MAYO CLINIC

CONCUSSION & VESTIBULAR ISSUES

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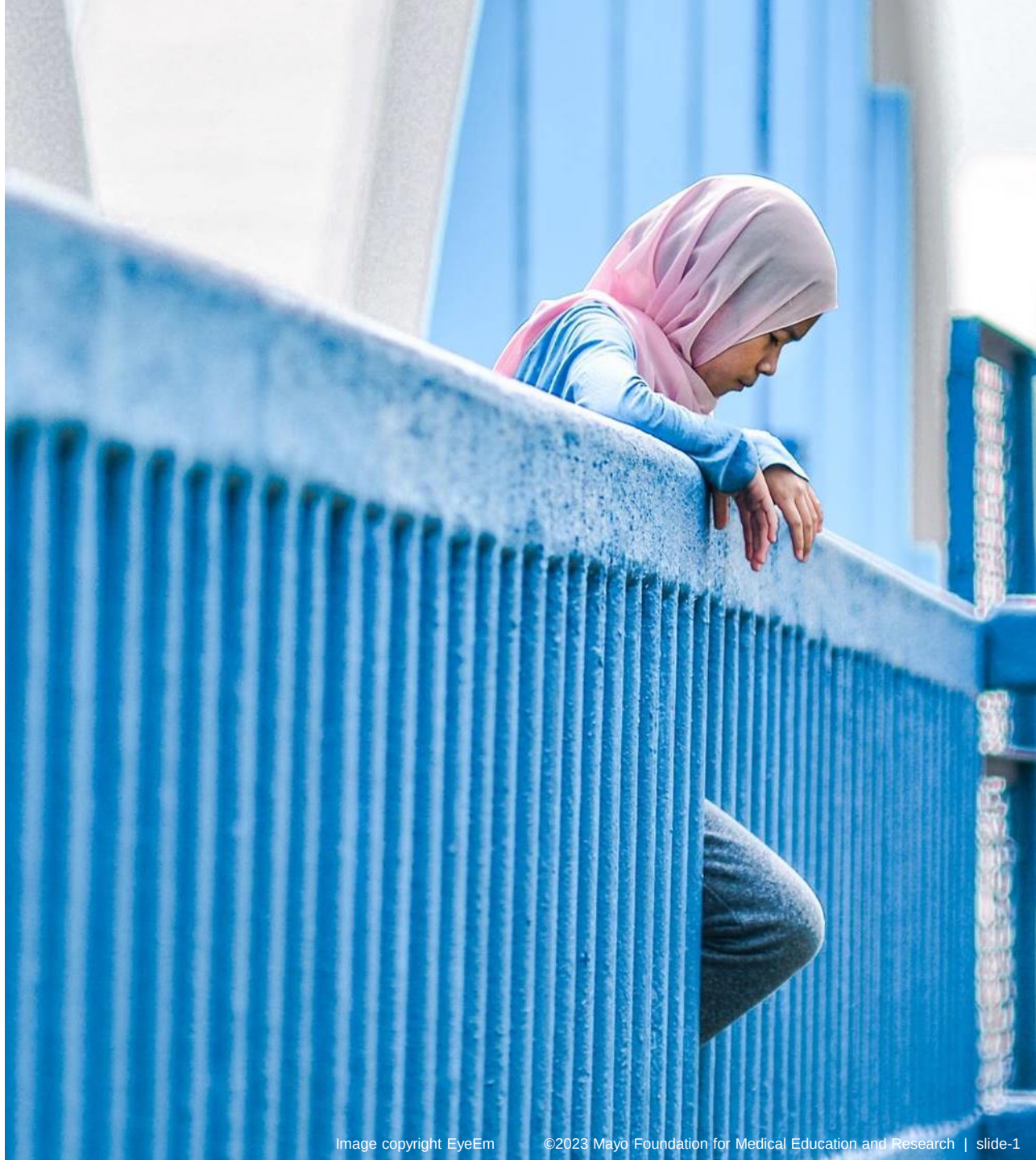
12 October 2023



DISCLOSURES

- Relevant financial disclosures: none
- Off-label investigational use: none
- Employed at Mayo Clinic Arizona
- Non-salaried faculty at the University of Colorado at Boulder, Gallaudet University, Salus University, Missouri State University
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LEARNING OBJECTIVE

1. To discuss the relevance of vestibular testing post-concussion
2. To review relevant vestibular laboratory results
3. To discuss next steps regarding concussion testing protocol and management

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CONCUSSIONS

CONCUSSION OVERVIEW

- Sport-related concussion is a significant public health concern.
- Professional / collegiate athletes recover in 7-10 days – maybe
- Pediatric patients take longer, 21-59% may take >1 month
  - Associated symptoms include anxiety, depression, migraine, reduced school performance

Babcock et al 2013; Barlow et al 2010; Casson et al 2010; Grubenhoff et al 2014; Guskiewicz et al 2003; Guskiewicz et al 2001; Leddy et al 2010; McCrea et al 2003; Meehan & Mannix 2010; Sady et al 2011; Willer & Leddy 2006; Yeates et al 1999

COMMON CONCUSSION SYMPTOMS

Physical	Headache Head pressure Slow to get up Balance problems Nausea, vomiting Dizziness Blurred vision Light / noise sensitivity
Cognitive	Feeling mentally foggy Feeling slowed down “Don’t feel right” or “feeling off” Drowsiness Dazed / confused Poor concentration Difficulty remembering Vacant look
Emotional	Irritability Sadness More emotional Anxiety

CONCUSSION OVERVIEW

- Vestibular / oculomotor system impairments are common and debilitating: dizziness, vertigo, fogginess, motion sensitivity, imbalance, gaze instability, blurry vision, diplopia
- 50-90% of adults
- 29-63% of pediatric patients

Alsalaheen et al 2010; Alvarez et al 2012; Ciuffreda et al 2008; Ciuffreda et al 2007; Ellis et al 2015 Goodrich et al 2007; Gottshall & Hoffer 2010; Kapoor & Ciuffreda 2002; Thiagarajan et al 2011

DIZZINESS & CONCUSSION

DIZZINESS IS COMMON

Up to 81% demonstrate dizziness symptoms

DIZZINESS PREDICTS PROLONGED RECOVERY

Those with dizziness symptoms take **3x** longer to return to school and **4x** longer to return to play

Corwin et al 2015; Ellis et al 2017; Smulligan et al 2022

DIZZINESS & CONCUSSION

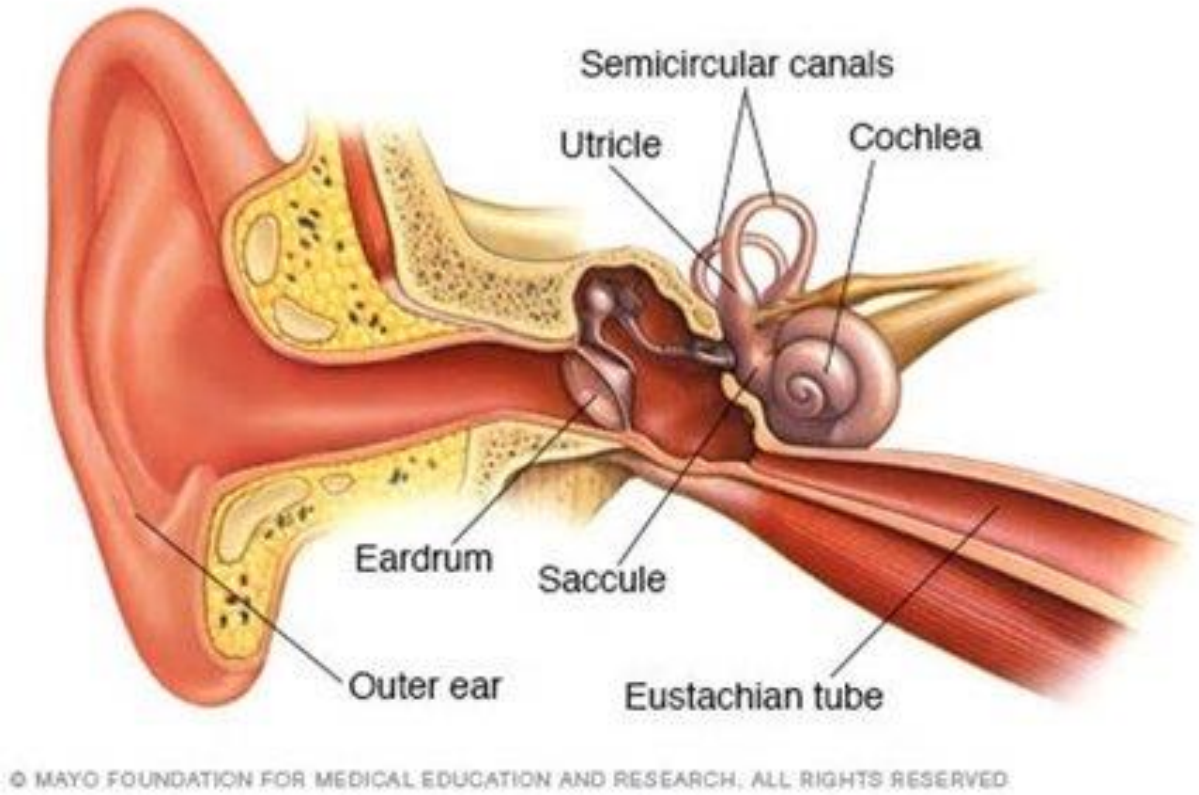
- Dizziness feels bad – address it quickly.
- Prolonged dizziness / imbalance?
  - Anxiety, depression
  - School accommodations, absences
  - General malaise
  - Lack of movement, exercise
  - Difficulty concentrating, remembering
  - Mental fogginess

Corwin et al 2015; Heyer et al 2018

WHAT DO YOU MEAN BY DIZZINESS?

- Vertigo
- Motion sickness, nauseous
- Imbalance
- Lightheaded

VERTIGO

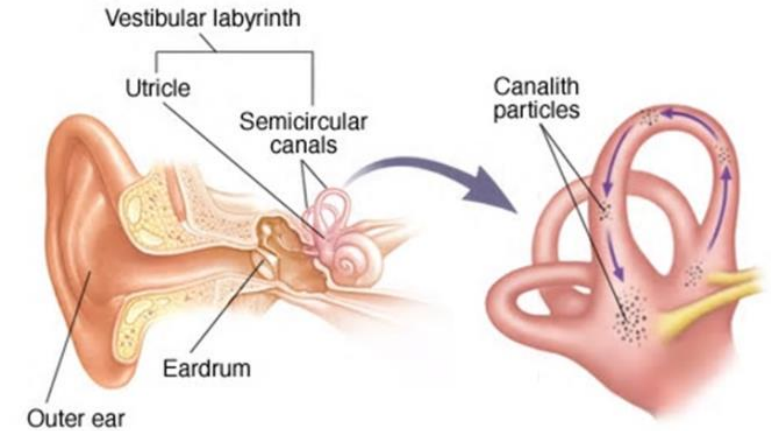


- Direct end organ injury
- BPPV
- Labyrinthine concussion
- Perilymph fistula
- Post-traumatic endolymphatic hydrops
- Superior semicircular canal dehiscence
- Otolith dysfunction
- Medication side effects

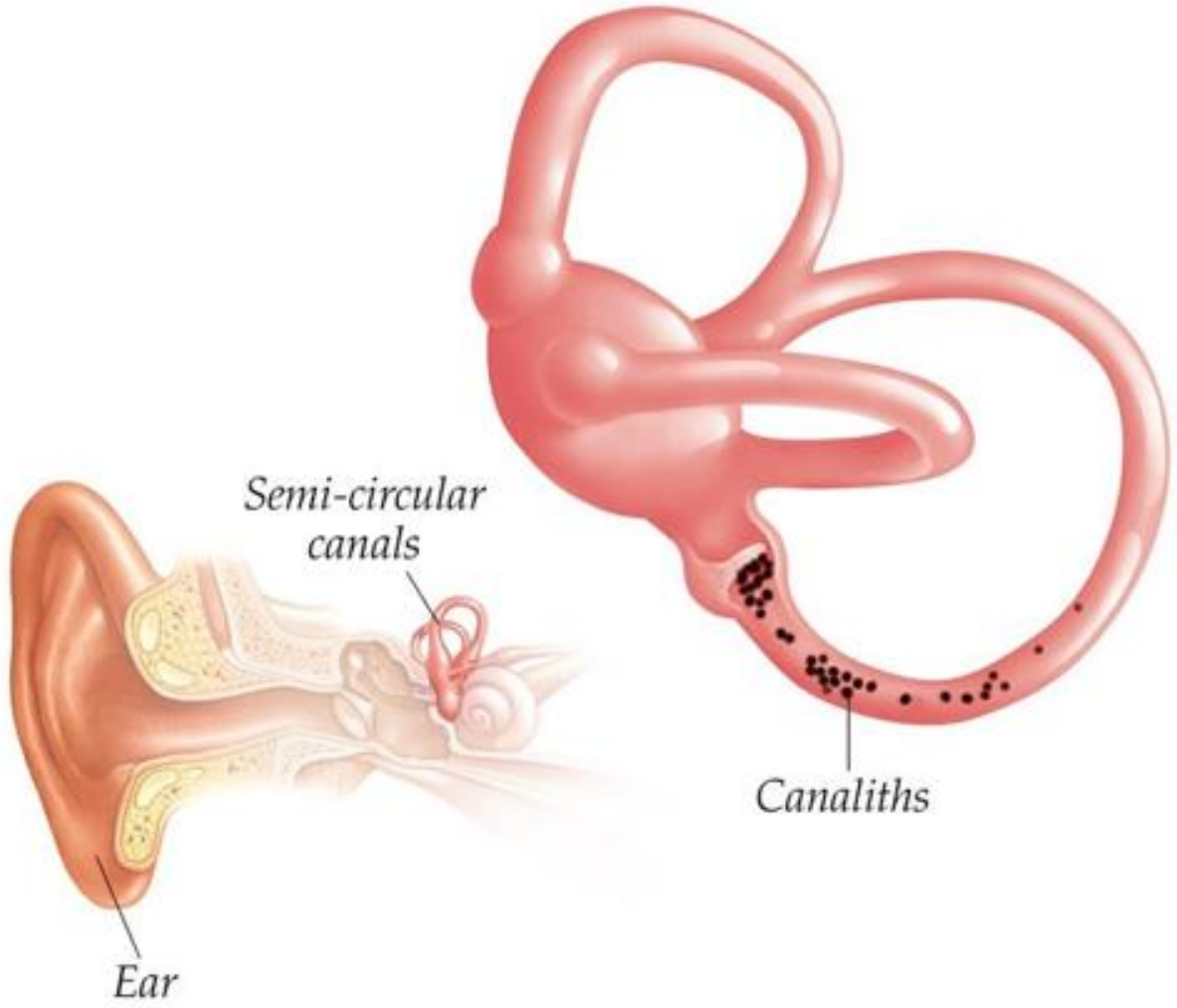
Ahn et al 2011; Barber 1964; Brodsky et al 2018; Davies & Luxon 1995; Gordon et al 2004; Hoffer et al 2004; Picciotti et al 2016; Reneker et al 2017; Telian & Shepard 1996

BENIGN PAROXYSMAL POSITIONAL VERTIGO

1. Debris from otolith (gravity sensor) is dislodged
2. Migrates to semicircular canal (spinning sensor)
3. Alters function of the spinning sensor – now sensitive to gravity
4. Abnormally triggers eye movement (nystagmus), spinning sensation with position change



Brodsky et al 2018; Gordon et al 2004; Motin et al 2005; Ouchterlony et al 2016



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BENIGN PAROXYSMAL POSITIONAL VERTIGO

- Short duration, intense vertigo occurring after a specific position change
- Post-concussion presentation
  - Pediatrics: 5-29%; increased risk in those with migraine history
  - Adults: 5-57%

Ahn et al 2011; Barber 1964; Brodsky et al 2018; Davies & Luxon 1995; Gordon et al 2004; Hoffer et al 2004; Picciotti et al 2016; Reimer et al; 2020; Reneker et al 2017; Telian & Shepard 1996; Wang et al 2021

Sport = 14
MVA = 4
Fall = 10

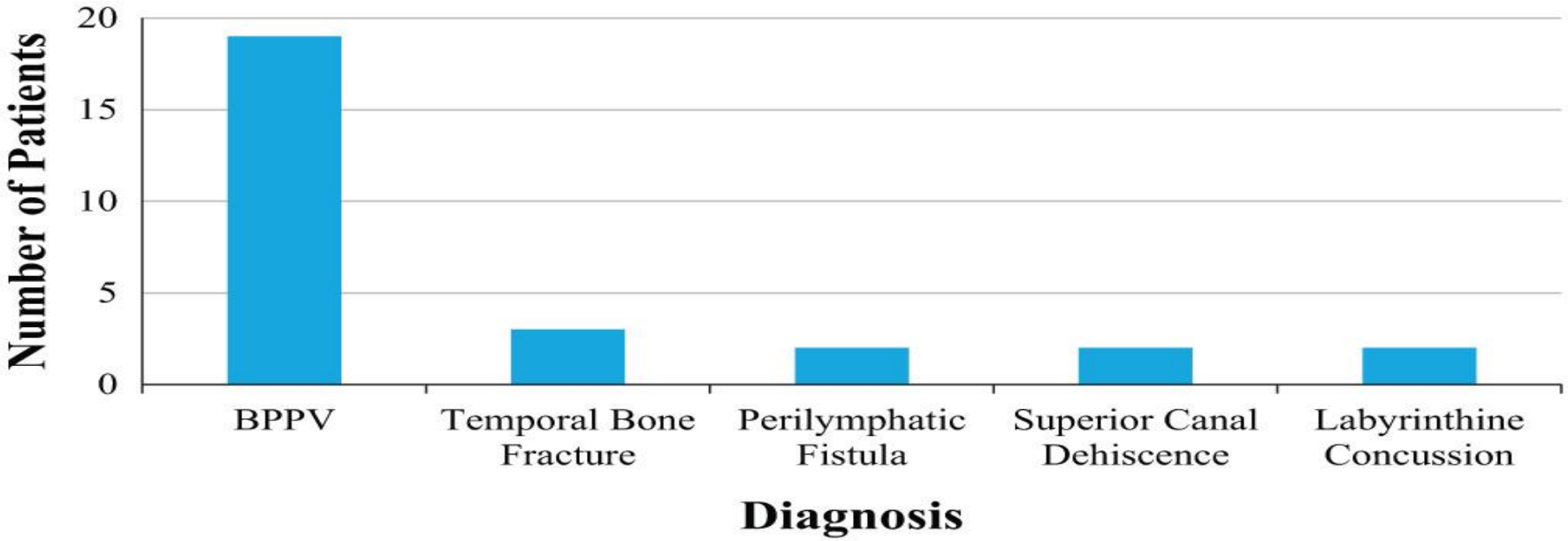
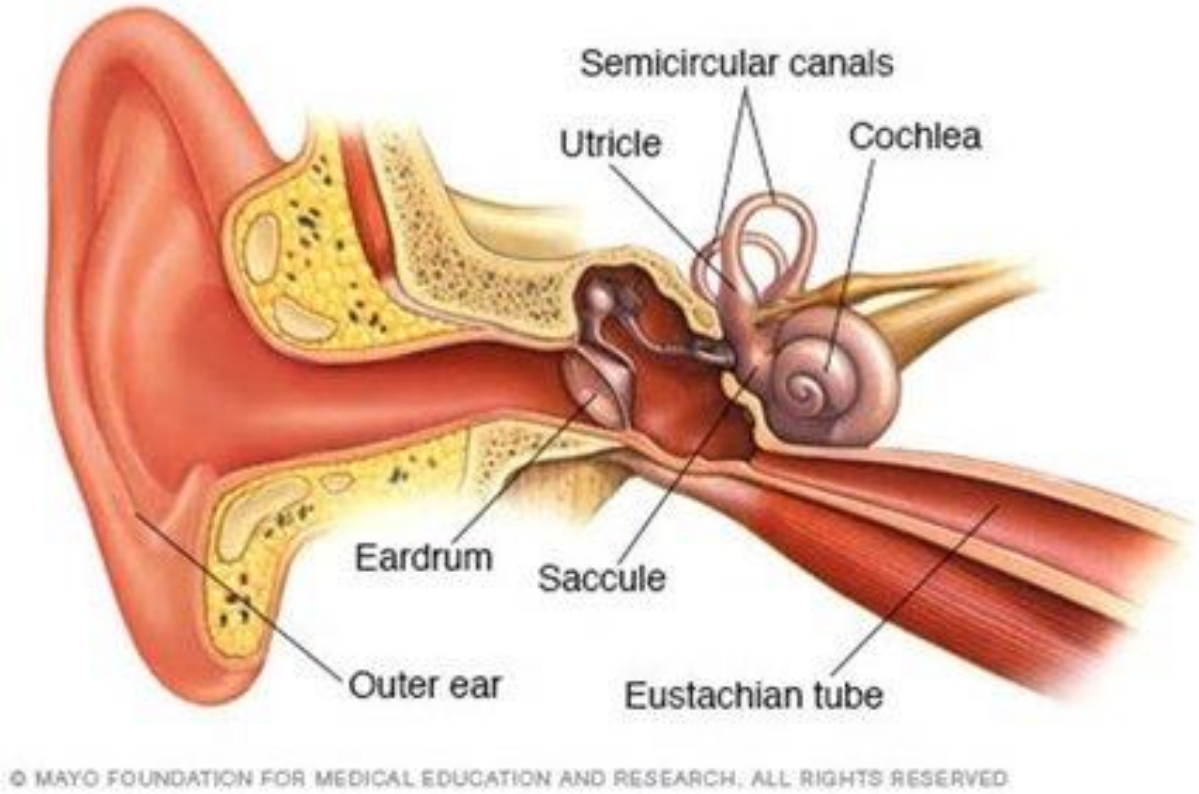


Figure 1. Peripheral vestibular disorders diagnosed in 28 patients in the setting of postconcussion syndrome in patients aged 7 to 20 years. BPPV, benign paroxysmal positional vertigo.

Published in: Jacob R. Brodsky; Talia N. Shoshany; Sophie Lipson; Guangwei Zhou; *Otolaryngol Head Neck Surg* 159, 365-370.
DOI: 10.1177/0194599818770618

VESTIBULAR SYSTEM PRESENTATION



- Abnormal vestibular testing (VOR)?
  - Commonly reported in earlier TBI / concussion literature
  - Up to 71%

Akin & Murnane 2011; Barber 1969; Basta et al 2005; Davies & Luxon 1995; Gannon et al 1978; Kay et al 1971; Linthicum & Rand 1931; Pearson & Barber 1973; Scherer et al 2011

VESTIBULAR SYSTEM PRESENTATION

Table 3. Itemized Abnormal Outcomes of Balance and Vestibular Workup.

Evaluation: Subtest/Measurement	No. of Patients Tested	Patients With Abnormal Outcomes	
		No.	%
Video nystagmography			
Spontaneous/evoked nystagmus	41	10	24
Ocular motor function	41	10	24
Bithermal caloric test	14	3	21
Rotation			
Vestibulo-ocular reflex gain	41	11	27
Vestibulo-ocular reflex phase	41	9	22
Asymmetry	41	8	20
Fixation	40	2	5
Visual vestibulo-ocular reflex	40	2	5
Dynamic Visual Acuity Test	23	13	57
Cervical vestibular evoked myogenic potential			
Threshold	38	7	18
Latency	38	2	5
Amplitude	38	4	10
Computerized dynamic posturography			
Sensory Organization Test composite score	40	16	40
Sensory analysis	40	16	40
Center-of-gravity alignment	40	10	25
Motor function	39	4	10
Adaptation	39	13	33
Subjective visual vertical test	38	5	13

- 9.5% within normal limits
- 57% abnormal DVAT
- 40% abnormal balance
- 25% abnormal VNG
- No BPPV noted

- Peripheral vestibulopathy remains questionable
  - Reneker et al (2018): 44% abnormal VOR
  - Alshehri et al (2016): no abnormal VOR

Alshehri et al 2016; Reneker et al 2018; Zhou & Brodsky 2015

VESTIBULAR SYSTEM PRESENTATION

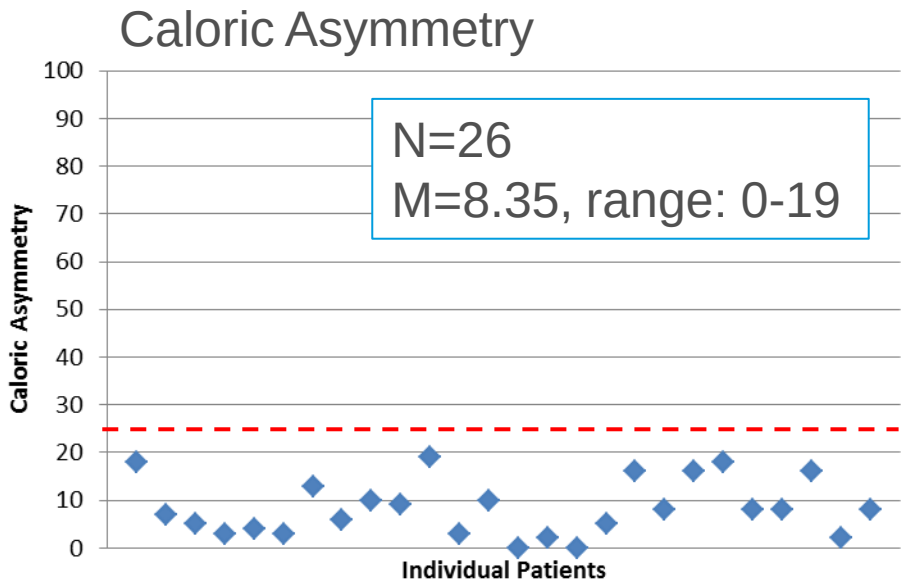
- Comparison of children (8-17 years) +/- concussion symptoms
- Mean time post-concussion: 60 days
- No significant differences noted: balance, cVEMP, SHA, SVV

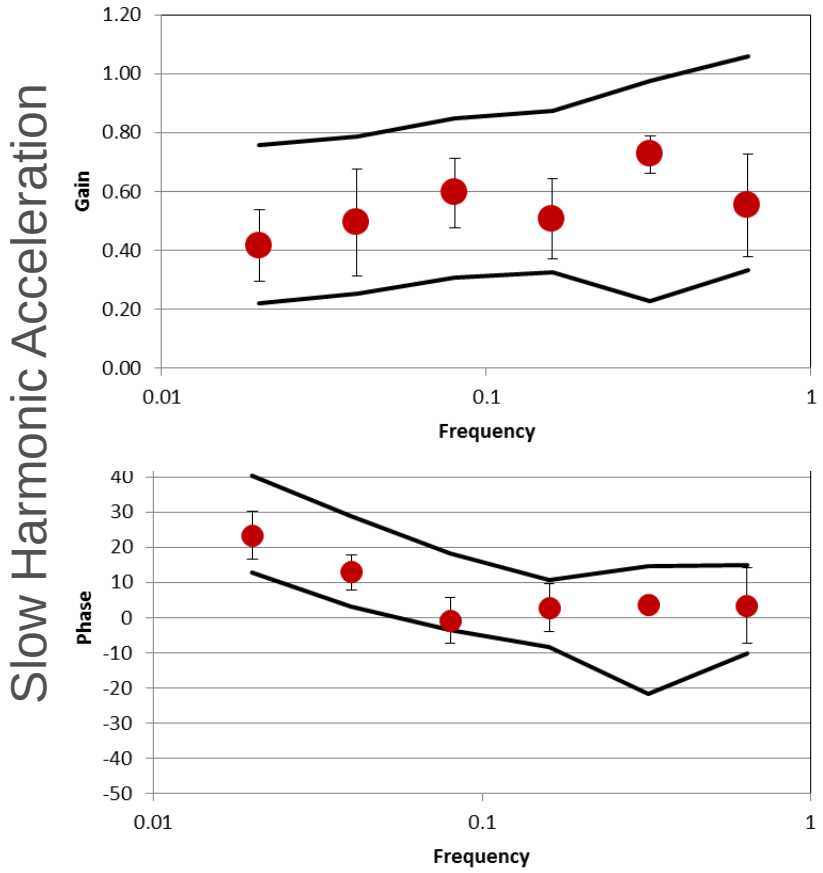
J Head Trauma Rehabil
Vol. 36, No. 4, pp. 264–273

Vestibular, Oculomotor, and Balance Functions in Children With and Without Concussion

Graham D. Cochrane, BA; Jennifer B. Christy, PhD, PT; Anwar Almutairi, DPT, PhD; Claudio Busettini, Eng, PhD; Hendrik K. Kits van Heyningen, BS; Katherine K. Weise, OD, MBA; Mark W. Swanson, OD, MPH; Sara J. Gould, MD, MPH

VESTIBULAR SYSTEM PATHOLOGY





All traditional caloric / rotational chair studies within normal limits, no evidence of compensated / acute vestibulopathy.

MCA Data

WHAT ABOUT VEMP?

- Patients post-concussion may demonstrate reduced oVEMP responses (reduced amplitude, greater asymmetries)
- Increased number of concussions is associated with poorer VEMP responses
- cVEMP is less involved than oVEMP
- Challenges? Sound tolerance; consider bone conduction

Rodriguez et al 2022

QUESTIONNAIRES

- **Pediatric Visually Induced Dizziness Questionnaire**
  - 6-17 years of age
  - Validated; children with migraine, concussion, vestibular disorders
  - Examples: riding in a car, walking down the aisle of a market, using the computer
- **Vestibular / Ocular Motor Screening – Child (VOMS-C)**
  - ≥ 5 years
  - Symptom provocation during oculomotor tasks: smooth pursuit, saccades, NPC, VOR, visual motion

Kaae et al 2022; Pavlou et al 2017; Trbovich et al 2022

DOES NORMAL MEAN NORMAL IN CONCUSSION?

Overall normal studies – the patient is still dizzy.

How does “normal” peripheral function integrate into the “abnormal” central system?

CENTRAL EFFECTS OF CONCUSSION

- Concomitant injury
- Diffuse axonal injury
- Post-concussion migraine
- Cervical vertigo

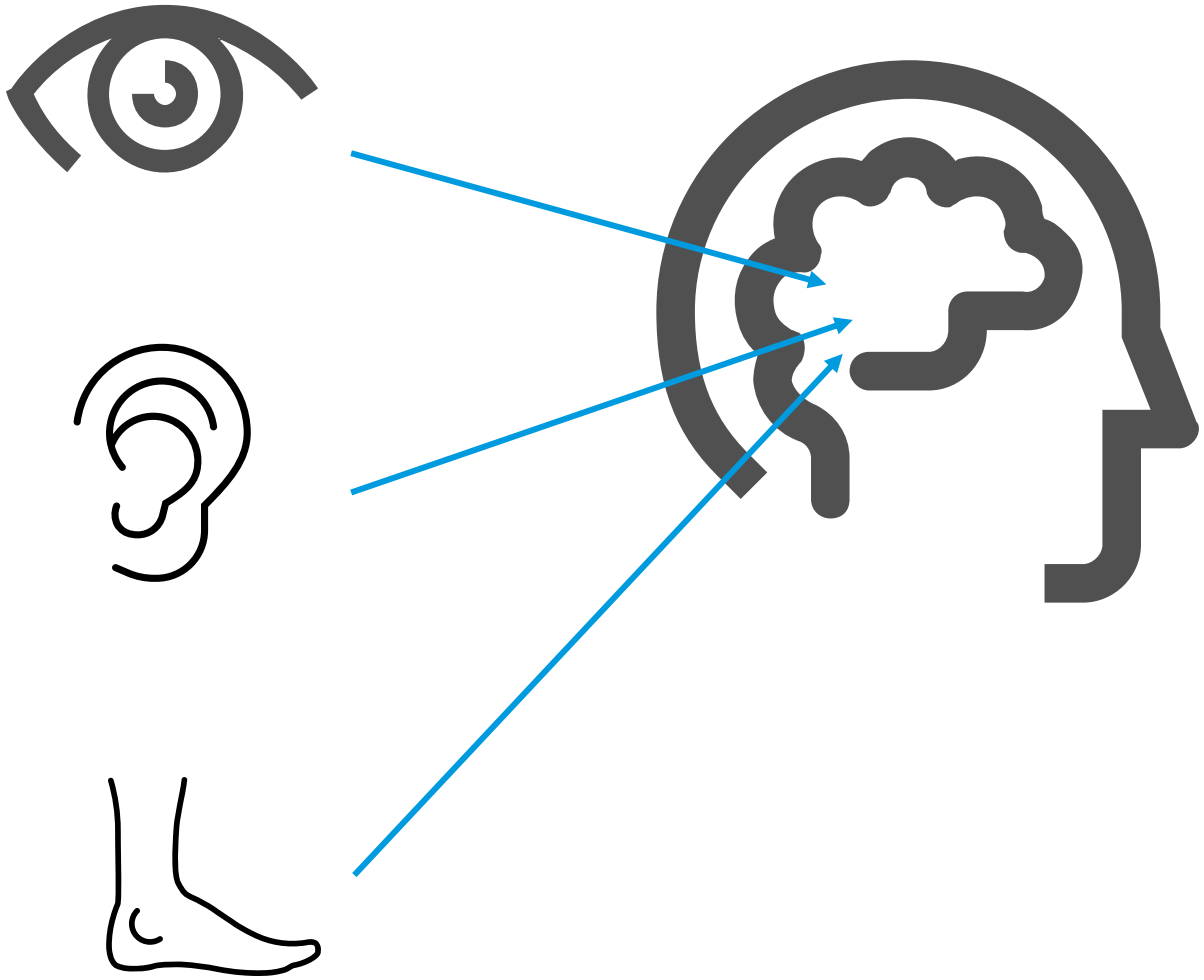
- Vestibular symptoms: cerebellum, fusiform gyri

- Convergence insufficiency: anterior thalamus, genicular nucleus optic tract

- Processing speed: anterior thalamus

Alhilali et al 2014

CENTRAL VESTIBULAR SYSTEM

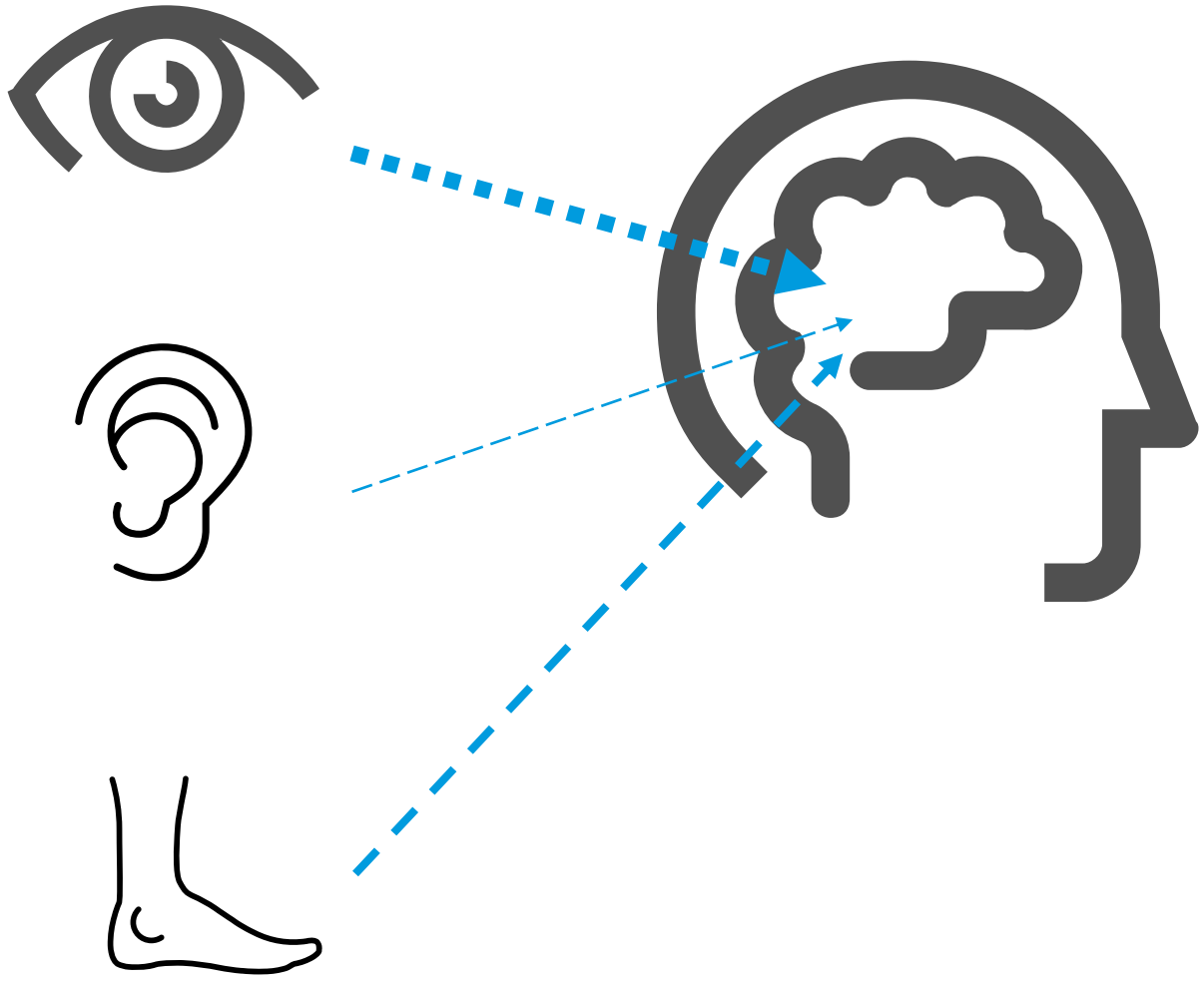


Sensory Integration

SENSORY INTEGRATION

- Vestibular system requires dynamic **flexibility** and **timing** of neural transmission
  - Peripheral damage alters input
  - Central damage alters spatial computations

- Sensory information is misinterpreted
  - E.g., overdependence on visual information, leads to movement illusions → instability, blurry vision, motion sickness



SENSORY INTEGRATION

- Symptoms
  - Dizziness (spinning, rocking, “off”)
  - Nausea
  - Blurry vision
  - Motion intolerance
- Triggers
  - Quick head, body movements
  - Busy visual environments
  - Visual tasks (e.g., reading, computer work, note taking)

SENSORY INTEGRATION

- Sensory integration abnormalities:
  - Motion sensitivity
  - Imbalance
  - Dizziness with:
    - quick head turns
    - busy places
    - scrolling text
    - action movies

Vestibular Rehabilitation

- Designed to alleviate primary and secondary symptoms due to balance / dizziness disorders
- Problem based approach to promote compensation
- Exercise based program
  - Reduce dizziness (habituation)
  - Improve gaze stability
  - Improve balance

Alsalaheen et al 2010; Brahm et al 2009; Capo-Aponte et al 2017; Goodrich et al 2003; Goodrich et al 2007; Gottsdall 2011; Gottshall et al 2005; Lew et al 2007; Magone et al 2014; Murray et al 2017; Park et al 2018; Schneider et al 2017; Schneider et al 2014; Stelmack et al 2009

AUTONOMIC DISORDERS

- Not all dizziness is vertigo
- Does your patient get dizzy / lightheaded / syncopal when standing up?

KEY POINT

Question dizziness triggers – orthostatic dizziness may be due to an autonomic disorder

- Consider orthostatic hypotension, autonomic dysfunction
- **COMMON** in concussion!
- May have a delayed onset, 3-4 weeks is common
- Central autonomic network is complex: cerebral cortex, amygdala, stria terminalis, hypothalamus, brainstem, etc

Bishop et al 2017; Conder & Conder 2014; Esteroy & Greenwald 2017; Gould et al 2022; Heyer et al 2018; Hilz et al 2016; Mccorry 2017; Thayer et al 2009

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DIAGNOSTIC PROTOCOLS

RETURN TO PLAY CLINIC

- Single morning, 3 providers
- Weekly / biweekly follow up until discharge

NEUROLOGY

- History
- Physical examination
- Headache management
- Exercise initiation

NEUROPSYCHOLOGY

- Cognigram
- Accommodations

AUDIOLOGY

- Objective evaluation

RETURN TO PLAY PROTOCOL

Rehabilitation Stage	Functional Exercise	Objective
1. No activity	Symptom limited rest	Recovery
2. Light aerobic exercise	Walking, swimming, stationary cycling	Increase heart rate
3. Sport-specific activity	Sport drills, no head impact activity	Sport movement
4. Non-contact training drills	More complex sport drills, resistance training	Coordination and cognitive load
5. Full-contact practice	Full training activities	Confidence, functional skills
6. Return to play	Routine game play	

McCrory et al 2013

ACUTE VESTIBULAR PROTOCOL (<1 MONTH)

- Balance
- Oculomotor
- Gaze stability

- Initial evaluation
- Monitoring during recovery
- discharge

- Why the limited protocol?
  - Tolerance
  - Time
  - Decision making

PROLONGED SYMPTOMS?

Not all concussions are managed acutely

- Multidisciplinary team
  - Neurology
  - Neuropsychology
  - Audiology
- May also include
  - Autonomic evaluation
  - Ophthalmology
  - PT/OT, vision therapy
  - Exercise rehabilitation
  - Psychiatry
  - Imaging

- Management
  - Headache
  - Exercise tolerance
  - Address maladaption
  - Address stress, anxiety, poor sleep
- Monitor 4-6 weeks, 3-6 months until plateau / resolution

VESTIBULAR REHABILITATION

- VOR adaptation
- Symptom habituation
- Oculomotor function
- Balance
- Gait
- Canalith repositioning (Epley maneuver)

- *Rehabilitation must be individualized in order to provide the most effective outcomes.*

Alsalaheen et al 2010; Gottshall 2011; Gottshall et al 2005; Murray et al 2017; Schneider et al 2017; Schneider et al 2014

WHAT'S THE EVIDENCE?

- Does vestibular rehabilitation work?
  - Weak/limited evidence… but promising!
    - Lack of controls, randomization
    - Overall evidence that VR is more effective than rest, graduated exertion
  - Decreases symptoms, recovery time
    - No significant negative effects

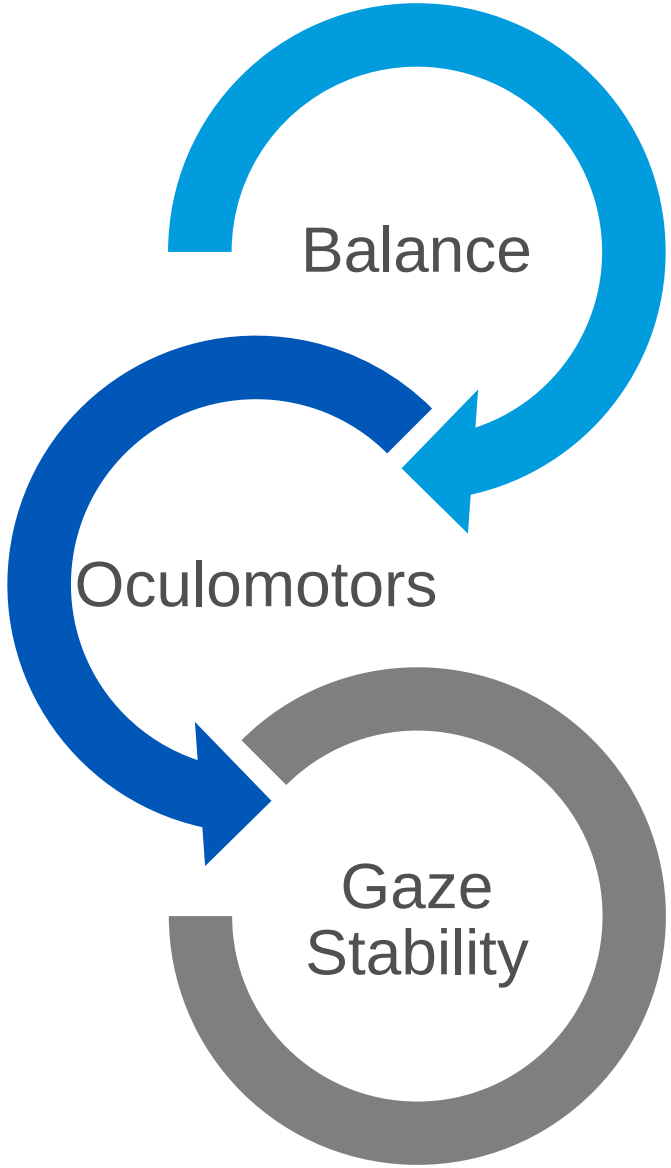
Alsalaheen et al 2010; Gottshall 2011; Gottshall et al 2005; Murray et al 2017; Schneider et al 2017; Schneider et al 2014

REHABILITATION CO-MORBIDITIES

- Cognitive, behavioral issues
- Visual-perception dysfunction
- Metabolic dysfunction
- Autonomic dysfunction

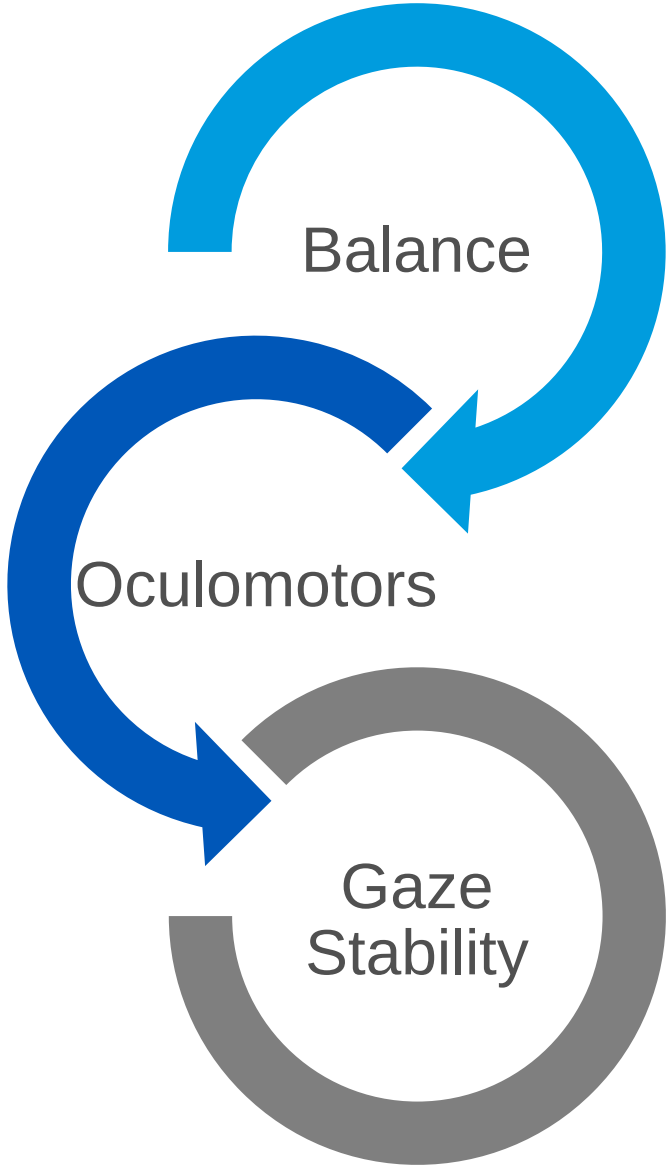
- *Any of these may lead to prolonged rehabilitation and must be addressed for recovery.*

Gurley et al 2013



DIAGNOSTIC PROTOCOL

Post-concussion evaluation and monitoring protocols



DIAGNOSTIC PROTOCOL

- **Balance**
  - Most reported in the literature – 52% abnormal static balance
  - Increased reliance on visual cues
  - **Poor use of vestibular input**

  - Abnormal sway → may not be outside normal limits
  - Prevalence of physiologically inconsistent patterns (~20%)

Akin & Murnane 2011; Basford et al 2003; Geurts et al 1996; Picket et al 2007; MCA data

BALANCE MEASURE

Balance System Maturation

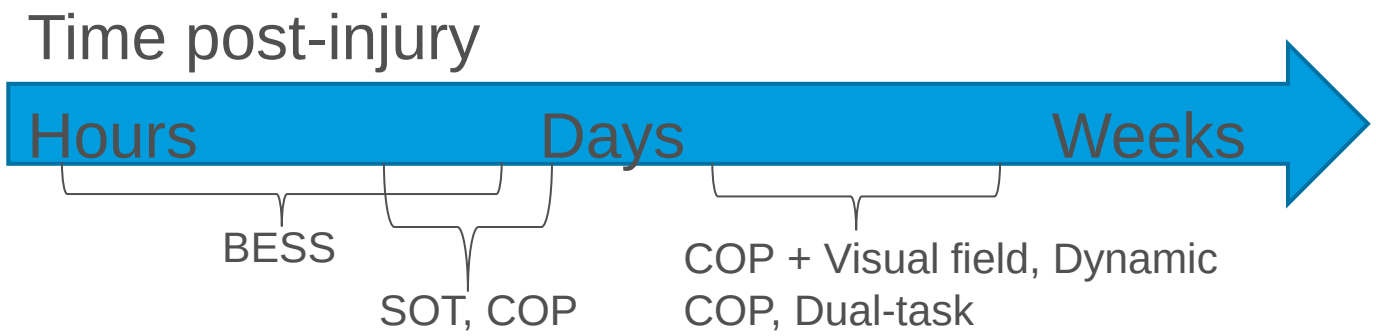
- Somatosensory: 3-4 years
- Vision, vestibular: 15-16 years
- Female > male

Clinical Balance Abnormalities

- Static balance: 28%
- Dynamic balance: 53%

Steindl et al 2008

BALANCE RECOVERY



Static Balance: 3-5 days

Dynamic Balance: > 30 days

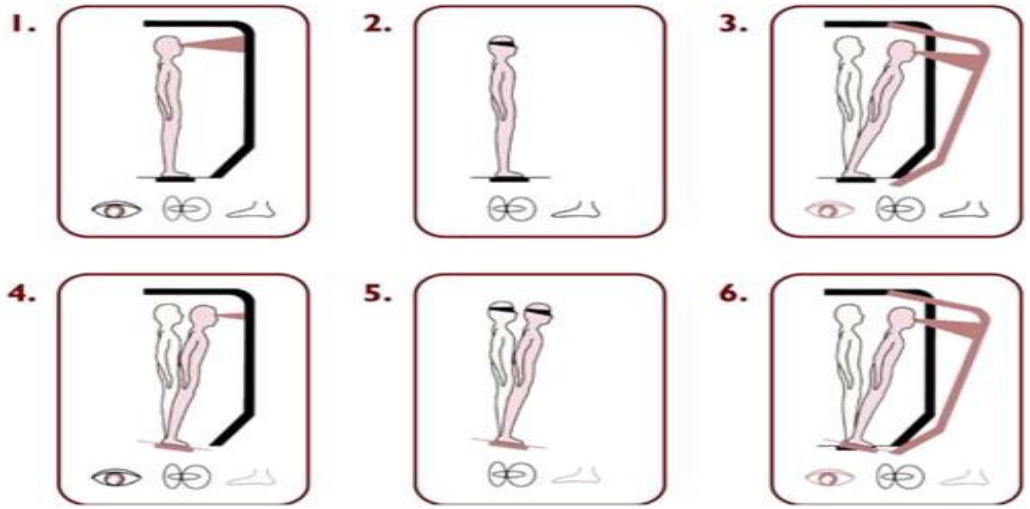
↑ Task Difficulty ↑ Recovery Duration

BESS: Balance Error Scoring System
SOT: Sensory Organization Test
COP: Center of Pressure

Cavanaugh et al 2006; Guskiewicz et al 1996; McCrea et al 2003; McCrea et al 2013; Parker et al 2006; Reimann et al 1999; Slobonouv et al 2006; Slobonouv et al 2008

IMBALANCE

- Romberg, BESS, mCTSIB
- Computerized dynamic posturography

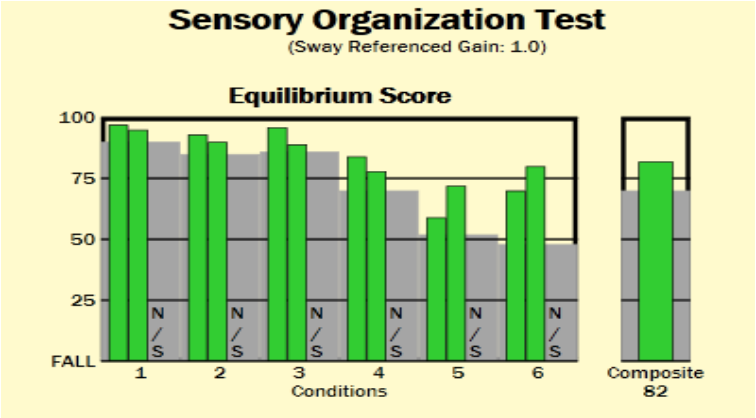


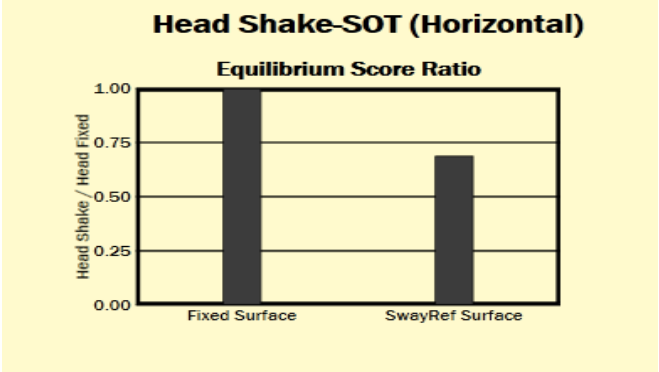
Often bedside and diagnostic tests are within normal limits for athletes / top performers.

IMBALANCE

Standard Condition 5

HS-SOT Condition 5



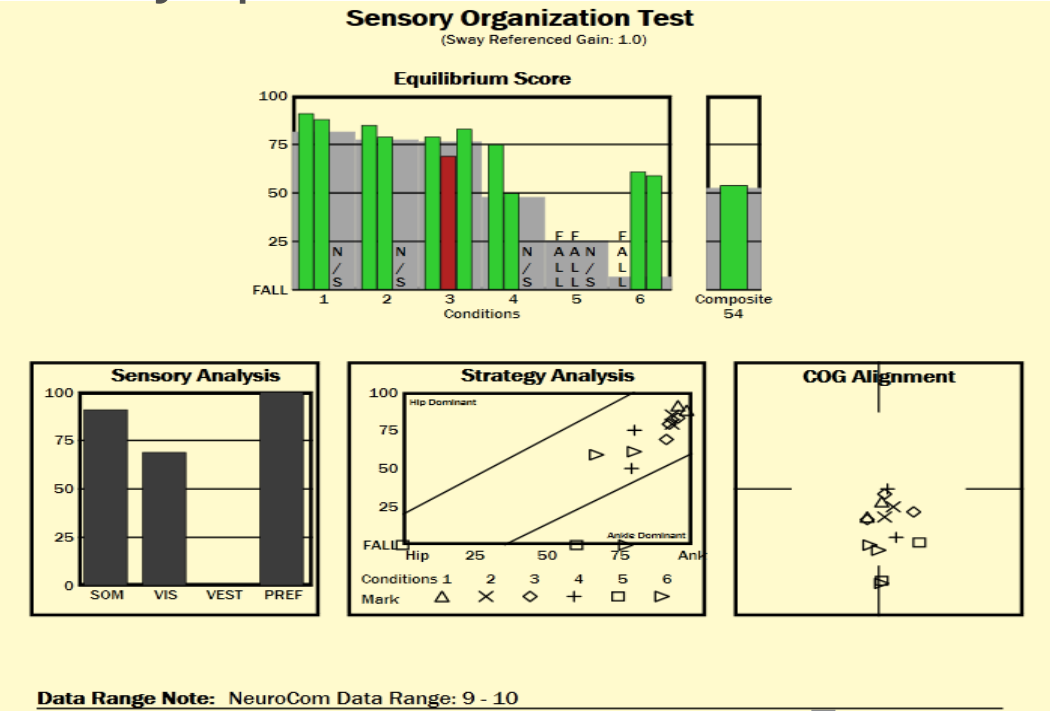


Abnormal ratio $\leq$ 0.7

Quantifies balance ability when accurate, dynamic changes in vestibular system information are required.

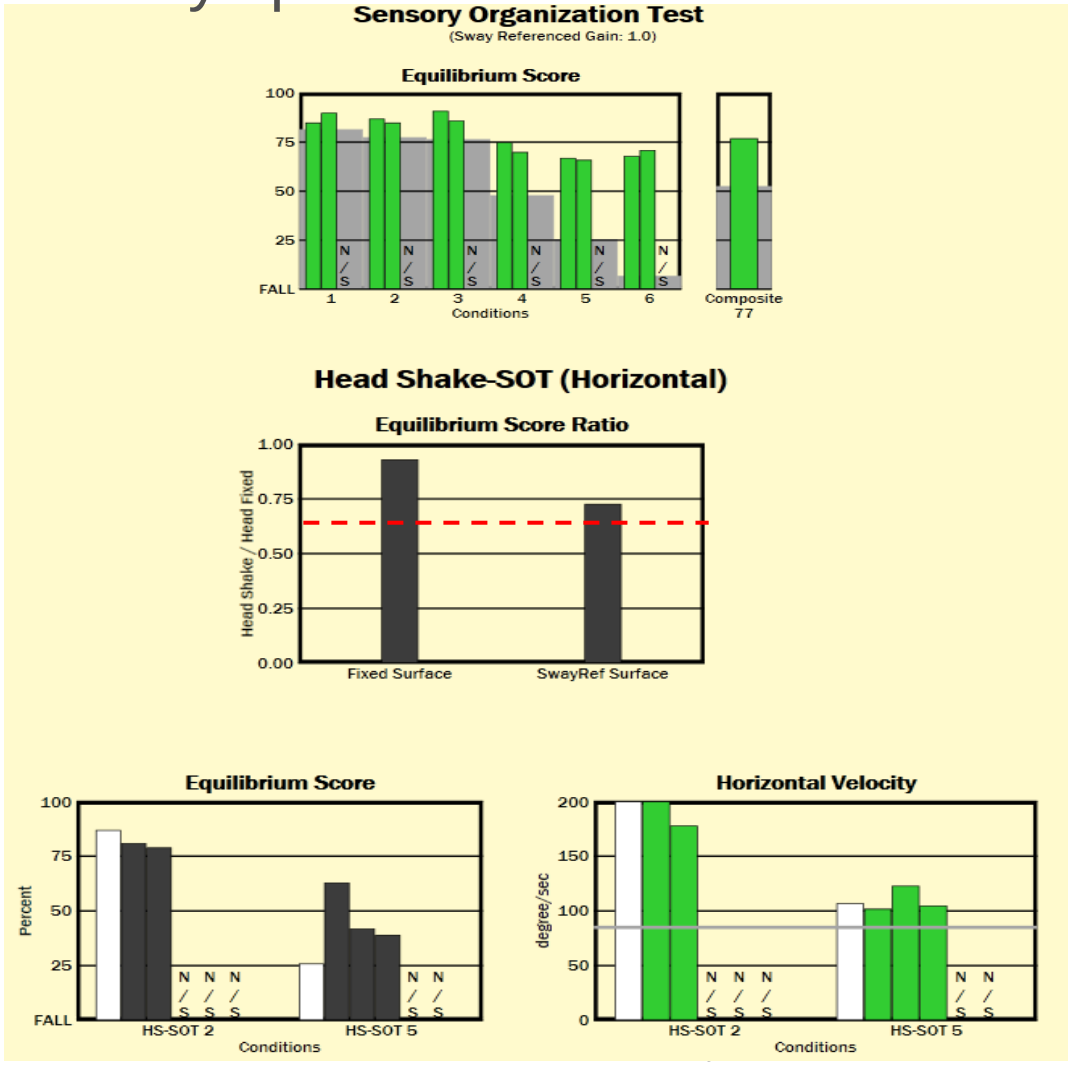
EXAMPLE

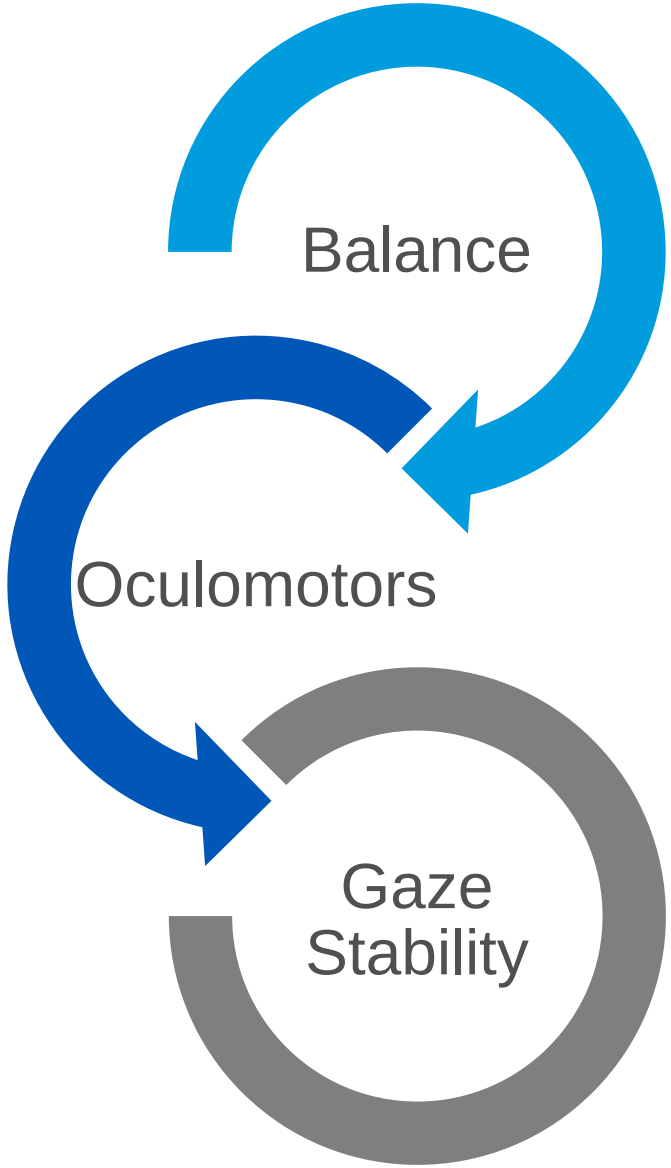
3 days post-TBI



- 10 yo, male
- Football

17 days post-TBI



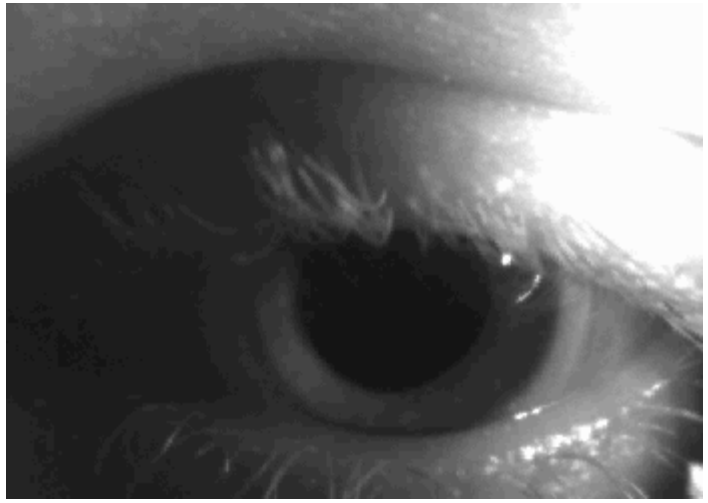


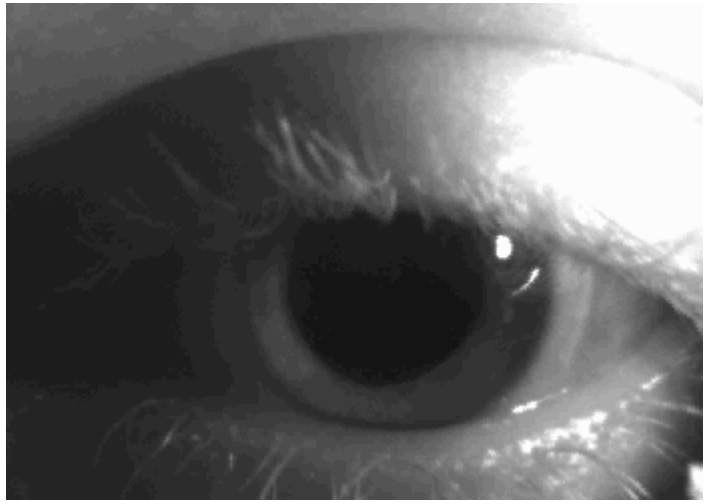
DIAGNOSTIC PROTOCOL

- **Oculomotors**
  - Up to 80% report vision problems post-concussion
    - Blurred vision
    - Diplopia
    - Impaired eye movement
    - Difficulty reading
    - Ocular pain
    - Poor vision-based concentration
  - Visual symptoms significantly impact academics

Alsalaheen et al 2010; Brahm et al 2009; Capo-Aponte et al 2017; Goodrich et al 2013; Goodrich et al 2007; Gottshall 2011; Gottshall et al 2005; Lew et al 2007; Magone et al 2004; Murray et al 2017; Park et al 2018; Schneider et al 2017; Schneider et al 2014; Stelmack et al 2009

OCULOMOTOR EVALUATION



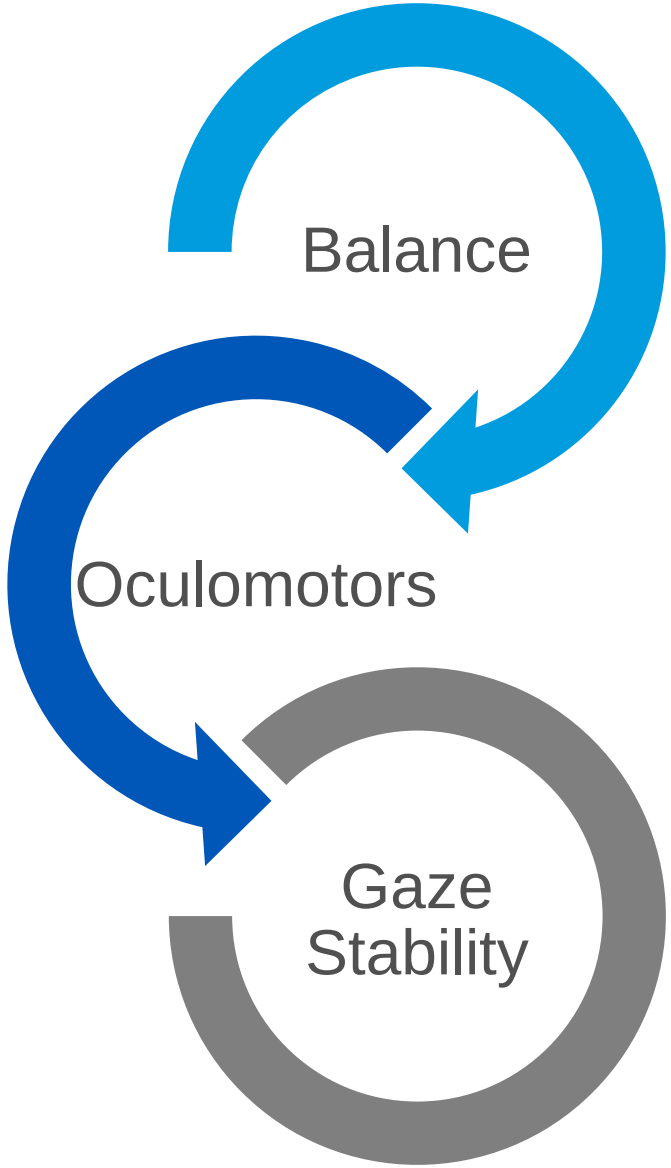


22-year-old male
Soccer goalie

- Gaze-evoked nystagmus
  - Look for saccadic intrusions
- Saccades
- Smooth pursuit / OKN
- Convergence / accommodation
  - Convergence: simultaneous movement of both eyes in opposite directions to obtain / maintain single binocular visions; up to 42% (3% controls)
  - Accommodation: eye response when shifting focus from a distant to near object; up to 73% (13% controls)

Abnormalities

Chinn et al 2022; Cochrane et al 2020; Reneker et al 2008



DIAGNOSTIC PROTOCOL

- **Gaze Stability**

VESTIBULO-OCULAR REFLEX

- Goal: to ensure best vision by moving the eyes contrary to the head, stabilizing gaze during movement

1. Semicircular canals / otolith organs
2. Central processing
3. Motor output

Alshehri et al 2016; MCA data

FUNCTIONAL VOR

Symptoms?

Dizziness

Nausea

Blurry vision

Difficulty working on computers, reading

Dizziness in busy visual environments

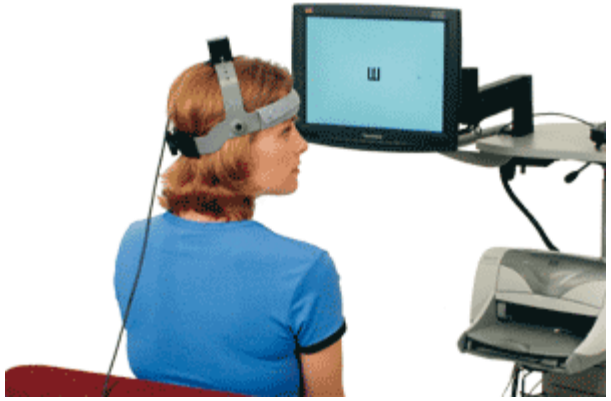
Motion intolerance

- AKA Gaze Stability
- Requires appropriate VOR function
  - Moderate to good reliability
- Quantifies the ***functional impact*** of underlying VOR abnormalities – **up to 50% abnormal**
- Documents function impact of central pathology
- Rehabilitation planning

Kaufman et al 2014; MCA data

GAZE STABILIZATION

- Dynamic Visual Acuity Test (DVAT)



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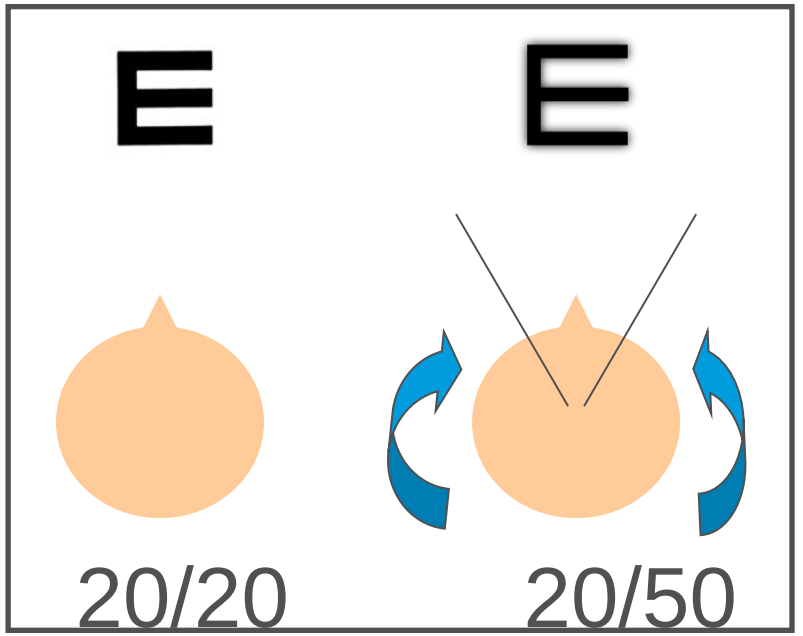
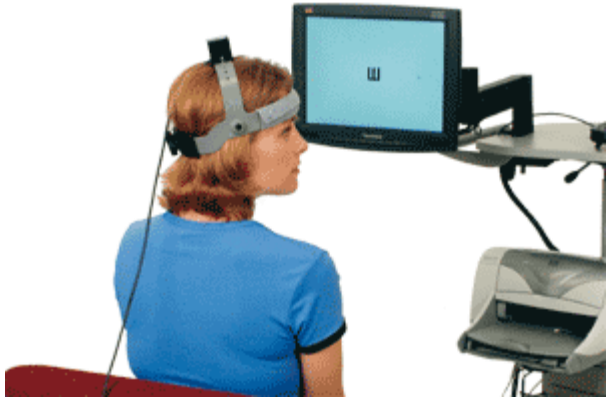
Static



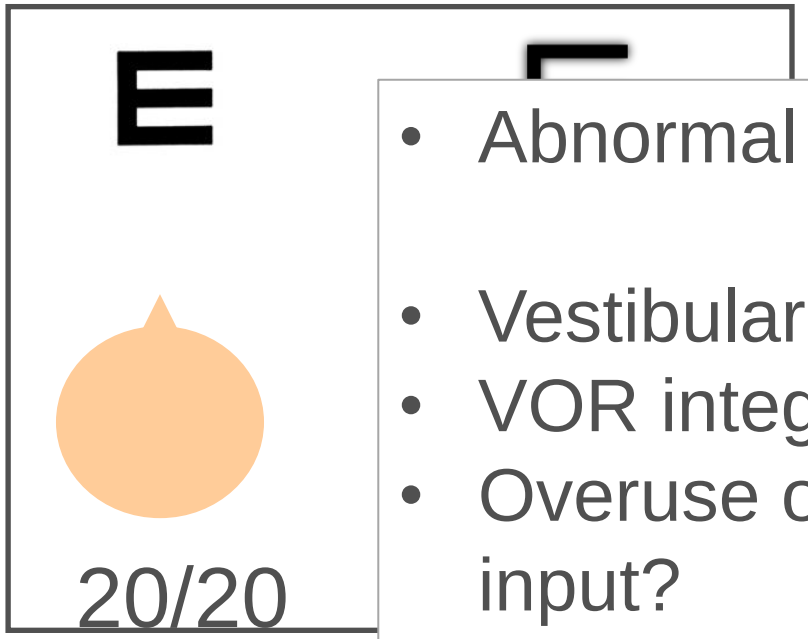
GAZE STABILIZATION

- Dynamic Visual Acuity Test (DVAT)



Neurocom

Dynamic

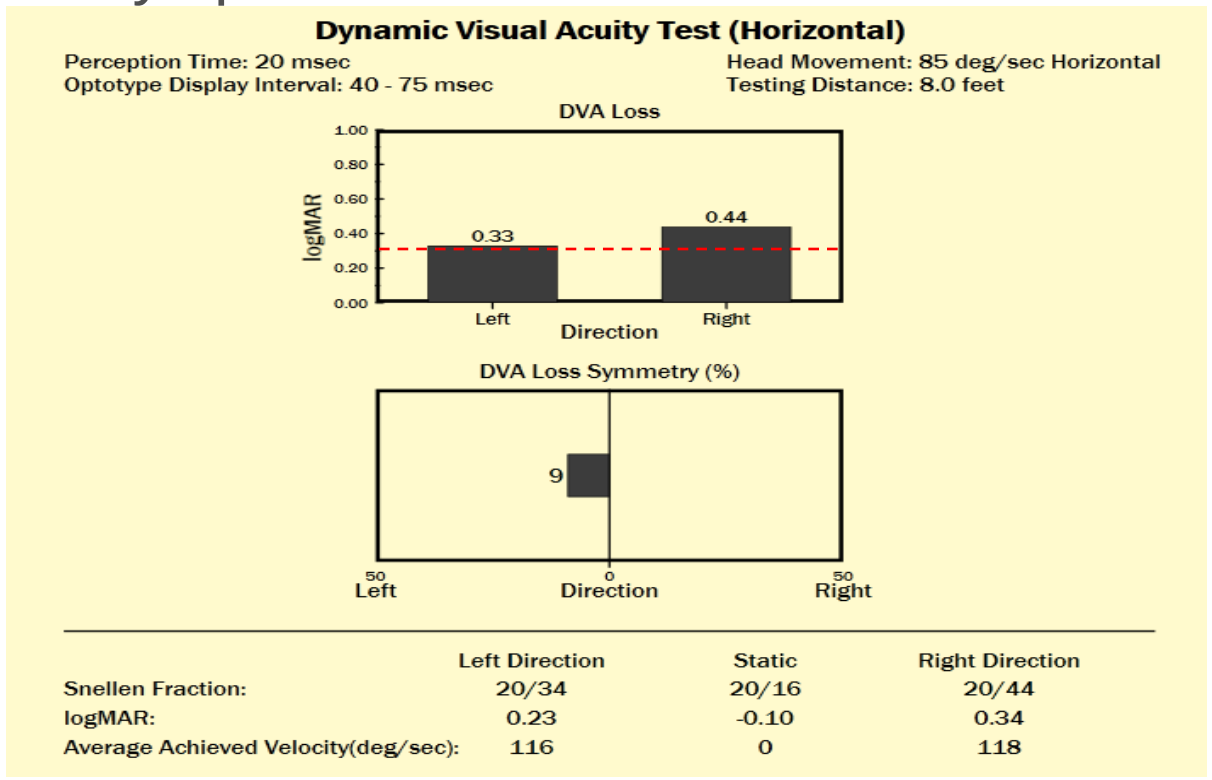


- Abnormal > 50%

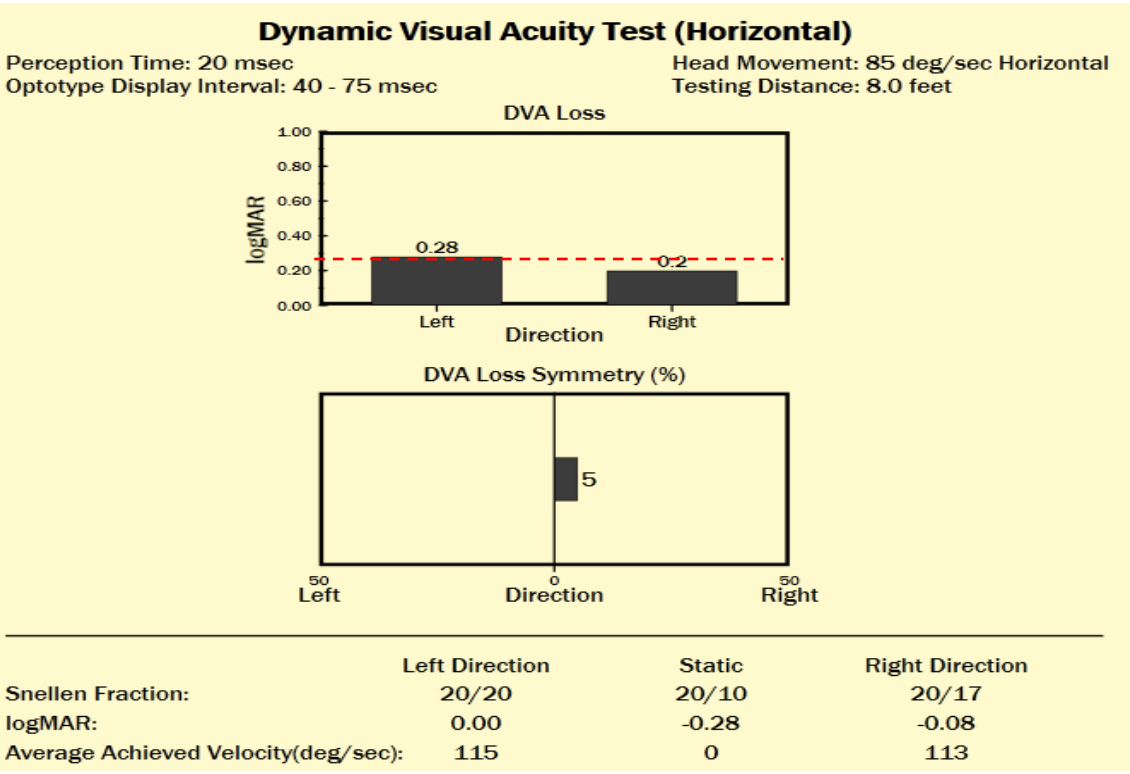
- Vestibular pathology?
- VOR integration?
- Overuse of visual input?
- Central integration?

EXAMPLE

3 days post-TBI



17 days post-TBI



- 10 yo, male
- Football

ACUTE INJURY MANAGEMENT

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Evaluation timeline

- Initial evaluation
- 1 week follow up
- Discharge

Protocol

- Balance
- Oculomotors
- Gaze stability

PROLONGED INJURY MANAGEMENT

Evaluation timeline

- Initial evaluation
- Variable follow up

Protocol

- Balance
- Oculomotors
- Gaze stability
- VOR
- Otolith reflexes
- Audiometry
- Etc

MANAGEMENT

Step 1: Define the dizziness	Step 2: What's the plan?	Step 3: Don't forget about…
Vertigo / sensory integration, oculomotor → refer to VRT, vestibular specialist	- Rehabilitation exercises, repositioning - Movement!	• Increased risk for depression • Reduced social engagement • Maladaptation • Influence of headache, migraine Include: • Back to school, work • Aerobic activity
Lightheadedness, autonomic symptoms → refer to medical team	- Medical observation, management - Avoid deconditioning… exercise is key!	

Esteroy & Greenwald 2017; Gurley et al 2013; Reneker et al 2017; Schneider et al 2014

REDUCE THE EFFECTS

- Establish a rehabilitation program early
  - Research demonstrates reduced days to medical clearance, symptom recovery
  - Get athletes back to school, sport sooner
  - Include aerobic activity
- Include a team – dizziness is complex!

Reneker et al 2017; Schneider et al 2014; Thomas & Newman-Toker 2016

MAYO CLINIC

THANK YOU

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