

St. Joseph's Health Orthopedic & Spine Care Sports Medicine Series

Sports-Related Concussions (SRC)

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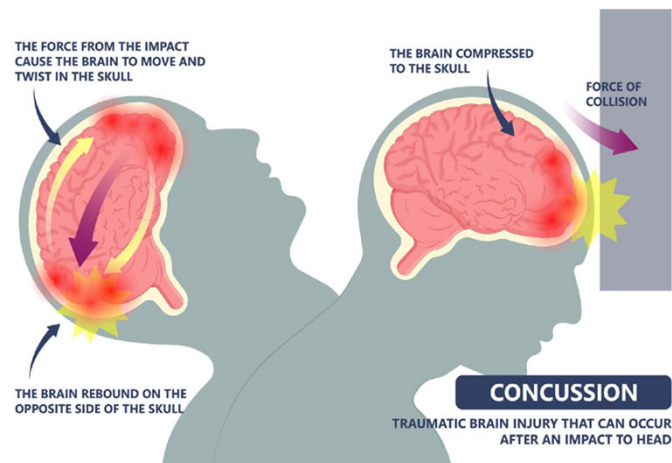
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Concussion Introduction

Concussions are a type of mild traumatic brain injury (mTBI).

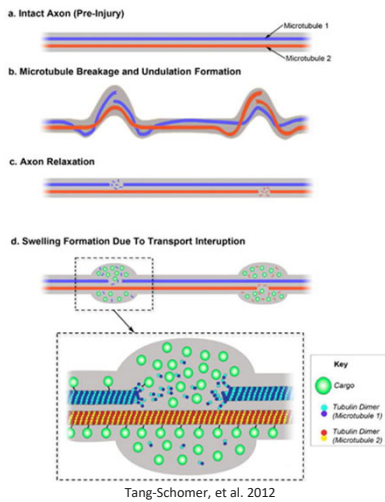
- Results from **direct or indirect** forces to the head or body, that cause the brain to move rapidly within the skull.
- Produces a pathophysiological process that affects brain function without evidence of structural injury on routine neuroimaging



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Concussion - Pathophysiology

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- Biomechanical force produces an injury to nerve axons, known as Diffuse Axonal Injury (DAI)
- Microtubule damage leads to transport interruption and varicosity formation
- At the same time, Ca^{2+} rushes in and triggers enzymes that break down structures further
- DAI damages the myelin sheath, which is why getting another concussion before the brain has healed can cause much more serious injury.

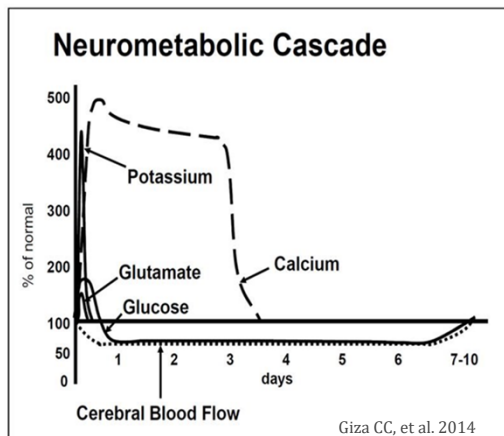
BOTTOM LINE

DAI causes biomechanical AND biochemical effects that impairs nerve signaling and weakens the nerve infrastructure, predisposing it to further injury if impacted again before it is fully healed

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Concussion - Pathophysiology

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- DAI sets off a **Neurometabolic Cascade**
 - Efflux of K^{+}
 - Influx of Ca^{2+}
 - Excessive Glutamate Release "Glutamate Storm"
- Neuronal depolarization and ionic gradient shifts
- Triggers the upregulation of the $\text{Na}^{+}, \text{K}^{+}$ -ATPase to restore ionic gradients
 - **Drastic increase in energy demand (glucose utilization)**
- Reduction in Cerebral Blood Flow

$$\uparrow \text{Glucose Demand} + \downarrow \text{Glucose Availability} + \downarrow \text{Cerebral Blood Flow} = \text{ENERGY MISMATCH}$$

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Concussion – Energy Mismatch & Symptoms

- Energy Mismatch & Dysfunction of the ANS
- MORE glucose/ATP (Energy) is needed to do the same workload while also trying to heal neurons and restore function
- BUT...Cerebral Blood Flow (which carries the glucose to the neurons) is also **REDUCED**
- This results in an **ENERGY MISMATCH**

$$\begin{array}{ccccccc} \uparrow & \text{Glucose} & + & \downarrow & \text{Glucose} & + & \downarrow & \text{Cerebral Blood} & = & \text{ENERGY} \\ & \text{Demand} & & & \text{Availability} & & & \text{Flow} & & \text{MISMATCH} \end{array}$$



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The Concussed Brain Needs More Fuel While Receiving Less Fuel

Healthy Brain

Needs 100 units of energy



Receives 100 units of energy



Everything works normally

Concussed Brain

Needs 150 units of energy to repair itself



Receives only 70 units
(because cerebral blood flow is reduced)



Result = Energy Deficit



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The Vestibular System & Concussion

What is the Vestibular System?

The vestibular system helps maintain balance, spatial awareness, and coordination

It integrates information from:

 **Eyes (visual system)**

 **Inner ear balance organs**

 **Proprioceptors** in muscles and joints that sense body position

Together, these systems help us stay upright, move efficiently, and keep our eyes focused during head movement.

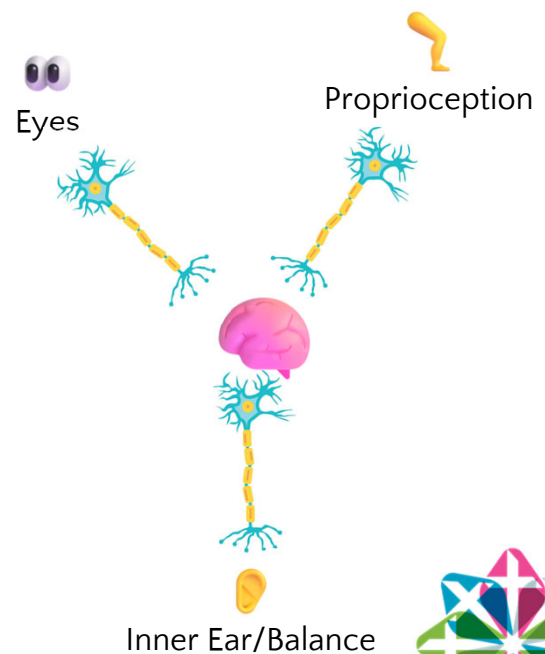


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The Vestibular System & Concussion

How Does a Concussion Affect the Vestibular System?

- Concussion disrupts the pathways that process vestibular information (e.g., Diffuse axonal injury)
- The brain receives **incorrect or poorly coordinated signals** from the eyes, inner ear, and body
- This **sensory mismatch** impairs balance, gaze stability, and motion processing.



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The Vestibular System & Concussion

Common Vestibular Symptoms

- Dizziness
- Feeling off-balance or unsteady
- Vertigo (spinning sensation)
- Motion sensitivity
- Blurred vision with movement
- Difficulty focusing or tracking objects
- Nausea
- Exercise intolerance

Vestibular Structures

HIGHLY metabolically active and dependent on a continuous ATP supply

Cerebellar and Brainstem Impact

Micro-dysfunction in the cerebellum & insular cortex can delay rapid postural adjustments and spatial orientation



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The Pathophysiology of Concussion

Take Home Points:

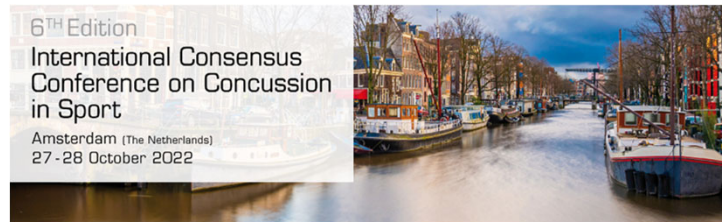
- Concussions result from forces that damage neurons: **Diffuse Axonal Injury (DAI)**
- DAI creates a physical and biochemical disruption in neural pathways
- **Cerebral blood flow is reduced** = reduced delivery of ATP needed for efficient signal transduction
- The healing process requires more ATP than it receives from the bloodstream
- The **energy mismatch** leads to uncoordinated or missing signals from vestibular organs, cerebellum and insular cortex, and proprioceptors in the peripheral nervous system, coupled with delayed healing



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Principles of Concussion Care: Consensus Statement on Concussion in Sport 2022

The 2022 Consensus Statement on Concussion in Sport summarizes the most recent guidelines developed by international experts at the 6th Concussion in Sport Group conference (Amsterdam)



- Introduced modernized assessment tools (Adult & Child SCAT6/SCOAT6)
- Emphasized active, sub-symptom aerobic recovery over strict rest



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Recognizing Concussions

Common Signs and Symptoms

What You (or a parent) Observe

- Appears dazed, stunned, or confused
- Difficulty remembering events before or after the injury
- Forgets instructions or seems disoriented
- Answers questions slowly
- Moves clumsily or appears unsteady
- Personality, mood, or behavior changes
- Loss of consciousness

What the Athlete Reports

- Headache, dizziness, nausea
- Light/noise sensitivity
- Fatigue
- Brain fog or difficulty concentrating
- Memory difficulties
- Anxiety, irritability, sadness
- Sleep disturbances

Clinical takeaway: Symptoms can be vague, underreported, may appear immediately or develop over hours to days

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Recognizing Concussions: Diagnostic Challenges

Symptoms are subjective & can be subtle and non-specific

Variability in presentation

Pediatric patients can have a difficult time describing symptoms

Signs & symptoms can be delayed and take minutes-to-days to present

Pre-existing factors can affect symptoms & testing

- Migraines/chronic headaches
- Learning disorders (ADHD, dyslexia, etc.)
- Mood disorders (anxiety, depression, bipolar, etc.)
- Prior concussions (Total #, time since last, recovery time)
- Other comorbidities in elderly patients that affect cognition, balance, sleep, etc.

BOTTOM LINE

Diagnosis may require a high index of suspicion

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Recognizing Concussions: Diagnostic Challenges

Concussion is a Multifaceted Injury

- **Affects multiple domains simultaneously — not a single-system injury:**

Cognition

Balance

Vestibular / Eye Movements

Reaction Time

Mood

Sleep

Autonomic Function

- **Presentation varies by athlete** — one may be primarily cognitive; another may look cognitively normal but have an undetected balance/vestibular deficit
- **Single-domain tests miss other domains** — e.g., a cognitive test won't catch a balance problem, and a symptom checklist won't confirm neurological recovery

BOTTOM LINE

A valid assessment must be a multi-domain battery — testing one domain is a piece of a protocol, not the full evaluation.

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Concussion Assessment

No single tool covers every domain — a full evaluation draws from each category.

AUC (Area Under the ROC Curve)

- Test accuracy
- Ranges from 0.5 (no better than chance) to 1.0 (perfect discrimination)

Sideline / Acute / Subacute Screening

SCAT6 — gold standard; symptoms + SAC + mBESS; ~10 min

SCOAT6 — office follow-up version, >72 hrs post-injury

Symptom scale (PCSS) likely the most useful component (AUC 0.80)

King-Devick: Quick oculomotor/reading-based screen; weaker as a standalone diagnostic.

Computerized Neurocognitive Testing

Tracks recovery against a baseline; poor at diagnosing. To be used as adjunct, not standalone

ImPACT — most widely used; memory, processing speed, reaction time

Individual cognitive composites have limited discriminative value

Vestibular-Oculomotor Assessment

VOMS — pursuits, saccades, convergence, VOR, visual motion sensitivity

- Largest effect size of any exam tool
- Only tool adding diagnostic value beyond symptoms alone (AUC 0.85)

BESS/mBESS — Measures postural stability; adjunct tool

Exercise Tolerance / Physiological Recovery

Buffalo Concussion Treadmill Test (BCTT) — graded exercise test

- Assesses autonomic / cerebral blood flow regulation via symptom-onset HR threshold
- 94% sensitivity / 95% specificity; reflects physiological, not vestibular-oculomotor, recovery

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TOOL COMPARISON

SCAT6 vs. SCOAT6: Two Tools, Two Phases

Complementary tools for different windows of concussion assessment.

AUC (Area Under the ROC Curve)

- Test accuracy
- Ranges from 0.5 (no better than chance) to 1.0 (perfect discrimination)

SCAT6

ACUTE · SIDELINE / FIELD

Timing & Setting

Sideline or field, within 72h of injury

Purpose

Initial recognition: determines if a concussion occurred, screens red flags (GCS <15, C-spine injury, LOC), guides removal from play

Scope

Symptom checklist, Maddocks questions, SAC, cervical spine screen, coordination, mBESS balance testing

SCOAT6

SUBACUTE · OFFICE-BASED

Timing & Setting

>72h post-injury (typically 3–30 days); used to monitor recovery

Purpose

Identifies deficits amenable to rehab and tracks recovery over time via serial use

Scope

Adds VOMS, cervical/neuro exam, autonomic testing, GAD-7 / PHQ-2, sleep screen, concussion & MH history, graded exercise test

Clinical takeaway: Symptom scores, tandem gait & VOMS best separate concussed athletes from controls (AUC 0.73–0.91); verbal cognition, orthostatic vitals & clinical balance are less useful but can be adjuncts (AUC <0.70).

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SUPPORTING TOOLS

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Adjuncts — Track Recovery, Not Stand-Alone Diagnosis

Neurocognitive Testing

ImPACT, CogState, ANAM. Best used against a pre-season baseline to track recovery over time.

BESS (Balance Error Scoring System)

Quick postural-stability check. One input among several — not diagnostic alone.

King-Devick Test

Rapid oculomotor/reading-speed screen. Fast sideline adjunct; weaker as a stand-alone test.

Why these aren't first-line...

Each captures one domain (cognition, balance, or eye movement) in isolation.

Strongest role: monitoring an individual athlete's recovery trajectory against their own baseline — not confirming or ruling out a concussion by itself.



Diagnostic Tools for Sport-Related Concussion

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Key Takeaways

AUC (Area Under the ROC Curve)

- Test accuracy
- Ranges from 0.5 (no better than chance) to 1.0 (perfect discrimination)

SCAT — Diagnostic OR of 31.65

- Odds Ratio 31.65 — shows how much better a test is at telling concussion apart from no concussion.
- The SCAT's high OR means it outperforms any other single tool.

VOMS — AUC of 0.85

AUC (Area Under the Curve) shows how accurate a test is, from 0.5 (a coin flip) to 1.0 (perfect). VOMS, an eye-movement and balance test, scores 0.85 — the highest of any single exam tool.

REMEMBER

- How you feel matters as much as any test score -> Track symptom scores
- No single test can prove — or rule out — a concussion by itself
- A pre-season baseline test usually will not change how your concussion is diagnosed

BOTTOM LINE

SCAT6 (acute) and SCOAT6 (subacute) have the strongest sport-concussion-specific validation. All other tools work best as components of a multimodal battery rather than standalone tests. The use of adjunct testing can help in tracking recovery

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Vestibular Ocular Motor Screening (VOMS)

Smooth Pursuits (10 reps)



Repetitive Saccades (30 reps)



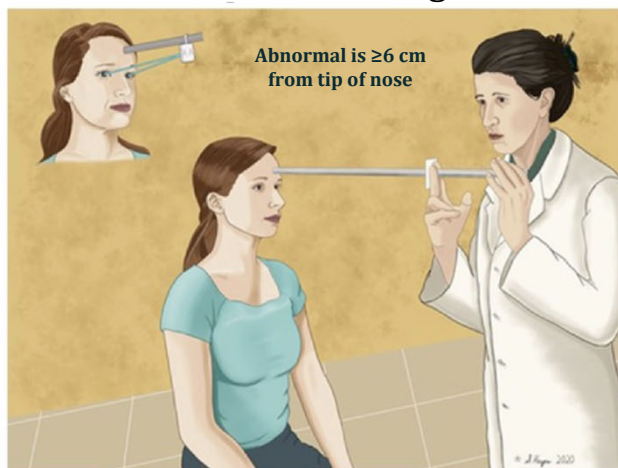
Symptom provocation (headache, dizziness, nausea, fogginess, eye strain, etc.) is recorded after each task.



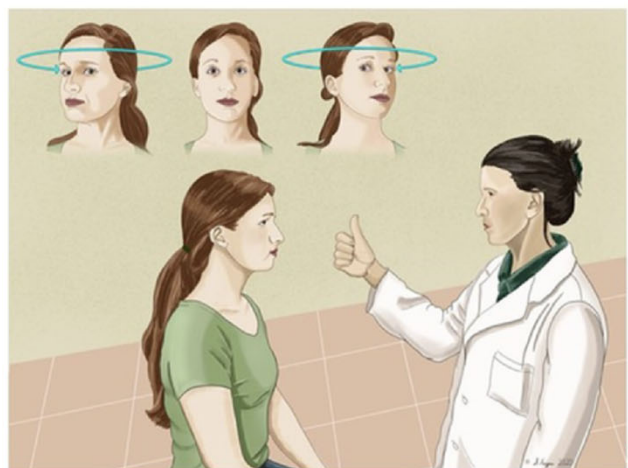
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Vestibular Ocular Motor Screening (VOMS)

Near Point Convergence



Vestibular-Ocular Reflex (10 reps)



Symptom provocation (headache, dizziness, nausea, fogginess, eye strain, etc.) is recorded after each task.



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Additional Components of the Physical Exam

- Tandem walk/stance
- Head & C-spine assessment
- Cranial Nerves (if indicated)
- Orthostatic Intolerance
 - Defined as a *symptomatic* HR increase of at least 30 bpm in adults and 40 bpm on adolescents when transitioning from supine to standing



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Symptom Checklist: Post-Concussion Symptom Score (PCSS)

- The most widely used concussion symptom inventory worldwide
- 22-item measure with each symptom scored on a 7-point Likert scale
- PCSS is more sensitive and specific when compared to balance and neurocognitive examination
 - The PCSS does 'return to normal' prior to full metabolic/functional brain recovery – it does not coincide with recovery (Barr et al.)
- Can help account for pre-existing/co-existing conditions
 - Migraines/chronic headaches
 - Mood disorders
 - Learning disorders



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Symptom Checklist: Post-Concussion Symptom Score (PCSS)



A Member of Trinity Health

St. Joseph's Health Sports Medicine
Sports-Related Concussion Clinic
Post-Concussion Symptom Scale (PCSS)

Name: _____

Date of Injury: _____

- PCSS is useful in diagnosis (AUC 0.80)
- Have the athlete fill out daily
- Recording before and after exertion can help with tracking exercise tolerance
- Adjunct to help track recovery

SYMPTOMS	DATE:	DATE:	DATE:	DATE:
Headache	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Nausea	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Vomiting	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Balance problems	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Dizziness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Fatigue	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Trouble falling to sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Excessive sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Loss of sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Drowsiness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Light sensitivity	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Noise sensitivity	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Irritability	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Sadness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Nervousness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
More emotional	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Numbness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Feeling "slow"	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Feeling "foggy"	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Difficulty concentrating	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Difficulty remembering	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Visual problems	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
TOTAL SCORE				

Use of the Post-Concussion Symptom Scale: The athlete should fill out the form, on his or her own, to give a subjective value for each symptom. This form can be used with each encounter to track the athlete's progress towards the resolution of symptoms. Many athletes may have some of these reported symptoms at a baseline, such as concentration difficulties in the patient with attention-deficit disorder or sadness in an athlete with underlying depression and must be taken into consideration when interpreting the score.



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Principles of Concussion Care

- Early, aerobic exercise rather than prolonged rest - No "cocooning"
- "Aerobic activity prescription at an intensity below the threshold that would cause more-than-mild exacerbation of concussion symptoms"
 - >2 points on a 0–10 symptom severity scale compared to baseline
- A BCTT can determine HR threshold to guide the aerobic activity prescription
- If formal exercise testing is unavailable, initiate a light aerobic activity (e.g., walking) at approx. 50% of the patient's age-predicted maximum heart rate (220 - age), starting **within 24 -72 hours after injury, even if the patient remains mildly symptomatic**
- RCTs have demonstrate that this approach leads to faster recovery and a lower risk of persistent symptoms compared to strict rest or placebo-like stretching.
- Vestibular therapy for persistent vestibular symptoms past 4 weeks



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Return-to-Sport (RTS) Protocol			St. Joseph's Health Sports Medicine
STEP	EXERCISE STRATEGY	ACTIVITY AT EACH STEP	GOAL
1	Symptom-limited activity	Daily activities that do not exacerbate symptoms (e.g., walking).	Gradual reintroduction of work / school
2	Aerobic exercise 2A — Light ($\leq 55\%$ maxHR) 2B — Moderate ($\leq 70\%$ maxHR)	Stationary cycling or walking at slow to medium pace. May start light resistance training that does not result in more than mild and brief exacerbation* of symptoms.	Increase heart rate
3	Individual sport-specific exercise	Sport-specific training away from the team environment (e.g., running, change of direction, and/or individual training drills). No activities at risk of head impact. Note: If sport-specific training risks inadvertent head impact, medical clearance should occur prior to Step 3.	Add movement, change of direction
Steps 4–6 begin only after resolution of symptoms, abnormalities in cognitive function, and other clinical findings related to the current concussion — including after physical exertion.			
4	Non-contact training drills	Exercise to high intensity, incl. more challenging training drills (e.g., passing drills, multiplayer training) integrated into a team environment.	Resume usual intensity, coordination & increased thinking
5	Full contact practice	Participate in normal training activities.	Restore confidence and assess functional skills by coaching staff
6	Return to sport	Normal game play.	Return to competition
* Mild and brief exacerbation of symptoms: A symptom increase of no more than 2 points (0–10 scale) lasting less than an hour, compared to baseline. Athletes may start Step 1 after 24 hours of symptom-limited activity, and each later step also requires at least 24 hours. Exceeding this during Steps 1–3 means stopping and retrying the next day; during Steps 4–6, return to Step 3 until symptoms fully resolve with exertion. A healthcare professional should confirm RTS readiness, per local laws and sporting regulations. Patricios JS, Schneider KJ, Dvorak J, Ahmed OH, Blauwet G, Carlu RG, Davis GA, Echemendia RJ, Makdissi M, McNamee M, Broglio S, Emery CA, Feddermann-Demont N, Fuller GW, Giza CC, Guskiewicz KM, Hairline B, Iverson GL, Kutcher JS, Laddy JJ, Maddocks D, Marley G, McCrea M, Purcell LK, Putukian M, Sato H, Tuominen MP, Turner M, Yates KO, Herring SA, Meeuwisse W. Consensus statement on concussion in sport: the 6th International Conference on Concussion in Sport—Amsterdam, October 2022. Br J Sports Med. 2023 Jun;57(11):695-711. doi: 10.1136/bjsports-2023-106898. PMID: 37316210.			

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Buffalo Concussion Treadmill Test (BCTT)	
Overview - Graded exercise test to assess exercise tolerance after concussion - Monitors symptoms and heart rate continuously during incremental exercise - Test ends when symptoms worsen by >2 points (0–10 scale) above resting level or at maximal exertion - The heart rate at symptom exacerbation = heart rate threshold (HRT)	
Clinical Uses Diagnosis: 94.4% sensitivity, 94.6% specificity for sport-related concussion when performed within 14 days of injury Exercise prescription: HRT guides individualized sub-symptom threshold aerobic exercise (80% of HRT, 20 min/day, 5–6 days/week) Prognosis: ΔHR (HRT minus resting HR) ≤ 50 bpm predicts prolonged recovery (>30 days) Recovery marker: Normal exercise tolerance on BCTT supports physiological recovery and return-to-play decisions	
Key Evidence RCT: Early aerobic exercise → median recovery 13 days vs. 17 days with stretching ($p=0.009$) Fewer persistent symptoms at 28 days with exercise (21% vs. 32%, $p=0.04$)	
Practical Considerations - Endorsed by If treadmill unavailable: prescribe exercise at 50% of age-predicted max HR ($220 - \text{age}$) - AMSSM, particularly for persistent post-concussive symptoms	

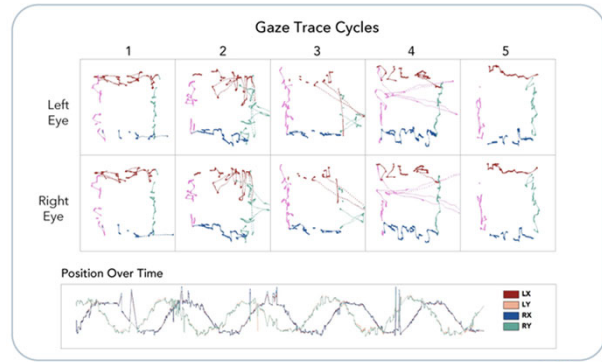
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Concussion Biotechnology & Research

Oculogica's EyeBOX



- FDA-cleared, non-invasive device that uses eye-tracking technology to aid in the diagnosis of concussions.
- It's a four-minute test that doesn't require a pre-injury baseline
- Helps identify subtle changes in eye movements associated with concussions.
- Individuals aged 5 to 67



EyeBOX
A visionary breakthrough in
concussion diagnosis.

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Concussion Biotechnology & Research

Salivary microRNAs

- Marker for both acute and prolonged concussion
- For acute concussion, large-scale studies in athletes have identified panels of salivary miRNAs that can accurately differentiate concussed individuals from controls, with high diagnostic accuracy (AUC > 0.9) at various time points post-injury, including immediately and up to 48 hours after the head injury.



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Questions?

Contact Information

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Return to Physical Activity Following Concussion			
Football			
Stage	Activity	Football Specific Exercise	Objective of the Stage
1	No physical activity; Complete physical and cognitive rest	No activity	Recovery and elimination of symptoms
2	Light aerobic activity	10-15 min of walking at home or at field, or stationary bike 20-30 min jogging w/helmet	Add light aerobic activity and monitor for symptom return
3	Moderate aerobic activity Light resistance training	Resistance training -body weight squats and push-ups 1 set of 10 reps each	Increase aerobic activity and monitor for symptom return
4	Non-contact football-specific drills	- Moving in/out 3 point stance, bear crawls through tunnel, tires, step over bags (vertical and lateral), QB/center exchange, QB drop backs, passing, break downs and plant, jump cuts, backpedaling, match the hips, up/downs *Start w/o helmet; progress to helmet and shoulder pads if symptom free	- Maximize aerobic activity - Accelerate to full speed with change of directions (cuts) - Introduce rotational head movements - Monitor for symptoms
5	Limited contact football drills	- Stage 4 workout in full pads - Hit/push pads then sled (focus on technique-head up, square up, stay low), step and hit, run and hit, leverage drill, punch drill	- Maximize aerobic activity - Add deceleration/rotational forces in controlled setting - Monitor for symptoms
6	Full contact practice (after medical clearance)	Normal training activities	- Reassess for symptoms every 30 minutes throughout the practice - Monitor for symptoms
7	Return to play	Normal game play	- Assess frequently - Monitor for symptoms - Consider one side of the ball only, no special teams play
- Progress to the next stage may occur every 24 hours as long as symptoms do not return. - It is recommended that you seek further medical attention if you fail more than 3 attempts to pass a stage			



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