BRAIN HUB
Dizziness & Concussion Clinic

Concussion or Whiplash

Can You Tell the Difference?

Dr Carlo Rinaudo

Ph.D Chiropractor

Thank you

AUSTRALIAN CHIROPRACTORS ASSOCIATION

A Little About Me…

Dr Carlo Rinaudo / Chiropractor Neuro-Rehabilitation
BMedSci (Hons) MChiro ICSSD DACNB FIBFN-CND FAICE Ph.D

- Clinic Director of Brain Hub – *changing lives through neuroplasticity* (Sydney)
- PhD in Vestibular Rehabilitation at Neuroscience Research Australia (NeuRA) and University of New South Wales (UNSW)
- Honorary Post-Doctorate Researcher : NeuRA
- Conjoint Associate Lecturer : UNSW School of Medicine and Health
- Past Chair of NeuroRehabilitation clinical practice group : ACA (AICE)
- Lecturer in clinical neuroscience and vestibular neuro-rehabilitation

BRAIN HUB
Dizziness & Concussion Clinic

UNSW
AUSTRALIA

Neuroscience Research Australia
Discover. Conquer. Cure.

BRAIN HUB ACADEMIA
Vestibular Neuro-Rehabilitation

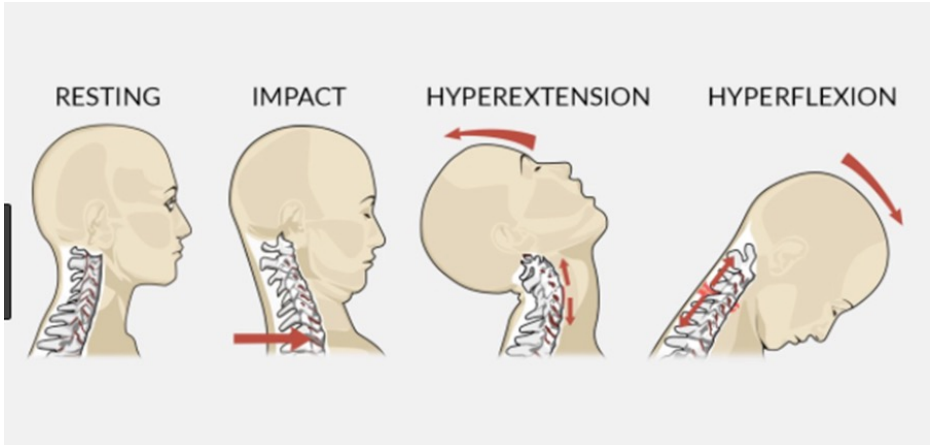
What are we covering?

- Definitions and pathophysiology between whiplash and concussion
- How to differentiate?
- Clinically relevant approach

What is Whiplash?

Defined as “an acceleration–deceleration mechanism of energy transfer to the neck. It may result from rear-end or side-impact motor vehicle collisions, but can also occur during physical injuries.

The impact may result in bony or soft-tissue injuries (whiplash-injury), which in turn may lead to a variety of clinical manifestations called Whiplash-Associated Disorders”



Gurumoorthy, Twomey. The Quebec Task Force on Whiplash-Associated Disorders. Spine. 1996 Apr 1;21(7):897-8

Quebec Task Force (QTF) classification of whiplash associated disorders.[32]

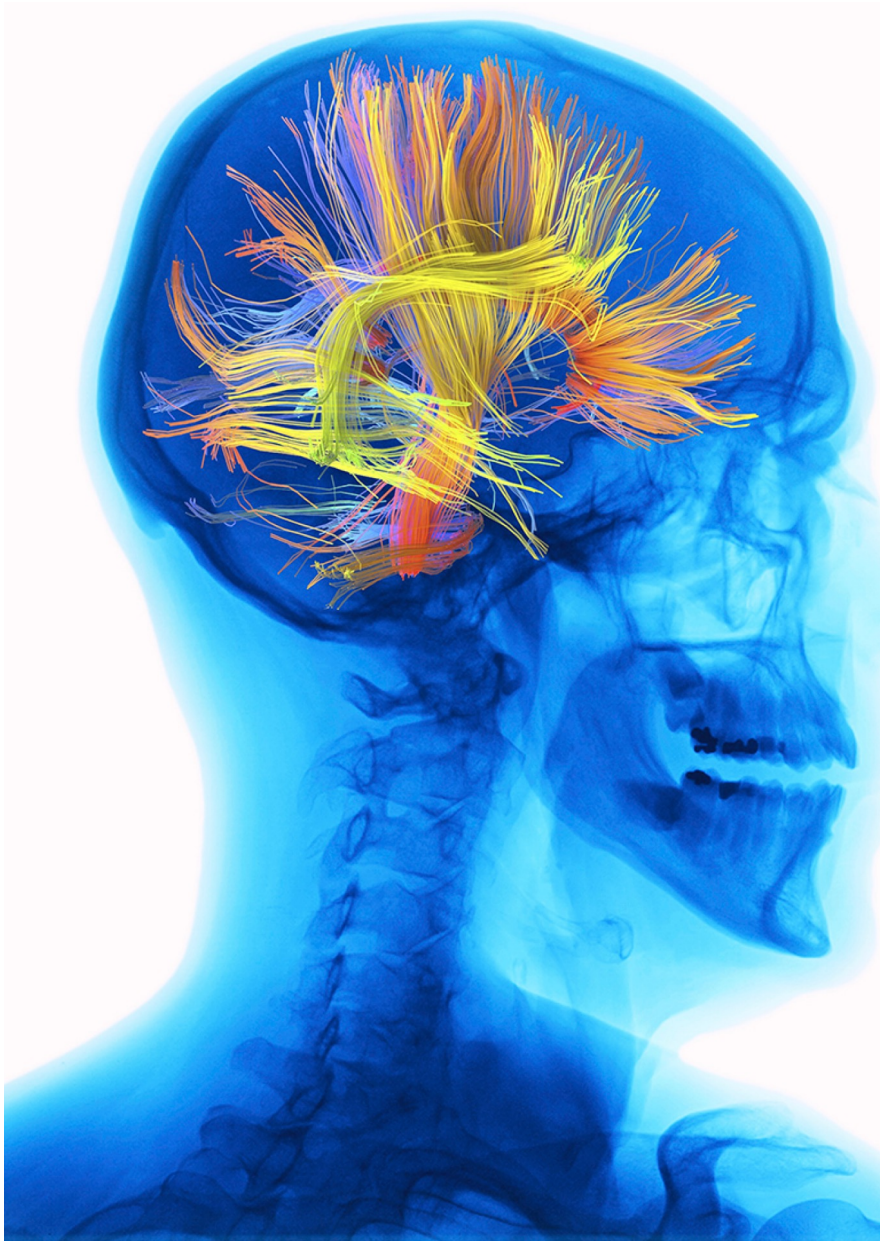
QTF classification grade	Clinical presentation
0	No complaint about neck pain No physical signs
I	Neck complaint of pain, stiffness or tenderness only No physical signs
II	Neck complaint Musculoskeletal signs including: • decreased range of movement • point tenderness
III	Neck complaint Neurological signs including: • decreased or absent deep tendon reflexes • muscle weakness • sensory deficits
IV	Neck complaint and fracture or dislocation

Gurumoorthy, Twomey, 1996

Whiplash Associated Disorder

- Whiplash-associated disorder (WAD) is the most common outcome of non-catastrophic motor vehicle collisions (MVCs).
- One in two people with WAD will develop long term neck-related disability and up to one in four will report widespread bodily pain.
- The cardinal feature of WAD remains neck pain and lack of mobility.
- Other signs/symptoms of the clinical course include motor weakness, and sensory hypersensitivity, blurred vision, headaches, dizziness and fatigue

Rebbeck et al (2019). *Concussion in Combination With Whiplash-Associated Disorder May Be Missed in Primary Care: Key Recommendations for Assessment and Management. Journal of Orthopaedic & Sports Physical Therapy, 1–41.*



What is a Concussion?

Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces, often in the absence of any structural damage and open skull injury

Concussions have also been referred to as mild traumatic brain injuries (MTBI). Concussions are a subset of MTBIs, on the less-severe end of the brain injury spectrum and are generally self-limited in duration and resolution.

Harmon et al. American Medical Society for Sports Medicine position statement: concussion in sport. Br J Sports Med. 2013 Jan;47(1):15-26.

What is a Concussion?

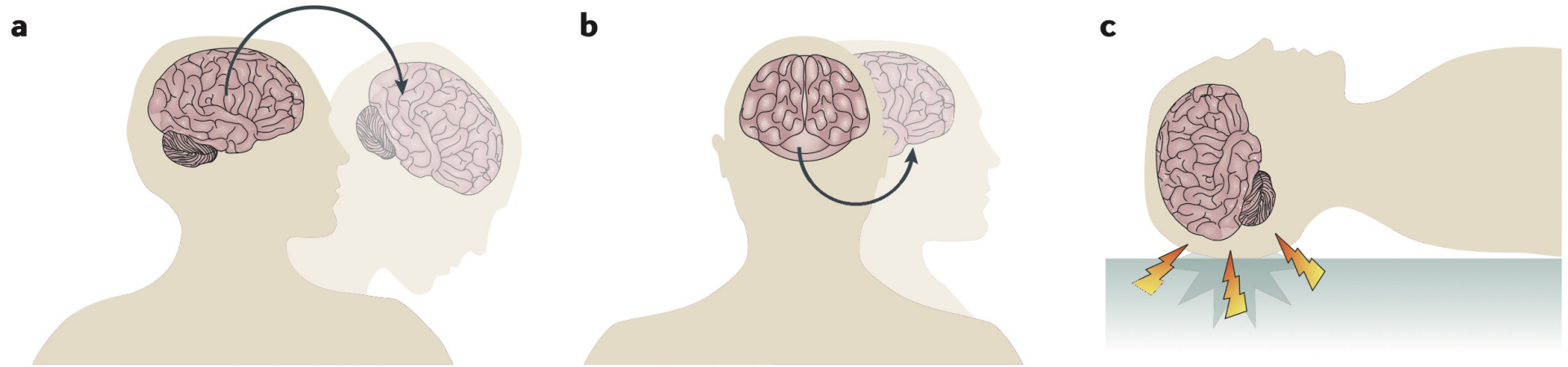
Concussion injuries, or mild traumatic brain injury (mTBI), have an estimated prevalence of 3.8 million per year in the United States and are considered one of the least understood injuries facing the sports medicine and neuroscience communities today.

In the majority of cases, concussion symptoms resolve within 7–10 days; however, ~10–15% of these patients develop persistent symptomatology lasting weeks, months or even years after injury.

Post-concussion syndrome (PCS) is defined as the persistence of three or more symptoms for 3 months (Diagnostic and Statistical Manual of Mental Disorders), following a minor head injury.

Permenter et al . Postconcussive Syndrome. 2022

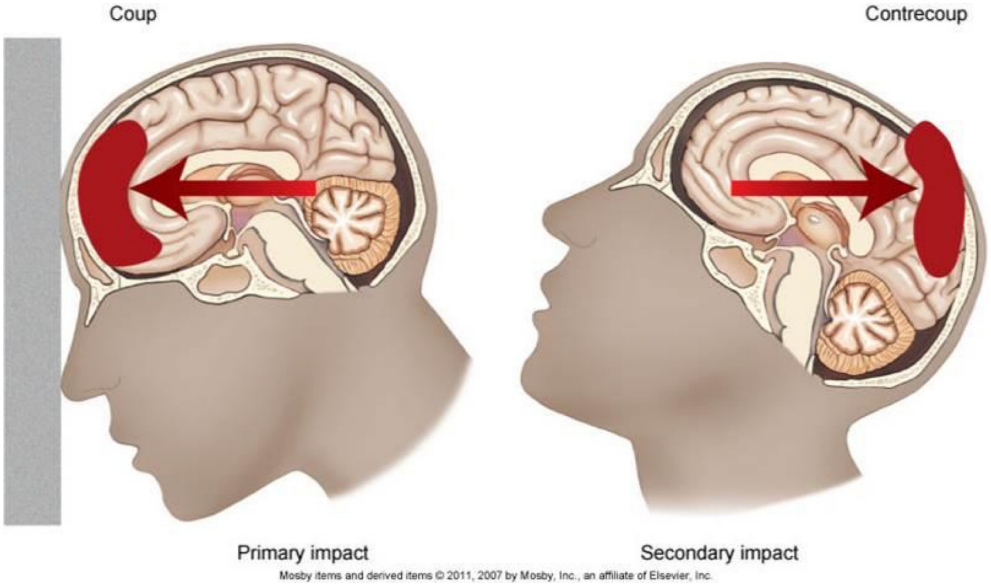
What happens to the brain during a mTBI?

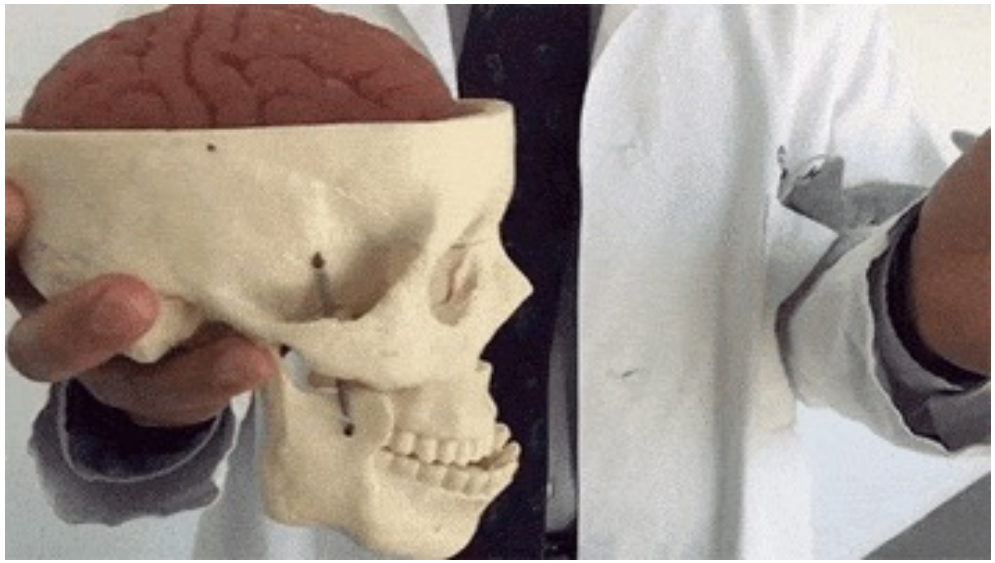


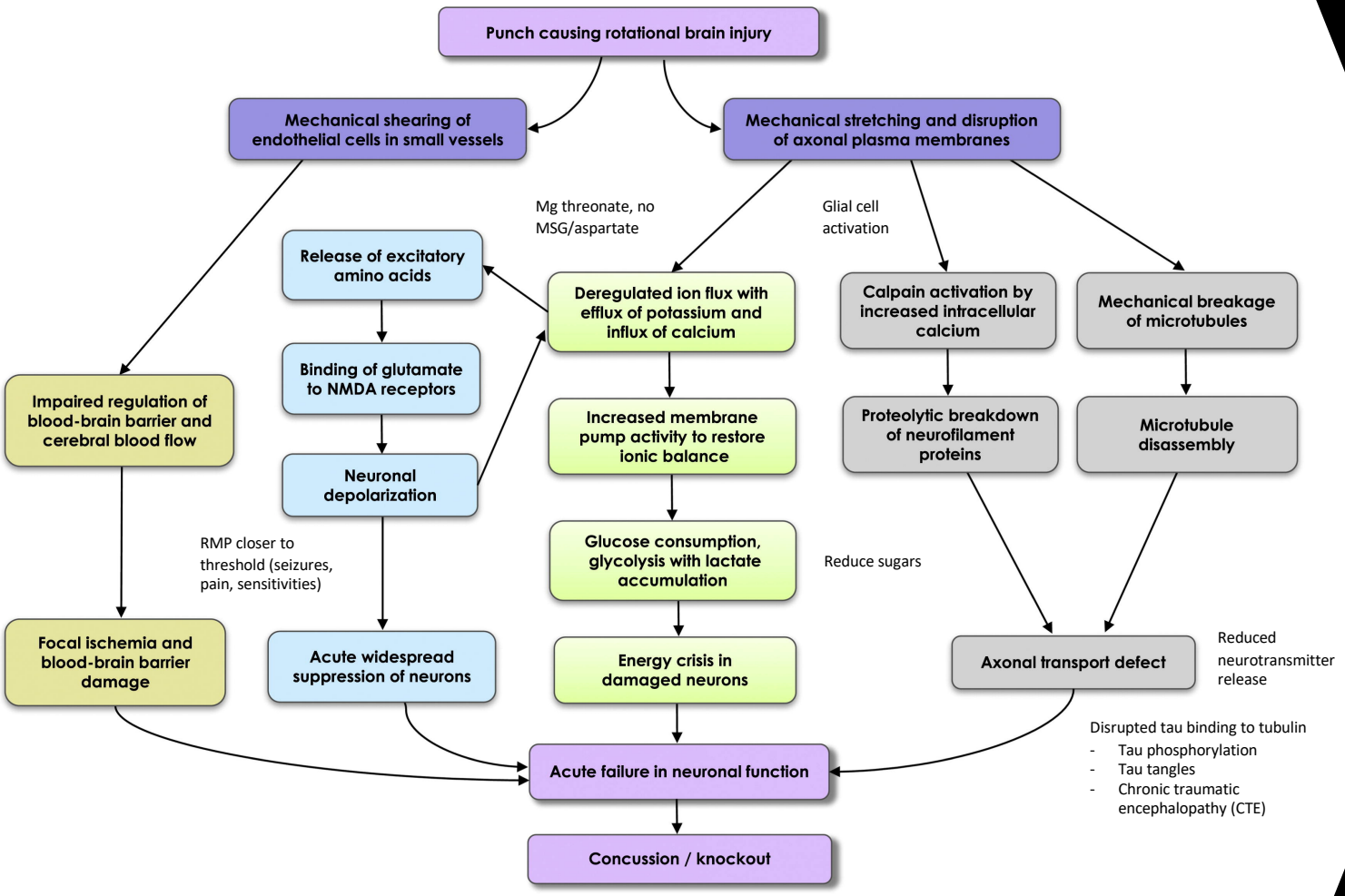
Examples of the types of forces in mild traumatic brain injury. The central mechanisms for neuronal damage in mild traumatic brain injury (TBI) are acceleration and deceleration biomechanical forces. These forces cause strain and shearing forces on axons in the brain, which result in diffuse axonal injury**. a | Linear (translational**) acceleration occurs as a result of forces that make the head move in the anterior–posterior direction (such as hitting the front or back of the head). **b | Rotational (angular) acceleration** occurs as a result of forces that make the head rotate sideways (such as a punch to one side of the head). **c | Impact deceleration** occurs when the head forcefully decelerates, for example, when the head hits the ground.

Blennow *et al* 2016

Coup / Countercoup







Neurometabolic Cascade

Blennow et al. The Neuropathology and Neurobiology of Traumatic Brain Injury . Neuron Volume 76, Issue 5, Pages 886-899 (December 2012)

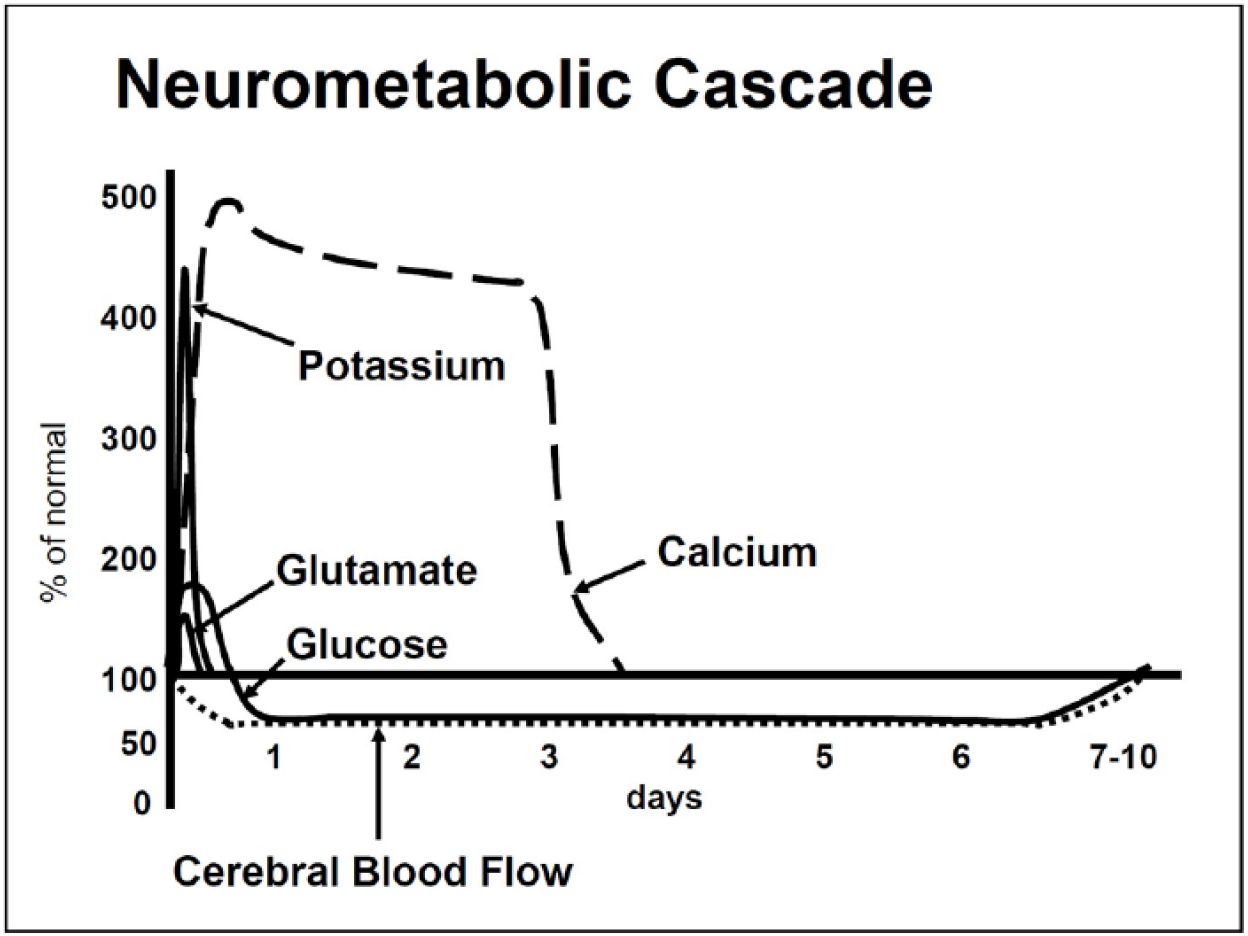


Figure 1.
Time course of the neurometabolic cascade of concussion.

Giza and Hovda. *The New Neurometabolic Cascade of Concussion*. Neurosurgery. 2014 October ; 75(0 4): S24–S33

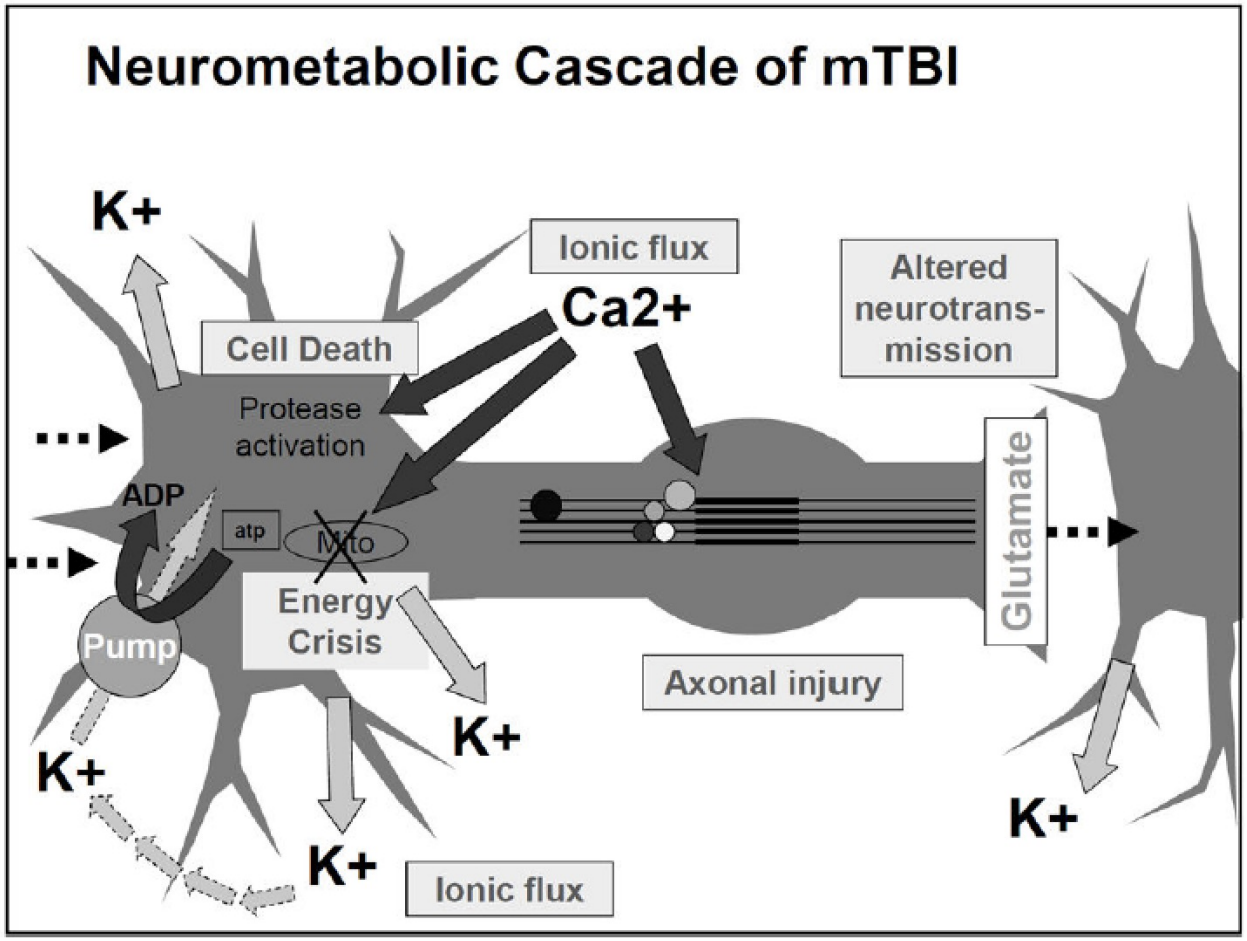


Figure 2.
Diagram of the acute cellular biological processes occurring after concussion/mild TBI.

Giza and Hovda. *The New Neurometabolic Cascade of Concussion*. Neurosurgery. 2014 October ; 75(0 4): S24–S33

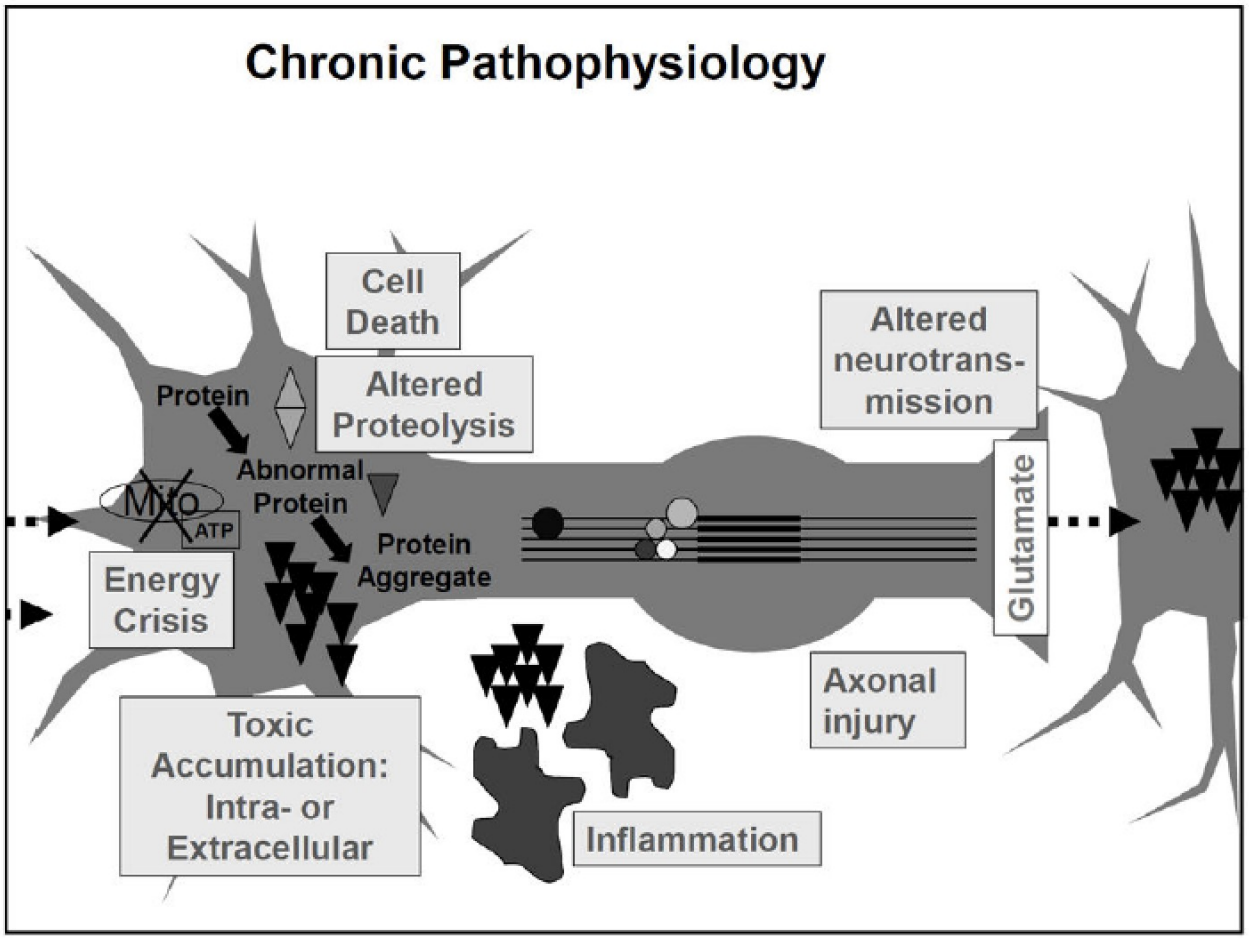
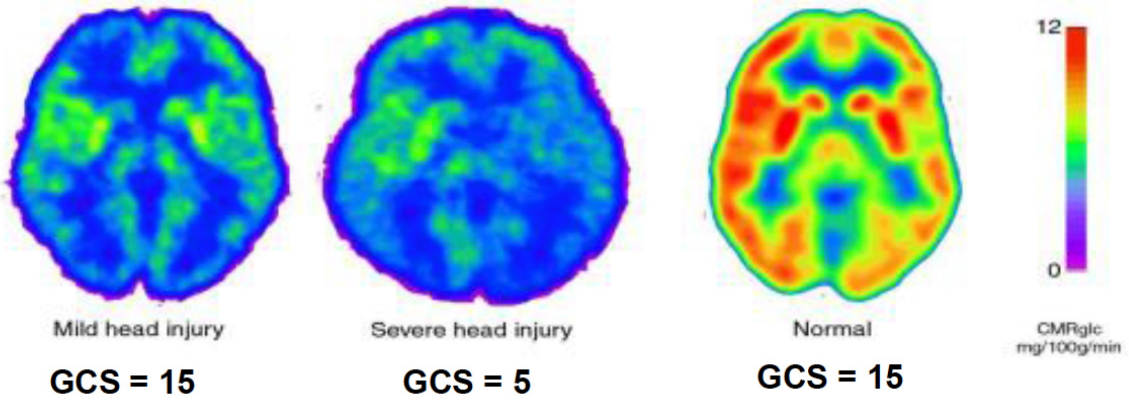


Figure 3.
Diagram of linkages between acute post-concussion pathophysiology and mechanisms for chronic impairment and possibly neurodegeneration.

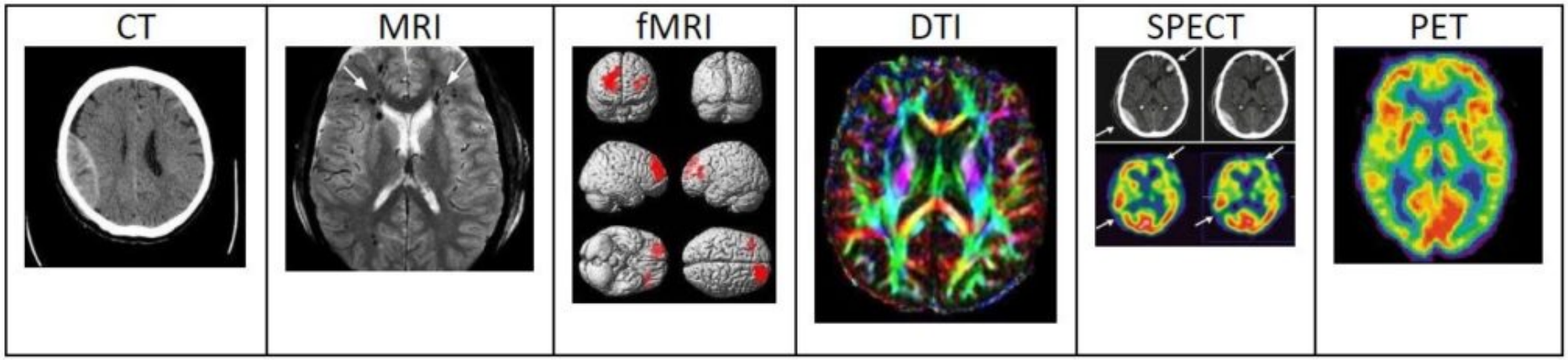
Giza and Hovda. *The New Neurometabolic Cascade of Concussion*. Neurosurgery. 2014 October ; 75(0 4): S24–S33

For reasons not completely understood, there is also decreased blood flow to the brain when glucose (energy) requirement is higher, leading to an “energy crisis” (the brain being starved of blood supply).

This ‘mismatch’’ increases the vulnerability of the brain to further injury



Advanced Brain Imaging



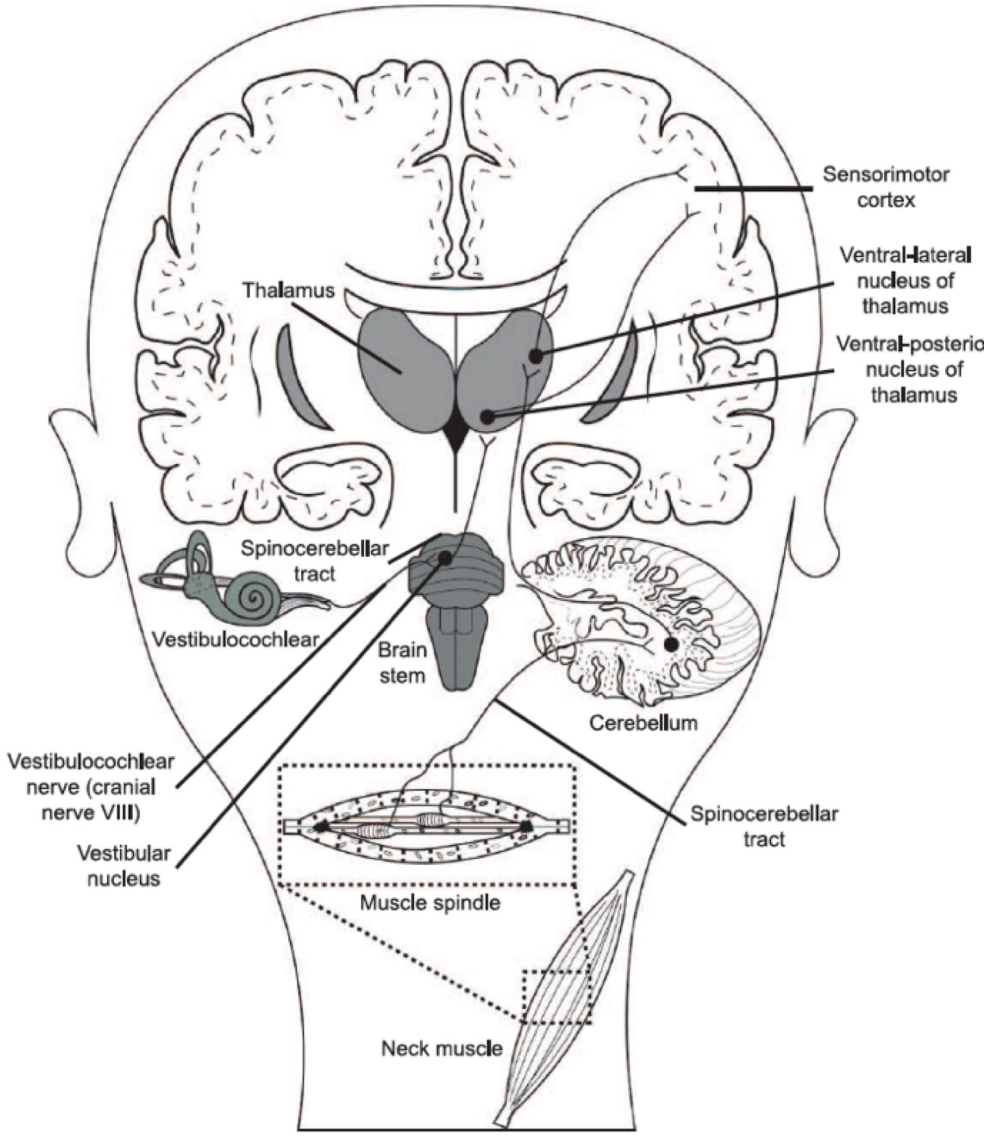
Raji et al. Clinical utility of SPECT neuroimaging in the diagnosis and treatment of traumatic brain injury: a systematic review. PLoS One. 2014 Mar 19;9(3):e91088

Khong et al Diffusion Tensor Imaging Findings in Post-Concussion Syndrome Patients after Mild Traumatic Brain Injury: A Systematic Review. Front Neurol. 2016 Sep 19;7:156

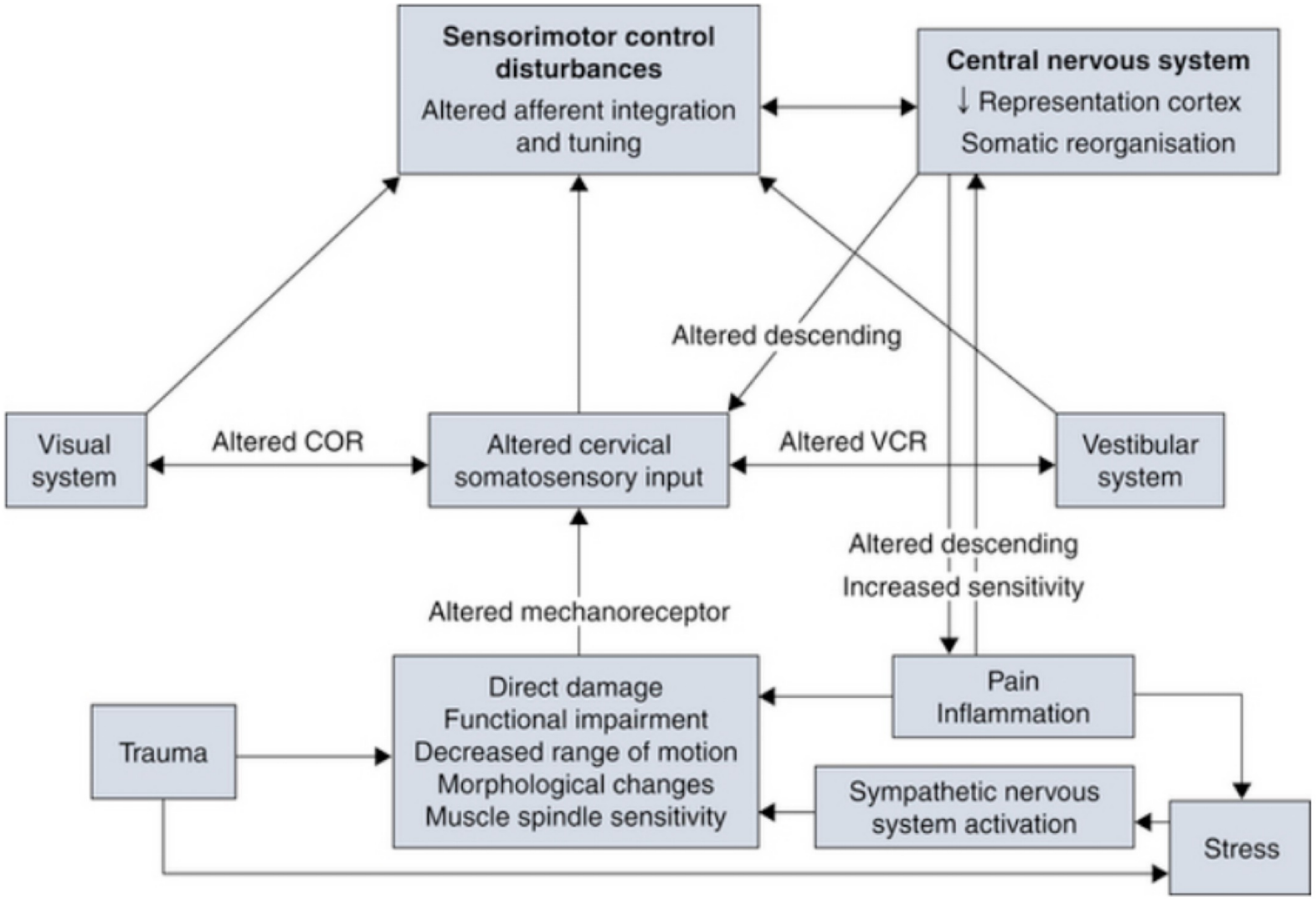
Byrnes et al. FDG-PET imaging in mild traumatic brain injury: a critical review. Front Neuroenergetics. 2014 Jan 9;5:13

Cervical afferents have a complex neurophysiologic interaction with the sensory and motor nuclei of the brainstem, as well as the cerebellum, and higher cortical areas that relate to sensorimotor function and body awareness

Cheever et al. A. Cervical Injury Assessments for Concussion Evaluation: A Review. J Athl Train. 2016 Dec;51(12):1037-1044.



Major structures related to cervicogenic injury and concussive symptoms.



Treleaven J. Sensorimotor disturbances in neck disorders affecting postural stability, head and eye movement control. Man Ther. 2008 Feb;13(1):2-11

Ambiguity in definitions

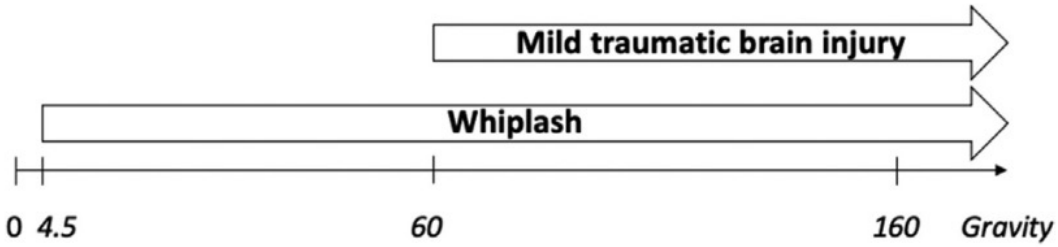
As it is challenging to define PCS and WAD, , as well as distinguish between them, this makes it also challenging to diagnose.

The diagnosis of WAD is made on the mechanism of the injury and patient reported symptoms – neck pain and related symptoms following a traumatic event, usually a road traffic crash.

The diagnosis of PCS is based on a constellation of symptoms commonly experienced following mild traumatic brain injury.

Can you have one and not the other?

The forces required for a whiplash to occur is around 4.5g (g = gravity) compared to that of a concussion which is around 60-160g



Broglio et al. High school and collegiate football athlete concussions: A biomechanical review. Ann Biomed Eng 2011;40:37–46.

Is concussion a brain only injury?

Concussion: Purely a Brain Injury?

Oliver Leslie, MD, CCFP and Neil Craton, MD, MHK, Dip Sport Med†*

Clin J Sport Med Volume 23, Number 5, September 2013

Brain or Strain? Symptoms Alone Do Not Distinguish Physiologic Concussion From Cervical/Vestibular Injury

John J. Leddy, MD,† John G. Baker, PhD,‡ Asim Merchant, MD,†§ John Picano, BS,¶ Daniel Gaile, PhD,‖ Jason Matuszak, MD,§ and Barry Willer, PhD***

Clin J Sport Med. 2015 May;25(3):237-42

- Symptoms after head injury may not be specific to the brain.
- Concussion is really a syndrome that does not require brain involvement in all cases and that concussion symptoms can emanate from the cervical spine.
- Concomitant injury to the cervical spine resembling whiplash may occur as a result of the acceleration–deceleration forces sustained in concussive trauma

Common Symptoms of Concussion and Cervicogenic Injury

Symptom	Condition	
	Concussion	Cervical Injury
Headache[3,10,15,16–19]	X	X
Dizziness[3,10,16–20]	X	X
Tinnitus[10]	X	X
Irritability[10,21]	X	X
Chronic traumatic encephalopathy[3]	X	
Sleep disturbances[3,10,17]	X	X
Blurred vision[10,17]	X	X
Neck stiffness[10,18]	X	X
Balance disturbances[13–17,20,21]	X	X
Depression[2,3]	X	
Cognitive deficits[10,17,21,22]	X	X
Memory deficits[10,17,18,21,22]	X	
Attention deficits[10,17,18,21,22]	X	X
Decreased cervical range of motion[18]		X
Decreased isometric neck strength[18]	X	X

Cheever et al. *Cervical Injury Assessments for Concussion Evaluation: A Review. Journal of Athletic Training*. 2016; 51(12):1037-1044

Clinical Challenge

Junior ‘A’ hockey players immediately following injuries that either appeared as whiplash mechanisms (i.e. a blow to the body with a whipping motion of the neck and head), or injuries that appeared as concussion mechanisms (i.e. a direct blow to the head). It was discovered that 100% of the injured athletes had signs and symptoms of both WAD and concussion indicating that these injuries are happening concurrently

Hynes LM, Dickey JP. Is there a relationship between whiplash- associated disorders and concussion in hockey? A preliminary study. Brain Inj 2006;20:179–88.

It’s important because

While most cases of concussion and whiplash resolve in the first 3 months following initial injury. However, a subgroup of people, around 33% for concussion (Leddy et al., 2012) and 50% for whiplash (Ritchie & Sterling, 2016) go on to have persisting symptoms.

Clinical Questions

Which condition are we treating?

Does it matter?

Do we need to treat them separately?

What treatments are we using to manage these conditions?

Are they effective?

From my experience

Clinically meaningful differences

Concussion will *generally* have more signs and symptoms associated with dysfunction in

- Brainstem (light/sound/vision motion sensitivity, eye movements, ANS)
- Cognitive (brain fog, memory, attention)

Whiplash will *generally* have more cervical spine dysfunction

- Pain and sensitization
- Proprioception, cervical-centric eye movement/balance function

From my experiences

Focus on (dys)function, not the condition

Don’t necessarily define the patient as having one or the other, until you have evaluated.

Even then, as Chiropractors, it may be prudent to say *‘patient x is displaying signs and symptoms consistent with PCS or WAD’,* rather than confirming a diagnosis

Focus on the functional impairments (than the condition)

- assess (function and subjective)
- base treatment on patient goals, assessment results and (physical and metabolic) capacity
- re-evaluate

From my experiences

Focus on (dys)function, not the condition

Start with assessments that have supportive evidence to identify functional outcome measures related to brain and cervical spine function

- ANS function
- Eye Movements
- Cervical
- Peripheral Vestibular function
- Central vestibular integration
- Cognition
- Balance

Collins et al. A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. Knee Surg Sports Traumatol Arthrosc. 2014 Feb;22(2):235-46.

Cervical Dysfunction Assessment

Reneker et al. The diagnostic utility of clinical tests for differentiating between cervicogenic and other causes of dizziness after a sports-related concussion: An international Delphi study. J Sci Med Sport. 2015 Jul;18(4):366-72.

Using the Delphi method, Reneker et al surveyed experts in the fields of concussion, physical therapy, and neurology to identify the clinical utility of several clinical tests for differentiating between cervical injury and symptoms originating from the vestibular region or central processing after a sport-related concussion.

- cervical joint-reposition error test (JPET),
- the smooth-pursuit neck-torsion test (SPNTT),
- the head-neck differentiation test (HNDT),
- the cervical flexion-rotation test (CFRT),
- motor-control assessment of deep cervical flexors (CCFT) and extensors

Table 2. Clinical Test Utility in the Diagnosis and Identification of Origin of Symptoms in Concussion Testing

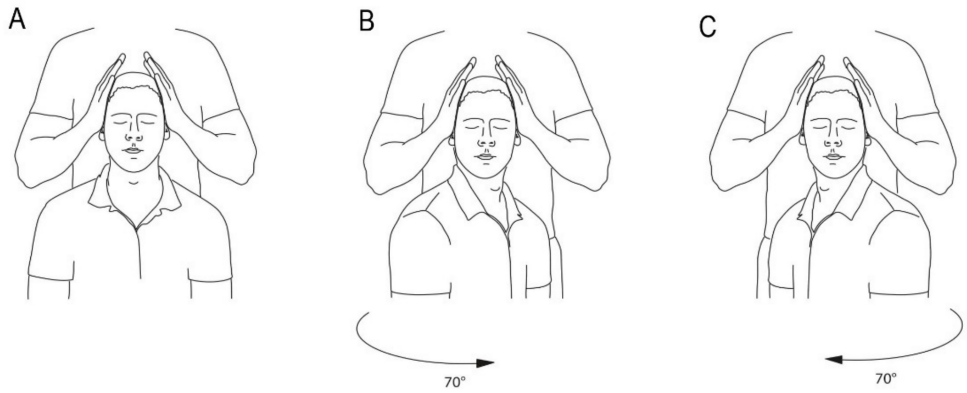
Clinical Test	Positive Test	Origin	Symptom	Treatment	Criterion Validity	Advantages and Disadvantages
Cervical joint-reposition error test[8,37]	Increased error in repositioning the neck to a neutral starting position	Damage to muscle spindles in the neck	Neck pain and stiffness	Neck-position–sense training	Specificity = 92% Sensitivity = 82%	Advantages: inexpensive, quick, and objective Disadvantage: requires some equipment (ie, pen laser, target, and chair)
Smooth-pursuit neck-torsion test[32,38]	Performing tracking task in the rotated position evokes symptoms	Has been linked to disturbances in the neck	Cervicogenic dizziness, vertigo, and balance disturbances	Manual therapy and gaze-stabilization training	Specificity = 91% Sensitivity = 90%	Advantages: quick and can be objectively measured with equipment Disadvantage: subjective when addressing only symptom provocation
Head-neck differentiation test[40]	Head cannot hold still while body spins on chair or with other symptom provocation	Cervicocollic reflex	Dizziness, vertigo, and balance disturbances	Head- and neck-differentiation training	Specificity and sensitivity unknown	Advantages: quick, requires no equipment, and allows the clinician to isolate neck movement while holding the head still Disadvantage: limited to subjective report of symptoms
Cervical flexion-rotation test[29,39]	Onset of symptoms with head movement	Afferent information from cervical proprioceptors to central nervous system does not match other sensory information	Cervicogenic dizziness	Manual therapy	Specificity = 91% Sensitivity = 90%	Advantages: quick, requires no equipment, and movement is only at the neck Disadvantage: limited to subjective report of symptom provocation
Motor-control assessment of deep cervical flexors and extensors[39]	Inability to dissociate head and neck movements, failed endurance, and onset of dizziness with movement	Vestibulocollic reflex	Dizziness, vertigo, balance disturbances, and headache	Manual therapy	Specificity and sensitivity unknown	Advantages: quick and requires no equipment Disadvantage: limited to subjective report of symptom provocation

Cheever et al. *Cervical Injury Assessments for Concussion Evaluation: A Review*. *Journal of Athletic Training*. 2016; 51(12):1037-1044

Cervical Testing

Cervical Neck Torsion Test (Fitz Fitson)

The patient begins seated on a swivel chair and turns their trunk 90° to the either the right or left, holding for 30 s, then returns their trunk to centre. The patient then repeats the same process in the opposite direction. Each position, including the centre positions, is maintained for 30 s. Throughout the test, the head is stabilized by the clinician and therefore motionless. The clinician also must continuously observe for nystagmus and symptoms



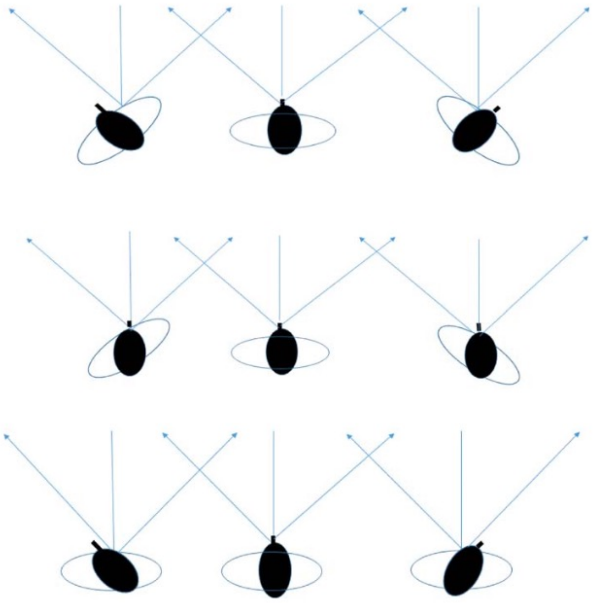
Treleaven et al. Normative Responses to Clinical Tests for Cervicogenic Dizziness: Clinical Cervical Torsion Test and Head-Neck Differentiation Test. Phys Ther. 2020 Jan 23;100(1):192-200.

Cervical Testing

Head-Neck Differentiating test

It is similar to the CTT, albeit performed using fast movement oscillations rather than sustained positions.

Clinical cervical torsion test procedures. (a) En bloc component (head and trunk rotation together). (b) Torsion component. (c) Rotation component. Trunk, head, or both move at least 45◦–90◦ degrees to left and right.



a) En bloc – head and trunk rotate together

Isolated vestibular

b) Torsion – trunk rotation on still head

Isolated cervical

c) Rotation – head rotation trunk still

Vestibular and cervical

Treleaven et al 2020

Cervical Testing

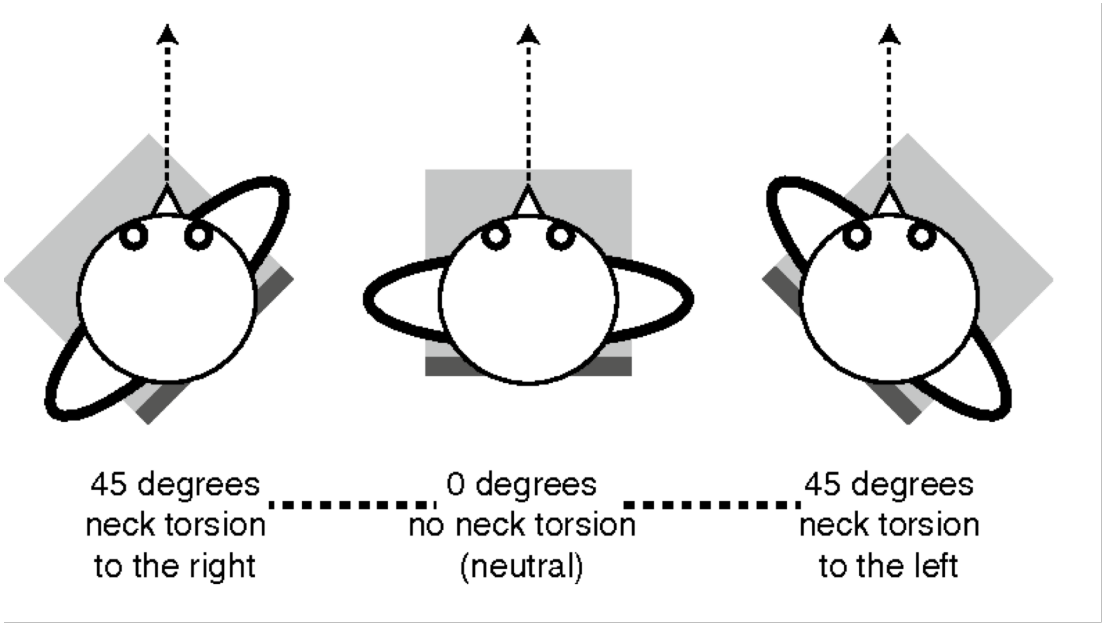
Smoot Pursuit Rotation Test

Comparison between smooth pursuit with head neutral vs head rotated, looking for

- eye movement
- Symptoms

Start with a neutral head position

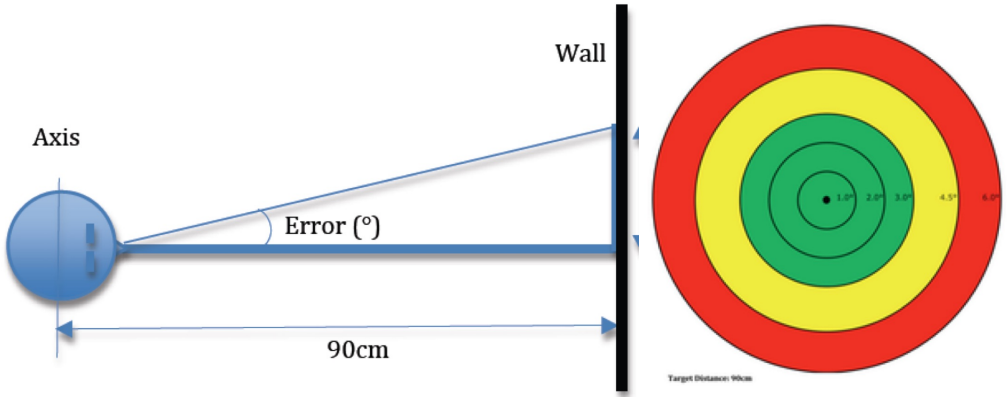
Then perform same test with the trunk rotated 45^{o} (head remains straight)

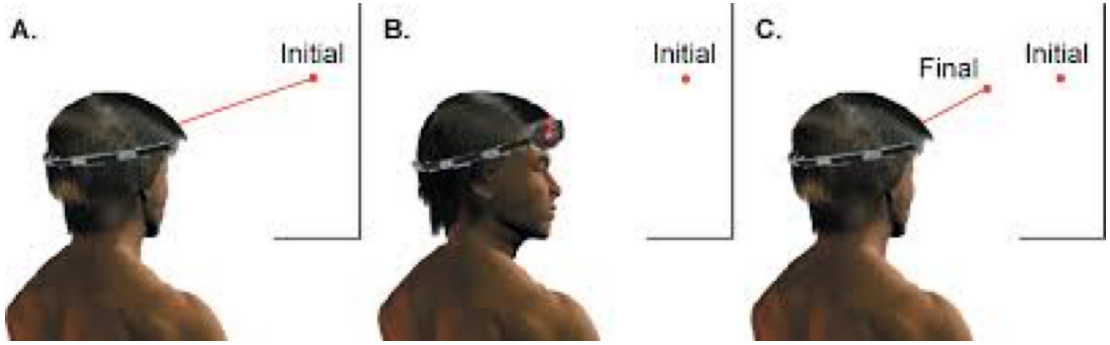


Cervical Testing

Cervical Relocation Test

The patient begins seated, facing a wall 90 cm away, and wearing a head-mounted laser pointer that is centred on a target on the wall. The patient keeps their eyes closed while moving their neck in a specified direction, then back to what they believe to be centred starting position. The patient verbally indicates when they believe they are back to centre. The patient repeats this process for right rotation, left rotation, flexion, and extension (in no particular order).





Cervical Testing

Cervical Flexion Rotation Test

The cervical flexion-rotation test is an objective method of determining upper cervical joint (C0-2) dysfunction.

The cervical spine is fully flexed, in an attempt to isolate movement to C1-C2, which has an unique ability to rotate in flexion, ruling out movement from other levels

Range of rotation in end-range flexion is normally 40–44° to each side. Dysfunction approx 20^{o}
high sensitivity (91%) and specificity (90%) in differentiating subjects with CGH from asymptomatic controls or subjects with migraine with aura..

Ogince et al. The diagnostic validity of the cervical flexion-rotation test in C1/2 related cervicogenic headache. Man Ther 2007;12:256-262

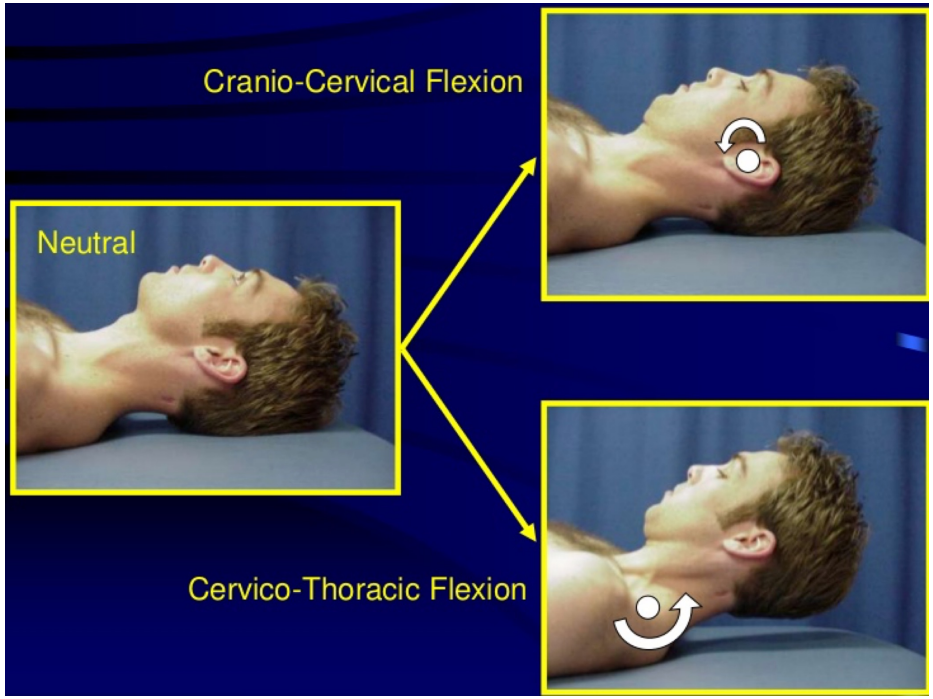
Cervical Testing

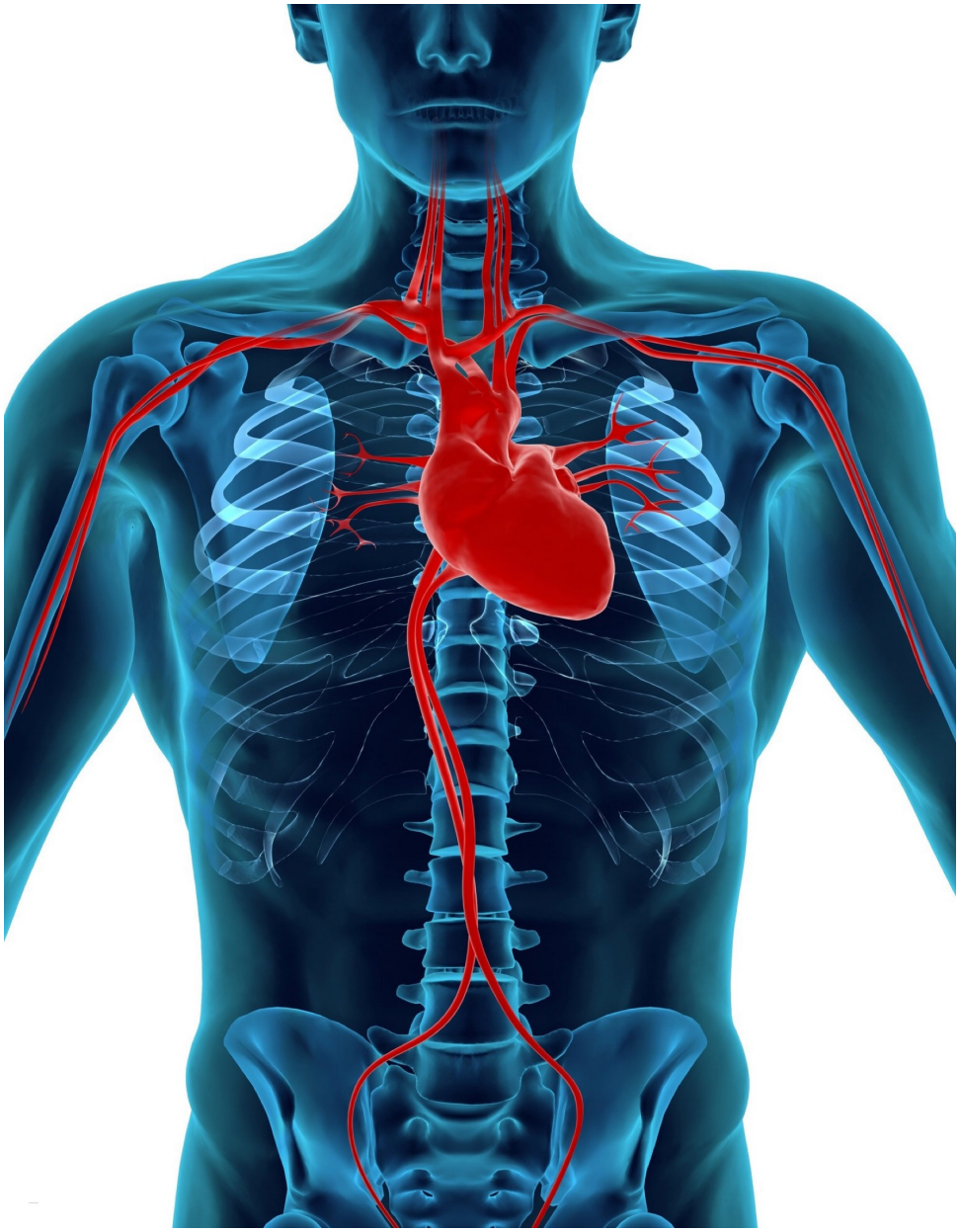
Cranio-Cervical Flexion Test

The CCFT has been described as a neuromotor control test that evaluates the activation and isometric endurance of the deep neck flexors.

The cranio-cervical movement aims to assess the anatomical action of longus capitis in synergy with longus colli, rather than that of the superficial flexors, sternocleidomastoid (SCM) and anterior scalene muscles, which flex the neck but not the head

Craniocervical flexion is described as flexion of the head over the upper cervical region without any flexion of the middle or lower cervical region





ANS Testing

The evidence supports the conclusion that it is likely that concussion causes autonomic nervous system anomalies.

An awareness of this relationship increases our understanding of the physical impact of concussion, partially explains the overlap of concussion symptoms with other medical conditions, presents opportunities for further research, and has the potential to powerfully inform treatment decisions

Pertab, et al. 'Concussion and the Autonomic Nervous System: An Introduction to the Field and the Results of a Systematic Review'. 1 Jan. 2018 : 397 – 427.

Table I. Summary of pathophysiology, predominant symptoms, pertinent physical examination findings, graded treadmill test results and treatment options in patients with PCDs.

	Physiologic PCD	Vestibulo-ocular PCD	Cerviogenic PCD
Pathophysiology	• Persistent alterations in neuronal depolarization, cell membrane permeability, mitochondrial function, cellular metabolism, and cerebral blood flow	• Dysfunction of the vestibular and oculomotor symptoms	• Muscle trauma and inflammation • Dysfunction of cervical spine proprioception
Predominant symptoms	• Headache exacerbated by physical and cognitive activity • Nausea, intermittant vomiting, photophobia, phonophobia, dizziness, fatigue, difficulty concentrating, slowed speech	• Dizziness, vertigo, nausea, lightheadedness, gait instability and postural instability at rest. • Blurred or double vision, difficulty tracking objects, motion sensitivity, photophobia, eye strain or brow-ache, and headache exacerbated by activities that worsen vestibulo-ocular symptoms (i.e. reading)	• Neck pain, stiffness, and decreased range of motion • Occipital headaches exacerbated by head movements and not physical or cognitive activity • Lightheadedness and postural imbalance
Physical exam findings	• No focal neurological findings • Elevated resting HR	• Impairments on standardized balance and gait testing • Impaired VOR, fixation, convergence, horizontal and vertical saccades	• Decreased cervical lordosis and range of motion • Paraspinal and sub-occipital muscle tenderness • Impaired head-neck position sense
Graded treadmill test	• Graded treadmill tests are often terminated early due to symptom onset or exacerbation	• Patients typically reach maximal exertion without exacerbation of vestibulo-ocular symptoms on graded treadmill tests	• Patients typically reach maximal exertion without exacerbation of cervicogenic symptoms on graded treadmill tests
Management options	• Physical and cognitive rest • School accommodations • Sub-symptom threshold aerobic exercise programs should be considered for adolescent and adult athletes	• Vestibular rehabilitation program • Vision therapy program • School accommodations • Sub-symptom threshold aerobic exercise programs should be considered for adolescent athletes	• Cervical spine manual therapy • Head-neck proprioception re-training • Balance and gaze stabilization exercises • Sub-symptom threshold aerobic exercise programs should be considered for adolescent and adult athletes

PCD, post-concussion disorder; VOR, vestibulo-ocular reflex.

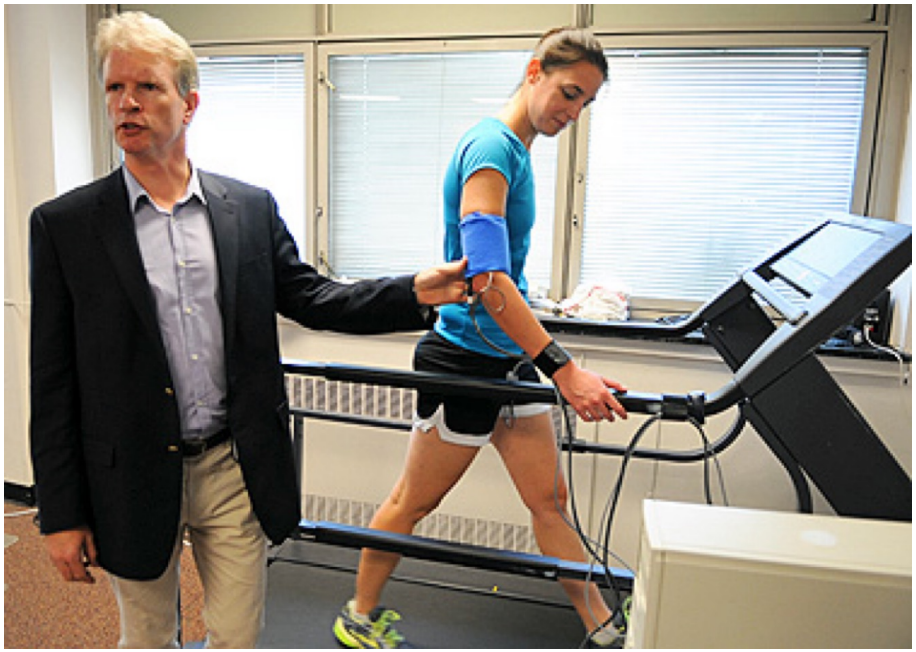
Ellis et al. Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: an evidence-based classification system with directions for treatment. Brain Inj. 2015;29(2):238-48.

Post-concussion disorders (PCDs) caused by impairments in global brain metabolism (Physiologic PCD) or neurological sub-system dysfunction (Vestibulo-ocular PCD and Cervicogenic PCD) that can be distinguished by features of the clinical history, physical examination and treadmill exercise testing.

ANS testing

Buffalo Concussion Treadmill Test

The Buffalo Concussion Treadmill Test (BCTT) is a validated test to measure the amount of aerobic exercise (exercise tolerance) following a concussion.
It is a graded provocation test using a treadmill that establishes the heart rate (HR) at which exercise-induced symptom exacerbation occurs after concussion.
It is an effective tool for diagnosing and managing concussions, as well as making the decision for return to play



Leddy & Willer. Use of Graded Exercise Testing in Concussion and Return-to-Activity Management. Current Sports Medicine Reports: 2013 - 12:6 - p 370-376

ANS testing

Buffalo Concussion Treadmill Test

The goals of it's use

1. Establish exercise intolerance
2. Establish differential diagnosis of PCD (physiological, cervicogenic, vestibulo-ocular)
3. Individualized management protocols
4. Safe Return To Play (RTP) through re-established exercise tolerance

ANS testing

Buffalo Concussion Treadmill Test

The heart rate (HR) achieved at symptom exacerbation on the BCTT is called the heart rate threshold (HRt)

- Modified Balke protocol
- Graduated exercise test
- Constant speed
- Increased incline, 1° per minute (up to 15°)
- Measure of physical exhaustion (Borg RPE) and/or exercise intolerance

ANS testing

Buffalo Concussion Treadmill Test

Absolute and relative contraindications to the Buffalo Concussion Treadmill Test

Absolute contraindications	
History	Unwilling to exercise
	Increased risk for cardiopulmonary disease as defined by the American College of Sports Medicine*
Physical examination	Focal neurologic deficit
	Significant balance deficit, visual deficit, or orthopedic injury that would represent a significant risk for walking/running on a treadmill
Relative contraindications	
History	β-blocker use
	Major depression (may not comply with directions or prescription)
	Does not understand English
Physical examination	Minor balance deficit, visual deficit, or orthopedic injury that increases risk for walking/running on a treadmill
	Resting systolic BP >140 mm Hg or diastolic BP > 90 mm Hg
	Obesity: body mass index ≥30 kg/m^2

BP = blood pressure.

* Individuals with known cardiovascular, pulmonary, or metabolic disease; signs and symptoms suggestive of cardiovascular or pulmonary disease; or individuals ≥45 years who have more than one risk factor, including (1) family history of myocardial infarction, coronary revascularization, or sudden death before age 55 years; (2) cigarette smoking; (3) hypertension; (4) hypercholesterolemia; (5) impaired fasting glucose level; or (6) obesity (body mass index ≥30 kg/m^2).

Leddy, et al. (2016). Active Rehabilitation of Concussion and Post-concussion Syndrome. PMR. 27. 437-454.

ANS testing

Buffalo Concussion Treadmill Test

Borg Rate of perceived exertion

The RPE scale is a measure of perceived physical activity, and can be explained to participants as a measure of “how hard you feel like your body is working”. The scale’s numbers (6-20) and descriptors should be pointed out

Borg’s Rating of Perceived Exertion (RPE) Scale

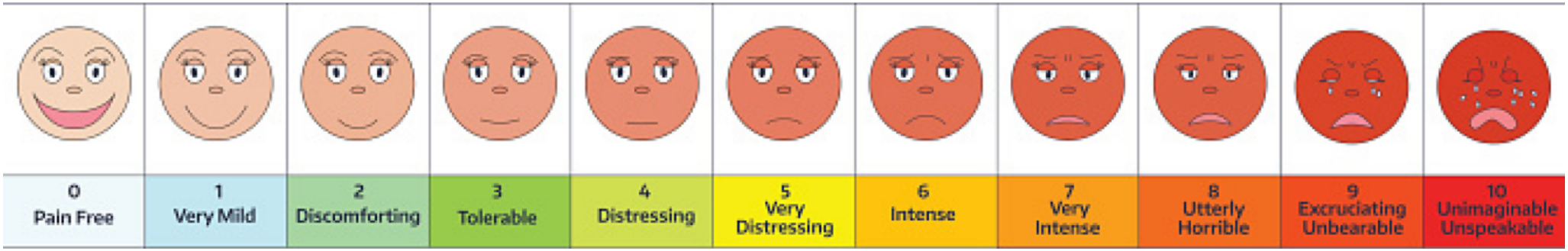
Perceived Exertion Rating	Description of Exertion
6	No exertion. Sitting & resting
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

ANS testing

Buffalo Concussion Treadmill Test

Visual Analogue Scale (VAS)

The Likert symptom scale is a measure of symptom severity (“how good/bad your symptoms are making you feel right now”), and should be distinguished as being distinct from RPE. The scale’s numbers (1-10) and pictures (expressions of physical pain) should be pointed out.



ANS testing

Buffalo Concussion Treadmill Test

Starting speed: brisk walk (approx. 3.3 mph)
Increase incline 1° per minute
Record HR, RPE and symptoms until:

- Participant reaches max HR or RPE of 19 (exhaustion), OR
- Symptoms increase by ≥ 3 points (new symptom or increased symptom load) on the Likert scale (symptom exacerbation)

ANS testing

Buffalo Concussion Treadmill Test

Establishing an exercise program

- For general patients 80% (90%) of HRt, 20 minutes per day after a five minute warm up
- For athletes 90% of HRt, 20 minutes per day, and if well tolerated, move to 2x per day

ANS testing

Buffalo Concussion Treadmill Test

A ΔHR (difference between resting HR and HRt) of ≤50 bpm on the BCTT is 73% sensitive and 78% specific for predicting prolonged recovery in concussed adolescents who were prescribed the current standard of care (i.e., cognitive and physical rest).

Haider et al. The Predictive Capacity of the Buffalo Concussion Treadmill Test After Sport-Related Concussion in Adolescents. Front Neurol. 2019 Apr 24;10:395.

ANS testing

Buffalo Concussion Bike Test

Buffalo Concussion Bike Test (BCBT), developed to assess exercise tolerance in patients with concussion or participants for whom treadmill testing is difficult or contraindicated, including if vestibular (head motion) symptoms persist when walking and if they're a risk of falling

The BCBT, takes longer to perform than the BCTT but elicits symptom exacerbation at a statistically equivalent HR to the BCTT

Haider et al. The Buffalo Concussion Bike Test for Concussion Assessment in Adolescents. Sports Health. 2019 Nov/Dec;11(6):492-497

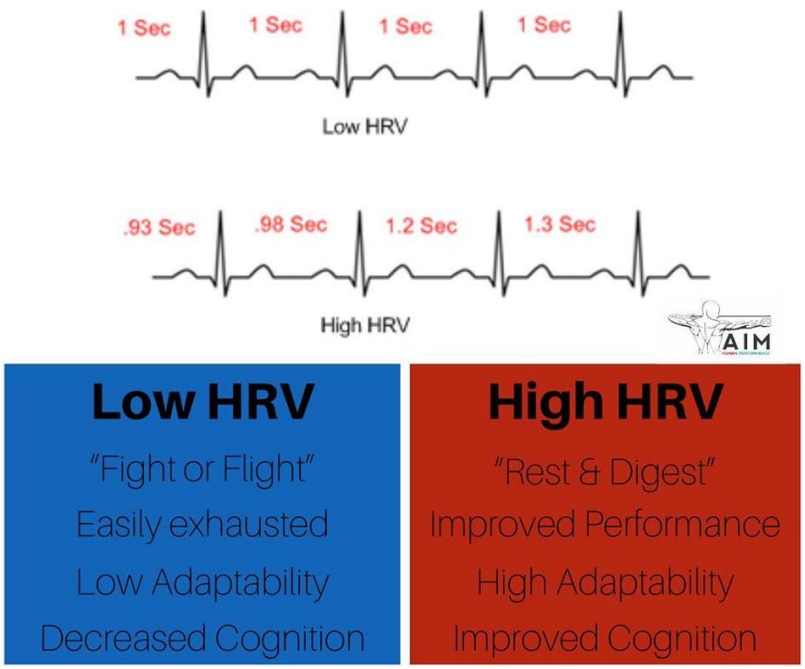
ANS testing

Heart Rate Variability

There is a bidirectional feedback between the brain and the cardiac system.

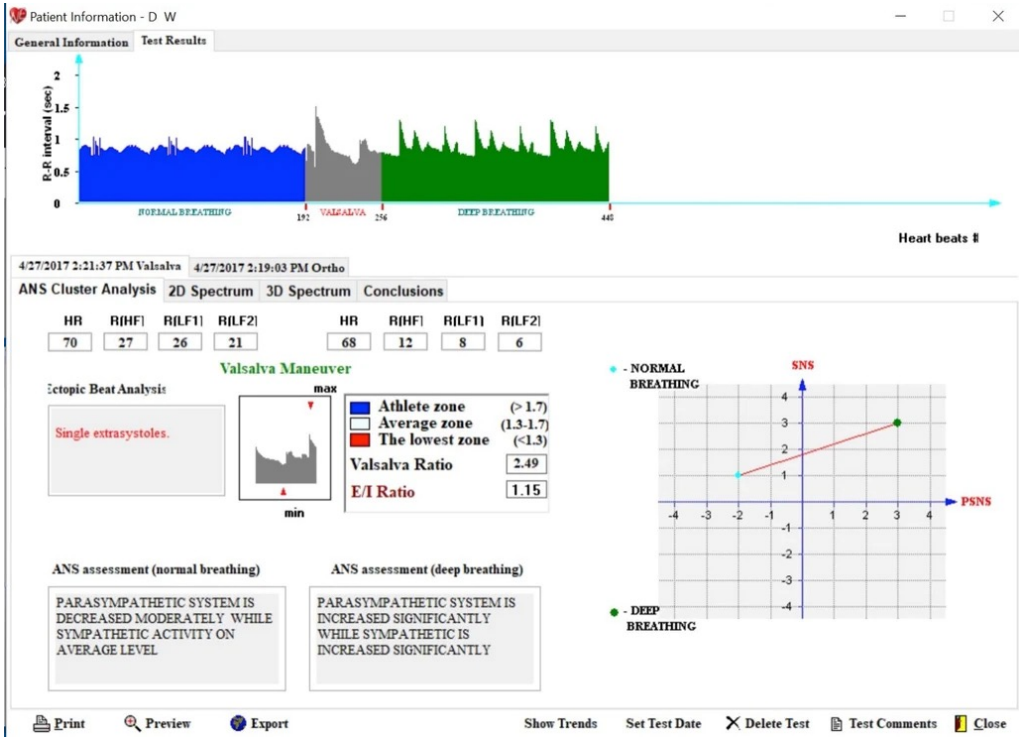
Heart Rate Variability (HRV), a non-invasive measure of the autonomic nervous system (ANS) and the beat-to-beat change in heart rate (HR), provides insight into this connection.

HRV provides insight into the balance between sympathetic and parasympathetic nervous activity, and may reflect imbalances arising from psychological and physiological stress levels.



ANS testing

Heart Rate Variability



nerveexpress

ANS testing

Heart Rate Variability

Athletes with a concussion history displayed suppressed cardiac autonomic recovery after moderate aerobic exercise compared with the non-concussed control group.

Players with multiple previous concussions exhibited an increased time to physiological recovery postexercise versus athletes with 1 or no concussions.

Allyssa et al. Long-Term Influence of Concussion on Cardio-Autonomic Function in Adolescent Hockey Players. *J Athl Train* 1 February 2021; 56 (2): 141–147.

ANS testing

Heart Rate Variability

Athletes with concussion displayed altered HRV measures compared with controls, and those with a history of concussion had more disturbances in HRV while symptomatic and post-RTP.

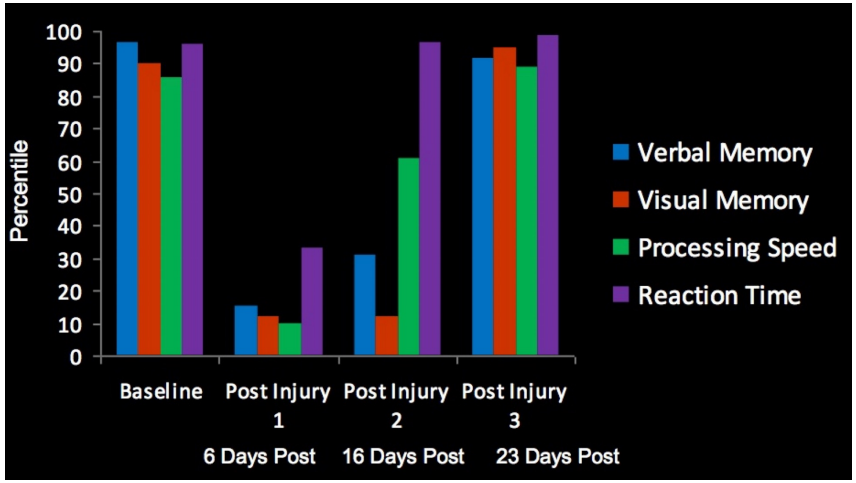
ANS disturbances in athletes post-concussion last beyond symptom resolution and medical clearance for progression to exercise and through RTP.

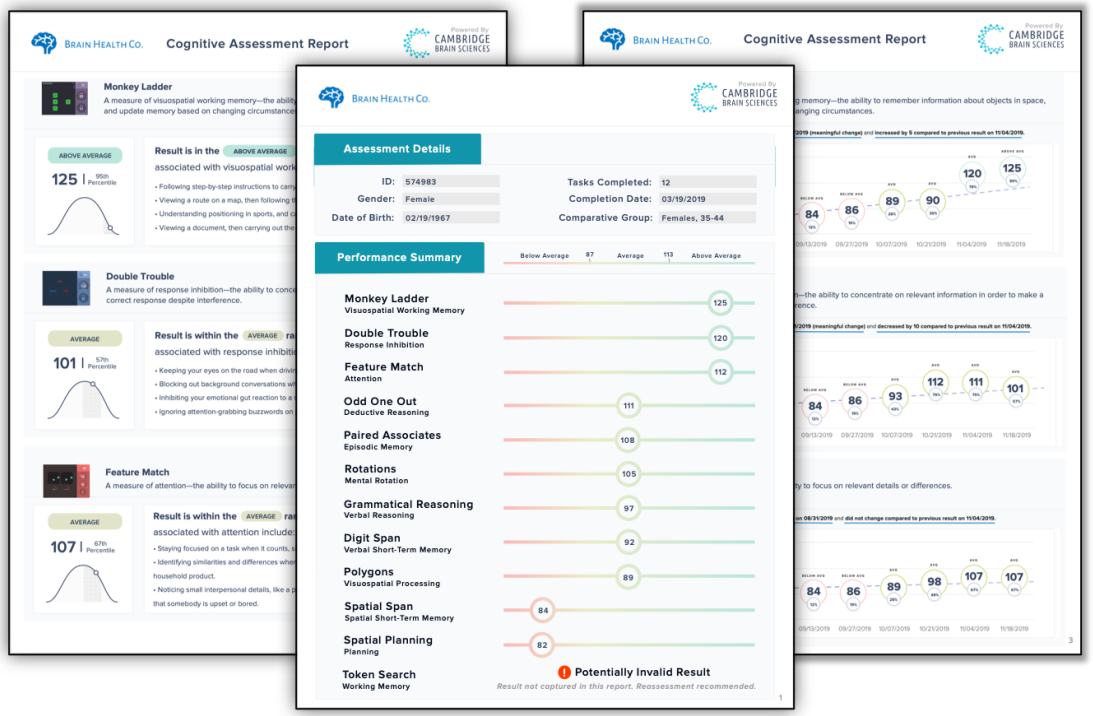
Heart rate variability has potential clinical utility to help clinicians facilitate safe RTP, but requires further investigation.

Senthinathan, et al. (2017). Heart Rate Variability of Athletes Across Concussion Recovery Milestones. Clinical Journal of Sport Medicine, 27(3), 288–295.

Neurocognitive

Screen for cognitive profiles





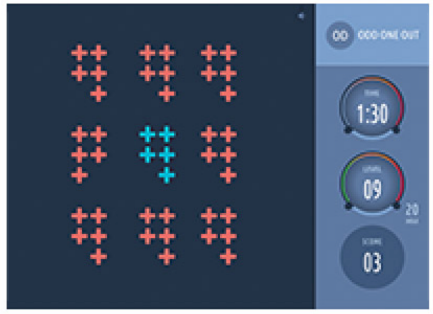
Cambridge Brain Science

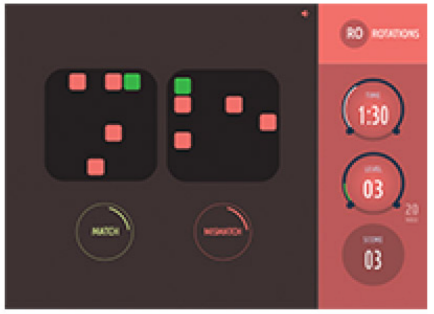
Neurocognitive

Screen for cognitive profiles

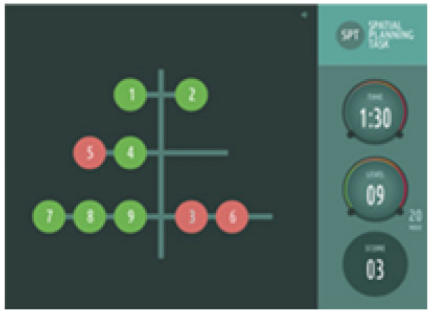
Concussion Vital Signs®

ImPACT®



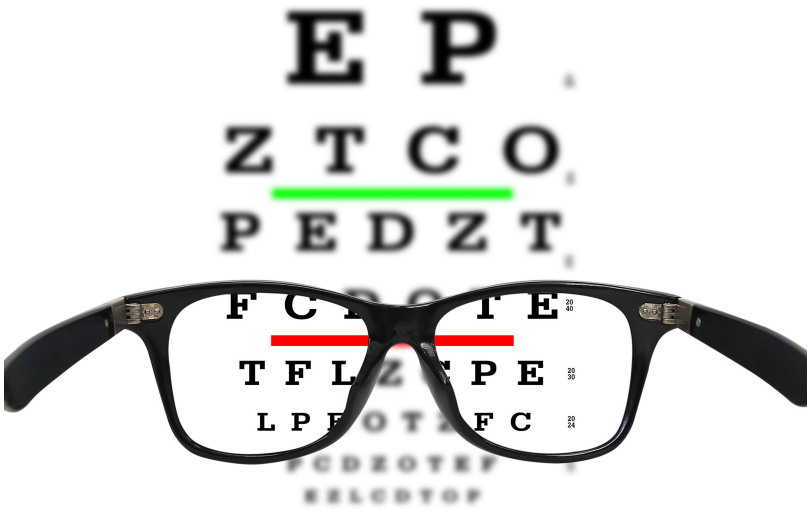


CAMBRIDGE BRAIN SCIENCES



Eye Movements

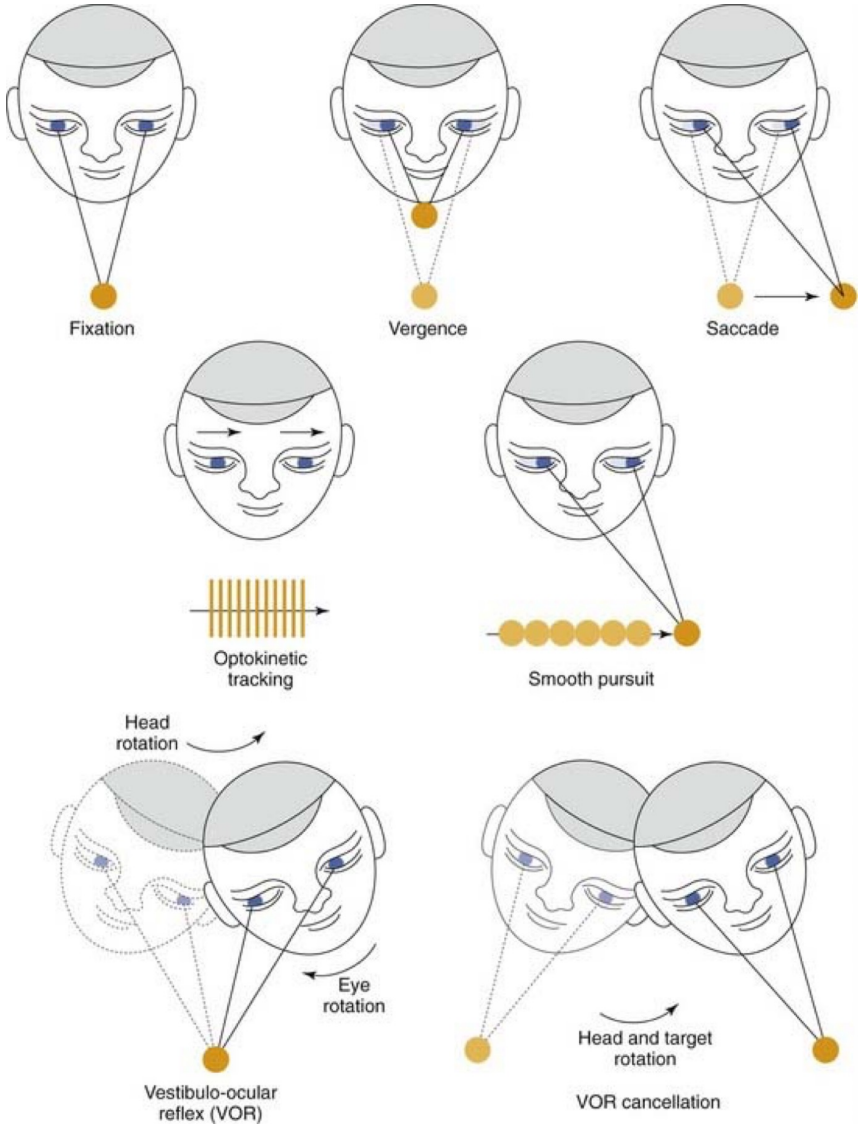
Eye Movement **vs** Vision



Eye Movements

Maintain visual fixation when the object, environment and/or person is moving

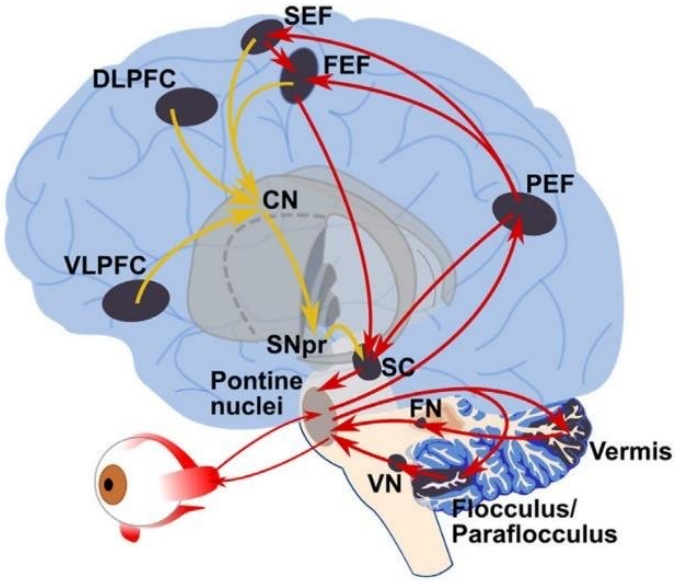
- gaze fixation
- pursuit (slow moving gaze fixation)
- saccade (fast moving/jumping gaze fixation)
- vergence (slow or fast convergence/divergence)
- vestibular-ocular reflex (head movement)
- optokinetic (tracking a moving repetitive environment)

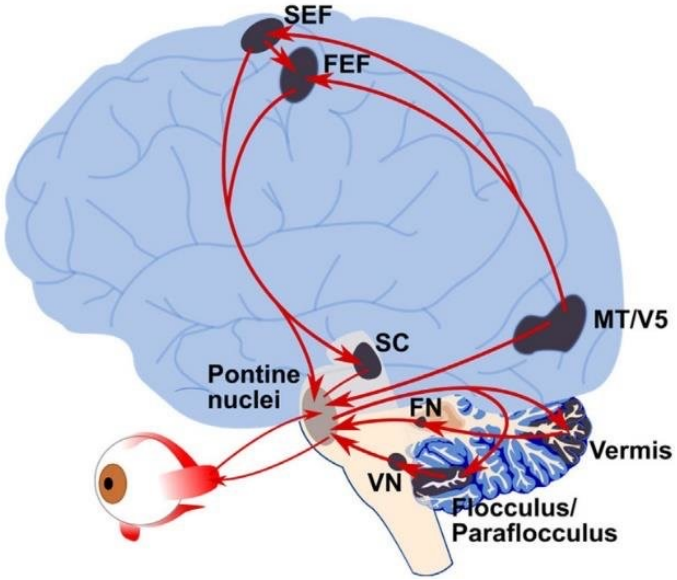


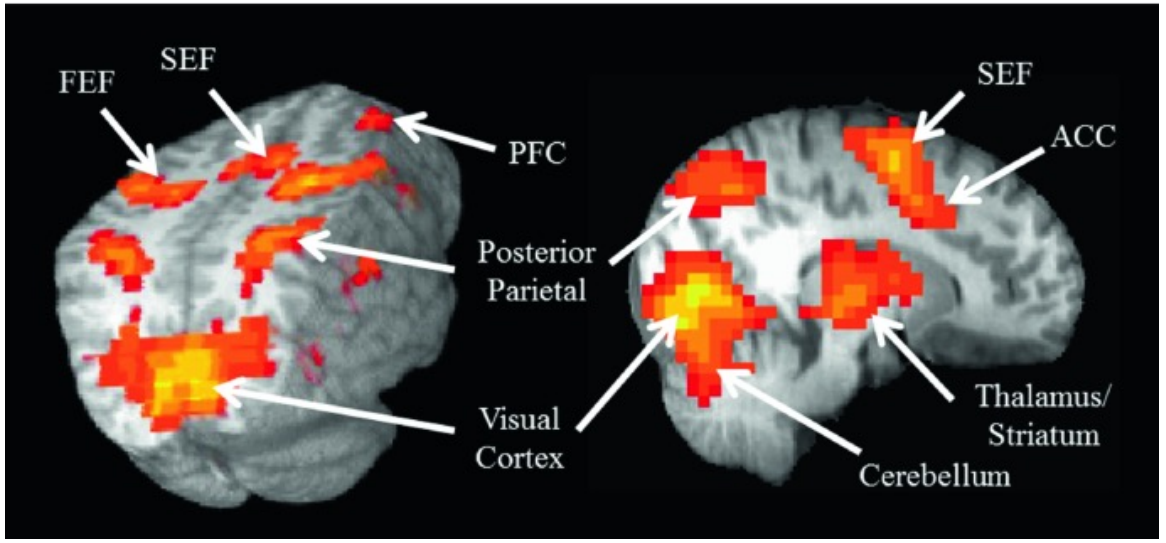
Eye Movements

“The window of brain function”

Neurology of Eye Movements







Pierce et al (2019). Saccades: Fundamentals and Neural Mechanisms. In: Klein, C., Ettinger, U. (eds) Eye Movement Research. Studies in Neuroscience, Psychology and Behavioral Economics. Springer, Cham.

Are eye movements affected in mTBI?

"Whenever possible, the SRC (sports related concussion) assessment should incorporate neurological, vestibular, ***ocular motor****, visual, neurocognitive, psychological and cervical aspects"*

Feddermann-Demont *et al* 2017

Eye Movement Impairments in mTBI

	% mTBI n = 20	% Controls n = 20	p
Convergence Insufficiency	55%	5%	0.0012*
Saccadic Impairment	30%	0%	0.0202*
Pursuit impairment	60%	0%	<0.0001*
Ocular Misalignments (Vertical Phoria)	55%	5%	0.0012*
Ocular Misalignment (Horizontal Phoria)	45%	5%	0.0084*
Accommodative Dysfunction	65%	15%	0.0031*

MILITARY MEDICINE, 177, 7:804, 2012

Visual Dysfunctions and Symptoms During the Subacute Stage of Blast-Induced Mild Traumatic Brain Injury

LTC José E. Capó-Aponte, MS USA; LTC Thomas G. Urosevich, MS USAR*; Leonard A. Temme, PhD Aaron K. Tarbett, OD†; Navjit K. Sanghera, OD‡*

What Does The Evidence Say?

Eye Movements, Strabismus, Amblyopia and Neuro-Ophthalmology

Eye Tracking Results in Postconcussive Syndrome Versus Normative Participants

Paul A. Wetzel,[1,2] Anne S. Lindblad,[3] Hardik Raizada,[3] Nathan James,[3] Caroline Mulatya,[3] Mary A. Kannan,[2] Zoe Villamar,[2] George T. Gitchel,[2] and Lindell K. Weaver[4–6]

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Purpose. Standard physical, neurologic, and neuropsychologic examinations may not detect abnormalities after mild traumatic brain injury (mTBI). An analysis of eye movements may be more sensitive to neurologic dysfunction.

Methods. We performed eye tracking assessments in 71 active duty and veteran military personnel with persistent postconcussive symptoms (3 months to 5 years after mTBI) and 75 volunteers with no history of brain injury. Both eyes were sampled at 500 Hz and analyzed for various eye measurement parameters during visual tasks involving the saccadic and smooth systems.

Results. No difference between mTBI and normal participants in main sequence profiles was observed. On the circular task, intersaccadic interval duration was shorter in mTBI compared with normal subjects (horizontal: Cohen's $D = -0.65$; vertical: Cohen's $D = -0.75$). For reading, absolute saccadic amplitudes (Cohen's $D = -0.76$) and average forward saccadic amplitudes were lower (Cohen's $D = -0.61$). Absolute fixation velocity was higher (Cohen's $D = 1.02$), and overall fixation durations (Cohen's $D = 0.58$), regression durations (Cohen's $D = 0.49$), and forward saccadic durations (Cohen's D=0.54) were longer. mTBI participants had more fixations (Cohen's $D = 0.54$) and regressions per line (Cohen's $D = 0.70$) and read fewer lines (Cohen's $D = -0.38$) than normal subjects. On the horizontal ramp task, mTBI participants had lower weighted smooth pursuit gains (Cohen's $D = -0.55$). On the horizontal step task, mTBI participants had shorter mean fixation times (Cohen's $D = -0.55$).

Conclusions. These results suggest vulnerability of the smooth pursuit and saccadic systems in mTBI. Eye tracking shows promise as an objective, sensitive assessment of damage after mTBI. (ClinicalTrials.gov number, NCT01611194, NCT01925963.)

J Head Trauma Rehabil
Vol. 30, No. 1, pp. 21–28

Differential Eye Movements in Mild Traumatic Brain Injury Versus Normal Controls

David X. Cifu, MD; Joanna R. Wares, PhD; Kathy W. Hoke, PhD; Paul A. Wetzel, PhD; George Gitchel, MS; William Carne, PhD

Objectives: Objective measures to diagnose and to monitor improvement of symptoms following mild traumatic brain injury (mTBI) are lacking. Computerized eye tracking has been advocated as a rapid, user friendly, and field-ready technique to meet this need. **Design:** Eye-tracking data collected via a head-mounted, video-based binocular eye tracker was used to examine saccades, fixations, and smooth pursuit movement in military Service Members with postconcussive syndrome (PCS) and asymptomatic control subjects in an effort to determine if eye movement differences could be found and quantified. **Participants:** Sixty Military Service Members with PCS and 26 asymptomatic controls. **Outcome Measures:** The diagnosis of mTBI was confirmed by the study physiatrist's history, physical examination, and a review of any medical records. Various features of saccades, fixation and smooth pursuit eye movements were analyzed. **Results:** Subjects with symptomatic mTBI had statistically larger position errors, smaller saccadic amplitudes, smaller predicted peak velocities, smaller peak accelerations, and longer durations. Subjects with symptomatic mTBI were also less likely to follow a target movement (less primary saccades). In general, symptomatic mTBI tracked the stepwise moving targets less accurately, revealing possible brain dysfunction. **Conclusions:** A reliable, standardized protocol that appears to differentiate mTBI from normals was developed for use in future research. This investigation represents a step toward objective identification of those with PCS. Future studies focused on increasing the specificity of eye movement differences in those with PCS are needed.
Key words: *eye tracking, fixations, mild traumatic brain injury, postconcussion syndrome, saccades, smooth pursuit*

Post-concussion syndrome (PCS) can affect up to 20%–30% of patients with mild closed head injury (mCHI), comprising incomplete recovery and debilitating persistence of post-concussional symptoms. Eye movements relate closely to the functional integrity of the injured brain and eye movement function is impaired post-acutely in mCHI. Here, we examined whether PCS patients continue to show disparities in eye movement function at 3–5 months following mCHI compared with patients with good recovery. We hypothesized that eye movements might provide sensitive and objective functional markers of ongoing cerebral impairment in PCS. We compared 36 PCS participants (adapted World Health Organization guidelines) and 36 individually matched controls (i.e. mCHI patients of similar injury severity but good recovery) on reflexive, anti- and self-paced saccades, memory-guided sequences and smooth pursuit. All completed neuropsychological testing and health status questionnaires. Mean time post-injury was 140 days in the PCS group and 163 days in the control group. The PCS group performed worse on anti-saccades, self-paced saccades, memory-guided sequences and smooth pursuit, suggesting problems in response inhibition, short-term spatial memory, motor-sequence programming, visuospatial processing and visual attention. This poorer oculomotor performance included several measures beyond conscious control, indicating that subcortical functionality in the PCS group was poorer than expected after mCHI. The PCS group had poorer neuropsychological function (memory, complex attention and executive function). Analysis of covariance showed oculomotor differences to be practically unaffected by group disparities in depression and estimated intellectual ability. Compared with neuropsychological tests, eye movements were more likely to be markedly impaired in PCS cases with high symptom load. Poorer eye movement function, and particularly poorer subcortical oculomotor function, correlated more with post-concussive symptom load and problems on activities of daily living whilst poorer neuropsychological function exhibited slightly better correlations with measures of mental health. Our findings that eye movement function in PCS does not follow the normal recovery path of eye movements after mCHI are indicative of ongoing cerebral impairment. Whilst oculomotor and neuropsychological tests partially overlapped in identifying impairment, eye movements showed additional dysfunction in motor/visuospatial areas, response inhibition, visual attention and subcortical function.

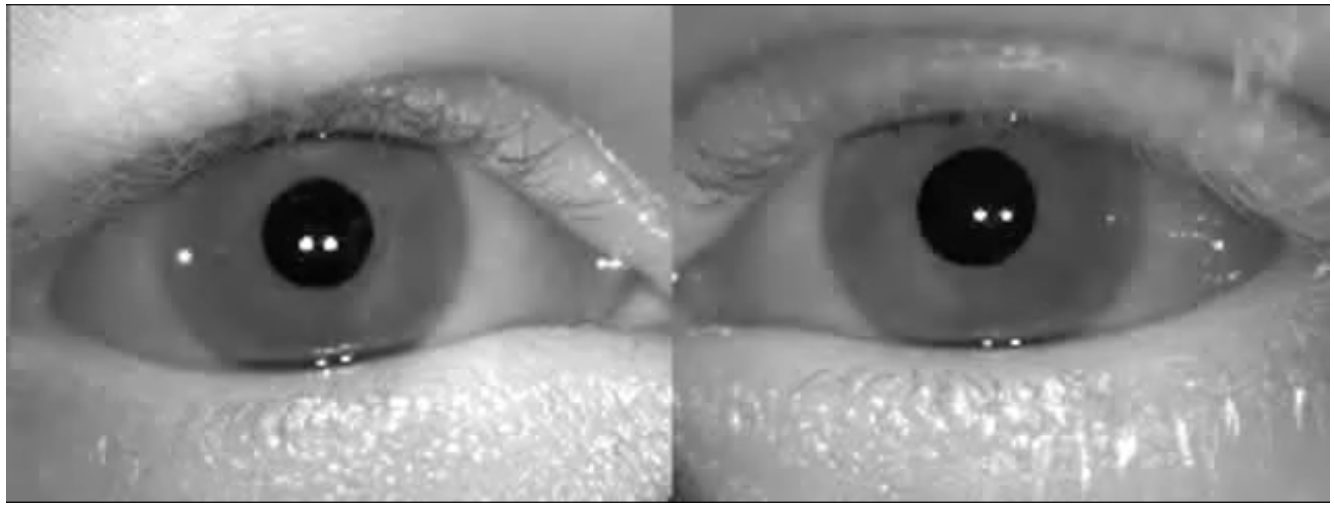
doi:10.1093/brain/awp181 Brain 2009: 132; 2850–2870 | 2850

BRAIN
A JOURNAL OF NEUROLOGY

Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability

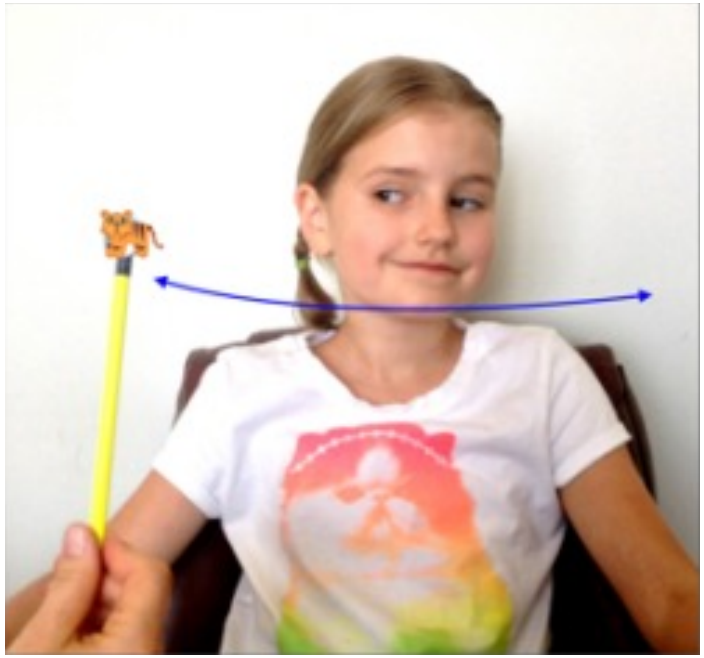
Marcus H. Heitger,[1,2] Richard D. Jones,[1,2,3] A. D. Macleod,[4] Deborah L. Snell,[4] Chris M. Frampton[1] and Tim J. Anderson[1,2,5]

What Do Impaired Eye Movements Look Like?



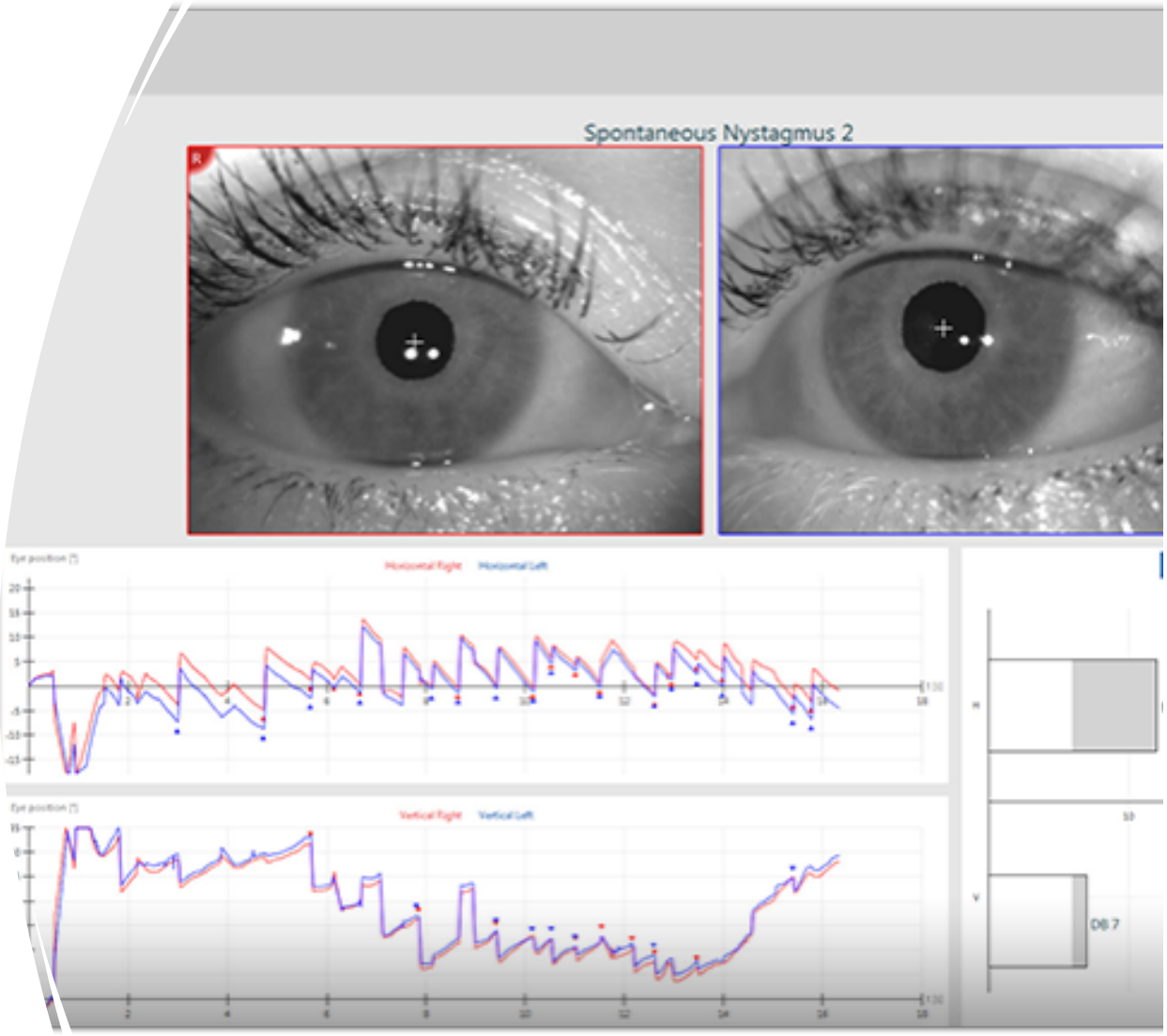
20yo male with post-concussion syndrome, performing a smooth pursuit test using infra-red camera goggles – VNG (video nystagmography)

How Do We Assess Eye Movements?



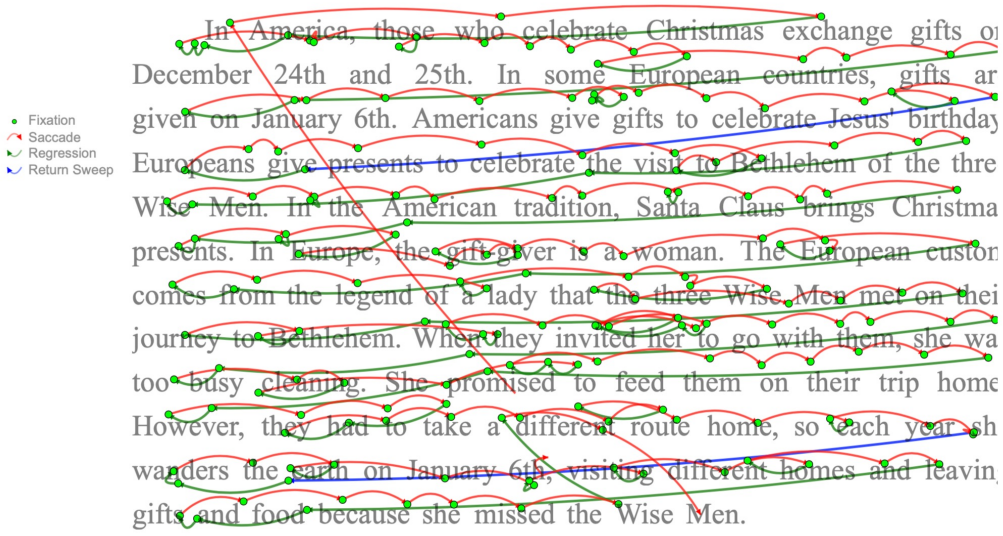
Eye-Tracking Technology vs Observation

"Most saccadic and pursuit deficits may be missed during clinical examination, and therefore eye tracking technology may be a useful and sensitive screening and monitoring tool for sports-related concussions"



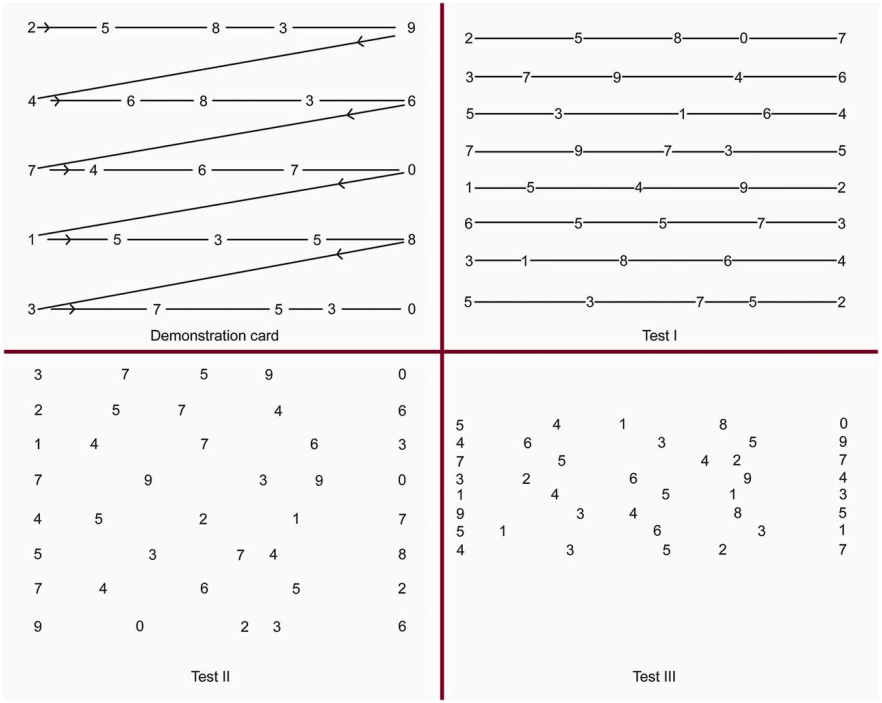
Snegireva *et al*. Eye tracking technology in sports-related concussion: a systematic review and meta-analysis. Physiol Meas. 2018 Dec 21;39(12)

Eye Tracking When Reading



In America, those who celebrate Christmas exchange gifts on December 24th and 25th. In some European countries, gifts are given on January 6th. Americans give gifts to celebrate Jesus' birthday. Europeans give presents to celebrate the visit to Bethlehem of the three Wise Men. In the American tradition, Santa Claus brings Christmas presents. In Europe, the gift-giver is a woman. The European custom comes from the legend of a lady that the three Wise Men met on their journey to Bethlehem. When they invited her to go with them, she was too busy cleaning. She promised to feed them on their trip home. However, they had to take a different route home, so each year she wanders the earth on January 6th, visiting different homes and leaving gifts and food because she missed the Wise Men.

Other Assessments for Eye Movements



VOMS Test	Headache[a]	Dizziness[a]	Nausea[a]	Fogginess[a]	Total Symptom Score[b]
Baseline symptoms					
Smooth pursuit					
Horizontal saccades					
Vertical saccades					
Near point convergence Measure 1: _____ Measure 2: _____ Measure 3: _____					
Horizontal VOR					
Vertical VOR					
Visual motion sensitivity					

Galetta *et al.* The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. J Neurol Sci. 2011 Oct 15;309(1-2):34-9.

Mucha *et al*. A Brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. Am J Sports Med. 2014

What are the Treatment Options?

Treatment is ALWAYS based on

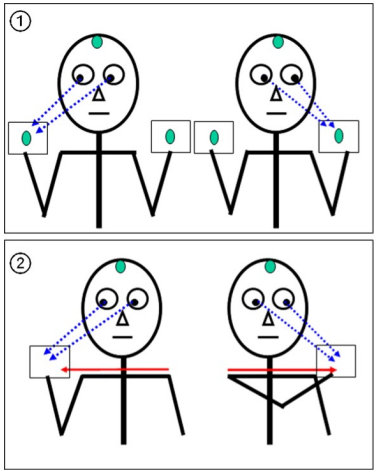
1. Assessment results
2. Patient goals

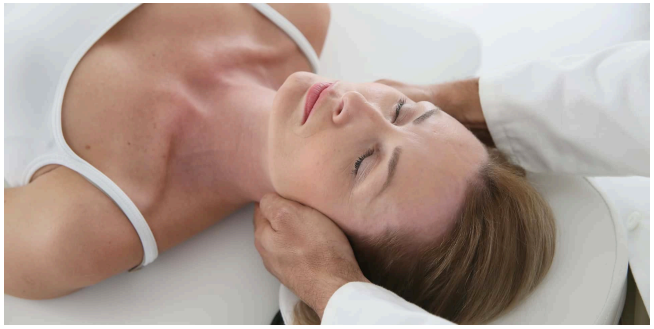
It's not based on condition, nor a set of standardized set of exercises or therapy

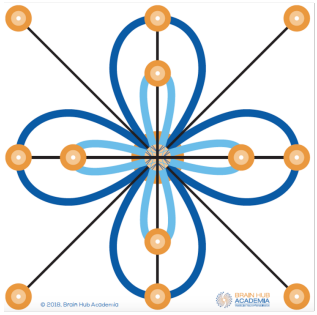
Ensure program is **"progressive, graded and engaging"**

Consider metabolic capacity (fatigue, level of function, lifestyle) *"titrate therapy"*

What are the Treatment Options?







Love your brain

Thank you

carlo@brainhub.com.au

BRAIN HUB
Dizziness & Concussion Clinic