CONCUSSION AND BRAIN HEALTH

POSITION STATEMENT 2023

February 2023

"If in doubt, sit them out"

CONTENTS

EXECUTIVE SUMMARY

There has been growing concern in sporting communities in Australia and internationally about the potential health ramifications for athletes from repeated head trauma (RHT) and sport-related concussion (referred to as concussion here on). Concussion affects athletes at all levels of sport, from the part-time recreational athlete to the full-time professional. If managed appropriately, most episodes of concussion resolve over a short period of time, with or without medical intervention. Complications can occur, however, including prolonged duration of symptoms and increased susceptibility to further injury. There is also concern about potential long-term consequences of RHT for long term brain health.

Chronic traumatic encephalopathy (CTE) is a neurodegenerative pathology associated with a history of RHT. There are a growing number of case studies and case series which document CTE neuropathological change (CTE-NC) in retired athletes with a history of RHT. There remain many uncertainties about the strength of the association between RHT, concussion, and CTE-NC. Further research is required to understand the prevalence of CTE-NC in athletic cohorts and the factors that predispose some athletes to the development of CTE-NC following exposure to RHT.

Over recent years there has been elevated public awareness of concussion and increased focus on the importance of diagnosing and managing the condition promptly, safely, and appropriately.

Sport administrators, medical practitioners, coaches, parents, and athletes are seeking information regarding the timely recognition and appropriate management of concussion. There is a need for clear, unequivocal, and reliable information to be readily accessible to all members of the community.

As the high-performance arm of the Australian Sport Commission, the Australian Institute of Sport (AIS) functions as a resource for sport organisations, providing expertise and education as required.

Funded by the Australian Government, this ***Concussion and Brain Health Position Statement 2023 (CBHPS23)*** brings together the most contemporary evidence-based information and presents it in a format that is appropriate for all stakeholders. This position statement is an update to the previous ***Concussion in Sport Australia position statement***, launched in 2019. Both the 2019 position statement and the 2023 update (i.e. ***CBHPS23***) is intended to ensure that participant safety and welfare is paramount when dealing with matters of RHT and concussion in sport.

This updated version includes the latest recommendations and addresses evidence specifically relating to concussion and brain health in female athlete and para athlete cohorts. This position statement provides an overview of the scientific literature in relation to the potential long-term effects of RHT and concussion in athletes.

This position statement recommends that sports operate on a principle of an 'abundance of caution'. 'If in doubt, sit them out'. Where there is any suspicion of concussion, an athlete should be removed from the field of play and should not be allowed to return, until cleared by a medical practitioner.

This position statement is intended as a general guide relating to current best practices for prevention, recognition, and management of concussion, underpinned by available empirical evidence. It should not be interpreted as a guideline for clinical practice or legal standard of care. Recommendations will evolve to reflect evidence and advances in science.

The ***CBHPS23*** will be further updated after the latest evidence presented by the Concussion in Sport Group at the 2022 Amsterdam Consensus Conference is made publicly available. This ensures that this position statement remains consistent with contemporary evidence.

INTRODUCTION

Concussion is a public health issue of concern, in Australia and globally. Repeated head trauma (RHT) includes head impacts that lead to a concussion or a mild traumatic brain injury, as well as head trauma that *do not* cause an individual to experience any subsequent symptoms. Contact or collisions during sport participation is one way an individual may experience RHT. 16% of all annual concussions that required hospital treatment in Victoria are related to participation in sport. [1]

Sport-related concussion (referred to as *concussion* here on) affects male and female athletes, para and able bodied, across all age groups and at all levels of sport. The risk of concussion can vary across sports, level of participation, session type (i.e., training or competition), and sex. [2] The rate of concussion has been reported to be higher in females than in males. [2, 3] Individuals who participate in contact, collision, and combat sports have a high risk of RHT and concussion as they can be exposed to multiple blows to the head (direct) and trunk (indirect). [2] It is important to note that although trunk impact may not directly impact the head, it can also cause concussion. As contact and collision sports gain popularity among groups such as females, and athletes with disabilities, it is anticipated that a concurrent rise in concussion injuries may be observed in these groups.

There is increasing concern about the long-term effects on the brains of individuals who experience RHT or multiple concussion, driven in part by highly publicised cases of dementia and mental health issues among American football players, boxers, rugby players, and Australian Football League (AFL) players. Concern about the possible short-term and long-term health ramifications for athletes has led to an increased focus on improving recognition and management of concussion.

The Australian Sports Commission (ASC) is the Australian Government agency responsible for supporting and investing in sport at all levels. The ASC's strategic vision is to ensure sport has a place for everyone and delivers results that make Australia proud. The ASC also plays a critical leadership role in guiding sporting organisations and the sport sector in relation to a range of issues impacting sport. The ASC is not a regulatory authority and has no power to enforce compliance or regulations. The Australian Institute of Sport (AIS) is the high-performance arm of the ASC. The AIS functions as a resource for sport organisations, providing expertise and education as required. The AIS seeks to guide, but not instruct sports on a range of policy positions, including sport-related concussion (referred to as concussion from here on).

Aims

There has been a rapid increase of publications on concussion. For instance, the United States National Library of Medicine's PubMed database had 1,840 concussion related publications in 2021 and a further 1,600 in 2022. The AIS is committed to ensure everyone involved in sport across the participation pyramid including athletes, coaches, parents, medical practitioners, and others can access the latest evidence-based resources on concussion. Funded by the Australian Government, the ***Concussion and Brain Health Position Statement 2023 (CBHPS23)*** aims to:

- provide access to up-to-date evidence-based information on concussion for all Australians
- provide improved safety and health outcomes for all individuals who suffer concussive injuries while participating in sport
- assist Australian sporting organisations to align their policy and procedures to the most up-to-date scientific evidence
- protect the integrity of sport through consistent application of best practice protocols and guidelines
- provide a platform to support the development of a national policy for the management of concussions in Australia.

It should be noted that this position statement operates on a principle of an "an abundance of caution ('***If in doubt, sit them out***')." Where there is any suspicion of concussion, an athlete should be removed from the field of play and should not be allowed to return, until cleared by a medical practitioner.

MEDICO-LEGAL CONSIDERATIONS

The ***CBHPS23*** is intended as a general guide relating to current best practices for prevention, recognition, and management of concussion, underpinned by available empirical evidence. It will be updated as new knowledge develops. This position statement therefore *should not* be interpreted as a guideline for clinical practice or legal standard of care. Recommendations will evolve to reflect evidence and advances in science. Owing to differences in risk profiles, rules, settings and resources, concussion guidelines need to be adopted for individual sport specific regulatory environments. Also, given the complex nature of recognition and management of concussion, individual treatments may depend on the circumstances of each case. At the same time, consistent application of the principles highlighted in this position statement and International Olympic Committee (IOC) consensus statement guidelines can facilitate a greater degree of standardisation in the recognition and management of concussion.

WHAT IS CONCUSSION?

A concussion occurs through a collision with another person or object where biomechanical forces to the head, or anywhere on the body transmit an impulsive force to the head/brain, resulting in transient neurological impairment. It should be noted that concussion can also occur with relatively minor 'knocks'. Concussion is often an evolving injury with symptoms changing over hours or days following the injury. [4, 5] There are often adverse effects on balance and cognitive function. [4] Recovery times following concussion vary between athletes. Pathophysiological recovery may take longer than measures of clinical recovery, [6] and the average time taken to resolve clinical symptoms may vary according to sex, age, presence of pre-injury medical conditions, and para-athlete status. [3, 7-9] The current clinical definition of concussion does not distinguish persistent symptoms, or the underlying processes that impair brain function or any potential brain abnormalities. To overcome this limitation, the Berlin panel of the Concussion in Sport Group (CISG) defined concussion as *"a traumatic brain injury induced by biomechanical forces"*. [4]

It remains unclear whether concussion involves microscopic structural changes, which would position it within the traumatic brain injury spectrum, or whether it's limited to physiological changes. As discussed below, some epidemiological data, particularly hospital data, do not distinguish between traumatic brain injury and concussion.

CONCUSSION EPIDEMIOLOGY

Currently, Australia does not have a national sports injury surveillance system. Therefore, precise data on the incidence, frequency, and prevalence of concussion in Australia is undetermined. This is further compounded by a lack of recognition of the signs and symptoms of concussion, [10, 11] under-reporting and failing to seek medical advice. [12-14]

Furthermore, the terms 'sex' (biology) and 'gender' (social construct) are inconsistently used within the literature. [15, 16] Most published studies do not report how participant sex and/or gender information were obtained, nor clearly distinguish between differences related to biological sex or gender. Differences discussed below therefore may represent a combination of differences due to biological sex and gender.

Concussion epidemiology in high performance sports

During the 2019 National Rugby League (NRL) season in Australia, an incidence of 15.4 diagnosed concussions per 1,000hrs match play was reported. During the COVID-19 affected 2020 season, the concussion incidence was 14.9 diagnosed concussions per 1,000 match play hours. [17] In the Australian Football League (AFL), the diagnosed concussion incidence for the 2019 and 2020 seasons were 6.5 per 1,000 player hours and 6.8 per 1,000 player hours respectively. These figures might be inaccurate due to under-reporting and failing to seek medical advice. Under-reporting of concussions and failing to seek medical advice range from 17% to 82% across different sports. [12-14, 18, 19] That large numbers of concussions are going undetected and, therefore, unmanaged is concerning. A survey during the 2020 NRL preseason reported that 17% of players did not report a likely concussion to medical staff during the 2018 and 2019 seasons despite 85% of surveyed players receiving concussion education through their club over the previous two seasons. [12] The reasons players have indicated that they decline to report concussions are primarily due to 'not wanting to be ruled out of the game or training session' (58%) or 'not wanting to let down the coaches or teammates' (23%). [12] These results are consistent with other survey data reviewing the knowledge and attitudes of athletes about concussion. [14, 18, 20]

In June 2021, Aboriginal and Torres Strait Islander people represented 4% of the total Australian population. [21] At the high performance level, First Nation Communities are highly represented per capita. For example 12% of the NRL players, 21% of State of Origin players and 35% of the players in the Australian National team in 2011 identified as Indigenous. [22] However, there are no studies comparing rates of concussion between Indigenous and non-Indigenous players. There is need for community codesigned models of research into the epidemiology of concussion in First Nations Communities, as well as an assessment of Aboriginal and Torres Strait Islander peoples' knowledge and attitudes relating to concussion. [23, 24]

Sex differences in concussion

Evidence supporting sex-based differences in risk and outcomes of concussion is growing. [9, 25, 26] The risk of concussion is higher in female athletes than in males. [25, 26] Females experience worse outcomes from prolonged symptoms compared to males. [9, 25, 26] In the Australian Football League Women's Competition, diagnosed concussion incidence for matches from 2017, 2018, 2019, 2020 and 2021 were 15.1, 17.2, 11.5, 4.76, 8.27 per 1,000 player hours, respectively. [27] Female soccer, basketball, and softball players have an almost two times greater risk of concussion compared to males despite playing under the same rules. [28-31] In sports like ice hockey and lacrosse female players are prohibited from intentional body contact (i.e., body checking). Concussion rates are similar between male and female ice hockey players [32, 33] but female lacrosse players report more concussions. [34] Injury surveillance data over 6 years from the elite women's rugby union players in England reported 5 concussions per 1,000 hours of match play. [35] Injury surveillance data over 5 years from the National Collegiate Athletic Association (NCAA) Injury Surveillance Program indicates concussion rates per 1,000 athlete-exposures were 6.3 (female) vs 3.4 (male) in soccer/football, 6.0 (female) vs 3.9 (male) in basketball and 3.3 (female) vs 0.9 (male) baseball and softball. Only in swimming and diving did the survey indicate that male rates (0.5) exceeded those of females (0.3). [36]

Many hypotheses exist as to why concussion is more common in females, however, evidence is limited. Combinations of intrinsic and extrinsic factors may contribute to these sex-based differences, such as female-specific head impact kinematics, and sex-specific physiological parameters. One hypothesis is the lower biomechanical threshold tolerance for head impacts resulting in more severe symptomology in females. [37] Intrinsic physical factors such as lower neck strength may predispose women to greater head-neck acceleration during impact, increasing the risk of concussion. [38] One of the first studies to analyse sex-specific head injury mechanisms demonstrated maximal isometric neck strength of female rugby union players to be 47% lower than males. [39] The same study demonstrated 51% of the head impact events led to whiplash-style head kinematics compared to only one occasion in a male player. In women's collegiate ice hockey, a mean peak linear acceleration of 43g ± 15g was generated by concussive impacts, [40] significantly lower than concussive impacts in male collegiate players. [41] The tolerance for linear head impacts and biomechanical threshold for concussions therefore may be lower in female athletes compared with males. [26] The reasons for such differences between sexes are currently not clear. When female soccer players were fitted with a helmetless head impact measurement device, the majority of linear accelerations between 20-40g occurred in practice rather than competition over the course of a season (11% vs 7%, respectively). [42] Common mechanisms of head injury between sexes also vary. Female soccer players more commonly have concussions through contact with objects (42%) compared to contact with another person (32%). [43] The opposite trends are seen in male soccer players.

A link is emerging between progesterone levels (i.e., menstrual cycle phase) and risk of concussion and/or outcomes following concussion. [44-46] For instance, the risk of concussion is high during the late luteal phase of the menstrual cycle (high progesterone concentration) and during the first two days of menstruation. [45] Further, those who sustained a concussion during the luteal phase of their menstrual cycle, report higher incidences of negative quality-of-life outcomes and neurologic symptoms after one month. [46] Concussion may also alter hypothalamic-pituitary-ovarian axis function consequently altering menstrual cycle. [26, 47, 48]

Another hypothesis is that female athletes are more attuned with their bodies than males. Therefore, female athletes are more likely to recognise subtle changes/signs and symptoms and more willing to report these changes to team staff than males. [49]

Research on female concussion is at an early stage and there is significant heterogeneity of data. Extrinsic factors such as rules, use of safety equipment, and variations of training and practices may also contribute to sex differences in concussion. Further knowledge about sex differences in concussion, and both short- and long-term impact of concussion is needed. It should be noted that owing to a lack of conclusive evidence, sex is not recognised as a modifier for the management of concussions in the 5th edition of the concussion consensus statement. Rather, sex may be a potential risk factor and/or increase the severity of concussions. [4]

Concussion epidemiology in high-performance para-athletes

The International Paralympic Committee (IPC) define para athletes as a sportsperson with a disability. [50] Concussion remains an issue of concern for para-sports. Based on experience and available data, the IPC Medical Committee has put together a 'best estimate' risk assessment for concussion which considers impairment, impact speed, collision potential, and use of protective wear. The risk of concussion varies across sports, for instance concussion risk rating for para athletics field (wheelchair) is 1 (low), for para athletics field (amputee) is 2, para athletics track (wheelchair) is 3, Para triathlon—bike (multiple impairments) and football 5-a-side (vision impairment) is 4 and bike and hand cycling, Para alpine downhill (sit-ski, VI and standing) have the highest risk rating of 5 (Table 1). [51]

Table 1: Para sports Summer and Winter with 'best estimate' of concussion risk based upon impairment type, speed, collision potential, protective wear and risk rating: 1 (low) to 5 (high) [51]

Abbreviations: SCI = spinal cord injury, CP = cerebral palsy, VI = visual impairment

Summer Sports	Impairment	Collision Potential	Impact Speed	Head Protection	Risk Rating
Archery	Multiple	Very low	Very low	No	1
Boccia	CP	Very low	Very low	No	1
Cycling Road	Handcycle	Moderate	High	Yes	5
Cycling Road	Trike	Moderate	Moderate-High	Yes	3
Cycling Road	Bike	Moderate	High	Yes	5
Cycling Track	Multiple	Moderate	Moderate	Yes	3
Equestrian	Multiple	Low	Moderate	Yes	2
Football 5-a-side	VI	High	Low	No	4
Football 7-a-side	CP	Moderate	Low-Moderate	No	2
Goalball	VI	Moderate	Moderate	No	3
Judo	VI	Moderate	Moderate	No	2
Para athletics Field	Wheelchair	Low	Very low	No	1
Para athletics Field	Amputee	Low	Moderate	No	2
Para athletics Field	VI	Low	Moderate	No	2
Para athletics Field	CP	Low	Moderate	No	2
Para athletics Track	Wheelchair	Moderate	Moderate	Yes	3
Para athletics Track	Amputee	Low	Moderate	No	1
Para athletics Track	VI	Low	Moderate	No	1
Para athletics Track	CP	Low	Moderate	No	1
Para canoe	Multiple	Low	Low	No	2
Para Powerlifting	Multiple	Very low	Very low	No	1
Para swimming	Multiple	Low	Low	No	2
Para-Triathlon - Bike	Multiple	Moderate	High	Yes	4
Para-Triathlon - Run	Multiple	Low	Low	No	2

Summer Sports	Impairment	Collision Potential	Impact Speed	Head Protection	Risk Rating
Para-Triathlon - Swim	Multiple	Low	Low	No	2
Rowing	Multiple	Very low	Low	No	2
Sailing	Multiple	Moderate	Moderate	No	3
Shooting Para sport	Multiple	Very low	Very low	No	1
Sitting Volleyball	Multiple	Low	Low	No	2
Table Tennis	Multiple	Low	Low	No	1
Wheelchair Basketball	Multiple	Low	Low	No	2
Wheelchair Fencing	T2-T10, Below	Low	Low	Yes	2
Wheelchair Rugby	SCI	High	Low	No	3
Wheelchair Tennis	Multiple	Low	Low	No	2

Winter Sports	Impairment	Collision Potential	Impact Speed	Head Protection	Risk Rating
Para alpine Downhill	Sitski	Very high	Very high	Yes	5
Para alpine Downhill	VI	Very high	Very high	Yes	5
Para alpine Downhill	Standing	Very high	Very high	Yes	5
Para alpine Other	Sitski	High	High	Yes	4
Para alpine Other	VI	High	High	Yes	4
Para alpine Other	Standing	High	High	Yes	4
Para alpine Slalom	Sitski	Moderate	High	Yes	3
Para alpine Slalom	VI	Moderate	High	Yes	3
Para alpine Slalom	Standing	Moderate	High	Yes	4
Para cross-country skiing/ Biathlon	Sitski	Low	Low	No	2
Para cross-country skiing/ Biathlon	VI	Low	Low	No	2
Para cross-country skiing/ Biathlon	Standing	Low	Low	No	4
Para ice hockey	Multiple	High	Moderate	Yes	1
Para snowboard	Standing	High	Moderate	Yes	2
Wheelchair Curling	Multiple	Very low	Very low	No	1

During the 2012 Summer Paralympic Games, head and face injuries accounted for 14% of total injuries sustained in 5-a-side football (players have visual impairment) and 7% of total injuries sustained in 7-a-side football (players have cerebral palsy). [52] Injury surveillance data from the 2016 Summer Paralympic Games also indicates a high frequency of head and face injuries in football 5-a-side (vision impaired football). From total injuries reported at the 2016 Summer Paralympic Games, 8% injuries were to the neck and 2% were to the head and face. Incidence rates were 0.7 and 0.1 per 1,000 athlete days respectively. [53] Despite head-to-head contacts being observed on review video footage with players holding their heads with apparent balance issues following the incident, no concussions were reported. [51]

Injury surveillance data from the 2018 Winter Paralympic games showed high frequencies of head and face injuries in Para Alpine Skiing, Para Ice Hockey and Para Snowboarding. [54] Injuries to the head/face/neck were reported as 20% of all injuries, with 13% of these (i.e., 2% of all injuries) being concussions treated with medical care.

Concussion epidemiology in recreational sports

The United States Centers for Disease Control and Prevention (CDC) estimates that 1.6 to 3.8 million concussions per year result from sports and recreational activities. [55] Extrapolating from this North American data, it is reasonable to estimate at least 100,000 sport related concussions occur in Australia each year. Most concussions occur in community sport, however many are not documented and do not come to the attention of medical health professionals. Most concussions follow an uneventful course of recovery over days or weeks. There is usually no requirement for medical intervention. However, of the cases that required medical treatment in a hospital, Victorian data demonstrated a significant increase in frequency from 443 per year in 2002-03 to 621 in 2010-11, an increase of 61% over the nine-year period. [1] This was not explained by increased participation, since rates of concussion per 100,000 participants also increased significantly during this time. Hospitalisation rates for concussion across different sports have been examined, and when adjustments were made for participation rates, the sports with the highest concussion rates were determined to be motorsports (181 per 100,000 participants), equestrian (130 per 100,000 participants), Australian football (80 per 100,000 participants), all codes of rugby (50 per 100,000 participants), and roller sports (45 per 100,000 participants). [1]

Concussion epidemiology in youth sports

Concussions are common in children and adolescents. [56-59] By the age of 10 years, one in five children will experience a concussion but only 25% of those concussions result from sport participation. [58] It is difficult to accurately quantify incidence and prevalence in this population due to the lack of data reporting within school sports, lack of awareness of clinical symptoms by parents and coaches, and youth athletes not reporting head injuries for fear of missing out on playing. [60, 61] Adolescent males seem to be at a higher risk than females for concussions caused by accidents, not just in sport-related incidents. [58] An Australian national study revealed that 4% of teenage males aged 14-15 years old required medical care for concussions in 2018. [62] This is higher than females of the same age where only 1% required medical care for a concussion.

Young skulls are large compared to their brains because their brains are not fully developed, therefore easily move within the skull. Young brains have less myelination than adult brains and continue to increase/grow in size throughout adolescence [63-65] until about 24 years. [63] Lack of myelination and the potential for brain to move easily within the skull predispose nerve fibres to be easily torn apart during RHT making youth more vulnerable to concussion. Also, weaker neck muscles in youth are proposed as being a confounding factor in impairing the attenuation of forces impacting the head and can increase the risk of concussions (compared to adult populations). [43]

Economic impact of concussion

Aside from health concerns, concussions and traumatic brain injuries represent a significant economic cost to the community. The majority of traumatic brain injuries occur in the 15-64 year age group, representing the group most likely to be engaged in the workforce. [66] Victorian data estimated the concussion-related hospital admissions cost $2 million per year, [1, 67] costing $1,583 per admission. The Victorian population represents approximately one quarter of the population of Australia. Therefore, extrapolating concussions nationally, the cost to the Australian health system is at least $50 million annually. [67] It should be noted that these cost estimates do not account for individuals seeking treatment from primary health care settings such as general practitioners, allied health services, or loss of productive life-years. These figures represent only a portion of the economic costs involved, as they do not reflect costs to the individual, income, and productivity losses, nor that of other regions within Australia.

PATHOPHYSIOLOGY

The pathophysiology of concussion is complex and multifactorial. The physiology of the symptoms following a concussion are not yet completely understood. The initial biomechanical impact can initiate a cascade of events resulting in abnormal function at the cellular level. There is also evidence that shearing experienced by the brain tissue can alter blood flow to the brain tissue and affect metabolism, affect membrane permeability, release excessive neurotransmitters and neuroinflammation. [68]

Theoretical models are based on animal research and functional neuroimaging studies. Evidence points toward a series of interrelated changes that result in impaired neuronal function [69, 70]. It is thought that biomechanical forces cause neuronal cell membrane disruption and axonal stretching. The ion channels on the cell membranes become dysregulated and allow an indiscriminate flux of ions. Potassium efflux and calcium influx will result in depolarisation leading to the release of the excitatory neurotransmitter glutamate. In attempting to restore the resting membrane potential, ATP-dependent membrane ion pumps become overactive. This increases glucose demand resulting in a temporary depletion of intracellular energy reserves. There may also be a reduction in cerebral blood flow during this time, further impacting the energy shortage. The intracellular accumulation of calcium due to uncontrolled influx may result in sequestration of calcium within the mitochondria. Mitochondrial calcium overload causes mitochondrial dysfunction, which would further aggravate energy supply issues. These changes are also thought to result in increased free radical production and inflammatory processes, which may be implicated in some of the longer-term symptoms associated with concussion. [71]

During head impact, gelatinous grey matter undergoes significant shear forces from sudden acceleration-deceleration and pulling/pushing of the brain tissue can cause structural damage. Impact forces can affect the brain in males and females in different ways due to structural differences of brain tissue. For instance, male brains are approximately 10% larger with more global grey matter proportions, whereas, the right hemisphere of the female brain has proportionally more grey matter. [72] Furthermore, female axons are smaller with fewer microtubules than male axons. [38] Thus, female axons are at greater risk of failure during trauma under the same applied forces compared to male axons. Further, when exposed to the same mechanical injury significantly more swelling and greater loss of calcium signalling function can be seen on female axons 24 hours post-injury compared to male axons. [38]

Functional imaging studies have been used to assess physiological alterations underlying concussion and their time course post-injury. Most imaging modality studies suggest long-term alterations beyond the return to normality in clinical and neuropsychological measures. As such, imaging modalities may be useful in research settings to detect changes consistent with concussion and monitor progress beyond recovery of symptoms. However, the current level of evidence in favour of their clinical application is low. Modalities include magnetic resonance spectroscopy (MRS), functional magnetic resonance imaging (fMRI), diffusion tensor imaging, cerebral blood flow measurements, electrophysiology and positron emission tomography (PET) scanning. MRS can detect metabolic changes associated with concussion up to 30 days post-concussion. [6] fMRI has found differences in functional brain activation patterns from three days up to 23 months post-concussion in concussed athletes compared to controls. [73] Different diffusion tensor imaging methods have revealed changes in white matter orientation up to six months after concussion. [74] Alterations in cerebral blood flow resolved 30–40 days post-concussion and electrophysiology did not return to normal levels until 45 days after the injury. [75, 76] PET scans have revealed changes in cerebral glucose metabolism in some brain regions when comparing military veterans with post-concussive symptoms to controls. This suggests metabolic abnormalities may be implicated in post-concussive symptoms. [77] These neuroimaging modalities suggest the presence of physiological alterations that continue beyond clinical recovery from concussion. However, they are currently limited to characterising the pathophysiology of concussion and are not considered to be tools for clinical assessment. Increased availability, further research and reliability assessment are required before implementation in a clinical setting.

An improved understanding of the pathophysiology of concussion will allow more accurate diagnosis and evidence-based management of the condition. It may provide an enhanced appreciation of the long-term consequences of RHT and concussion and particularly recurrent concussions, to inform risk profiling and mitigation.

RECOGNISE, REMOVE, REFER

When an athlete is suspected of having a concussion, first aid principles apply. A systematic approach to the assessment of airway, breathing, circulation, disability, and exposure applies in all situations. Cervical spine injuries should be suspected if there is any loss of consciousness, neck pain or an injury mechanism that could have led to spinal injury. Manual in-line stabilisation (MILS) should be undertaken, and a hard collar applied until a cervical spine injury is ruled out.

All athletes suspected or confirmed of sustaining a concussion should be immediately removed from the sporting environment and should not be permitted to return to physical activity until they have been assessed by a medical practitioner [***'if in doubt, sit them out'***]. Referral to a medical practitioner should occur as a matter of priority. Recognising concussion is critical to correct management and prevention of further injury. A medical review is recommended for any athlete with a suspected concussion.

At the high-performance level, some football codes, including the AFL, NRL, and World Rugby/Rugby Australia, have developed criteria for mandatory removal of athletes from sport following head trauma (Note: this policy only applies at the elite level of the sport). These criteria are intended to provide a decision-making support process for doctors to determine the requirement for removal from the sport. The criteria are subdivided into those that require 'immediate removal and no return to sport' and those indicating 'immediate removal from the sport for further assessment with concussion assessment tools'.

In recreational sport, there may not be trained medical staff present. In this situation, any suspicion by a match official, coach, athletic trainer, first aider, or dedicated observer, should result in the permanent removal of the athlete from the field of play. The athlete is not permitted to return to play that same day, or prior to seeking a medical clearance to return to contact training and/or match play. *'If in doubt, sit them out'.*

In 2018, Rugby Australia introduced the mandatory use of Blue Cards in all club, school and domestic representative rugby. When a player exhibits signs and/or symptoms of concussion or suspected concussion, the referee will show the player a Blue Card. The Blue Card is a visual cue for team's support sport staff and triggers an off field medical process to begin. The AIS applauds this initiative. Referees and match officials are one of the 'constants' in the sporting arena. Having these individuals trained to recognise overt signs of potential concussion, to collaborate with team support staff, and empowered to issue a Blue Card is highly likely to contribute to the early recognition of concussion, particularly at the community level. Other sport codes could consider introducing a blue card system.

Clinical features of concussion

Concussed athletes may exhibit signs of disorientation, clumsiness, or loss of balance and will often display difficulty concentrating and answering specific questions. [4] Accurate and timely diagnosis of concussion can be challenging due to the lack of definitive diagnostic markers or investigations and the overlap of symptoms with other neurological, musculoskeletal, and psychological diagnoses. Hence, concussion is a clinical diagnosis – i.e., identifying a concussion is based on the individual's history, symptoms, and signs on physical examination. [4]

A key concept in on field assessment is the rapid screening for a suspected concussion, rather than the definitive diagnosis of head trauma. *The trigger for a concussion evaluation in contact and collision sports across all playing levels is when an athlete experiences a direct or indirect impact to their head and/or trunk associated with visible signs of a concussion and/or the athlete reports symptoms and/or clinical suspicion by medical staff and/or when a possible concussion event is reported by match officials.* [78] ***'If in doubt, sit them out'.***

To guide the immediate course of action, mandatory or discretionary visible signs of concussion have been identified by several sporting codes, for use in high performance athletes. [78] It should be noted that there are minor variations between sporting codes as to what signs of concussion are mandatory or discretionary. Further, there is variation between sporting codes for the course of action following a player displaying mandatory signs of concussion (i.e., immediate removal from the field of play/ game, on field assessment and off field management).

Mandatory signs of concussion (immediate removal and no further play)

Athletes displaying any of the following clinical features (i.e., mandatory signs of concussion) should be immediately removed from sport/field of play/game:

- loss of consciousness
- lying motionless for >5 s
- no protective action was taken by the athlete in a fall to the ground, directly observed or on video
- impact seizure or tonic posturing
- confusion, disorientation
- memory impairment/amnesia
- balance disturbance or motor incoordination (e.g., ataxia)
- athlete reports significant, new, or progressive concussion symptoms
- dazed, blank/vacant stare or not their normal selves
- behaviour change atypical of the athlete. [78]

When an athlete is removed from the field of play/game owing to mandatory signs of concussion, some sporting codes do not allow that athlete to return to the field of play/game. [78] In other sporting codes mandatory signs of a concussion is a trigger for mandatory clinical assessment in a quiet and distraction-free environment to determine if the player should return to the field of play/game. [78]

Discretionary signs of concussion (immediate removal for further assessment)

Athletes displaying any of the following discretionary signs of concussion should be immediately removed from sport/field of play/game for further assessment. Clinical assessment should be conducted in a quiet and distraction-free environment to diagnose or rule out a concussion. [78]

- clutching their head*
- being slow to get up*
- suspected facial fracture
- possible balance disturbance or ataxia
- behaviour change atypical of the athlete †
- other clinical suspicions. [78]

* The clinician should exercise his or her medical judgement regarding whether to remove the player for an acute evaluation.

† Some sports consider this a definitive removal criterion.

Red flag signs of concussion (immediate referral to emergency department)

Some features suggest more serious injury and any athlete displaying any of these signs should be immediately referred to the nearest emergency department:

- neck pain
- increasing confusion, agitation, or irritability
- repeated vomiting
- seizure or convulsion
- weakness or tingling/burning in the arms or legs
- deteriorating conscious state
- severe or increasing headache
- unusual behavioural change - double vision. [78]

RE-EVALUATE

Symptoms of concussion

Concussive presentations and symptomology may vary significantly and can be complex in nature. [79-81] There are several clinical presentations that can exist following concussion and these can be classified into 5 domains: somatic, musculoskeletal, neurological, fatigue and sleep. [82-84] Any combination of these domains can form clusters of symptoms. Although evidence in this space is emerging, common symptom clusters have been identified post-concussion. Cognitive and emotional symptoms coexist together most frequently, and fatigue has been associated more commonly with this grouping rather than with physical symptoms. [82] Furthermore, there are several systems that can be affected following concussion including cervical/musculoskeletal, vestibular and oculomotor (VOM), autonomic (exertional tolerance and aerobic exercise), motor and neurological function. [84, 85] Prolonged recovery and more complex symptomology have been associated with the presence of VOM impairments. [82, 86, 87] Evidence suggests females tend to have greater symptom severity with prolonged recovery following concussion than their male counterparts. [86, 88, 89]

The severity of acute and subacute symptoms has been found as the most consistent predictor of slower recovery. [90] Furthermore, subacute symptoms involving headaches or depression are linked to persistent symptoms. The risk of developing persistent symptoms is greater in individuals with a history of mental health problems, attention deficit hyperactivity disorder (ADHD), learning disabilities and migraine. [90]

Thorough subjective and objective assessment to identify impairments can help guide rehabilitation improving prognosis, and minimising potential complications such as post-concussive syndrome (PCS). [83] Tools now exist that can not only help build a clinical diagnosis of concussion but also help differentially diagnose affected domains.

There is currently no conclusive evidence for a modulating effect of sex on outcomes following a concussion. Nonetheless, there is a growing body of evidence pointing to sex differences in symptom patterns, and neurocognitive function. [15, 28] Although there is a pattern of females reporting greater overall symptoms than males, when examining individual symptoms or symptom clusters, there are mixed findings between the sexes. [3, 8, 43, 91] Acute symptom scores are higher in females compared to males however no difference exists between the number of symptoms between groups. [15, 92-98] Male high school athletes reported more cognitive symptom clusters while females reported more somatic and neurobehavioral symptoms clusters. [92] Disorientation/confusion and amnesia are the most common primary symptoms reported by males. [92, 99] Drowsiness and sensitivity to light are the most common primary symptoms reported by females. [92] Another study found that symptoms within the somatic, emotional, and migraine-cognitive-fatigue clusters were more common in females than males. [89] For instance, compared to males, "pressure in the head", headache, "feeling slowed down", difficulty concentrating, feeling more emotional, irritability, and sadness are rated higher by females following a concussion. [95, 100] Females are 2 to 3 times more likely to have migraines, which increases to 3 to 4 times after puberty, than males. [101] This may explain greater reporting of migraine-cognitive-fatigue symptom cluster in females following a concussion.

Female athletes experience greater neurocognitive impairment following concussion compared to males. [15, 28] Visual memory composite scores [96-98, 102] and reaction times are lower in females compared to males following concussion. [37] Furthermore, cognitive impairment after a concussion is 1.7 times higher in females compared to male athletes. [103] Neuropsychological studies generally showed females performing more poorly than males on measures of visual memory following concussion, though this finding was not consistently reported.

It should be noted that the majority of studies discussed above used subjective assessment tools to investigate sex differences. [15] Similarly, owing to lack of conclusive evidence, the 5th edition of the Concussion Consensus Statement did not consider sex difference as a modifier for management of concussions. Rather it was considered a potential risk factor for concussion that may increase the severity of symptoms. [4] Further research is needed to better understand the interplay between sex hormones, physiological and biological differences and concussion signs and symptoms, risk factors and severity.

Diagnosis of concussion

The diagnosis of concussion should be made by a qualified medical practitioner based on clinical judgement. It should be noted that currently there is no specific diagnostic test that confirms the presence of a concussion. Therefore, in diagnosing concussion, medical practitioners need to conduct a clinical history and examination across a range of domains including the mechanism of injury, symptoms and signs, cognitive functioning and neurological assessment, including balance testing. [104, 105] As part of the overall clinical assessment to assess potential concussion, medical professionals can use the Sport Concussion Assessment Tool 5 (SCAT5) for athletes aged 13 years and older. [106] The diagnosis accuracy of concussion can be significantly increased when the aforementioned clinical features (i.e., mandatory or discretionary signs) are combined with the mechanism of injury. [107]

SCAT5 encompasses an on field assessment to be used at the time of the concussion, which includes a brief history of the injury, a Glasgow Coma Score and a series of questions known as Maddocks questions. These questions have been validated as an indicator of concussion and are more sensitive in this context than the standard orientation questions. [104] The questions assess athlete orientation (in time and place) and they should be preceded by: ‘I am going to ask you a few questions, please listen carefully and give your best effort.’

The modified Maddocks questions are:

- What venue are we at today?
- Which half is it now?
- Who scored last in this match?
- What team did you play last week/game?
- Did your team win the last game?

The remainder of the SCAT5 is for use off field, in the medical room, or in the consulting room after a referral for a suspected concussion has been made. A possible 22 symptoms of concussion are listed in SCAT: [106]

- Headache
- “Pressure in head”
- Neck Pain
- Nausea or vomiting
- Dizziness
- Blurred vision
- Balance problems
- Sensitivity to light
- Sensitivity to noise
- Feeling slowed down
- Feeling like “in a fog“
- “Don’t feel right”
- Difficulty concentrating
- Difficulty remembering
- Fatigue or low energy
- Confusion
- Drowsiness
- More emotional
- Irritability
- Sadness
- Nervous or Anxious
- Trouble falling asleep (if applicable)

It should be noted that the current SCAT5 is under review and once SCAT6 becomes available, content and the link above will be updated accordingly.

SCAT5 is relatively insensitive and describes non-specific symptoms. Furthermore, the diagnostic utility of the Sport Concussion Assessment Tool 3 (SCAT3) decreases 3–5 days post-concussion. [108]

Computerised neurocognitive testing can be incorporated in the assessment, but again, it should not be used in isolation. [108] Baseline neurocognitive testing in the pre-season period can be useful for comparison with post-injury scores. Many programs, however, have reference ranges that can be applied in the absence of a baseline test.

It is important to note that SCAT5 was developed in English, which limits its use in culturally and linguistically diverse populations. There is no evidence that SCAT5 is a culturally appropriate tool for Aboriginal or Torres Strait Islander peoples and Australians with culturally and linguistically diverse backgrounds, especially for those individuals whose first language is not English and might have a different second language. [109, 110]

Concussion assessment in para-athletes

The SCAT5 [106] and Concussion Recognition Tool 5 (CRT5) [111, 112] might be used in the para-athlete population to assess for suspected concussion, but their use may be limited in this population. For instance, one of the assumptions of the SCAT5 tool is that athletes can see, hear, read, and understand information with competence, they have 'normal' baseline speech and language skills, manual dexterity, and range of movement of the cervical spine to enable participation in neurological examination with a comprehensive assessment of mental status, cognitive functioning, gait, and balance. [4, 106] Yet, para-athletes may experience one or a combination of impairments such as morphological (amputation, dysmelia, congenital deformity), visual impairments, auditory impairments, spinal cord injuries and central neurologic injuries (cerebral palsy, spina bifida, stroke), posing challenges for suspected concussion assessment. [113] For example, male soccer athletes with cerebral palsy report higher total severity scores, more baseline symptoms, worse scores for immediate memory and Balance Error Scoring System (BESS) measures compared to male athletes without a disability on the SCAT3. [7] Baseline assessments are used to establish a point of reference, and appropriate considerations should be given to baseline cognitive function as well as visual or physical abilities of the para athlete. Periodic baseline pre-participation assessments are recommended in para-athlete populations. [113] It should be noted that baseline scores between different disability groups can significantly vary and in addition para athletes' cognitive function may also vary with the progression of their disability (without a concussive event). Therefore, for effective concussion assessment and management the attending clinician (ideally a team clinician with prior knowledge of the athlete) must have a comprehensive understanding of the preinjury cognitive function and abilities of the para-athlete. [113]

It has recently been suggested that the SCAT5 and other guidelines should also include modifications for use with athletes with disability. [114, 115] Para athletes are not a homogeneous population and impairments they experience may vary within individual and team para sports. Currently, internationally recognised concussion assessment tools specific to para-athlete populations do not exist and clinicians have highly variable methods for recognition and management of concussions. [113, 114, 116] The need for adopting and validating internationally recognised tools such as SCAT5 in disabled athlete groups was raised by the IPC. [114] Therefore, the Concussion in Para Sport (CIPS) Group utilised sections of the SCAT5, *'immediate or on field assessment'* and *'office or off field assessment'*, to develop a traffic light system as a guide to interpreting SCAT5 results for para-athletes with:

- (Single) upper limb deficiency,
- (Bilateral) upper limb deficiency,
- (Single) lower limb deficiency,
- (Bilateral) lower limb deficiency,
- Impaired vision,
- Absent vision,
- Globe absent,
- Spinal cord injury (SCI) with quadriplegia,
- SCI with paraplegia,
- Cerebral palsy (CP) with spastic diplegia,
- CP with spastic hemiplegia,
- CP with spastic quadriplegia,
- Dyskinetic CP,
- Ataxic CP,
- Mixed CP,
- Intellectual impairment,
- Achondroplasia,
- Arthrogryposis,
- Polio,
- Muscular dystrophy,
- Multiple sclerosis,
- Spina bifida. [117]

The traffic light system rates whether additional considerations are required for para-athletes during recognition and assessment of concussion, as well as the return to sport phases. The rating system moves from green = no anticipated considerations, to yellow = potential additional considerations, and red = SCAT5 item not appropriate for para-athletes. Tables of the rating system that are specific to impairments can be found within the supplementary material of the Concussion in para sport: the first position statement of the CIPS Group.

Concussion assessment in recreational athletes

At the recreational level, the athlete should be permanently removed from play if an athlete, coach, first aider/sport trainer, parent, match official, or dedicated spotter has any suspicion of a concussion, particularly given medical professionals, sideline spotters, and sideline technology may not be available. [78] ***If in doubt, sit them out***. Medical professionals often rely on self-reported symptoms to diagnose concussion in individuals who play recreational sports. CRT5 a free resource available to individuals without medical training, to help identify concussions in children and adolescents and adults. Thus CRT5 is the most appropriate tool for recreational sport The CRT5 is a simplified summary of the key signs and symptoms and 'red flags' that should raise a concern about a possible concussion. 20 symptoms listed in the CRT5 are: [111, 112]

- Headache
- "Pressure in head"
- Balance problems
- Nausea or vomiting
- Drowsiness
- Dizziness
- Blurred vision
- Sensitivity to light
- Sensitivity to noise
- Fatigue or low energy
- "Don't feel right"
- More emotional
- More irritable
- Sadness
- Nervous or anxious
- Neck pain
- Difficulty concentrating
- Difficulty remembering
- Feeling slowed down
- Feeling like "in a fog"

It should be noted that the current CRT5 is under review and once CRT6 becomes available, content and the link above will be updated accordingly.

Once a possible concussion is identified, the CRT5 advises that the individual *must be removed from sport immediately and not be allowed to return to activity until they are assessed medically*. [111, 112] ***'If in doubt, sit them out'***. It should be noted that CRT5 is relatively insensitive to non-specific symptoms.

Concussion assessment in children aged 5-12 years

The Child Sport Concussion Assessment Tool 5 (Child-SCAT5) was developed as a standardised tool to be used by medical professionals to evaluate children suspected of having suffered a concussion. [118] It is a modified version of the SCAT5 for children aged 5–12 years. The key differences are that the symptom evaluation is written in language more appropriate for this age group and the severity score is marked out of three rather than six. The Child SCAT5 also includes a parent's report of symptoms and severity. The Child-SCAT5 lists 21 child reported symptoms and 21 parent reported symptoms. It is recommended that the symptom evaluation be performed with the child in a resting state. [119] It should be noted that due to the questionable reliability and usefulness in young children, the modified Maddocks questions and orientation questions were removed from Child SCAT5 [119] and the balance examination for children aged 10–12 years includes only the single-leg stance. [118, 119]

Child report symptoms	Parent report the child
I have headaches	has headaches
I feel dizzy	feels dizzy
I feel like the room is spinning	has a feeling that the room is spinning
I feel like I'm going to faint	feels faint
Things are blurry when I look at them	has blurred vision
I see double	has double vision
I feel sick to my stomach	experiences nausea
My neck hurts	has a sore neck
I get tired a lot	gets tired a lot

Child report symptoms	Parent report the child
I get tired easily	gets tired easily
I have trouble paying attention	has trouble sustaining attention
I get distracted easily	is easily distracted
I have a hard time concentrating	has difficulty concentrating
I have problems remembering what people tell me	has problems remembering what he/she is told
I have problems following directions	has difficulty following directions
I daydream too much	tends to daydream
I get confused	gets confused
I forget things	is forgetful
I have problems finishing things	has difficulty completing tasks
I have trouble figuring things out	has poor problem solving skills
It's hard for me to learn new things	has problems learning

It should be noted that the current Child-SCAT5 is under review and once Child-SCAT6 becomes available, content and the link above will be updated accordingly.

Individuals without medical training can use the CRT5 to help identify possible concussions in children and adolescents and adults. The 20 symptoms included in the CRT5 are listed above. [111, 112]

Clinical features that mandate '*immediate removal and no return to sport*' include:

- loss of consciousness;
- no protective action in fall to the ground observed directly or on video;
- impact seizure or tonic posturing;
- confusion;
- disorientation;
- memory impairment (e.g., fails Maddocks questions – see above);
- balance disturbance (e.g., ataxia);
- athlete reports significant new or progressive concussion symptoms;
- dazed; blank/vacant stare;
- not their normal selves; or observed behaviour change.

Where suspicion remains or concussion is confirmed, the athlete *must not* return to sport on the day of injury and *must* seek medical clearance from a qualified practitioner prior to returning to play. '***If in doubt, sit them out***'.

Decision trees to support *on field* concussion recognition and management for non-medical and medical personnel can be found in Figures 1 and 2 respectively.

Similar decision trees can be found in Figures 3 and 4 to support non-medical and medical personnel respectively through the off field recognition of concussion.

Figure 1: Non-medical personnel *on field* concussion recognition decision tree

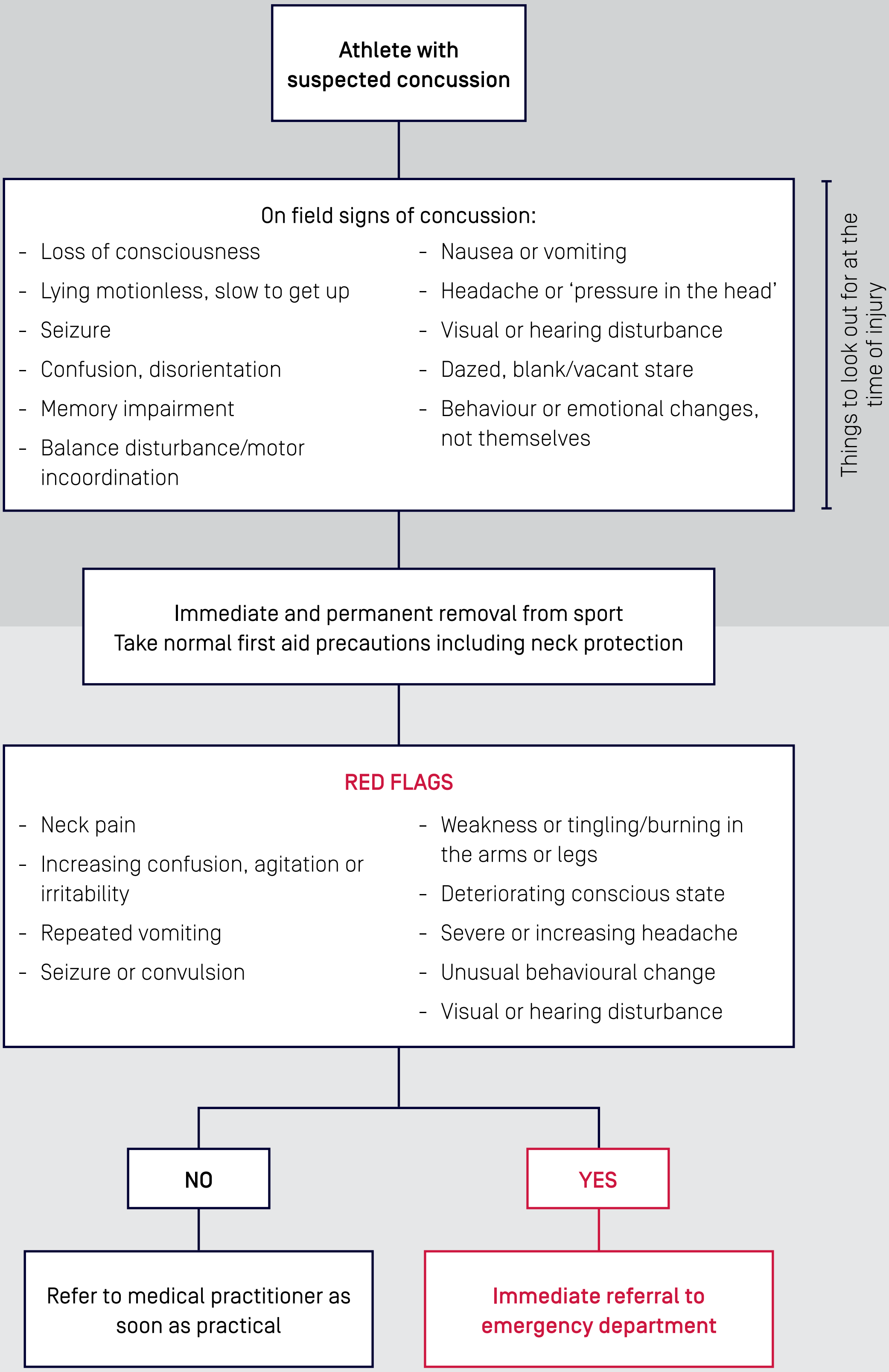


Figure 2: Medical personnel *on field* concussion management decision tree

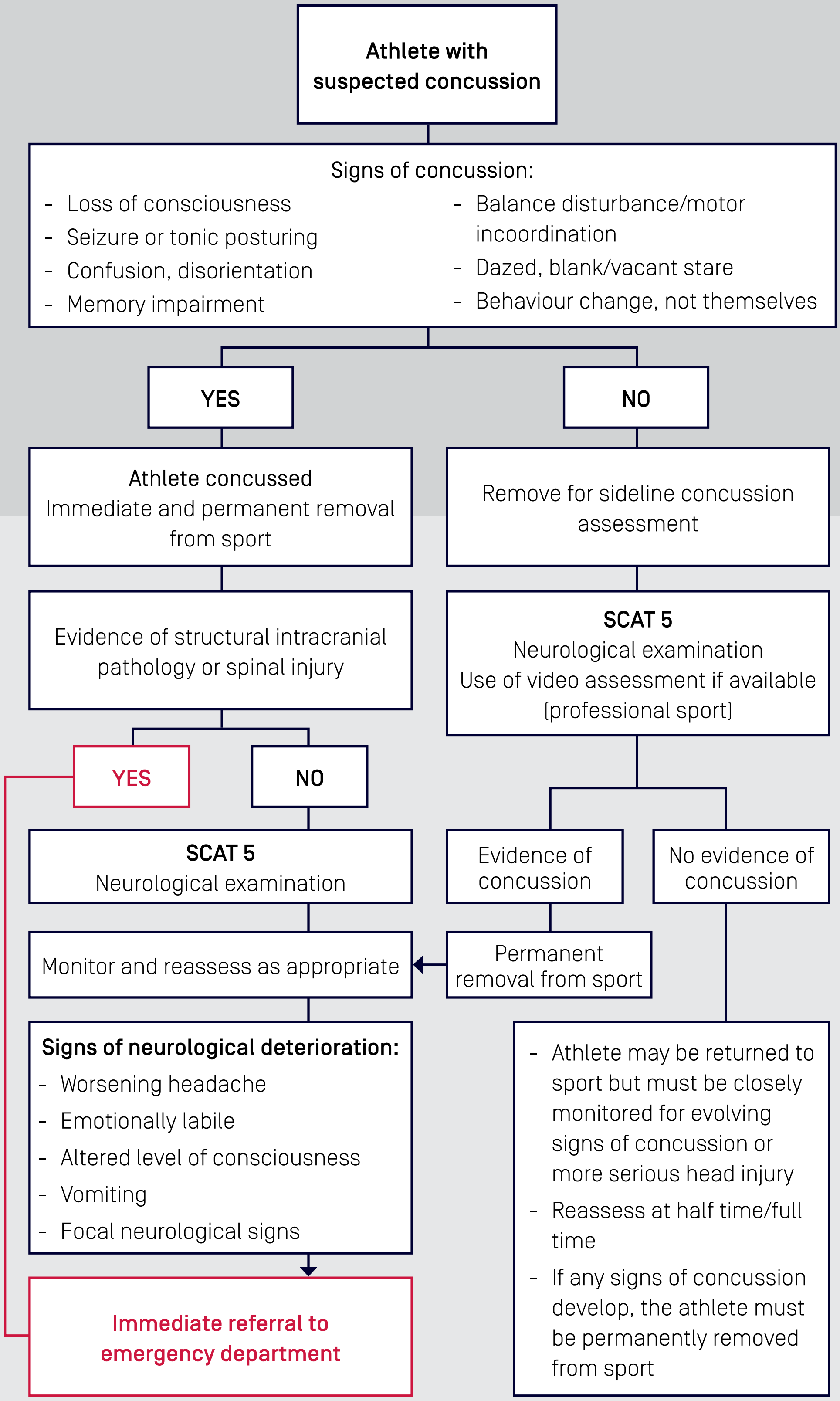


Figure 3: Non-medical personnel *off field* concussion recognition decision tree

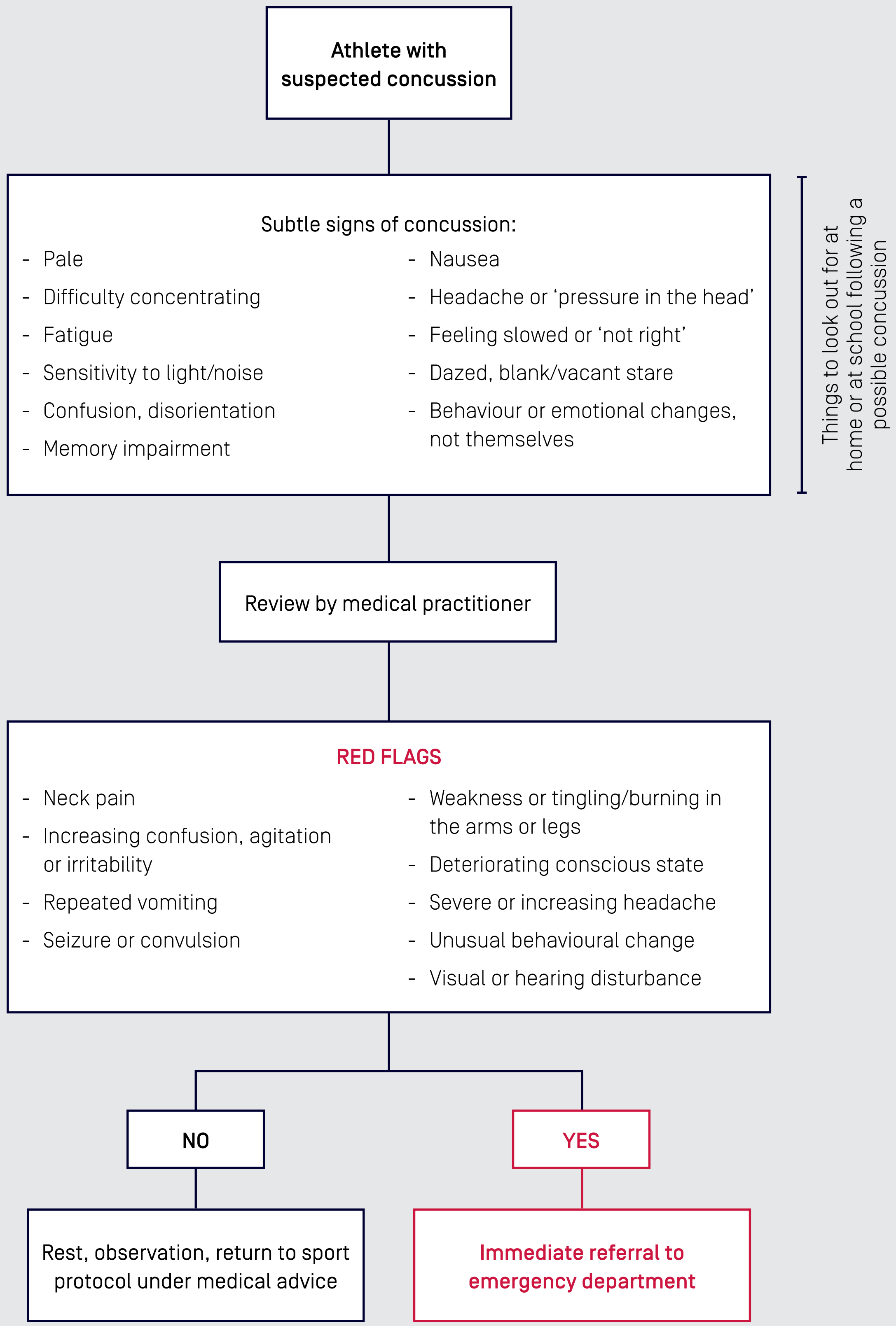
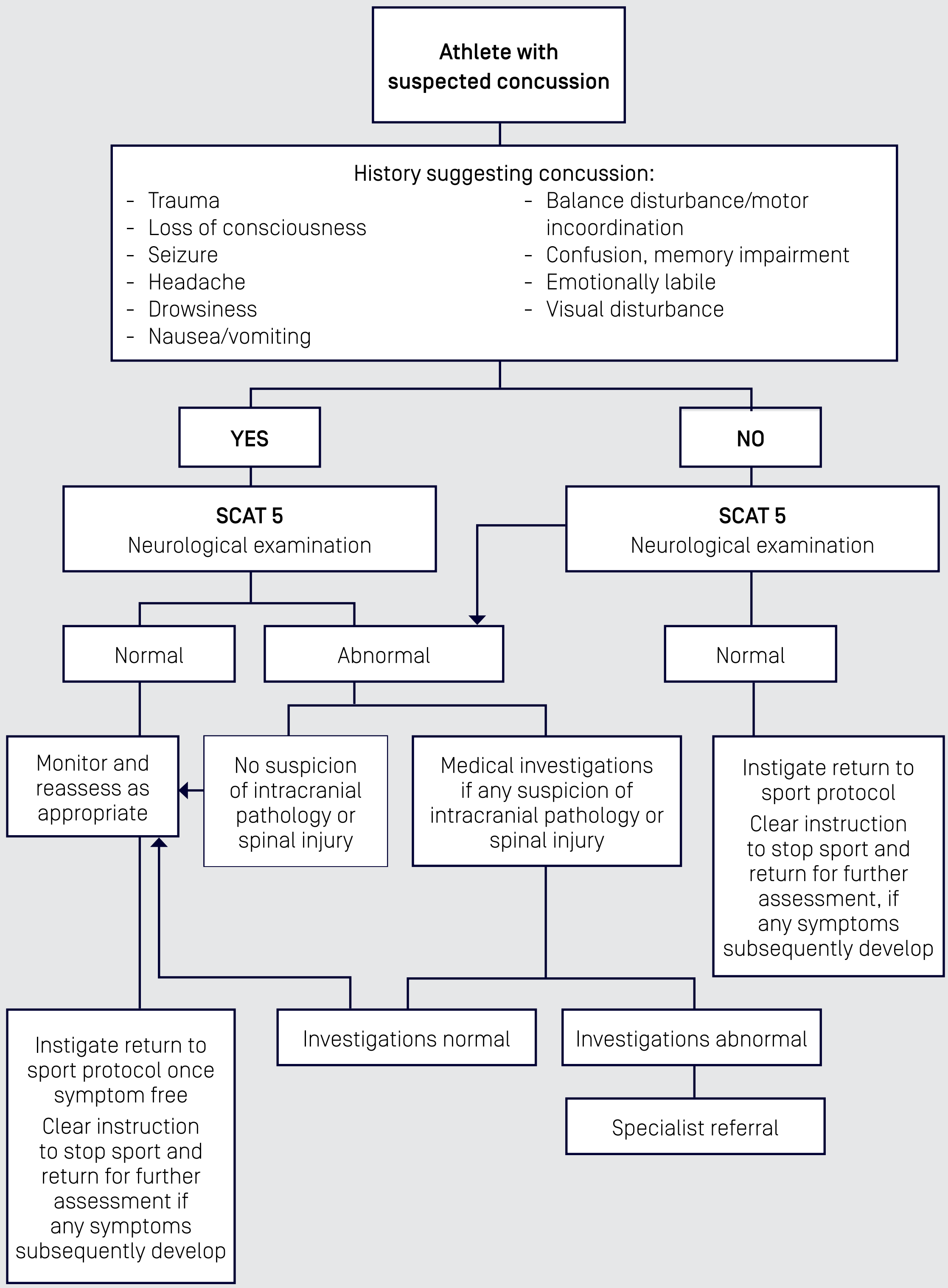


Figure 4: Medical personnel *off field* initial concussion management decision tree



CONCUSSION MANAGEMENT

There is agreement regarding key principles of concussion management policies by a broad array of organisations, including the CISG, American Academy of Neurology (AAN), US CDC, and sporting organisations. The key principles include a brief period (24-48 hours) of relative rest, followed by a supervised and graduated return to cognitive and non-contact physical activity, with no return to contact and collision activities, until medically cleared to do so.

All individuals dealing with potentially concussed athletes must understand that concussion is an evolving phenomenon. Therefore, signs and symptoms can change or be delayed reflecting the changing underlying physiological injury status of the brain. The diagnosis of a concussion is based on the clinical judgement of a healthcare professional. [4, 106] In some instances, it will be obvious that there has been a significant injury where the athlete immediately suffers a loss of consciousness, has a seizure or has significant balance difficulties. However, signs and symptoms of concussion can be variable, non-specific, subtle, and may be difficult to detect. Symptoms that are initially subtle can become more significant in the hours and days following the injury and require repeat/serial evaluations. Owing to delays in presentation, it may take up to 48 hours following a head contact to exclude a diagnosis of concussion. [105] Parents, coaches and attending medical personnel need to be alert to behaviour that is unusual or out of character.

The role of physiotherapy in concussion

There is increasing evidence to support the involvement of physiotherapists in the assessment and management of concussion. [79] While ideally, a medical practitioner should be involved early in the clinical management team (CMT), it is often a physiotherapist who will recognise suspected concussion and be responsible for removing an athlete from the field of play. Whether as a primary care practitioner in community sport, or as the consistent point of athlete contact in high-performance environments, the physiotherapist's role also places them in a position to observe evolving concussion symptoms.

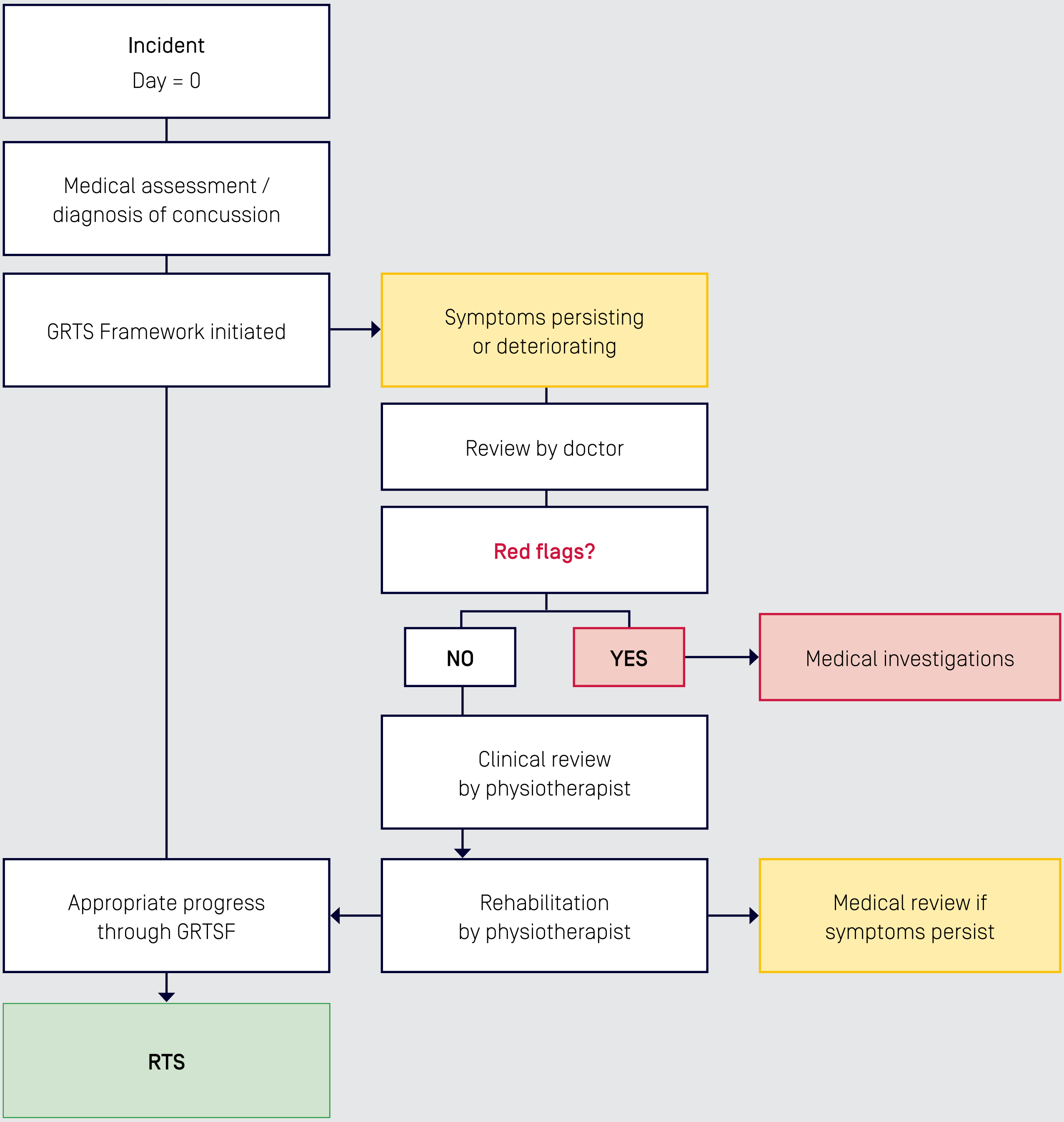
Most concussion cases are uncomplicated in nature, with 70 – 80% recovering within expected timeframes and requiring minimal to no input from the CMT. [80-84] The physiotherapist's role in these cases may involve oversight and guidance through the graded return to sport (GRTS) However, up to 30% of concussion cases are more complex with prolonged symptoms and recovery. [80, 82, 83] The physiotherapist can play a crucial role in complex case management including further clinical review of cases that do not progress as expected through the GRTS, or who are identified as having VOM dysfunction in initial/ early assessment post-concussion. Several studies demonstrate appropriate rehabilitation, including cervical and VOM rehabilitation delivers faster symptom resolution, faster return to function and more complete recovery highlighting the value physiotherapists can play in concussion management. [79, 120-122] The Interdisciplinary care for athletes with concussion (Figure 5) provides a guide that may be helpful for health practitioners involved in the CMT of an athlete post-concussion.

Interdisciplinary care for athletes with concussion

Effective communication and clear CMT role delineation promotes effective and efficient patient-centred care. The structure of the CMT may vary between sport environments, reflecting resource capacity, and the availability and skills of medical practitioners and physiotherapists. Assuming the availability of a medical practitioner, and a physiotherapist with skills in VOM assessment and rehabilitation, Figure 5 illustrates an appropriate system for managing athletes with concussion.

Figure 5: Interdisciplinary care for athletes with concussion

Figure 5, outlines appropriate steps to follow when managing an athlete post-concussion. In an ideal situation, a medical practitioner and physiotherapist with skills in vestibular and oculomotor rehabilitation are part of the clinical management of each concussion case.



Physiotherapists can play a role in post-concussion management through:

- Supervision and management of a graded return to sport framework (GRTSF)
- Recognition and identification of vestibular and oculomotor (VOM) impairments
- Recognition of the deterioration of an athlete's condition
- Clinical review of complex cases

RELATIVE REST

The current principles of concussion management involve a brief period of cognitive and physical rest during the acute period post-injury, followed by a gradual increase in activities of daily living and cognitive activity, prior to a progressive return to sport. Most current evidence supports relative rest during the acute period (24–48 hours post-injury). [123, 124] In a randomised control trail (45 intervention, 43 control), individuals (age 11 to 22 years) who were prescribed strict rest for 5 days reported more symptoms and recovered more slowly than those who engaged in some physical activity. [124] Strict rest beyond the initial period is not recommended.

One of the aims of concussion management is to minimise disruption to learning for children, adolescents, and young adults. There is evidence that abstaining from screen time during the first 48 hours of recovery is associated with a shorter duration of symptoms. [125] As with physical activity, cognitive stimulation such as using screens, reading, undertaking learning activities should be gradually introduced after 48 hours.

REHABILITATION

Throughout the rehabilitation process, consideration of age, para or able-bodied categorisation, sex, cultural and linguistic background and level of sport is required for each individual athlete to ensure optimal recovery.

As noted above, most concussion cases will follow a relatively uncomplicated rehabilitation and return to life and sport with minimal, if any, intervention being required. However, 20-30% of athletes experience complex symptomology involving multiple domains which can include:

- greater severity of symptoms,
- longer time to symptom resolution and recovery, and
- persistent symptoms. [79, 83]

All affected domains need to be addressed to achieve complete resolution of symptoms and a successful return to life and sport. [126]

Submaximal aerobic exercises have been shown to lower symptom scores following a concussion, however, may not have any effect on recovery times. [79, 126, 127] Individuals with a concussion, particularly those with persistent symptoms, may benefit from tailored multimodal interventions for a faster return to sport. [128] Management of rehabilitation is therefore best undertaken by a CMT, where experts in each area assist in the rehabilitation of specific impairments.

It is recommended that a return to all aspects of life approach is used when rehabilitating an athlete post-concussion. This ensures that the five domains i.e., physical, cognitive, emotional, fatigue and sleep are targeted appropriately (Figure 6), as illustrated in Appendix A Physiotherapy guided rehabilitation of concussion.

Vestibular and oculomotor impairments

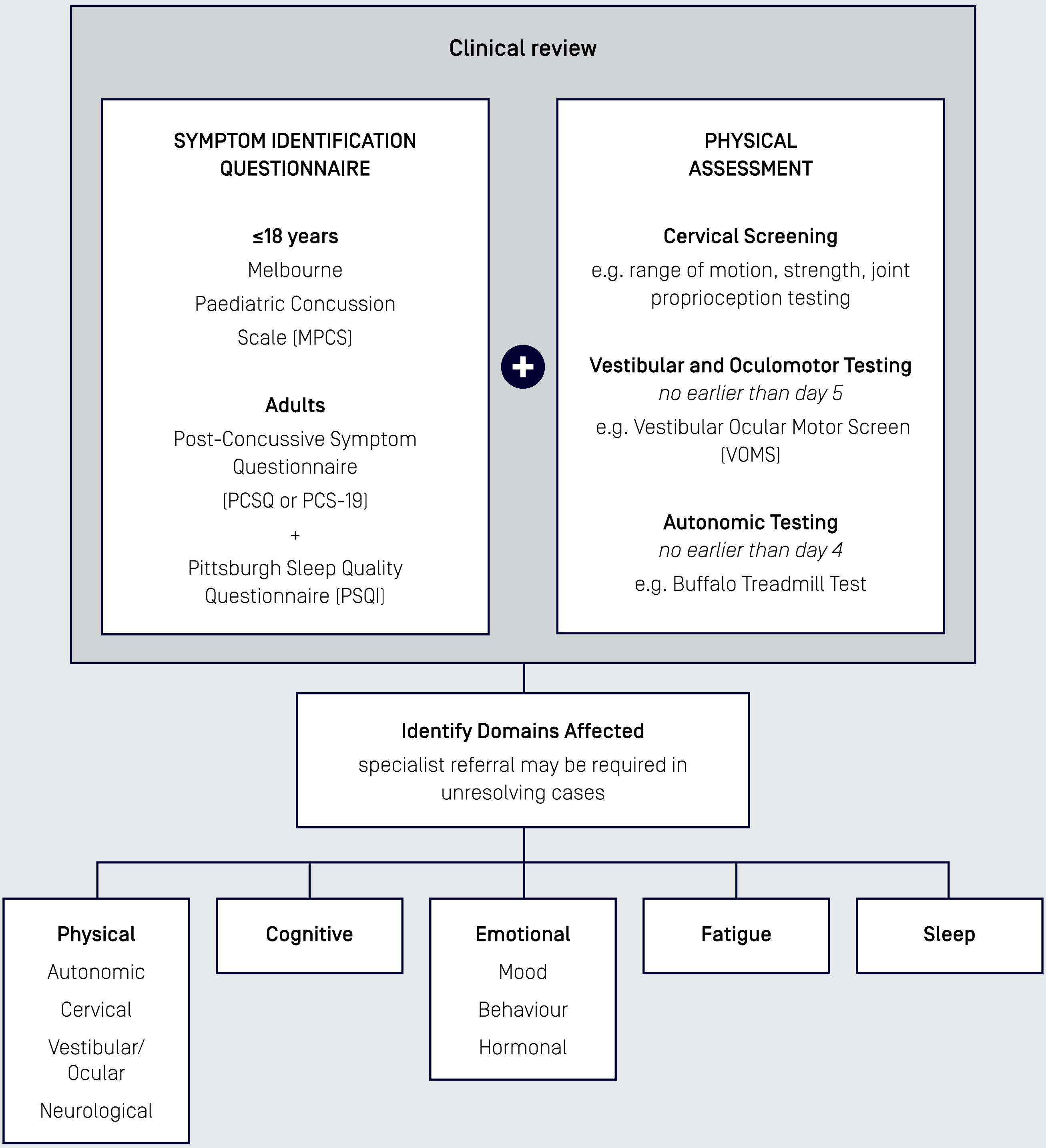
In addition to the SCAT5, there are evidence-based tools that can assist the CMT (e.g., physiotherapists or medical practitioners) to identify impairments. Tools such as the BESS (the modified-BESS is a component of the SCAT5), [88, 89, 129-131] Near Point of Convergence (NPC) [129, 131, 132] and VOMS [86, 87, 129, 132-140] can be used to identify VOM impairments in athletes' post-concussion. [130, 131, 135, 138, 141, 142] None of these tools can or should replace clinical judgement when reviewing a concussed athlete. They may however help guide the CMT in the rehabilitation of athletes' post-concussion.

Correct identification of clinical impairments post-concussion can help guide which member of the CMT is best equipped to support rehabilitation. [83] Clinical guidelines for further review post-concussion (Figure 6), can be a useful tool to guide the clinical review process.

The combination of validated symptom questionnaires and clinical tools assessing physical impairments (Figure 6) can guide management and referral onto appropriate practitioners within the CMT. [82, 83, 136] Various symptom identification questionnaires have been developed for adult populations including the Post-concussive Symptom Questionnaire (PCSQ) and its shorter form the PCS-19. [143] The Melbourne Paediatric Concussion Scale (MPCS) is the first questionnaire developed and validated specifically for paediatric populations. The MPCS combines the 21-item Post Concussion Symptom Inventory (PCSI) with 10 expert agreed-upon clinical questions. [83]

Figure 6: Clinical guidelines for further review post-concussion

Initiation of a graded return to sport (GRTS) is recommended following a concussion. Prolonged or severe exacerbation of symptoms that do not return to baseline for the concussed individual can result in failure to progress through the GRTS. In these situations or if vestibular and oculomotor (VOM) impairments are suspected clinical review with an appropriately trained physiotherapist as part of the clinical management team (CMT) is recommended. Below is a guide for physiotherapists and medical practitioners involving specific assessment of cervical, VOM and autonomic systems. Physical assessment and symptom identification questionnaires can be helpful to identify affected symptom domains, guide rehabilitation and ensure complete recovery post-concussion.



RETURN TO SPORT

A collaborative multidisciplinary approach to concussion management with shared decision making is encouraged. However, the final return to sport decision should be made by an appropriately qualified medical professional, such as a team physician.

As knowledge of concussion management improves, more sporting organisations are opting for longer stand down periods, before return to contact or collision activities is permitted. The updated graded return to sport framework (GRTSF) (Figure 7) assists practitioners to guide athletes through the recovery process and return to sport.

The AIS return to sport protocol includes;

- Introduction of light exercise after an initial 24-48 hours of relative rest
- Several checkpoints to be cleared prior to progression
- Involvement of the CMT for identification and review of complex cases
- Consideration of all domains throughout the recovery process.

Reintroduction of daily activities is appropriate if the activities do not severely exacerbate symptoms following the initial 24-48 hour period of rest. [123, 124] Early resumption of activities of daily living is associated with improved symptom resolution and shorter recovery time. [79, 124]

After the initial period of relative rest, graded return to school and/or work is advised. Concussion is an evolving injury and symptoms can change over time in one or more domains. All affected domains may not be evident during the early stages of the graded return. Care should be taken when returning to activities that involve multiple domains, such as school or work, with dosage and environment considered. [79, 84]

Recent studies encourage initiation of low-intensity exercise 24-48hours post-concussion irrespective of the presence of low-level symptoms. [4, 129, 144] Mild exacerbation of symptoms may occur during progression through the GRTSF. This is acceptable as long as the exacerbations are temporary, that is, the symptoms return to baseline before the next exercise session. [145] If there is moderate or severe exacerbation of symptoms or symptoms persist until the next scheduled bout of activity (considered prolonged symptoms) then CMT review is recommended. [145] Earlier clinical review may be warranted if VOM dysfunction is suspected. Reviewing the athlete allows symptom domains that may be affected to be identified and appropriate intervention to be implemented.

The "clinical guidelines for further review post-concussion" (Figure 6) outlines evidence-based assessment tools that can be used by the CMT to guide athlete management and rehabilitation. No single assessment tool exists for the diagnosis of concussion nor for the identification of symptom domains affected. Thus, clinical judgement of the CMT is vital in the rehabilitation and return to sport process.

Several checkpoints need to be passed prior to the athlete returning to sport post-concussion. These checkpoints combine subjective and objective findings and provide opportunity for the CMT to make decisions on the status of a recovering athlete. Key insights can also be gained on recovery status from coaches, parents, members of the athletes' close network as well as from the recovering athlete. Education of both athlete and their support network is crucial as part of this rehabilitation and graduated return to sport process.

Children and adolescents, take longer to recover from concussion than adults. [119] A more conservative approach should be taken with those aged 18 years or younger. *The GRTSF requires those aged 18 or under to be symptom free for 14 days prior to medical clearance to return to contact or high-risk activity.* To be clear, that is *not* 14 days *from the time of concussion*. It is *14 days from when the athlete becomes symptom-free*. This recommendation allows for the individual case variability in symptom duration. It ensures that the most vulnerable individuals have demonstrated a clear capacity to perform all normal activities of daily living, including non-contact exercise, without symptoms, before they return to the field of play.

Figure 7: Graded return to sport framework (GRTSF)

Following a suspected concussive episode a graded return to sport framework (GRTSF) should be initiated after appropriate removal from play has occurred. After a period of 24 hours of relative rest, resumption of daily activities can begin. Each stage, highlighted in orange or green below, should be at least 24 hours and symptoms should return to baseline prior to commencing the next activity or stage. If symptoms do not return to baseline and are prolonged or severely exacerbated, further testing may be warranted. In these situations review by a member of the clinical management team, ideally a physiotherapist or doctor, is recommended.

Incident
Day = 0

Recognise, remove from play, rest for 24-48 hours. No contact. Avoid training environment temporarily.

Diagnosis of concussion

Resumption of activities of daily living
[Mild temporary symptoms are acceptable]

Light aerobic exercise
Start graded return to school or work [Consider modifying days/hours or environment, e.g. working from home, social exposures with school recess or lunch]

Stationary sport-specific skills with minimal head movements
[e.g. partner passing drills from front on only]

Moderate walk or stationary bike
[moderate = breathing heavily, but able to maintain a short conversation]

Introduction of sport-specific skills involving head movements
[e.g. partner passing drills with directional changes, rotations or whilst walking or jogging]

CHECKPOINT 1
No earlier than day 6 post-concussion
Can athlete complete 1-minute of sport-specific skills with head movement without ANY symptoms?

Add resistance training

Increase cardiovascular activities up to 80% HRmax
Initiate sport-specific training drills

Increase sport-specific training drills, up to 90% HRmax

Return to full capacity of school or work
Up to 90% HRmax
Up to 90% of full training
[NO CONTACT OR HIGH-RISK ACTIVITY]

CHECKPOINT 2
When symptom-free for at least 14 days for ≤18 years and 10 days for ≥ 19 years
Have you remained concussion symptom-free? Y N
Do you get symptoms during or after activity? N Y
Is skill-level below what is expected? N Y
Do you simply "not feel right"? N Y

CHECKPOINT 3
Medical review for clearance to return to contact and high-risk activities

Return to full contact training

Return to competition simulation

Return to competition

NO CONTACT OR HIGH-RISK ACTIVITIES

Persistent symptoms or deterioration of symptoms at any stage
REFER TO CLINICAL MANAGEMENT TEAM FOR REVIEW

EMERGING TOOLS FOR CONCUSSION DIAGNOSIS

Emerging tools

Detecting a concussion in routine brain imaging is difficult as it is predominantly considered a functional neurological disturbance rather than a structural injury. Currently, there is a growing interest in Point of Care (PoC) devices that use biomarkers to provide an objective assessment tool to assist with concussion diagnosis and clinical decision-making. For instance, in a prospective observational study of 1,028 male professional players, salivary small non-coding RNAs (sncRNAs) were identified as unique signatures of concussion. [146, 147] There is also research underway to explore the potential clinical utility of blood biomarkers as an objective PoC to diagnose concussion. [99, 148-151]

Although, imaging modalities may be useful in research settings to detect changes consistent with concussion, current evidence does not support the clinical use of these modalities to diagnose or manage concussion.

Given the rapid technical advancements, prudent use of technological advances may improve the accuracy of concussion assessment. However, caution needs to be exercised when using such tools and validation is required before their global adaptation. At present, the evidence base is insufficient to recommend the routine use of any medical imaging or biomarker tests in the diagnosis and management of concussion.

Vestibular and oculomotor assessment

Technologies such as eye tracking devices, neurocognitive tablet applications (i.e., Apps), and other sensory organisation testing devices may have a role in VOM assessment. Access to such tools may vary however, and there is limited evidence for clinical utility in athletic populations. Furthermore, due to the limited accessibility to specialist equipment, many studies are conducted with small sample sizes which can limit applicability of findings in the general population. Ongoing research in this area is required to achieve greater validity and reliability of these tools to be used in the diagnosis and management of concussion.

GUIDELINES FOR SPORTS ORGANISATIONS

The AIS seeks to guide, but not instruct sports on a range of policy positions, including the recognition and management of RHT, concussion and long-term brain health. This document (i.e., ***CBHPS23***) provides recommendations that sporting organisations can utilise and modify to suit their unique sporting environment.

Many sport organisations in Australia however have aligned their concussion policies with the principles of the AIS guidance documents. All sport organisations within the participation pyramid, from grassroots sport to high performance sport, can utilise this position statement to inform their approach to concussion and long-term brain health. Sports with significant resource capacity, particularly professional sports, may have their own policies in relation to concussion and long-term brain health suitable for their unique environment.

OTHER CONCUSSION RESOURCES

The AIS provides subsidised access to a web-based cognitive assessment tool, for National Institute Network partners, National Sporting Organisations (NSO), and National Sporting Organisations for People with Disability (NSOD) partners. This facilitates a high degree of standardisation and consistency in assessing cognitive function in athletes affected by concussion.

It should be noted that the current web-based cognitive assessment tool maybe updated in the near future and once a new version becomes available, the link above will be updated accordingly.

CONCUSSION AND LONG-TERM BRAIN HEALTH

There is concern about potential long-term consequences of concussion or RHT resulting from ongoing participation in contact, collision, and combat sports. [152-154] There is an association between a history of exposure to RHT and cognitive deficits later in life. [155] There are a growing number of cases of individuals who are posthumously diagnosed with Chronic Traumatic Encephalopathy Neuropathological Change (CTE-NC), following a sporting career involving RHT. [156] *"A challenge of evaluating the long-term consequences of repetitive head impacts is that the outcomes are chronic, but the exposures are acute and, in this setting, remote. Each impact is of short duration, can be ambiguous, and rarely quantified."* [155] It should also be noted that in the 80's, 90's and early 2000s, it was common for athletes to return to play on the same day of the concussion, or to not be removed from play following a concussion. For the past decade, regulations regarding stand down times following concussion have evolved in most sports.

CTE-NC is defined by the accumulation of hyperphosphorylated tau (p-tau) in neuronal cell bodies and processes, located around small blood vessels, at the depths of cortical sulci. [157] As with many neurodegenerative conditions, there is an imperfect correspondence between neuropathology and clinical phenotype. [156] The term CTE-NC has more recently been adopted to distinguish the neuropathology from associated clinical symptoms (referred to as Traumatic Encephalopathy Syndrome, TES). CTE-NC can only be confirmed post-mortem, based on histopathological examination of brain tissue at autopsy. [155, 158] In 2021 researchers published the following;

i. a revised consensus criteria for classifying the neuropathology of CTE-NC [157] and

ii. the first-ever consensus criteria for diagnosing TES, the clinical condition believed to be caused by repetitive mild neurotrauma. [159]

While CTE-NC is a neurodegenerative pathology associated with a history of RHT, there currently is a lack of high quality evidence indicating the *degree of association* between RHT, concussion in contact and collision sport with CTE-NC, a condition with broad clinical diagnostic criteria (i.e., TES). [152] Some studies suggest a 'dose effect' of repeated concussions increasing the risk of CTE-NC. [160, 161] The evidence linking RHT and concussion with CTE-NC consists of case reports, case series, and retrospective and post-mortem analyses. Due to the study design, and the reliance on retired athletes volunteering for an autopsy diagnosis, there is significant selection bias in many of the reports. [153, 162] The research data on CTE-NC is almost universally obtained from sport brain bank studies. Those who donate their brain for these studies almost universally have pre-existing clinical symptoms of degenerative brain disease. The brain donations are made in good faith but the skewed representation makes it difficult to apply the findings to the general population. [153] The clinical data obtained from sport brain bank studies has also largely relied on retrospective interviews with athletes and athlete-relatives for information such as playing time, RHT and exposure, symptom patterns, mental health issues and substance abuse. Recall bias is highly likely to affect the reliability of such information, as is the case with research into other forms of degenerative brain disease. [152] Retrospective clinical analysis is insufficient for creating robust clinical diagnostic criteria for CTE-NC in living patients. [162] CTE-NC is not an inevitable consequence of RHT. [163] Studies to date have not adequately controlled for the potential contribution of confounding variables such as alcohol abuse, drug abuse, personality factors, genetic predisposition, education exposure, family history of mental health and neurological problems. [152]

A recent study used the Bradford Hill criteria to review the evidence for the link between RHT, concussion and CTE-NC. [164] The authors concluded that *"we found convincing evidence of a causal relationship between RHI and CTE, as well as an absence of evidence-based alternative explanations."* [164] It should be noted however that Sir Austin Bradford Hill CBE FRS himself emphasised that this method of analysis does not remove the requirement to differentiate between correlation and causation. [165, 166]

A large scale study of 636 cases of community-based cohort of ageing and neurodegeneration from the Sydney Brain Bank collection, CTE-NC was identified in five cases (prevalence 0.8%). Three of the five cases with CTE-NC had a history of traumatic brain injury and two cases had no known history of neurotrauma (including repetitive head impacts from sports). [167] Low prevalence of CTE-NC is further corroborated from similar sample of 532 cases from the United States and 323 cases from Europe, where CTE-NC was 0.6% [168] and 0%. [169] This low prevalence of CTE-NC in the general community highlights the need for further well-structured longitudinal studies exploring the strength of the link between RHT, concussion, and CTE-NC.

The fundamental concern regarding CTE-NC is that individuals who have participated in contact and collision sports have experienced damage to the microstructure of their brains, through repetitive neurotrauma, [170] which places them at future risk for accelerated brain aging, and neurodegenerative diseases - including mild cognitive impairment, Parkinson's disease, amyotrophic lateral sclerosis, CTE-NC, and Alzheimer's disease. [171] With respect to cognitive changes, a combination of factors such as frequency of RHT and/or concussion, severity, timeframe, age, and sex might predict cognitive changes better than frequency of RHT/concussion alone. [117, 172] The degree of cognitive reserve or brain reserve has been shown to protect against brain injury or disease. [173-175] For example, when an individual is completing a task with increased difficulty, cognitive reserve mediates the establishment of efficient neural networks (i.e., recruiting new and/or less injured networks) to complete the task. [173, 175]

Recent descriptions of the clinical features of TES has proposed "neurobehavioral dysregulation" (e.g., 'poor regulation or control of emotions and/or behavior, including (but not limited to) explosiveness, impulsivity, rage, violent outbursts, having a short fuse or emotional lability (often reported as mood swings) [159] Cognitive impairment, typically affecting memory and executive function has been proposed to emerge later, [159, 176, 177] and has been described as being 'progressive'. [159, 176, 177] Studies reporting evidence of an association between elite male sport participation and long-term cognitive, psychiatric, and neurobehavioural problems [178, 179] invite the hypothesis that such neuropsychiatric features might reflect the early manifestations of CTE-NC.

A number of studies indicate that elite athletes enjoy greater longevity. [32, 180, 181] The death rates of 9,932 current and retired elite male Australian football players was 21 % lower than the death rates of aged-matched males in the general population. [182] Similarly, a large-scale retrospective epidemiological study of 3,439 retired male National Football League players (played from 1959 to 1988) reported lower risk for suicide compared to men in the general population. [183] In contrast, another study reported a disproportionate number of suicides over the period from 2009 among current and former professional football players. [184] The causes of suicide are complex. The evidence to support the causal relationship between contact and collision sports, RHT and/or concussion, depression and suicide and CTE-NC is inconclusive as no data from peer-reviewed cross-sectional, epidemiological or prospective studies are available. [185, 186]

Several studies are being conducted around the world investigating the brain health of former collision sports athletes. In Australia, the *Former Elite Level Athlete Brain Health Research Program*, is a prospective, longitudinal clinicopathological study, that was established in 2012 to investigate many variables that affect brain health and aging, in order to evaluate the extent to which modifiable risk factors may contribute to the risk of poor health outcomes. This research program includes elite level former rugby league and rugby union players and comparison groups that consist of age- and education-matched healthy community-based control participants without a history of neurotrauma or contact sport participation and former Australian able-bodied Olympians from non-contact, collision, or combat sports (for example, swimmers, rowers, and track and field athletes). The evaluation includes a number of self-report health questionnaires, a clinical interview, an in-person evaluation (including cognitive testing and brain MRI), and a brain donor program. To date, preliminary data published from this research program has revealed no significant differences between groups (former players vs control groups) on measures of depression, anxiety, or cognitive functioning. [187] Within the player group, smaller subcortical volumes were significantly associated with greater alcohol consumption. Alcohol Use Disorders Identification Test (AUDIT) score was higher in former rugby players compared to controls. [188, 189] Extending earlier findings from this cohort, a group of 141 former rugby league players (median age = 52.6 years (13.8), range = 30-89 years) who played professional sports for a median of 8 years playing (interquartile range (IQR) 3.5-11) reported a median of 15 lifetime concussions (IQR 6-30). [190] 29% of former rugby players included in the study reported at least mild current depression. Depression, Anxiety, and Stress Scale (DASS) scores were not significantly correlated with lifetime concussions. Multiple regression analysis revealed that 35% of the variance in DASS depression was accounted for by 'age, concussion history, years played professionally, the CD-RISC, Brief Pain Inventory-pain interference score, and Epworth Sleepiness Scale score. [190] No relationship was found between objective cognitive test performance and perceived cognitive decline in 135 retired players (mean age 53.1 years (13.9), range 30-89 years). Depressive symptoms were the strongest predictor of perceived cognitive decline. [191] No significant difference in the size of the brain ventricles was observed between 41 retired players and 41 controls. Further, there were no significant differences between those with and without an abnormal cavum septum pellucidum and age of first exposure to rugby league, the number of lifetime concussions, years of exposure to repetitive neurotrauma, perceived cognitive decline, cognitive decline on any neuropsychological test, depression, or impulsivity. [192]

These findings should be interpreted with consideration for the representativeness of the sample, the sample size, the generational/era differences of the study participants (i.e., the game play of the sport, the physical demands of the sport, the professionalism and training commitments, and injury management differ greatly across generations), self-selection of ‘super controls,’ that may not reflect the population base rates of condition/disease/illness, and the role of comorbidities and/or confounding variables (e.g. acting as moderators, mediators of various health outcomes).

Long-term brain health in female athletes

Many sports have recently established professional female leagues, providing female athletes with a pathway into elite sports, including contact and collision sports. With this growth in female sports, there is a need to evaluate the long-term brain health in female contact and collision sport athletes. Currently, there is a lack of research on how the female brain responds to concussion. There is also a lack of research investigating the long-term brain health of female athletes. In the general population, compared to men of the same age the incidence of dementia (85 years) and Alzheimer’s disease (80 years) is greater in women. [193] Female axons are at greater risk of axonal damage during trauma which may trigger Amyloid-β peptide production and the accumulation of amyloid pathology, a core pathological feature of Alzheimer’s disease. [194] Although the reasons are unclear, the prevalence of autoimmune disorders amongst women is greater, occurring at a rate of 2 to 1. [195] The Amyloid-β peptide plaques that cause Alzheimer’s disease, are an innate immune protein activated as part of the brain’s immune system to fight infections. [196] The female immune system response is stronger compared to males [197] and females may therefore have more Amyloid-β peptides, which may increase their risk of Alzheimer’s disease. The role of biological differences in women, and any associated effect on predisposition to TES, CTE-NC or other neurodegenerative diseases, remains unclear.

Long-term brain health in para athletes/athletes with disabilities

It is important to consider the unique environments that para-athletes navigate. To date there are no reports in the medical or scientific literature on the long term brain health of para athletes exposed to RHT and/or concussion. Assessment of brain health changes in athletes with a disability presents a unique challenge because of the various para-classifications (e.g., athletes with neurological conditions, learning disorders, and/or intellectual disability).

QUESTIONS TO BE ANSWERED IN IMPROVING UNDERSTANDING OF CONCUSSION AND LONG-TERM BRAIN HEALTH

Knowledge regarding the effects of RHT and concussion continues to evolve. Many questions however, remain unanswered. Well-structured scientific investigations are needed to address knowledge gaps. The AIS encourage co-design research models incorporating athlete voices and voices of under represented communities. Future research should be targeted to answer the following questions;

- What is the prevalence of CTE-NC in female, male, and para-sport athletes?
- What is the strength of the association between RHT, concussion, and development of CTE-NC?
- What is the strength of association between histopathological changes of CTE-NC and the clinical syndrome of TES?
- Which athletes are susceptible to development of CTE-NC, and why?
- What role do modifying factors play in susceptibility to the development of CTE-NC?
- What is the natural history of CTE-NC? Is it an inexorably progressive disease, similar to neurodegenerative diseases such as Alzheimer's disease?
- Are female athletes more susceptible to CTE-NC than males, for a set dose of RHT exposure?
- Are para-athletes more susceptible to CTE-NC than able-bodied athletes, for a set dose of RHT exposure?
- Are specific cultural cohorts more susceptible to CTE-NC than athletes from Anglo-Saxon background, for a set dose of RHT exposure?
- What is the sex based differences in risk of and clinical picture of RHT and concussion in sport?
- What is the prevalence of RHT and concussion in First Nations Communities and culturally and linguistically diverse populations?
- What changes can be made to better capture nationwide data on RHT and concussion in sport?
- What sport-specific measures are efficacious in preventing RHT and concussion?
- What is the impact of RHT and concussion on developing brains of youth athletes and the long term impact?
- What is the long term mental and physical health in those exposed to RHT and concussion?
- What is the effect of more conservative return to sport protocols on the acute and long term sequalae of concussion?
- What are the most effective therapeutic interventions for recovery from episodes of concussion?
- What rule/regulation modifications could be effective in reducing incidence of RHT in individual sports?

These unanswered questions present an enormous challenge to the medical and scientific community. Prospective, longitudinal clinicopathological studies can help identify possible early clinical features, progression (if CTE-NC is a progressive disorder), and potentially help with interventions.

RISK REDUCTION/PREVENTION

All sporting organisations have a duty of care to ensure that their sport is conducted in the safest manner possible. Risk of injury, including concussion, is inherent in many sports, including but not limited to snow sports, cycling, equestrian, contact, collision, and combat sports. It is not possible to remove all risk from sport. Prevention of RHT in sport is challenging. The main pathways to reduce RHT incidents are via changes to rules/regulations within sport and by modification to training methods to decrease the likelihood of head trauma. Changes to rules and regulations within a particular sport should be based upon analysis of head trauma risk within the sport and evidence supporting the hypothesis that the rule/regulation changes will decrease risk of head trauma. Evidence-based RHT and concussion prevention programs need to be developed, to reduce modifiable risk factors, followed by their implementation in real world settings.

Personal protection equipment (PPE) such as helmets, soft-shell headgear and mouthguards have not been shown to prevent concussion, in studies to date. [198-201] PPE can reduce other injuries such as lacerations, skull fractures and dental trauma. PPE research continues investigating the use of novel materials but at this stage PPE cannot be recommended for the purpose of preventing concussion.

Several studies have raised the possibility that neck muscle strength is a modifiable factor that influences risk of concussion. [202, 203] The evidence regarding the relationship between neck strength and concussion risk is inconsistent but a majority of studies suggest that greater neck strength is protective. [204] Optimising neck strength in those participating in combat, contact and collision sports is a reasonable strategy in concussion prevention.

Beyond prevention, the best way to protect athletes against acute and long-term effects of concussion is to ensure that every concussion is treated seriously and that concussed athletes are removed from the field of play and are not return to sport prematurely. Over the past two decades, regulations regarding stand down times following concussion have evolved in most sports. In the early 2000s, it was common for athletes to return to play on the same day of the concussion. For the past decade, most sports have had post-concussion stand down times of at least 6 days, and longer in children. Recently there has been a move by several sport bodies, including the AIS, to increase stand down times to at least 12 days. The effects of these evolving regulations on acute and chronic sequelae to concussion, will take years if not decades to be realised. It is important that research continues into the acute and chronic sequelae of RHT and concussion. This ***CBHPS23*** operates on a principle of an 'abundance of caution'. Where there is any suspicion of concussion, an athlete should be removed from the field of play and should not be allowed to return, until cleared to do so by a medical practitioner ('***if in doubt, sit them out***').

EDUCATION

General awareness and knowledge about concussion, although improved over recent years with the availability of guidelines and educational materials, remains less than optimal. [205-207] To effectively improve awareness and understanding in the community, education must be targeted at groups that are at risk of concussion. [205, 208] The Concussion in Sport Australia webpage has relevant information for each key takeholder group.

Athletes – need to have a good understanding of concussion to appreciate the importance of reporting symptoms and complying with rest and return to sport advice. [209]

Parents, coaches, and teachers – must be able to recognise symptoms and signs of concussion to improve detection at the recreation level where there is no to limited medical supervision present. [207, 210]

Sporting and medical organisations – need to continue to develop specific recommendations around concussion to inform their members/participants. However, complexity of the return to sport protocol has been highlighted as a potential barrier for community sport. [211]

One of the key aims of this ***CBHPS23*** is to take the latest information from medical and scientific journals, synthesise the information into an easily digestible format and make the information available to all Australians involved in sport or who have an interest in RHT and/or concussion.

Key points for athletes, coaches, parents, teachers, and support staff

- Concussion is a type of brain injury that occurs from a knock to the head or body.
- Recognising concussion is critical to ensure appropriate management and prevention of further injury.
- The Concussion Recognition Tool 5 (CRT5) is recommended to help recognise the signs and symptoms of concussion. CRT5 can be downloaded here
- First aid principles apply in the management of an athlete with suspected concussion. This includes observing first aid principles for protection of the cervical spine.
- Any athlete suspected of having concussion should be removed from sport and not allowed to return to sport until cleared by a medical practitioner.
- Features that suggest more serious injury and prompt immediate emergency department referral include neck pain, increased confusion, agitation or irritability, repeated vomiting, seizure, weakness or tingling/burning in the arms or legs, reduced level of consciousness, severe or increasing headache, or unusual behaviour.
- There is no single test that can determine whether someone has sustained a concussion.
- When assessing a patient with suspected concussion, a medical practitioner will ask about details of the event, past medical history, then assess the patient. This can include asking about symptoms, signs, testing memory function and concentration, balance, and neurological function.
- Once diagnosis of concussion has been confirmed, initial treatment for concussion is relative rest. After 24–48 hours of rest, light intensity physical activity is indicated, that does not cause a significant and sustained deterioration in symptoms.
- An active recovery following the Graded Return to Sport Framework (GRTSF) should proceed after the initial period of relative rest. Each stage outlined requires a minimum of 24 hours and progression should not be made unless symptoms have returned to baseline for the concussed athlete.
- If symptoms are severely exacerbated or remain for a prolonged period, review by a member of the clinical management team (CMT) is recommended.
- Several checkpoints are required to be passed to progress through the GRTSF and review by a medical practitioner is required prior to return to contact or high-risk activity.
- Some athletes exposed to RHT develop CTE-NC. The factors that influence susceptibility to CTE-NC remain poorly understood.
- ***If in doubt, sit them out***.

Key points for clinical practitioners

- The diagnosis of concussion can be difficult. The signs and symptoms can be varied, non-specific and subtle. Athletes with suspected concussion should be removed from sport and assessed by a member of the clinical management team (CMT).
- When assessing acute concussions, a standard initial assessment and management of trauma patient should be followed to ascertain whether there is any suggestion of neck or intracranial structural pathology.
- Concussion is an evolving condition. Athletes suspected of, or diagnosed with, concussion require close monitoring and repeated assessment.
- The diagnosis of concussion should be based on a clinical history and examination that includes a range of domains such as mechanism of injury, symptoms and signs, cognitive function, and neurology, including balance assessment.
- Sport Concussion Assessment Tool 5 (SCAT5) is currently the concussion assessment tool recommended internationally and covers the above-mentioned domains. It can be downloaded here. SCAT5 should not be used in isolation, but as part of the overall clinical assessment.
  It should be noted that the current SCAT5 is under review and once SCAT6 becomes available, the link above and the content will be updated accordingly.
- Computerised neurocognitive testing can be undertaken as part of the assessment but should not be used in isolation.
- Blood tests are not indicated for uncomplicated concussion. Medical imaging is not indicated unless there is suspicion of more serious head, neck, or brain injury.

- Standard head-injury advice should be given to all athletes suffering concussion and their carers.
- Once the diagnosis of concussion has been made, immediate management is relative physical and cognitive rest. This includes time off school or work and deliberate rest from cognitive activity for 24–48 hours. After this period, the patient can return to light intensity physical activity that does not cause a significant and sustained deterioration in symptoms.
- Children and adolescents take longer to recover from concussion. A more conservative approach should be taken with those aged 18 or younger. The Graded Return to Sport Framework (GRTSF) requires **for those aged 18 and under, *there must be a period of 14 days where the athlete is symptom-free*** (i.e., is *not* 14 days *from the time of concussion*), before return to contact activities can be considered.
- Some sports have their own guidelines or recommendations around the management of concussion in sport which should also be considered.
- ***If in doubt, sit them out***. *The athlete should not be return to sport until cleared to do so by a medical practitioner.*
- Where an athlete has had multiple concussions, the medical practitioner will counsel the athlete regarding the dangers of RHT, the potential long-term effects of RHT and the need for the athlete to think carefully about their continued involvement in high risk sports, including contact and collision sports.
- Some athletes that have been exposed to RHT may develop CTE-NC. The evidence regarding the association between RHT and CTE-CE consists of case reports, case series and retrospective analyses. The ***degree of association*** between RHT and development of CTE-NC is unknown. The reliance on retired athletes nominating to posthumously undergo autopsy for this research generates significant bias in the samples examined. Confounding factors such as alcohol abuse, drug abuse, genetic predisposition, education exposure and psychiatric illness have not been controlled for adequately in studies conducted to date. Well-designed prospective studies are needed to better understand the possible relationship between RHT, concussion, and long term brain health.

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APPENDIX A: PHYSIOTHERAPY GUIDED REHABILITATION OF CONCUSSION

The following table outlines the five systems that should be considered when designing a rehabilitation plan for an athlete recovering from concussion and is based on the graded return to sport framework (GRTSF). These systems are closely interconnected; care must be taken to avoid over stimulation, particularly early in the GRTSF. The requirements for each sport and individual athlete will differ as will the symptoms associated with each concussive episode so the following table should merely act as an example. Some considerations are included at each stage that can challenge/be useful for practitioners and coaches.

Autonomic	Cervical	Visual	Vestibular	Cognitive
Activities of daily living	**Full pain-free range of motion (active and passive)** Physiotherapy assessment will guide rehabilitation but can involve passive, active and active-assisted range of motion exercises	**Activities of daily living**	**Activities of daily living**	**Activities of daily living**
Steady-state exercise Up to 60% HRmax with minimal movement of head e.g. moderate walk over flat ground or stationary bike seated only	**Address referred pain and headaches** Physiotherapist-led treatment as appropriate for each individual. May include manual therapy, exercise therapy. **Deep neck flexion exercises initiated** Motor control and stability exercises can be prescribed in seated, supine or prone positions depending on individual requirements. Consider: Sport-specific positions for head/neck such as: - 4-point kneeling for rugby, cycling - prone holds with rotation for swimming, gymnastics - seated for waterpolo, artistic swimming - standing multidirectional for AFL	**Gradual resumption of school or work** e.g. depending on symptoms begin with several hours or part days at work or school Consider: Decrease work of visual system by sitting at front of class, schedule short periods at computer & avoid watching fast paced or complex visuals **Hand-eye coordination with minimal head movements** e.g. - Ball drills in front only - Steady state run at 50-60% max speed - Kickboard swim with snorkel	**Continue activities of daily living**	**Gradual resumption of school or work** See visual column for details Progressions will naturally increase as rehabilitation in other areas progresses. If complications and impairments in cognitive function are recognised during rehabilitation referral to a medical doctor is recommended for assessment. If there are known impairments in cognitive function post-concussion close communication with the managing doctor is highly recommended for an integrated management approach and best outcomes to occur

<table>
<thead>
<tr><th>Autonomic</th><th>Cervical</th><th>Visual</th><th>Vestibular</th><th>Cognitive</th></tr>
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<tbody>
<tr>
<td rowspan="2">Progress steady-state exercise

Maintain single plane of movement, e.g. straight line running, etc.

Incremental increase in heart rate up to 80% HRmax e.g. 5min increments @50%, 60%, 65%, 70% Hrmax

e.g. start with stationary seated bike or walking and progress to sport-specific mediums such as:
- Running (straight line only)
- Swimming (minimal to no rotation, no tumbling at ends of pool)
- Cycling return to road riding (bike paths or quiet roads)

<u>Consider:</u>

Concussive symptoms may be exacerbated by environments that challenge the visual or vestibular system. These can include: noise, lights, movements in athlete's visual background, team/squad training, uneven surfaces, etc.</td>
<td rowspan="2">Cervical proprioception exercises

e.g. joint position training seated with eyes open

<u>Consider:</u>

Progress difficulty with eyes closed or standing on firm and soft surfaces.

Visual backgrounds, sport-specific environments can increase complexity such as:
- Seated on exercise ball
- Eggbeater position on plinth and progressing to pool
- 4-point kneeling
- Prone</td>
<td><u>Consider:</u>

Speed, height, type of ball (if using) and predictability of activity performed. Start in quiet environment with bland visual background to avoid exacerbation of symptoms due to visual and cognitive loads</td>
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<td colspan="2">Controlled non-reactive hand-eye coordination with head movements

e.g.
- Ball drills against wall or with partner from various directions to encourage head rotations, up and downs, etc.
- Increase running pace to add greater visual input, run around track
- Swimming strokes with usual movement patterns (no tumbling)

<u>Consider:</u>

Complex visual backgrounds, busy environments such as sideline of team/squad training, crowd noises, lights can challenge visual and cognitive system but may also exacerbate symptoms</td>
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<td colspan="5">CHECKPOINT 1 - no earlier than day 6 post-concussion</td>
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Autonomic	Cervical	Visual	Vestibular	Cognitive
Continue progressing steady-state exercise (as above)	**Introduce strength training** Introduce resistance training in gym, building strength loads back to squad/ individual requirements <u>Consider:</u> Re-integration with squad/team during S&C sessions to challenge visual, vestibular, and cognitive loads as appropriate	**Continue controlled non-reactive hand-eye coordination with head movements** (as above)		See above for details
		More complex hand-eye (or foot-eye) coordination involving head and body movements e.g. - Ball drills involving 90degree rotations progressing to 360deg - Introduce small volumes of tumbling at ends of pool and diving from blocks - Starting from blocks and reacting to start signal - Shooting practice from greater distances (waterpolo, soccer, AFL, archery, shooting, basketball, etc.) <u>Consider:</u> - Volume of skills being introduced. Sport specific coordination skills, e.g. groundballs, high balls, cycling with visual input e.g. simulator and increase complexity by performing tasks in busy training environments and progressing pace of tasks.		
Interval training e.g. - increase run speeds to 90% with straight-line run-throughs, flying 60s, etc. - swimming interval sets <u>Consider:</u> Ensure time allocated between sets for recovery and any potential symptom provocation	**Continue strength training** (as above)	**Hand-eye (or foot/eye) coordination whilst moving** e.g. - walk-through ball skills such as walking dribbling, partner passing whilst walking - progress skills involving rotations, twisting, precision, e.g. gymnastics, diving, artistic swimming, archery, shooting <u>Consider:</u> Environment of activities and increase complexity with multiple balls and/or players, performing multiple skills consecutively, volume, noise, lights, etc		

Autonomic	Cervical	Visual	Vestibular	Cognitive
Agility and multi-directional activity e.g. - Incorporte planned or athlete-led directional changes into running, pool sessions - with unrestricted tumbling, progressively return to busier roads on bike <u>Consider:</u> Progress to reactionary change of directions to increase cognitive load. Use speed, volume, sport specific skills to increase challenge	**Continue strength training** (as above)	**Controlled sport-specific activities** e.g. controlled team non-contact or high-risk training activities such as: - kicking or hand-balling drills (No match simulation drills) - 5v0 drills <u>Consider:</u> Volume if all other parameters are back to full training capacity. Number of athletes, noise, external and internal stress may increase cognitive and visual load		See above for details
Build training volumes and sport-specific requirements Incremental increase to meet usual training volumes for squad/ individual <u>Consider:</u> All systems being rehabilitated simultaneously		**Reactive sport-specific activities** e.g. Uncontrolled non-contact training or physiotherapist-led reactive drills. involving: - Kick, chase, marking skills - Rebounding drills - Uncontrolled terrains <u>Consider:</u> Vary reactionary component with location, timing or skill required. Increase complexity with multiple balls and/or players, competition against teammates, noise, lights, etc		
CHECKPOINTS 2 & 3 - when symptom-free for at least 14 days for ≤18 years and 10 days for ≥ 19 years				
Full Training				
Competition or Match Simulation				
Match or Competition Play				

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