isometric Strength (mm Hg)					
Trial:	Flexion	Extension	Right Lateral Flexion	Left Lateral Flexion	Right SCM	Left SCM
1.						
2.						
3.						

Appendix J

Clinical Profiles Screen

CONCUSSION CLINICAL PROFILES SCREEN

INSTRUCTIONS: Please indicate if you are **currently** experiencing any of the following symptoms.

Symptom	Please indicate your symptom severity below:			
1. <i>Feeling sad</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
2. <i>Headache when you wake up</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
3. <i>Difficulty or headache when looking at phone or computer screen</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
4. <i>Dizziness when you move your head</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
5. <i>Difficulty turning off your thoughts (e.g., rumination)</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
6. <i>Headache with nausea or upset stomach</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
7. <i>Trouble focusing your eyes while reading</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
8. <i>Frontal headache</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
9. <i>Difficulty or discomfort in busy environments</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
10. <i>Constantly thinking about your symptoms</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
11. <i>Headache with sensitivity to light or noise</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
12. <i>Feeling motion sick ("sea or car sick")</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
13. <i>Feeling more tired at the end of the day</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
14. <i>Blurry or double vision</i>	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe
15. <i>Feeling or sensation of slow wavy</i>	☐ None	☐ Mild	☐ Moderate	☐ Severe

dizziness (i.e., lightheadedness)	(Not Experiencing This Symptom)				
16. Neck pain or stiffness	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
17. Sleeping more than usual	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
18. Sleeping less than usual	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
19. Eye strain (eyes feel tired) during visual activities	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
20. Visual aura (e.g., flashes, stars, spots, flickering light) with or without headache	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
21. Feeling or sensation of fast spinning dizziness (i.e., vertigo)	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
22. Difficulty falling asleep	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
23. Difficulty staying asleep	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
24. Trouble remembering things (e.g., what you completed today or having to re-read information)	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
25. Difficulty moving your neck	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
26. Feeling nervous or anxious	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
27. Increased headache following physical activity	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
28. Increased headache following cognitive activity	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	
29. Feeling more stressed than usual	☐ None (Not Experiencing This Symptom)	☐ Mild	☐ Moderate	☐ Severe	

Appendix K

Patient Health Questionnaire-9

PATIENT HEALTH QUESTIONNAIRE (PHQ-9)

Over the <u>last 2 weeks</u> , how often have you been bothered by any of the following problems? <i>Circle the appropriate box to indicate your answer</i>	Not at all	Several days	More than half the days	Nearly every day
1. Little interest or pleasure doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself – or that you are a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed? Or the opposite – being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9. Thoughts that you would be better off dead or of hurting yourself in some way	0	1	2	3
	Not at all difficult	Somewhat difficult	Very difficult	Extremely difficult

10. If you checked off any problems, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?

☐☐☐☐

Appendix L

Generalised Anxiety Disorder-7

GENERALISED ANXIETY DISORDER-7 (GAD-7)

Over the last 2 weeks, how often have you been bothered by the following problems?

Circle the appropriate box to indicate your answer

	Not at all	Several days	More than half the days	Nearly every day
1. Feeling nervous, anxious, or on edge	0	1	2	3
2. Not being able to stop or control worrying	0	1	2	3
3. Worrying too much about different things	0	1	2	3
4. Trouble relaxing	0	1	2	3
5. Being so restless that it's hard to sit still	0	1	2	3
6. Becoming easily annoyed or irritable	0	1	2	3
7. Feeling afraid, as if something awful might happen	0	1	2	3

	Not at all difficult	Somewhat difficult	Very difficult	Extremely difficult
8. If you checked off any problem on this questionnaire so far, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?	☐	☐	☐	☐

Appendix M

Neck Bournemouth Questionnaire

NECK BOURNEMOUTH QUESTIONNAIRE

Instructions: The following scales have been designed to find out about your neck pain and how it is affecting you. Please answer ALL the scales, and mark the ONE number on EACH scale that best describes how you feel.

1. Over the past week, on average, how would you rate your neck pain?

No pain 0 1 2 3 4 5 6 7 8 9 10 Worst pain possible

2. Over the past week, how much has your neck pain interfered with your daily activities (housework, washing, dressing, lifting, reading, driving)?

No interference 0 1 2 3 4 5 6 7 8 9 10 Unable to carry out activities

Please

Describe: _____

3. Over the past week, how much has your neck pain interfered with your ability to take part in recreational, social, and family activities?

No interference 0 1 2 3 4 5 6 7 8 9 10 Unable to carry out activities

Please

Describe: _____

4. Over the past week, how anxious (tense, uptight, irritable, difficulty in concentrating/relaxing) have you been feeling?

Not at all anxious 0 1 2 3 4 5 6 7 8 9 10 Extremely anxious

5. Over the past week, how depressed (down-in-the-dumps, sad, in low spirits, pessimistic, unhappy) have you been feeling?

Not at all depressed 0 1 2 3 4 5 6 7 8 9 10 Extremely depressed

6. Over the past week, how have you felt your work (both inside and outside the home) has affected (or would affect) your neck pain?

Have made it no worse 0 1 2 3 4 5 6 7 8 9 10 Have made it much worse

Please

Describe: _____

7. Over the past week, how much have you been able to control (reduce/help) your neck pain on your own?

Completely control it 0 1 2 3 4 5 6 7 8 9 10 No control whatsoever

Please

Describe: _____

Appendix N

Migraine Disability Assessment

MIGRAINE DISABILITY ASSESSMENT

Instructions: Please answer the following questions about ALL of the headaches you have had over the last 3 months. Select your answer in the box next to each question. Select zero if you did not have the activity in the last 3 months.

Section A:	Response
1. On how many days in the last 3 months did you miss work or school because of your headaches?	_____ days
2. How many days in the last 3 months was your productivity at work or school reduced by half or more because of your headaches? (Do not include days you counted in question 1 where you missed work or school.)	_____ days
3. On how many days in the last 3 months did you not do household work (such as housework, home repairs and maintenance, shopping, caring for children and relatives) because of your headaches?	_____ days
4. How many days in the last 3 months was your productivity in household work reduced by half or more because of your headaches? (Do not include days you counted in question 3 where you did not do household work.)	_____ days
5. On how many days in the last 3 months did you miss family, social or leisure activities because of your headaches?	_____ days
Section B:	
1. On how many days in the last 3 months did you have a headache? (If a headache lasted more than 1 day, count each day.)	_____ days
2. On a scale of 0 - 10, on average how painful were these headaches? (where 0= no pain at all, and 10= pain as bad as it can be.)	
0 1 2 3 4 5 6 7 8 9 10	

Appendix O

Pittsburgh Sleep Quality Index

PITTSBURGH SLEEP QUALITY INDEX (PSQI)

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

	Response			
1. During the past month , what time have you usually gone to bed at night?	_____			
2. During the past month , how long (in minutes) has it usually taken you to fall asleep each night?	_____			
3. During the past month , what time have you usually gotten up in the morning?	_____			
4. During the past month , how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)	_____			
5. During the past month , how often have you had trouble sleeping because you...				
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
<i>a. Cannot get to sleep within 30 minutes</i>	☐	☐	☐	☐
<i>b. Wake up in the middle of the night or early morning</i>	☐	☐	☐	☐
<i>c. Have to get up to use the bathroom</i>	☐	☐	☐	☐
<i>d. Cannot breathe comfortably</i>	☐	☐	☐	☐
<i>e. Cough or snore loudly</i>	☐	☐	☐	☐
<i>f. Feel too cold</i>	☐	☐	☐	☐

<i>g. Feel too hot</i>	☐	☐	☐	☐
<i>h. Have bad dreams</i>	☐	☐	☐	☐
<i>i. Have pain</i>	☐	☐	☐	☐
<i>j. Other reason(s), please describe below:</i> _____	☐	☐	☐	☐
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
6. During the past month, how often have you taken medicine to help you sleep (prescribed or “over the counter”)?	☐	☐	☐	☐
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	☐	☐	☐	☐
	No problem at all	Only a very slight problem	Somewhat of a problem	A very big problem
8. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	☐	☐	☐	☐
	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality overall?	☐	☐	☐	☐

Appendix P

Table 1: Percentile ranks for Immediate Post-Concussion Assessment and Cognitive Testing scores

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>All</i>	<i>Verbal Memory</i>	62.5	74.0	81.0	96.0	99.0	100.0	100.0
	<i>Visual Memory</i>	49.5	53.0	60.0	79.0	84.7	92.0	92.0
	<i>Visual Motor Speed</i>	25.2	29.7	34.0	41.7	44.3	50.0	51.0
	<i>Reaction Time</i>	0.9	0.8	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	51.2	25.7	17.0	3.0	1.0	0.0	0.0
<i>Adolescent</i>	<i>Verbal Memory</i>	57.3	70.7	80.8	90.8	95.7	98.0	98.3
	<i>Visual Memory</i>	47.1	51.0	56.8	75.8	80.4	89.0	89.7
	<i>Visual Motor Speed</i>	23.4	28.0	29.3	37.1	40.4	42.4	43.0
	<i>Reaction Time</i>	0.9	0.8	0.8	0.7	0.6	0.6	0.6
	<i>Post-Concussion Symptom Score</i>	65.5	37.3	24.1	4.0	1.6	1.0	0.7
<i>Adult</i>	<i>Verbal Memory</i>	64.9	74.9	82.0	96.0	99.0	100.0	100.0
	<i>Visual Memory</i>	50.9	54.0	61.0	81.2	86.3	92.0	92.0
	<i>Visual Motor Speed</i>	27.8	32.4	35.7	42.6	45.3	50.7	51.6
	<i>Reaction Time</i>	1.0	0.8	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	30.0	23.0	16.0	3.0	0.0	0.0	0.0
<i>Elite</i>	<i>Verbal Memory</i>	71.2	75.0	83.4	94.5	99.0	99.0	99.2
	<i>Visual Memory</i>	52.5	54.0	61.0	80.2	84.0	91.8	93.1
	<i>Visual Motor Speed</i>	27.1	29.8	34.6	41.1	43.9	50.6	51.8
	<i>Reaction Time</i>	1.0	0.7	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	30.7	23.0	17.8	3.0	0.0	0.0	0.0
<i>Non-Elite</i>	<i>Verbal Memory</i>	61.1	71.0	80.3	96.0	99.0	100.0	100.0
	<i>Visual Memory</i>	48.8	52.4	59.3	79.0	85.7	91.2	92.0
	<i>Visual Motor Speed</i>	25.5	29.8	33.2	41.8	44.7	49.9	50.1
	<i>Reaction Time</i>	0.9	0.8	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	59.5	26.7	16.0	3.0	1.0	0.0	0.0
<i>Concussion History</i>	<i>Verbal Memory</i>	61.6	67.3	79.5	93.0	96.9	99.2	99.5
	<i>Visual Memory</i>	47.1	51.4	60.5	78.2	84.8	92.0	92.0
	<i>Visual Motor Speed</i>	25.1	30.5	31.9	42.1	44.3	46.8	48.7
	<i>Reaction Time</i>	0.8	0.8	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	35.4	26.7	15.0	2.8	1.7	0.0	0.0
<i>No Concussion History</i>	<i>Verbal Memory</i>	63.0	75.4	82.0	96.0	99.0	100.0	100.0
	<i>Visual Memory</i>	51.0	53.4	60.0	80.0	84.6	91.0	91.9
	<i>Visual Motor Speed</i>	25.8	29.5	34.1	41.5	44.3	50.0	50.6
	<i>Reaction Time</i>	1.0	0.8	0.7	0.6	0.5	0.5	0.5
	<i>Post-Concussion Symptom Score</i>	58.3	25.3	17.0	3.0	1.0	0.0	0.0

Appendix Q

Table 2: Percentile ranks for Sport Concussion Assessment Tool 5th Edition

Participants	Outcome	Impaired (<1.9th %ile)	Borderline (9th %ile)	Low Average (24th %ile)	Average (75th %ile)	High Average (90th %ile)	Superior (97th %ile)	Very Superior (>98th %ile)
Graded Symptom Checklist								
All	Total Symptom Score	18.0	12.0	9.0	2.0	1.0	0.0	0.0
	Symptom Severity Score	32.9	22.0	13.0	3.0	1.0	0.0	0.0
Adolescent	Total Symptom Score	19.6	17.3	12.0	3.0	2.0	0.1	0.0
	Symptom Severity Score	48.4	29.0	19.1	3.0	2.0	0.2	0.0
Adult	Total Symptom Score	14.2	11.0	8.0	2.0	1.0	0.0	0.0
	Symptom Severity Score	27.2	17.0	11.0	2.0	1.0	0.0	0.0
Elite	Total Symptom Score	15.8	13.6	6.9	2.0	0.0	0.0	0.0
	Symptom Severity Score	28.4	22.0	12.9	2.0	0.0	0.0	0.0
Non-Elite	Total Symptom Score	18.2	12.0	9.4	2.0	1.0	0.0	0.0
	Symptom Severity Score	35.9	20.1	12.4	3.0	1.0	0.0	0.0
Concussion History	Total Symptom Score	13.5	11.7	10.0	2.0	2.0	1.8	1.5
	Symptom Severity Score	24.5	21.0	16.8	3.0	2.6	2.0	2.0
No Concussion History	Total Symptom Score	18.0	13.0	8.0	2.0	1.0	0.0	0.0
	Symptom Severity Score	34.0	23.1	11.8	2.0	1.0	0.0	0.0
Standardized Assessment of Concussion								
All	Orientation	4.0	4.0	5.0	5.0	5.0	5.0	5.0
	Immediate Memory	13.0	15.0	17.0	22.0	23.7	26.0	26.0
	Digits Backwards	1.0	2.0	2.0	4.0	4.0	4.0	4.0
	Months Backwards	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	Concentration	2.0	3.0	3.0	5.0	5.0	5.0	5.0
	Delayed Memory	3.0	4.0	5.0	8.0	9.0	9.0	9.4
Adolescent	Orientation	3.7	4.0	4.6	5.0	5.0	5.0	5.0
	Immediate Memory	12.7	15.0	17.0	21.0	22.0	23.0	23.6
	Digits Backwards	1.0	1.2	2.0	3.0	4.0	4.0	4.0
	Months Backwards	0.0	0.2	1.0	1.0	1.0	1.0	1.0
	Concentration	1.0	2.0	3.0	4.0	5.0	5.0	5.0
	Delayed Memory	4.0	4.2	5.0	7.0	9.0	9.9	10.0
Adult	Orientation	4.0	4.0	5.0	5.0	5.0	5.0	5.0
	Immediate Memory	13.8	15.0	18.0	23.0	24.0	26.0	26.0
	Digits Backwards	1.0	2.0	3.0	4.0	4.0	4.0	4.0
	Months Backwards	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	Concentration	2.0	3.0	4.0	5.0	5.0	5.0	5.0
	Delayed Memory	2.6	3.0	5.0	8.0	8.5	9.0	9.0
Elite	Orientation	3.7	4.0	4.1	5.0	5.0	5.0	5.0
	Immediate Memory	14.2	15.0	16.2	22.0	23.0	23.0	23.2
	Digits Backwards	1.7	2.0	2.1	3.5	4.0	4.0	4.0
	Months Backwards	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	Concentration	2.0	3.0	3.0	4.5	5.0	5.0	5.0
	Delayed Memory	2.2	3.4	5.0	7.0	8.2	9.0	9.0
Non-Elite	Orientation	4.0	4.0	5.0	5.0	5.0	5.0	5.0
	Immediate Memory	13.0	15.0	17.0	23.0	24.0	26.0	26.0

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>Concussion History</i>	<i>Digits Backwards</i>	1.0	2.0	2.0	4.0	4.0	4.0	4.0
	<i>Months Backwards</i>	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	<i>Concentration</i>	1.8	2.5	3.0	5.0	5.0	5.0	5.0
	<i>Delayed Memory</i>	3.0	4.0	5.0	8.0	9.0	9.2	10.0
	<i>Orientation</i>	4.0	4.0	4.2	5.0	5.0	5.0	5.0
	<i>Immediate Memory</i>	12.0	15.7	19.0	22.0	23.0	23.4	24.0
	<i>Digits Backwards</i>	1.5	2.0	2.0	4.0	4.0	4.0	4.0
	<i>Months Backwards</i>	0.0	1.0	1.0	1.0	1.0	1.0	1.0
<i>No Concussion History</i>	<i>Concentration</i>	2.0	2.3	3.0	5.0	5.0	5.0	5.0
	<i>Delayed Memory</i>	2.0	5.0	5.0	7.5	8.4	9.2	9.5
	<i>Orientation</i>	4.0	4.0	5.0	5.0	5.0	5.0	5.0
	<i>Immediate Memory</i>	14.0	15.0	17.0	22.0	24.0	26.0	26.0
	<i>Digits Backwards</i>	1.0	2.0	2.0	4.0	4.0	4.0	4.0
	<i>Months Backwards</i>	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	<i>Concentration</i>	2.0	3.0	3.0	5.0	5.0	5.0	5.0
	<i>Delayed Memory</i>	3.0	4.0	5.0	8.0	9.0	9.0	9.0
<i>Neurological Screen</i>								
<i>All</i>	<i>Finger-to-nose test</i>	6.5	5.8	5.1	3.8	3.3	2.8	2.8
	<i>Tandem gait test</i>	37.9	33.6	30.4	22.3	20.1	19.3	19.0
<i>Adolescent</i>	<i>Finger-to-nose test</i>	5.9	5.5	5.0	3.9	3.6	2.9	2.8
	<i>Tandem gait test</i>	38.6	35.9	32.9	23.7	21.0	20.0	19.9
<i>Adult</i>	<i>Finger-to-nose test</i>	6.8	5.8	5.1	3.6	3.2	2.8	2.8
	<i>Tandem gait test</i>	36.1	32.6	28.9	22.1	20.0	19.0	19.0
<i>Elite</i>	<i>Finger-to-nose test</i>	6.8	5.9	5.2	3.6	3.3	2.9	2.8
	<i>Tandem gait test</i>	33.9	32.5	29.2	22.1	19.5	19.0	18.3
<i>Non-Elite</i>	<i>Finger-to-nose test</i>	6.1	5.8	5.0	3.8	3.2	2.8	2.7
	<i>Tandem gait test</i>	38.4	35.0	31.0	22.4	20.5	19.7	19.7
<i>Concussion History</i>	<i>Finger-to-nose test</i>	5.9	5.6	5.0	4.0	3.4	3.3	3.3
	<i>Tandem gait test</i>	41.0	37.4	32.4	21.4	20.0	19.0	19.0
<i>No Concussion History</i>	<i>Finger-to-nose test</i>	6.7	5.8	5.1	3.8	3.2	2.8	2.7
	<i>Tandem gait test</i>	36.0	33.2	29.8	22.5	20.4	19.7	19.5
<i>Modified Balance Error Scoring System</i>								
<i>All</i>	<i>BESS Total Score</i>	20.0	14.0	8.0	3.0	1.0	0.0	0.0
	<i>BESS Double-Leg Score</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	6.0	2.0	1.0	0.0	0.0
	<i>BESS Tandem Gait Score</i>	10.0	5.0	2.0	0.0	0.0	0.0	0.0
<i>Adolescent</i>	<i>BESS Total Score</i>	20.9	15.0	12.4	5.0	3.0	3.0	2.4
	<i>BESS Double-Leg Score</i>	1.6	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	10.0	3.0	2.0	1.0	1.0
	<i>BESS Tandem Gait Score</i>	10.0	8.8	4.0	1.0	1.0	0.0	0.0
<i>Adult</i>	<i>BESS Total Score</i>	15.0	12.0	7.0	2.0	1.0	0.0	0.0
	<i>BESS Double-Leg Score</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	6.0	2.0	0.6	0.0	0.0
	<i>BESS Tandem Gait Score</i>	10.0	4.4	2.0	0.0	0.0	0.0	0.0
<i>Elite</i>	<i>BESS Total Score</i>	13.5	10.6	7.0	2.5	1.0	0.0	0.0
	<i>BESS Double-Leg Score</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	9.2	5.0	2.0	1.0	0.0	0.0

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>Non-Elite</i>	<i>BESS Tandem Gait Score</i>	10.0	3.0	1.9	0.0	0.0	0.0	0.0
	<i>BESS Total Score</i>	20.0	14.5	9.4	3.0	1.0	0.0	0.0
	<i>BESS Double-Leg Score</i>	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	6.4	2.0	1.0	0.0	0.0
<i>Concussion History</i>	<i>BESS Tandem Gait Score</i>	10.0	5.0	3.0	0.0	0.0	0.0	0.0
	<i>BESS Total Score</i>	17.5	12.3	8.8	3.0	1.6	1.0	1.0
	<i>BESS Double-Leg Score</i>	0.5	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	6.0	2.0	1.0	0.8	0.5
<i>No Concussion History</i>	<i>BESS Tandem Gait Score</i>	10.0	6.7	3.0	0.0	0.0	0.0	0.0
	<i>BESS Total Score</i>	20.0	14.0	8.0	3.0	1.0	0.0	0.0
	<i>BESS Double-Leg Score</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>BESS Single-Leg Score</i>	10.0	10.0	6.0	2.0	1.0	0.0	0.0
	<i>BESS Tandem Gait Score</i>	10.0	5.0	2.0	0.0	0.0	0.0	0.0

Appendix R

Table 3: Percentile ranks for vestibular-ocular motor screening

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>All</i>	<i>Smooth Pursuits</i>	1.5	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.5	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	3.5	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	4.5	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.5	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	5.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	5.5	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	5.9	2.5	0.0	0.0	0.0	0.0	0.0
<i>Adolescent</i>	<i>Smooth Pursuits</i>	1.3	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.3	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	2.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	5.6	2.5	1.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	5.6	3.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	5.3	2.8	1.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	4.6	2.0	0.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	5.8	2.4	1.1	0.0	0.0	0.0	0.0
<i>Adult</i>	<i>Smooth Pursuits</i>	1.2	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.2	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	4.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	2.0	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	3.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	5.2	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	5.1	2.6	0.0	0.0	0.0	0.0	0.0
<i>Elite</i>	<i>Smooth Pursuits</i>	1.3	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.3	1.6	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	4.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	5.6	2.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.3	2.6	0.9	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	5.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	4.1	1.6	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	6.1	2.9	0.0	0.0	0.0	0.0	0.0
<i>Non-Elite</i>	<i>Smooth Pursuits</i>	1.2	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.2	1.5	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	3.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	2.2	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.2	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	3.4	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	5.2	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	5.2	2.5	0.1	0.0	0.0	0.0	0.0
<i>Concussion History</i>	<i>Smooth Pursuits</i>	1.5	1.0	0.8	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.5	2.0	1.0	0.0	0.0	0.0	0.0

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>No Concussion History</i>	<i>Vertical Saccades</i>	4.5	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	6.0	1.7	1.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.5	3.0	2.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	4.0	2.0	2.0	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	4.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	9.1	6.1	0.4	0.0	0.0	0.0	0.0
	<i>Smooth Pursuits</i>	1.0	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Saccades</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Vertical Saccades</i>	3.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence</i>	3.0	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Horizontal Vestibulo-Ocular Reflex</i>	4.0	1.0	0.0	0.0	0.0	0.0	0.0
	<i>Vertical Vestibulo-Ocular Reflex</i>	5.0	1.0	0.8	0.0	0.0	0.0	0.0
	<i>Visual Motion Sensitivity</i>	6.0	1.6	0.0	0.0	0.0	0.0	0.0
	<i>Near Point of Convergence, cm</i>	4.2	2.4	0.0	0.0	0.0	0.0	0.0

Appendix S

Table 4: Percentile ranks for neck strength normalised to body mass

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>All</i>	<i>Neck Flexion (N/kg)</i>	0.5	0.7	1.0	1.4	1.6	1.7	1.7
	<i>Neck Extension (N/kg)</i>	0.7	0.8	1.0	1.5	1.7	1.9	2.0
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.6	0.9	1.2	1.3	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.6	0.8	1.2	1.3	1.4	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.5	0.6	0.8	0.9	1.1	1.2
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.3	0.4	0.5	0.8	0.9	1.0	1.0
<i>Adolescent</i>	<i>Neck Flexion (N/kg)</i>	0.4	0.6	0.9	1.5	1.7	1.7	1.8
	<i>Neck Extension (N/kg)</i>	0.5	0.9	1.0	1.6	1.7	2.0	2.0
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.6	0.7	0.9	1.2	1.2	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.4	0.6	0.8	1.1	1.3	1.3	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.4	0.5	0.8	0.9	1.2	1.2
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.3	0.4	0.5	0.8	0.9	1.1	1.1
<i>Adult</i>	<i>Neck Flexion (N/kg)</i>	0.6	0.8	1.0	1.4	1.5	1.7	1.7
	<i>Neck Extension (N/kg)</i>	0.7	0.8	1.0	1.5	1.7	1.9	1.9
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.6	0.8	1.2	1.3	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.6	0.8	1.2	1.3	1.4	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.5	0.6	0.8	0.9	1.1	1.1
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.3	0.4	0.5	0.8	0.9	1.0	1.0
<i>Elite</i>	<i>Neck Flexion (N/kg)</i>	0.7	0.8	1.0	1.5	1.5	1.7	1.7
	<i>Neck Extension (N/kg)</i>	0.8	1.0	1.1	1.5	1.7	1.9	2.0
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.6	0.7	0.8	1.2	1.4	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.6	0.7	0.9	1.2	1.3	1.4	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.5	0.6	0.8	1.0	1.2	1.2
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.4	0.5	0.6	0.8	0.9	1.0	1.0
<i>Non-Elite</i>	<i>Neck Flexion (N/kg)</i>	0.5	0.7	0.9	1.3	1.6	1.7	1.7
	<i>Neck Extension (N/kg)</i>	0.6	0.8	1.0	1.5	1.7	1.9	2.0
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.6	0.9	1.2	1.3	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.4	0.6	0.8	1.1	1.3	1.4	1.5
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.4	0.5	0.7	0.9	1.1	1.1
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.3	0.4	0.5	0.7	0.9	1.0	1.0
<i>Concussion History</i>	<i>Neck Flexion (N/kg)</i>	0.6	0.7	1.0	1.4	1.5	1.6	1.7
	<i>Neck Extension (N/kg)</i>	0.7	0.9	1.1	1.5	1.6	1.7	1.7
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.6	0.6	0.9	1.2	1.3	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.6	0.7	0.8	1.2	1.2	1.4	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.5	0.6	0.7	0.8	0.9	1.0	1.0
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.4	0.5	0.6	0.8	0.9	1.0	1.0
<i>No Concussion History</i>	<i>Neck Flexion (N/kg)</i>	0.5	0.8	1.0	1.4	1.6	1.7	1.7
	<i>Neck Extension (N/kg)</i>	0.7	0.8	1.0	1.5	1.7	1.9	2.0
	<i>Dominant Side Lateral Flexion (N/kg)</i>	0.5	0.7	0.9	1.2	1.3	1.4	1.4
	<i>Non-Dominant Side Lateral Flexion (N/kg)</i>	0.4	0.6	0.8	1.2	1.3	1.4	1.4
	<i>Dominant Side Rotation (N/kg)</i>	0.4	0.4	0.5	0.8	0.9	1.1	1.2
	<i>Non-Dominant Side Rotation (N/kg)</i>	0.4	0.4	0.5	0.8	0.9	1.1	1.2

Appendix T

Table 5: Percentile ranks for clinical profile screen

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>All</i>	<i>Total Score</i>	29.4	19.9	10.0	3.0	1.0	0.0	0.0
	<i>Cognitive/Fatigue</i>	1.7	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Ocular</i>	1.5	0.8	0.6	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.5	1.2	0.6	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.8	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	1.0	0.6	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.5	1.0	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.5	0.5	0.0	0.0	0.0	0.0	0.0
<i>Adolescent</i>	<i>Total Score</i>	34.5	27.5	17.4	3.0	1.6	0.1	0.0
	<i>Cognitive/Fatigue</i>	1.8	1.3	0.7	0.3	0.0	0.0	0.0
	<i>Ocular</i>	1.6	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.7	1.4	1.0	0.2	0.0	0.0	0.0
	<i>Migraine</i>	1.0	0.8	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	1.1	1.0	0.5	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.7	1.0	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.5	0.9	0.0	0.0	0.0	0.0	0.0
<i>Adult</i>	<i>Total Score</i>	23.1	17.0	9.0	3.0	0.8	0.0	0.0
	<i>Cognitive/Fatigue</i>	1.7	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Ocular</i>	1.4	0.8	0.6	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.2	0.8	0.5	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.6	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	0.6	0.2	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.3	0.8	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.6	0.5	0.0	0.0	0.0	0.0	0.0
<i>Elite</i>	<i>Total Score</i>	27.4	22.0	10.0	3.0	0.0	0.0	0.0
	<i>Cognitive/Fatigue</i>	1.7	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Ocular</i>	1.6	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.5	0.9	0.5	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.6	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	0.9	0.6	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.3	0.8	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.9	0.5	0.0	0.0	0.0	0.0	0.0
<i>Non-Elite</i>	<i>Total Score</i>	29.2	18.0	10.9	3.0	1.0	0.0	0.0
	<i>Cognitive/Fatigue</i>	1.7	1.2	0.7	0.3	0.0	0.0	0.0
	<i>Ocular</i>	1.4	0.8	0.5	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.4	1.2	0.8	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.8	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	1.0	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.5	1.0	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.5	0.5	0.0	0.0	0.0	0.0	0.0
<i>Concussion History</i>	<i>Total Score</i>	27.6	19.6	13.8	3.0	1.0	0.8	0.5
	<i>Cognitive/Fatigue</i>	2.0	1.6	1.0	0.3	0.0	0.0	0.0

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>No Concussion History</i>	<i>Ocular</i>	1.5	1.3	0.7	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.1	0.9	0.6	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.6	0.3	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	1.0	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.1	1.0	0.8	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.0	0.5	0.4	0.0	0.0	0.0	0.0
	<i>Total Score</i>	29.0	19.4	10.0	3.0	0.7	0.0	0.0
	<i>Cognitive/Fatigue</i>	1.7	1.0	0.7	0.0	0.0	0.0	0.0
	<i>Ocular</i>	1.2	0.8	0.6	0.0	0.0	0.0	0.0
	<i>Anxiety/Mood</i>	1.6	1.2	0.6	0.0	0.0	0.0	0.0
	<i>Migraine</i>	0.8	0.4	0.2	0.0	0.0	0.0	0.0
	<i>Vestibular</i>	1.0	0.6	0.2	0.0	0.0	0.0	0.0
	<i>Sleep</i>	1.5	0.8	0.5	0.0	0.0	0.0	0.0
	<i>Neck</i>	1.5	0.5	0.0	0.0	0.0	0.0	0.0

Appendix U

Table 6: Percentile ranks for health questionnaires

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>All</i>	<i>Patient Health Questionnaire-9</i>	12.3	8.0	5.0	1.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	15.4	10.8	4.6	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	29.9	15.8	8.0	0.8	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	21.3	7.9	2.0	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	10.5	8.0	7.0	3.0	2.0	1.0	1.0
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 2: Sleep Latency</i>	3.0	3.0	2.0	1.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	2.4	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	2.0	1.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	1.8	1.0	0.0	0.0	0.0	0.0
<i>Adolescent</i>	<i>Patient Health Questionnaire-9</i>	17.6	10.8	7.4	2.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	17.6	13.8	9.0	1.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	29.0	25.8	12.7	1.0	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	23.6	15.3	6.0	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	12.9	8.8	7.0	3.0	3.0	1.0	1.0
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.6	0.0	0.0
	<i>Component 2: Sleep Latency</i>	3.0	3.0	3.0	1.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	1.3	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	2.3	1.8	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	3.0	2.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.3	2.0	1.0	0.0	0.0	0.0	0.0
<i>Adult</i>	<i>Patient Health Questionnaire-9</i>	10.1	7.0	4.0	1.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	12.1	7.0	4.0	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	31.6	12.4	6.5	0.0	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	10.7	7.0	2.0	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	10.0	8.0	7.0	3.0	2.0	1.0	0.9
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 2: Sleep Latency</i>	3.0	2.3	2.0	1.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	2.1	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	2.0	1.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
<i>Elite</i>	<i>Patient Health Questionnaire-9</i>	10.2	8.4	4.4	1.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	12.0	6.8	3.4	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	33.0	15.6	6.8	0.0	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	8.6	6.4	1.4	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	9.0	8.0	7.0	3.0	2.0	1.0	1.0
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.0	0.0	0.0

<i>Participants</i>	<i>Outcome</i>	<i>Impaired (<1.9th %ile)</i>	<i>Borderline (9th %ile)</i>	<i>Low Average (24th %ile)</i>	<i>Average (75th %ile)</i>	<i>High Average (90th %ile)</i>	<i>Superior (97th %ile)</i>	<i>Very Superior (>98th %ile)</i>
<i>Non-Elite</i>	<i>Component 2: Sleep Latency</i>	3.0	2.5	2.0	0.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	1.2	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	2.0	1.4	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	2.0	1.0	1.0	1.0	1.0	0.2	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	1.4	1.0	0.0	0.0	0.0	0.0
	<i>Patient Health Questionnaire-9</i>	14.6	8.0	5.0	1.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	16.0	11.5	6.0	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	29.4	15.5	8.0	1.0	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	23.4	8.3	3.0	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	11.2	8.5	7.0	3.0	3.0	1.0	0.9
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.0	0.0	0.0
<i>Concussion History</i>	<i>Component 2: Sleep Latency</i>	3.0	3.0	2.0	1.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	3.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	2.2	1.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	1.5	1.0	0.0	0.0	0.0	0.0
	<i>Patient Health Questionnaire-9</i>	13.0	8.7	5.8	1.5	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	11.5	10.7	5.5	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	27.5	16.0	9.0	1.8	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	8.3	7.0	3.7	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	9.5	8.7	7.8	3.5	3.0	1.8	1.5
	<i>Component 1: Subjective Sleep Quality</i>	2.5	2.0	2.0	1.0	0.6	0.0	0.0
<i>No Concussion History</i>	<i>Component 2: Sleep Latency</i>	3.0	3.0	2.0	0.5	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	1.5	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	1.0	1.0	1.0	1.0	1.0	0.8	0.5
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	2.0	1.0	0.5	0.0	0.0	0.0
	<i>Patient Health Questionnaire-9</i>	11.0	8.0	5.0	1.0	0.0	0.0	0.0
	<i>Generalised Anxiety Disorder-7</i>	16.0	9.7	4.3	0.0	0.0	0.0	0.0
	<i>Neck Bournemouth Questionnaire</i>	30.9	15.4	7.0	0.0	0.0	0.0	0.0
	<i>Migraine Disability Index</i>	22.9	8.2	2.0	0.0	0.0	0.0	0.0
	<i>Pittsburgh Sleep Quality Index</i>	11.0	8.0	7.0	3.0	2.0	1.0	1.0
	<i>Component 1: Subjective Sleep Quality</i>	2.0	2.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 2: Sleep Latency</i>	3.0	3.0	2.0	1.0	0.0	0.0	0.0
	<i>Component 3: Sleep Duration</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 4: Sleep Efficiency</i>	3.0	2.0	1.0	0.0	0.0	0.0	0.0
	<i>Component 5: Sleep Disturbance</i>	2.0	1.0	1.0	1.0	0.0	0.0	0.0
	<i>Component 6: Use of Sleep Medication</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Component 7: Daytime Dysfunction</i>	2.0	1.0	1.0	0.0	0.0	0.0	0.0