Children's Hospital Colorado
Orthopedics Institute

ORTHOPEDICS
INSTITUTE

# Vestibular and Oculomotor Dysfunction in Pediatric Concussion

*Margot Gray  PT, DPT*
*PT Vestibular Program Lead*
*Children's Hospital Colorado*

Affiliated with
School of Medicine
UNIVERSITY OF COLORADO
ANSCHUTZ MEDICAL CAMPUS

Children's Hospital Colorado
Orthopedics Institute

ORTHOPEDICS
INSTITUTE

# Vestibular and Oculomotor Dysfunction in Pediatric Concussion

*Margot Gray  PT, DPT*
*PT Vestibular Program Lead*
*Children's Hospital Colorado*

Affiliated with
School of Medicine
UNIVERSITY OF COLORADO
ANSCHUTZ MEDICAL CAMPUS

ORTHOPEDICS INSTITUTE

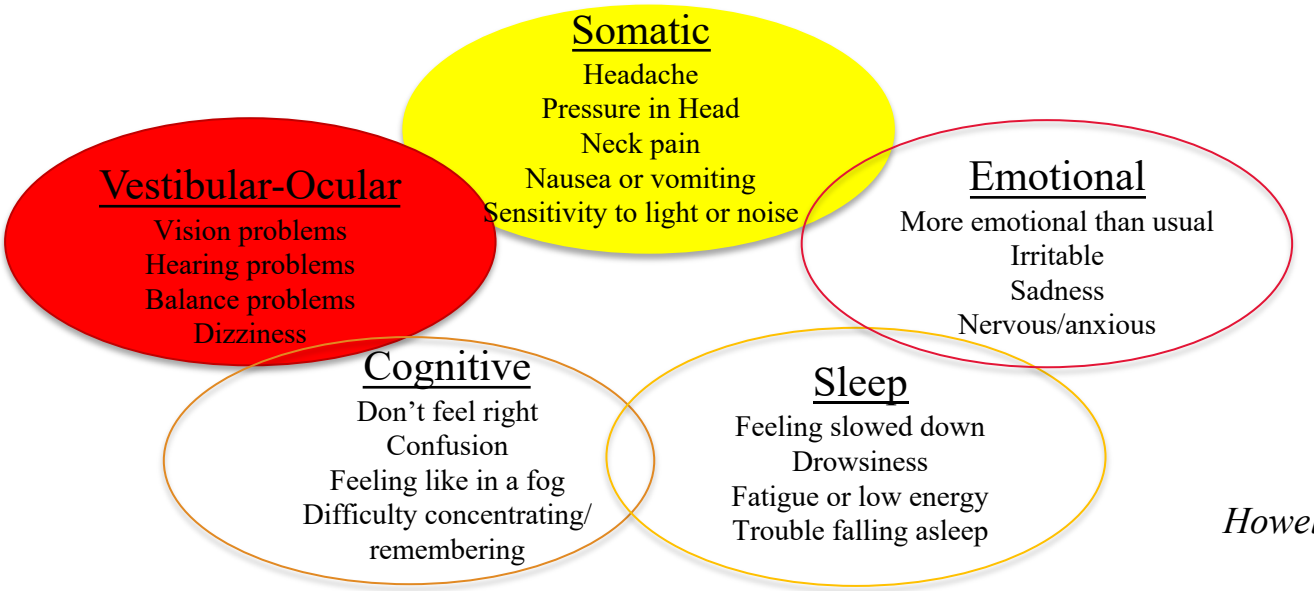
Children's Hospital Colorado

Affiliated with University of Colorado Anschutz Medical Campus

# Introduction

## Children's Hospital Colorado: Pediatric Balance and Vestibular Disorders Clinic

# Not all concussions are the same



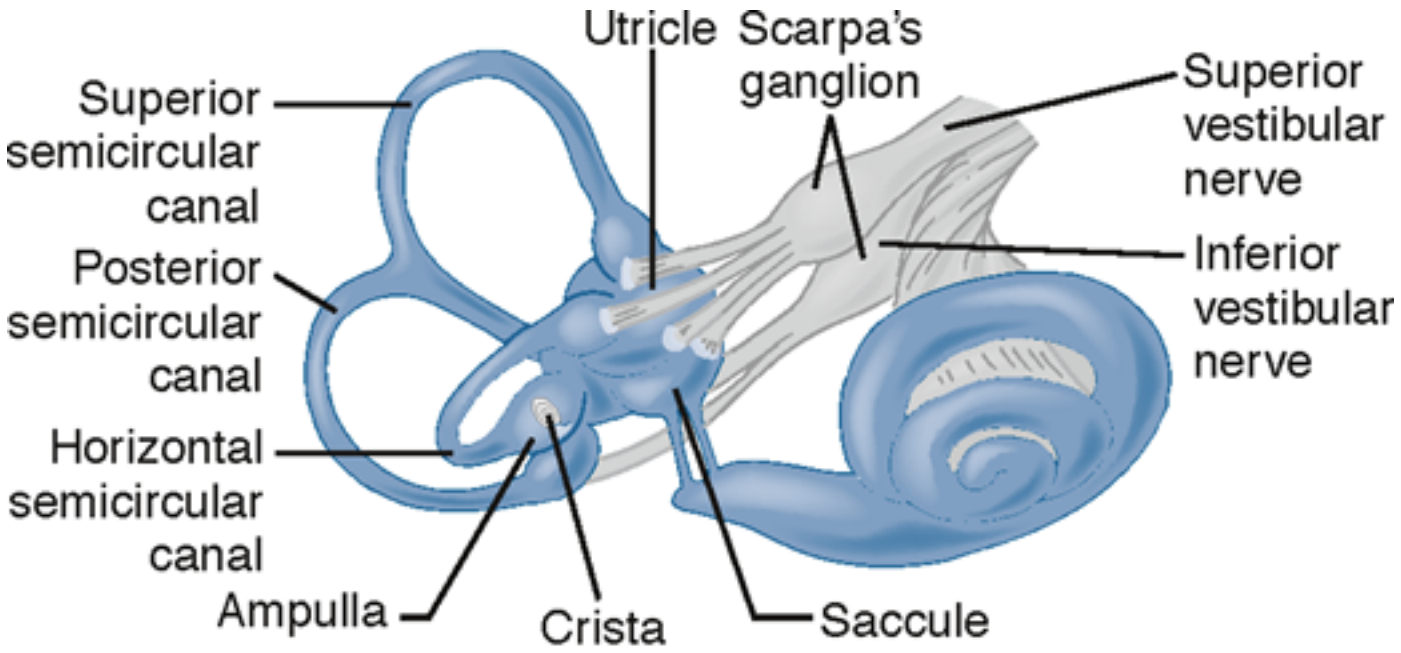

*Howell et al., Acta Ped, 2016*

- **Symptom scales are subjective and non-specific to concussion**
  - **Athletes may over- or under-report their symptoms**
- **Symptoms may not accurately reflect physiologic healing**

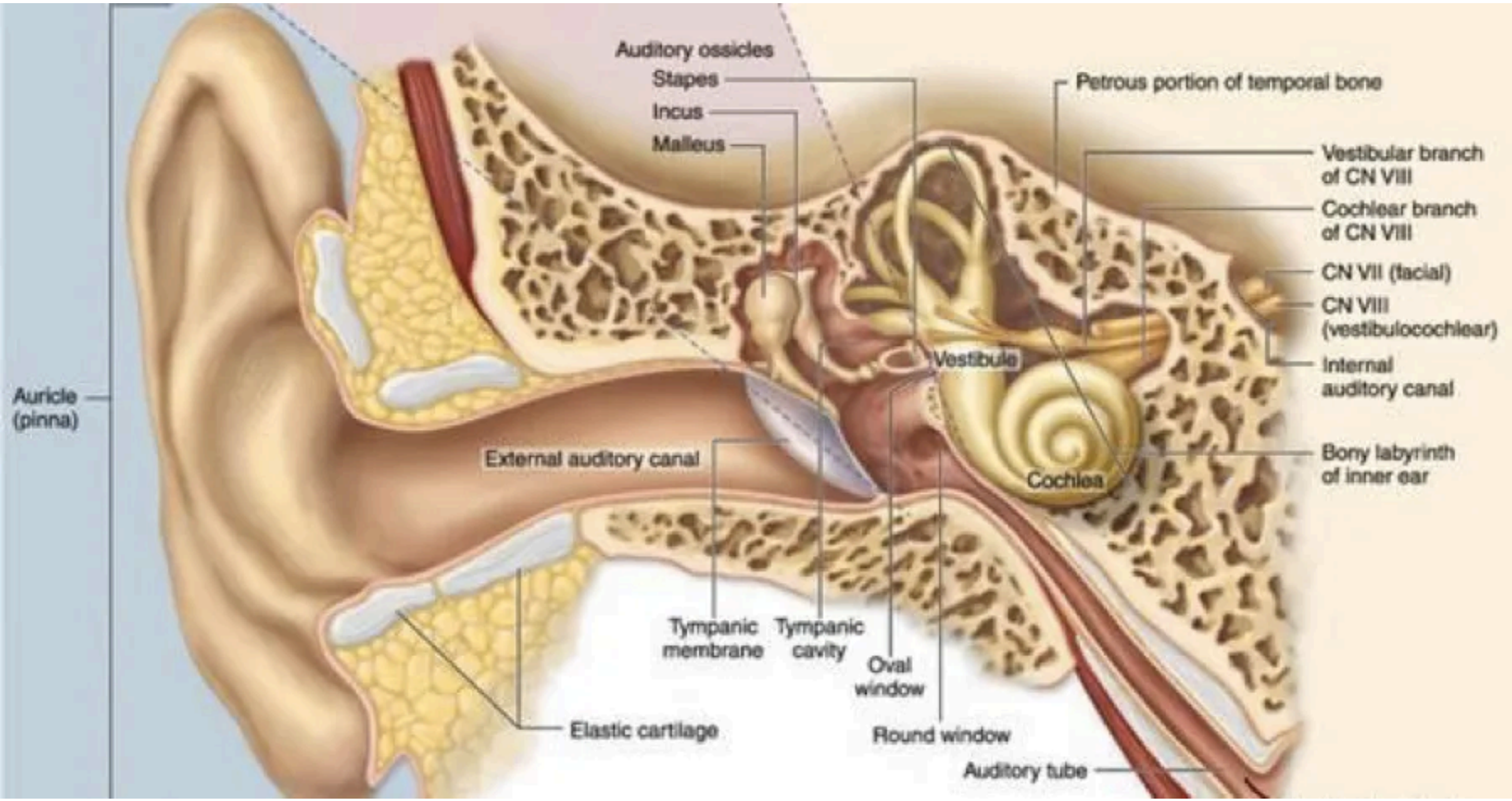

Vestibular/Ocular
Vision problems
Hearing problems
Balance problems
Dizziness

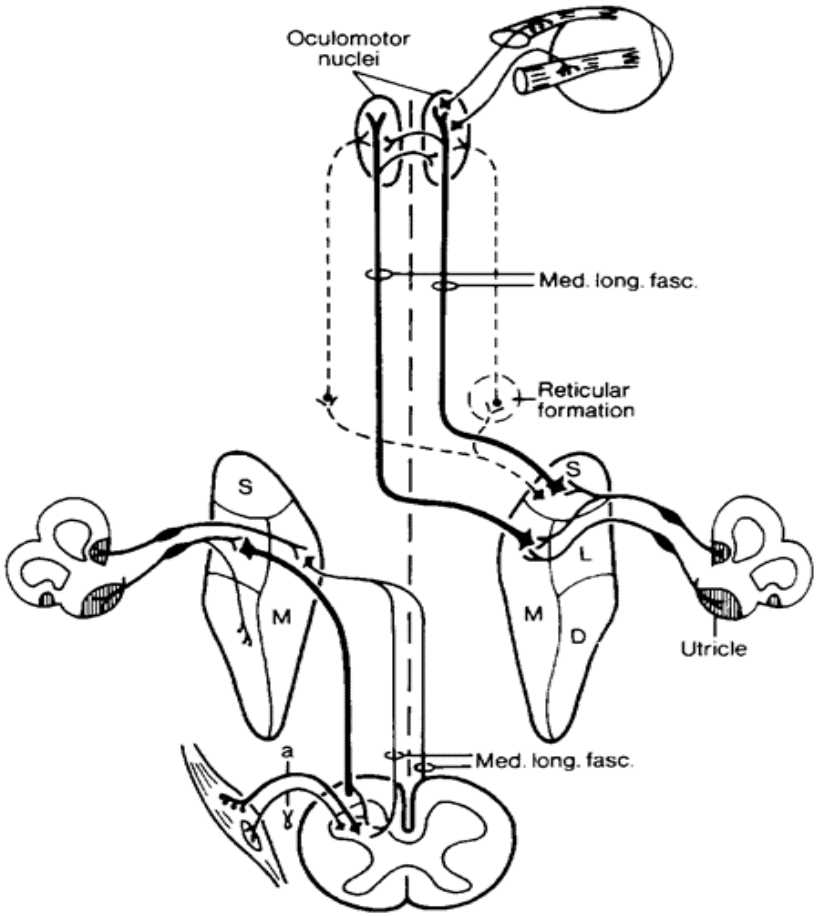
# Vestibular Anatomy

# Peripheral Vestibular System




Source: Susan B. O'Sullivan, Thomas J. Schmitz: Improving Functional Outcomes in Physical Rehabilitation, Second Edition, www.FADavisPTCollection.com


Auditory ossicles
Stapes
Incus
Malleus
Petrous portion of temporal bone
Vestibular branch of CN VIII
Cochlear branch of CN VIII
CN VII (facial)
CN VIII (vestibulocochlear)
Internal auditory canal
Vestibule
Auricle (pinna)
External auditory canal
Cochlea
Bony labyrinth of inner ear
Tympanic membrane
Tympanic cavity
Oval window
Round window
Elastic cartilage
Auditory tube


Oculomotor
nuclei
Med. long. fasc.
Reticular
formation
S
S
L
M
M
D
Utricle
a
Med. long. fasc.

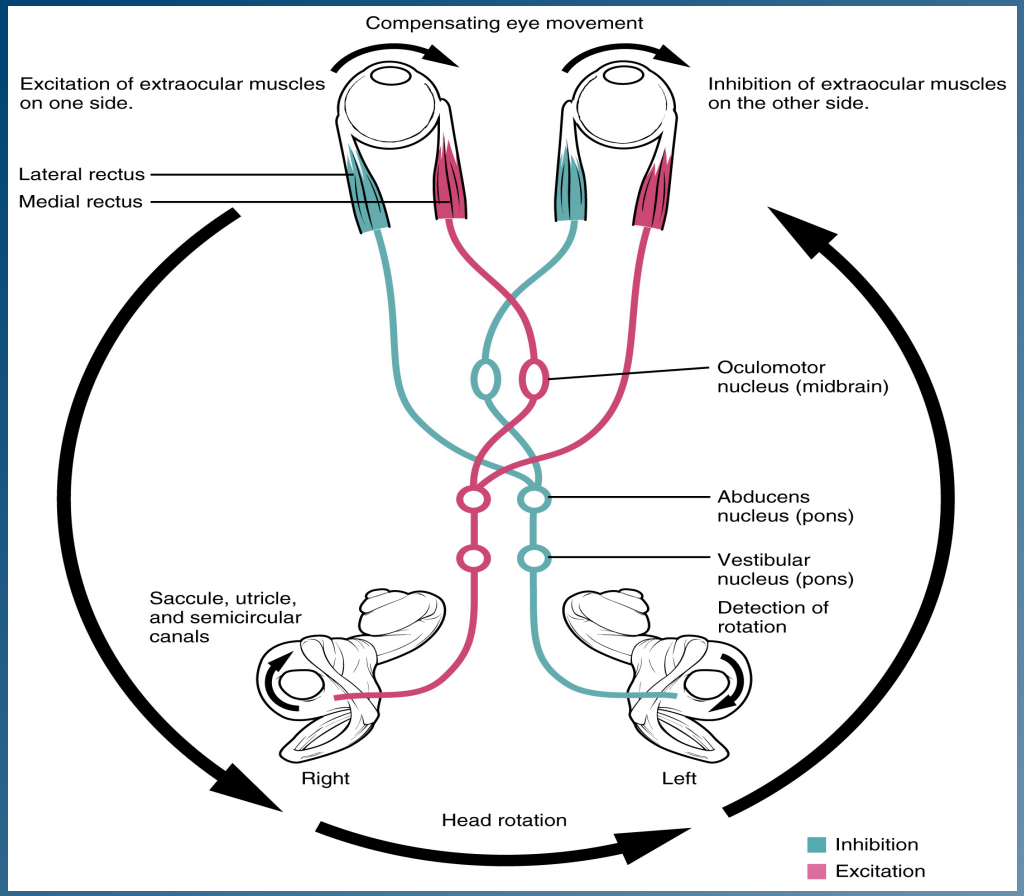
# Vestibular Systems

## Vestibulo-ocular reflex

- Gaze stabilization: ability to maintain focus on a target with head movements


## Vestibulospinal reflex

- Postural control – most active when vision and proprioception are reduced

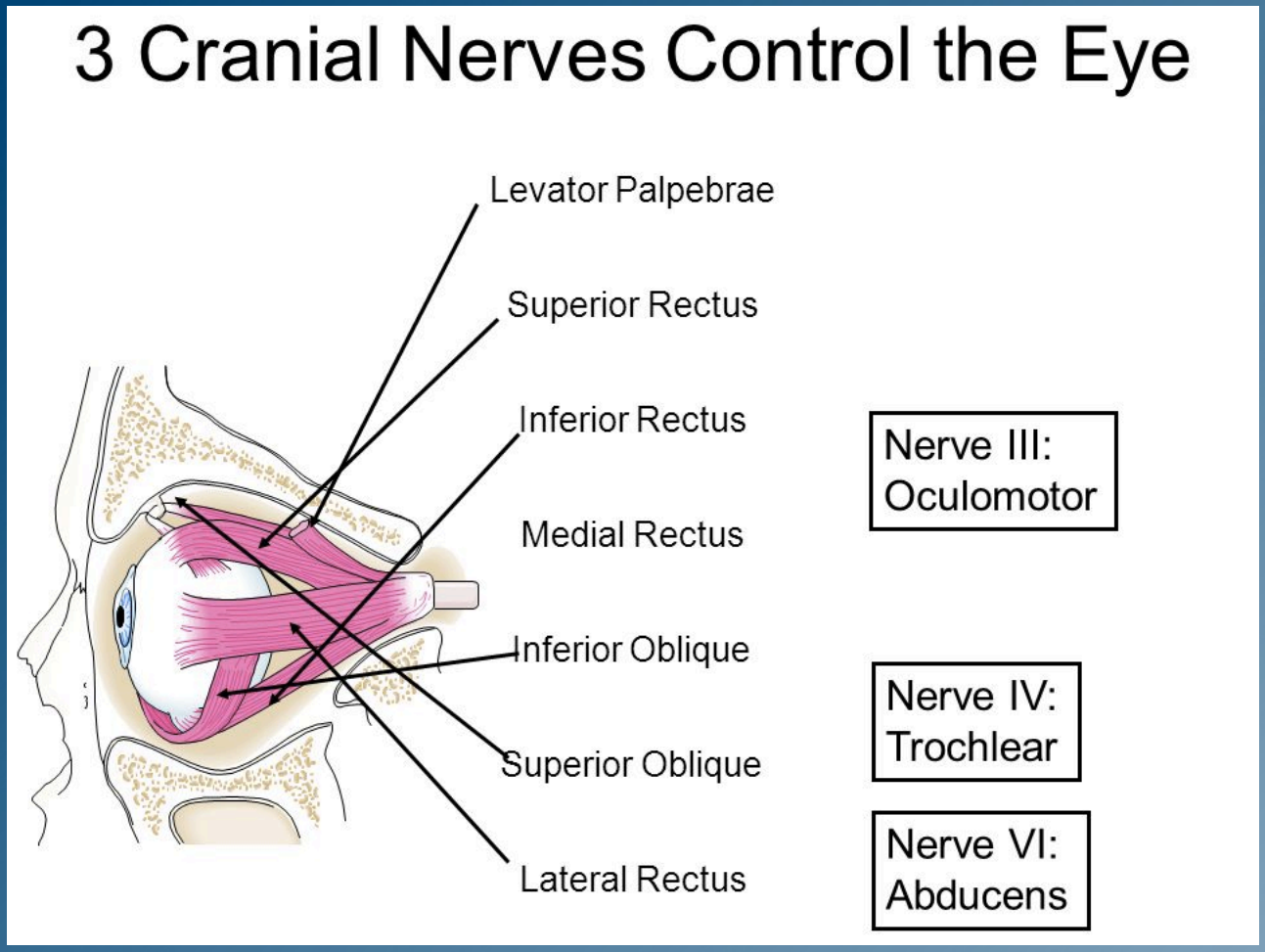

Compensating eye movement
Excitation of extraocular muscles on one side.
Inhibition of extraocular muscles on the other side.
Lateral rectus
Medial rectus
Oculomotor nucleus (midbrain)
Abducens nucleus (pons)
Vestibular nucleus (pons)
Saccule, utricle, and semicircular canals
Detection of rotation
Right
Left
Head rotation
Inhibition
Excitation

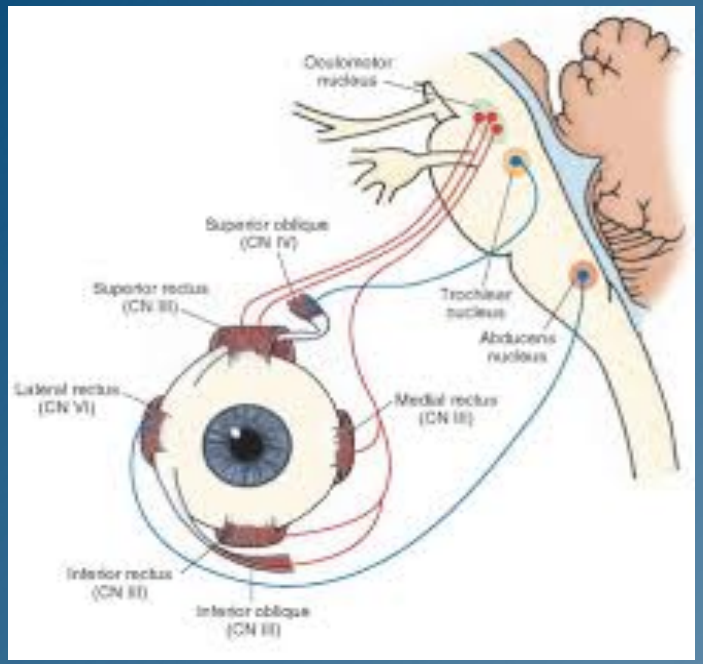
# Development

## Vestibular System

- Fully developed by 49 weeks gestation
- FIRST sensory system to develop in utero
- CN 8 is the first cranial nerve to myelinate
- By 1 year of age vestibulo-ocular relflex (VOR) is functional
- Maturity of VOR at age 8 years
- Balance vestibular system not mature until 17 years

# Oculomotor System

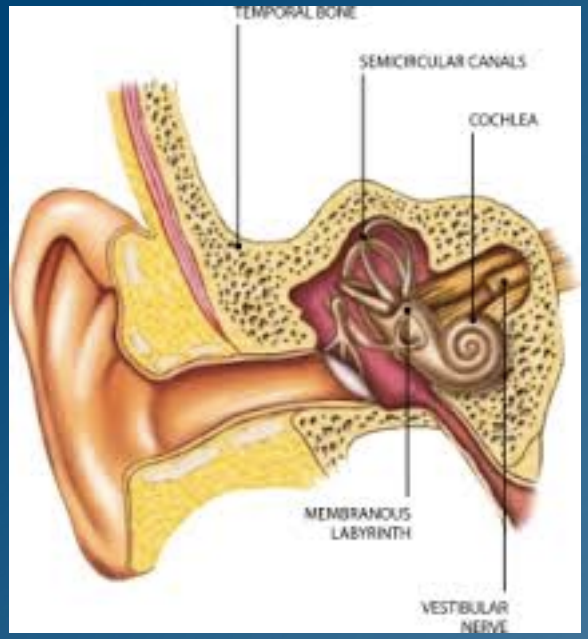



Oculomotor nucleus
Superior oblique (CN IV)
Superior rectus (CN III)
Trochlear nucleus
Abducens nucleus
Lateral rectus (CN VI)
Medial rectus (CN III)
Inferior rectus (CN III)
Inferior oblique (CN III)

# OM Symptoms

- Diplopia
- Eye strain
- Difficulty reading
- Headaches
- Trouble with convergence and divergence

# Concussion and Vestibular Dysfunction




# Vestibular Diagnoses and Concussion

- Labyrinthine Concussion
- Benign paroxysmal positional vertigo (BPPV)
- Post traumatic endolymphatic hydrops
- Central lesions
- Perilymphatic fistula
- Temporal bone fracture
- Vestibular migraines

# Vestibular Diagnoses in Children

- Benign Paroxysmal Vertigo of Infancy (BPVI)
- Benign Paroxysmal Vertigo of Childhood (BPVC)
- Migraines
- Vestibular neuritis and labyrinnthitis
- Vestibulopathy
- OME – otitis media with effusion
- Schwannoma
- Meneires
- BPPV
- Tumor
- Congenital CMV
- Ushers
- Concurrent with SNHL
- Ototoxicity
- Pedreds
- Secondary to cochlear implantation
- Enlarged vestibular aquaduct
- Perilymphatic Fistula
- TBI
- Central lesions

## Central

- Not true vertigo
- Disequilibrium
- Possible gaze instability
- Motion sensitivity possible
- Could be episodic (like a migraine)

## Peripheral

- Irritative- BPPV or fistula
  - Positional vertigo
- Unilateral hypofunction
  - Vertigo (positional)
  - Motor/balance
  - Gaze instability
- Bilateral hypofunction
  - Disequilibrium
  - Severe gaze instability- 6 line loss
  - Poor tolerance for movement

# Vestibular Impairments: Body Structure and Function

- Vestibular hypofunction
- Gaze stabilization with head movements
- Distinguishing self from environmental movements: dizziness, vertigo
- Balance impairments: related to vestibulospinal system (uneven surfaces without vision or visually challenging environment)
- Motor function:
  - gross motor developmental delay
  - Gait, tandem gait, dual task gait
- Coordination

# Vestibular Dysfunction and Concussion

- Athletes who experienced SRC demonstrated abnormal VOR cancellation gain, subjective visual vertical and horizontal variances on the SOT within the first 2 weeks post concussion *(Christy et al 2019)*

- *Alkathury et al 2019:*
  - 1. no evidence of dysfunction in the peripheral horizontal semicircular canals at high rotation speeds (vHIT) after concussion,
  - 2. adolescents with SRC had worse VOMS items scores than those without concussion
  - 3. No significant correlations among vHIT gain and VOMS or BESS

# Evidence, cont.

Physical exam of dizziness in athletes after a concussion: A descriptive study *(Reneker et al 2017)*

- Results: high majority (90%) of the participants demonstrated dizziness that appeared multifactorial in nature and not attributed to one main type of dysfunction.
  - central dysfunction = 100%, oculomotor deficits = 97.8%, motion sensitivity = 70.7%  central vest. deficits = 15%
  - peripheral dysfunction = 46.3%, unilateral hypofunction = 43.9%, BPPV = 4.9%,
  - cervical dysfunction = 82.9%, cervicogenic dizziness = 26.8%, altered neuromotor control = 75.6%

# Peripheral Vest. Disorders and Concussion

- Peripheral disorders in children and adolescents with a concussion
- *(Brodksy 2018)*
  - case series with chart review
  - looked at 109 pts seen in the concussion clinic at Boston Children's Hospital Sept. 2012 – July 2015
  - mean 133 days after concussion
  - 28 patients or 25.7% diagnosed with per. disorders – 19/28 BPPV , other diagnoses included temporal bone fx, superior canal dehiscence, labyrinthine concussion, and perilymphatic fistula

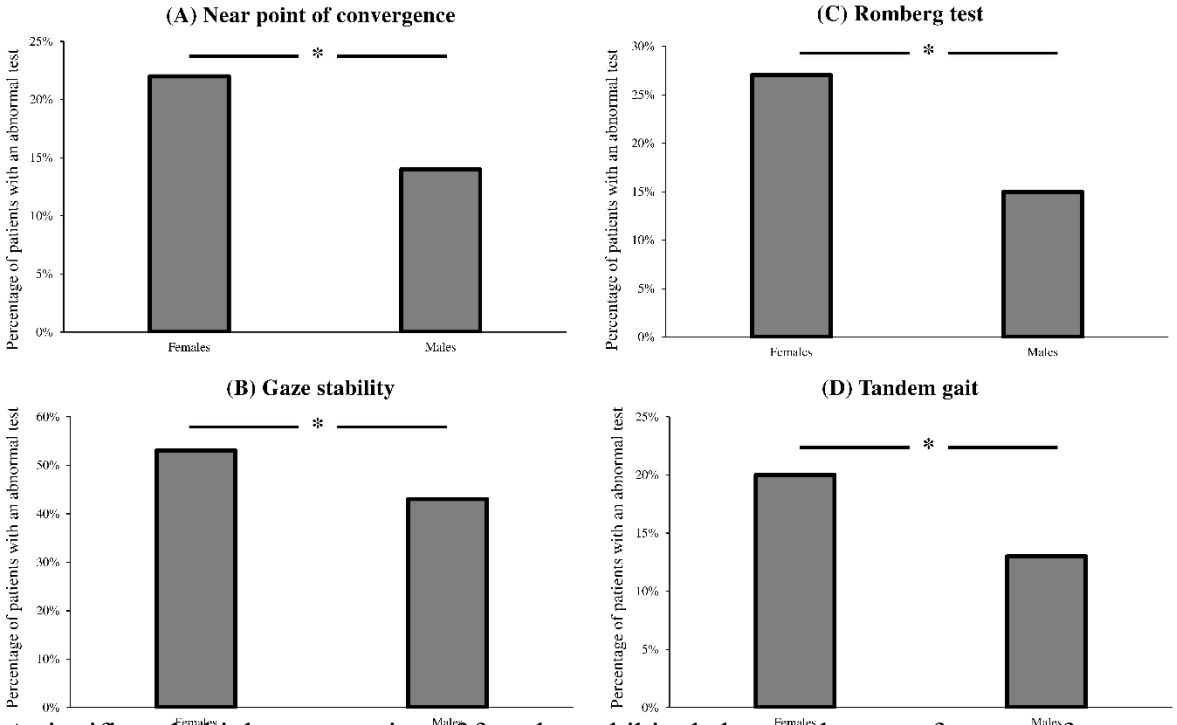
# Prognosis

- Vestibular impairments are common after a concussion and may delay recovery from the injury *(Hoffer 2010, Naguib 2012)*
- Dizziness is associated with 6.4 times greater risk, compared to other on field factors in predicting protracted symptoms (*Lau 2011)*
- Vision and vestibular dysfunction predicts prolonged concussion recovery in children *(Master et al 2017)*
- Females tend to present with worse outcomes:
  - present with higher PCSS and greater VOMS VOR scores as compared to males. *(Sufrinko et al. 2017)*

# Female adolescents demonstrate greater oculomotor and vestibular impairments than male adolescents following concussion

*Margot Gray DPT [1], Julie Wilson MD [2-4], Morgan Potter BA [2], Aaron Provance MD [2,3], David Howell PhD [2,3]*

**Figure 1.** Univariable comparisons of the proportion of females and males who demonstrated abnormal (A) near point of convergence, (B) gaze stability, (C) Romberg, and (D) tandem gait tests.




- A significantly higher proportion of females exhibited abnormal test performance for near point of convergence (p=0.017),
- gaze stability (p=0.028); Romberg (p=0.002), and tandem gait (p=0.026) tests.

# Physical Therapy Evaluation

# Current Evidence

- Dizziness reported in 50% of concussed athletes *(Kontos 2011)*
- Most recent consensus statement on the management of SRC suggests that all athletes receive a comprehensive exam including oculomotor, vestibular, gait and balance function *(Echemndia 2017)*

# History/Systems Review

- History:
  - H/o ear infections, hearing tests, vision, motion sickness, migraines or headaches, ringing in the ears?
  - Symptoms:
    - feeling? How long last? What makes better/worse?
  - Family h/o migraines, vertigo or motion sickness
  - Vestibular testing?
  - Medications?
  - Activity and Participation Limitations
- Systems Review:
  - Cardiopulmonary: cystic fibrosis, shortness of breath?
  - Integumentary
  - Msk: headaches, neck pain?
  - Neuro: seizures
  - Psych: anxiety or depression

# Diagnostic Testing

- Caloric Testing: identifies unilateral hypo function (gold standard for unilateral testing)
- Rotary Chair Test: identifies bilateral hypo function (gold standard for bilateral hypo function)
- Vestibular - Evoked Myogenic Potentials (VEMPs) – reliable for testing the otolith vestibulospinal pathways.
- vHIT: measures VOR function
- Audiogram: test hearing
- Computerized Dynamic Posturography: identifies reliance on particular sensory system

# PT Exam

- Neurologic and MSK exam
  - Posture
  - Upper cervical ligament tests
  - Upper and lower quarter screen- includes dermatomes, myotomes, and reflexes
  - Joint mobility
  - Soft tissue mobility
  - Cervical ROM
  - Thoracic ROM

# PT Exam, cont.

- Neurological examination:
  - CN testing
  - Coordination
  - Oculomotor
  - Vestibular
- Gait/Balance testing
  - BESS or mCTSIB
  - Tandem gait
  - Dual task
- Exertional Test- Buffalo Concussion Treadmill or Bike Test

# Balance Assessments

# The Balance Error Scoring System (BESS)

*Obtain Preseason Baseline Score; Compare with Post-Concussion Score*[33-34]

The Balance Error Scoring System[33-34] provides a portable, cost-effective and objective method of assessing static **postural stability**. The BESS can be used to assess the effects of mild head injury on static postural stability. Information obtained from this clinical balance tool can be used to assist clinicians in making return to play decisions following mild head injury. The BESS can be performed in nearly any environment and takes approximately 10 minutes to conduct.

The balance-testing regime consists three stances on two different surfaces. The three stances are **double leg stance**, **single leg stance** and **tandem stance**. The two different surfaces include both a **firm** (ground) and **foam** surface. **Athletes' stance should consist of the hands on the iliac crests, eyes closed and a consistent foot position depending on the stance**. Shoes should not be worn.

In the **double leg stance**, the feet are flat on the testing surface approximately pelvic width apart.

In the **single leg stance** position, the athlete is to stand on the non-dominant leg with the contralateral limb held in approximately 20° of hip flexion, 45° of knee flexion and neutral position in the frontal plane.

In the **tandem stance** testing position, one foot is placed in front of the other with heel of the anterior foot touching the toe of the posterior foot. The athlete's non-dominant leg is in the posterior position. Leg dominance should be determined by the athlete's kicking preference.

**Administering the BESS**: Establish baseline score prior to the start of the athletic season. After a concussive injury, re-assess the athlete and compare to baseline score. Only consider return to activity if scores are comparable to baseline score. Use with Standardized Symptom Scale Checklist.

**Scoring the BESS:** Each of the trials is **20 seconds.** Count the number of errors (deviations) from the proper stance. The examiner should begin counting errors only after the individual has assumed the proper testing position.

Double Leg Stance Firm Surface | Single Leg Stance Firm Surface | Tandem Stance Firm Surface | Double Leg Stance Foam Surface | Single Leg Stance Foam Surface | Tandem Stance Foam Surface

**Errors**:
- **Moving the hands off the hips**
- **Opening the eyes**
- **Step, stumble or fall**
- **Abduction or flexion of the hip beyond 30°**
- **Lifting the forefoot or heel off of the testing surface**
- **Remaining out of the proper testing position for greater than 5 seconds**

*The maximum total number of errors for any single condition is 10.*

*If a subject commits multiple errors simultaneously, only one error is recorded.*

| B.E.S.S. SCORECARD | | |
|---|---|---|
| Count Number of Errors max of 10 each stance/surface | FIRM Surface | FOAM Surface |
| **Double Leg Stance** (feet together) | | |
| **Single Leg Stance** (non-dominant foot) | | |
| **Tandem Stance** (non-dominant foot in back) | | |
| **TOTAL SCORES:** total each column | | |
| **B.E.S.S. TOTAL:** (Firm+Foam total) | | |

Airex™ Foam Balance Pads available at **www.power-systems.com** or through most sporting goods stores.

# Balance Error Scoring System (BESS)

- Consists of 3 stances (all with hands on hips and eyes closed) on 2 different surfaces (floor and foam)
- Double leg stance: feet are approximately pelvic width apart
- Tandem stance: one foot is placed in front of the other with heel of front foot touching the toe of the back foot, non-dominant leg in in the back (determine dominance by kicking preference)
- Single leg stance: stand on non-dominant leg with other limb held in about 20 degrees of hip flexion and 45 degrees of knee flexion
- Each trial is 20 seconds. Count the number of deviations/ errors
  - Errors: moving hands off hips, opening eyes, step/stumble or fall, abduction or flexion of the hip beyond 30 degrees, lifting the forefoot or heel off of the testing surface, remaining out of the proper testing position for greater than 5 seconds
  - Maximum number of errors is 10 for any single condition
  - If subject commits multiple errors simultaneously, only 1 error is recorded

# BESS Norms

| Condition | Age Group | Overall | | | Males | | | Females | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean ± SD | Median | Minimum–Maximum | Mean ± SD | Median | Minimum–Maximum | Mean ± SD | Median | Minimum–Maximum |
| Total BESS[a] | Youth | 16.58 ± 8.10 | 16 | 0–42 | 18.97 ± 8.14 | 19 | 2–42 | 13.09 ± 6.66 | 12 | 0–33 |
| | High school | 14.19 ± 6.75 | 13 | 0–50 | 14.45 ± 6.85 | 13 | 0–50 | 13.63 ± 6.48 | 13 | 0–47 |
| | College | 12.57 ± 6.06 | 12 | 0–38 | 12.53 ± 6.01 | 12 | 0–38 | 12.66 ± 6.17 | 12 | 2–37 |
| Firm BESS[b] | Youth | 5.27 ± 3.90 | 4 | 0–20 | 6.41 ± 4.16 | 6 | 0–20 | 3.61 ± 2.75 | 3 | 0–13 |
| | High school | 3.80 ± 3.22 | 3 | 0–22 | 4.02 ± 3.30 | 3 | 0–22 | 3.31 ± 2.96 | 3 | 0–20 |
| | College | 3.16 ± 2.80 | 3 | 0–19 | 3.23 ± 2.71 | 3 | 0–15 | 3.01 ± 2.95 | 2 | 0–19 |
| Foam BESS[b] | Youth | 11.31 ± 5.17 | 11 | 0–30 | 12.56 ± 5.10 | 12 | 1–30 | 9.49 ± 4.72 | 9 | 0–27 |

Ozinga et al 2018

# Tandem Gait and Dual Task

Gait & Posture 62 (2018) 157–166

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Review article

# Detecting gait abnormalities after concussion or mild traumatic brain injury: A systematic review of single-task, dual-task, and complex gait

Peter C. Fino[a,e,*,1], Lucy Parrington[a,1], Will Pitt[b,1], Douglas N. Martini[a,e], James C. Chesnutt[c], Li-Shan Chou[b], Laurie A. King[a,d]

[a] Department of Neurology, Oregon Health & Science University, United States
[b] Department of Human Physiology, University of Oregon, United States
[c] Department of Orthopedics & Rehabilitation and Family Medicine, Oregon Health & Science University, United States
[d] National Center for Rehabilitative Auditory Research, Veterans Affairs Portland Health Care System, United States
[e] Veterans Affairs Portland Health Care System, United States

Critical Review

# Gait Deviations Associated With Concussion: A Systematic Review

Thaer S. Manaseer, PT, MSc,* Douglas P. Gross, PT, PhD,* Liz Dennett, MLIS,† Kathryn Schneider, PT, PhD,‡ and Jackie L. Whittaker, PT, PhD*§

**Abstract**

**Background:** Gait deviations resulting from concussion are important to consider in the diagnosis, treatment progression, and return to activity after a concussion. **Objective:** To identify quantifiable gait deviations associated with concussion across populations and time since injury. **Methods and Materials:** Six electronic databases were systematically searched from January 1974 to September 2016. Studies selected included original data, had an analytic design, and reported a quantifiable gait parameter in individuals who had sustained a concussion as defined by the American Congress of Rehabilitation Medicine or related definitions. Preferred Reporting Items for Systematic reviews and Meta-Analysis guidelines were followed. Two independent authors assessed study quality [Downs and Black (DB) criteria] and level of evidence (Oxford Center of Evidence-Based Medicine Model). **Results:** Of 2650 potentially relevant articles, 21 level 4 studies were included. The median DB score was 12/33 (range 10-16). Heterogeneity in gait parameters and timing of postconcussion testing precluded meta-analysis. There is consistent level 4 evidence of increased medial-lateral center-of-mass displacement, and inconsistent level 4 evidence of decreased gait velocity after concussion. Further, there is preliminary level 4 evidence that gait deficits may exist beyond the typical 10-day recovery period and return to activity. **Conclusion:** These findings suggest that individuals who have suffered a concussion may sway more in the frontal plane, and walk slower compared to healthy controls. Consensus about the most important gait parameters for concussion diagnosis and clinical management are lacking. Further, high-quality prospective cohort studies evaluating changes in gait from time of concussion to return to activity, sport, recreation and/or work are needed.

**Key Words:** concussion, gait, mild traumatic brain injury

(*Clin J Sport Med* 2017;0:1–18)

IJSPT

SYSTEMATIC REVIEW

# GAIT DEFICITS UNDER DUAL – TASK CONDITIONS IN THE CONCUSSED ADOLESCENT AND YOUNG ATHLETE POPULATION: A SYSTEMATIC REVIEW

Larisa Grants, SPT[1]
Bailey Powell, SPT[1]
Cody Gessel, SPT[1]
Faith Hiser, SPT[1]
Amy Hassen, PT, DPT, OCS, MTC[1]

## ABSTRACT

***Background:*** There are no current sport concussion assessments that capture the effects of dual-task conditions on gait. Multiple studies have evaluated changes, but none have comprehensively examined literature related to the adolescent and young adult population.

***Purpose:*** The purpose of this systematic review is to synthesize documented changes in gait under dual-task conditions in adolescents and young adults after sustaining a concussion.

***Study Design:*** Systematic Review

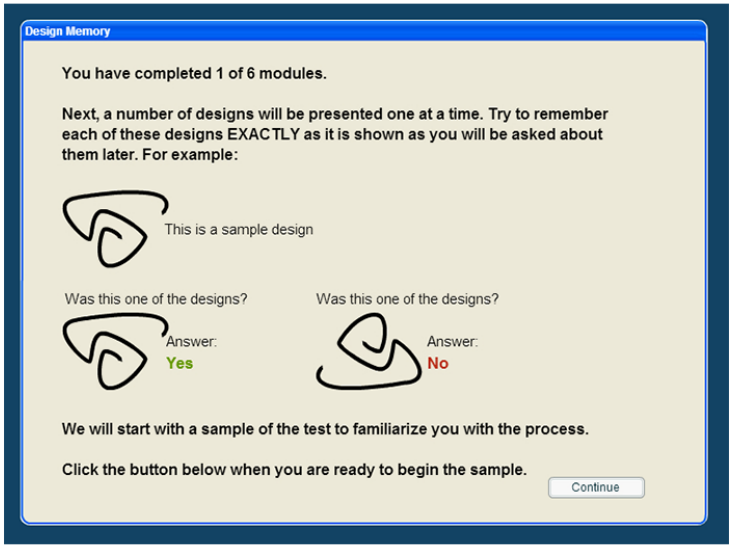
[ RESEARCH REPORT ]

MICHELLE KLEINER, PT, MCIScPT[1] • LYNNE WONG, PT, MCIScPT[1] • ALEXANDRA DUBÉ, PT, MCIScPT[1]
KATIE WNUK, PT, MCIScPT[1] • SUSAN W. HUNTER, PT, PhD[1] • LAURA J. GRAHAM, PT, PhD[1]

# Dual-Task Assessment Protocols in Concussion Assessment: A Systematic Literature Review

# Dual-Tasks

+



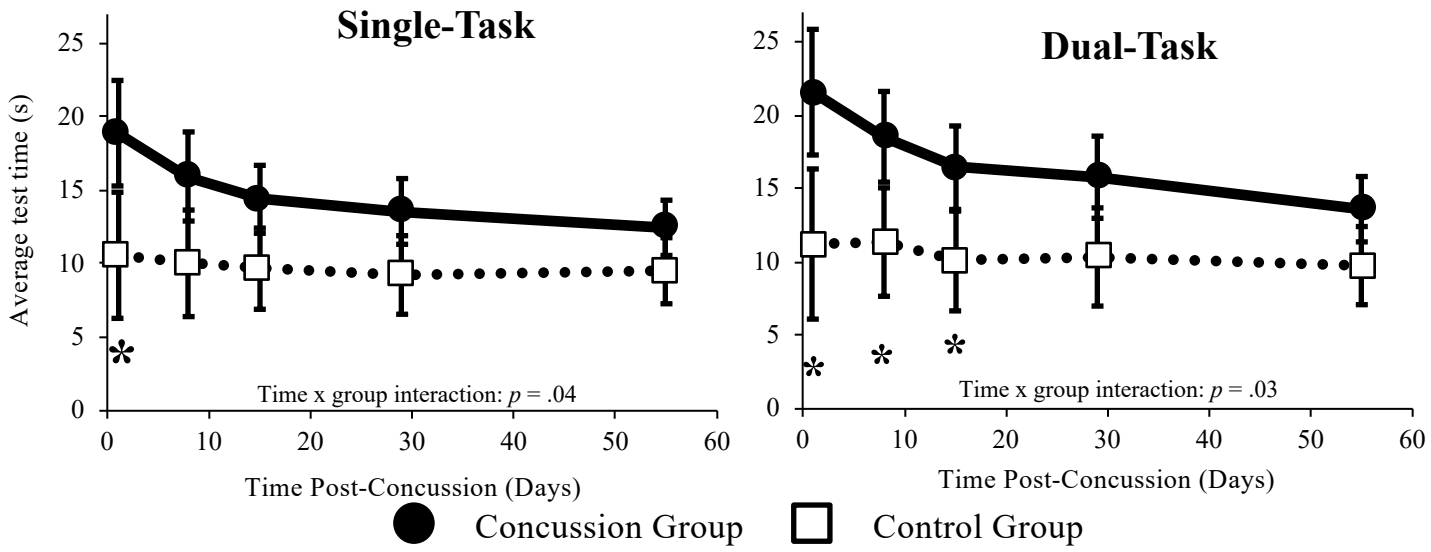

*Isolated Motor Task (Gait)*

*Isolated Cognitive Task (Computerized Test)*

*Dual-Task (Gait and Cognitive)*

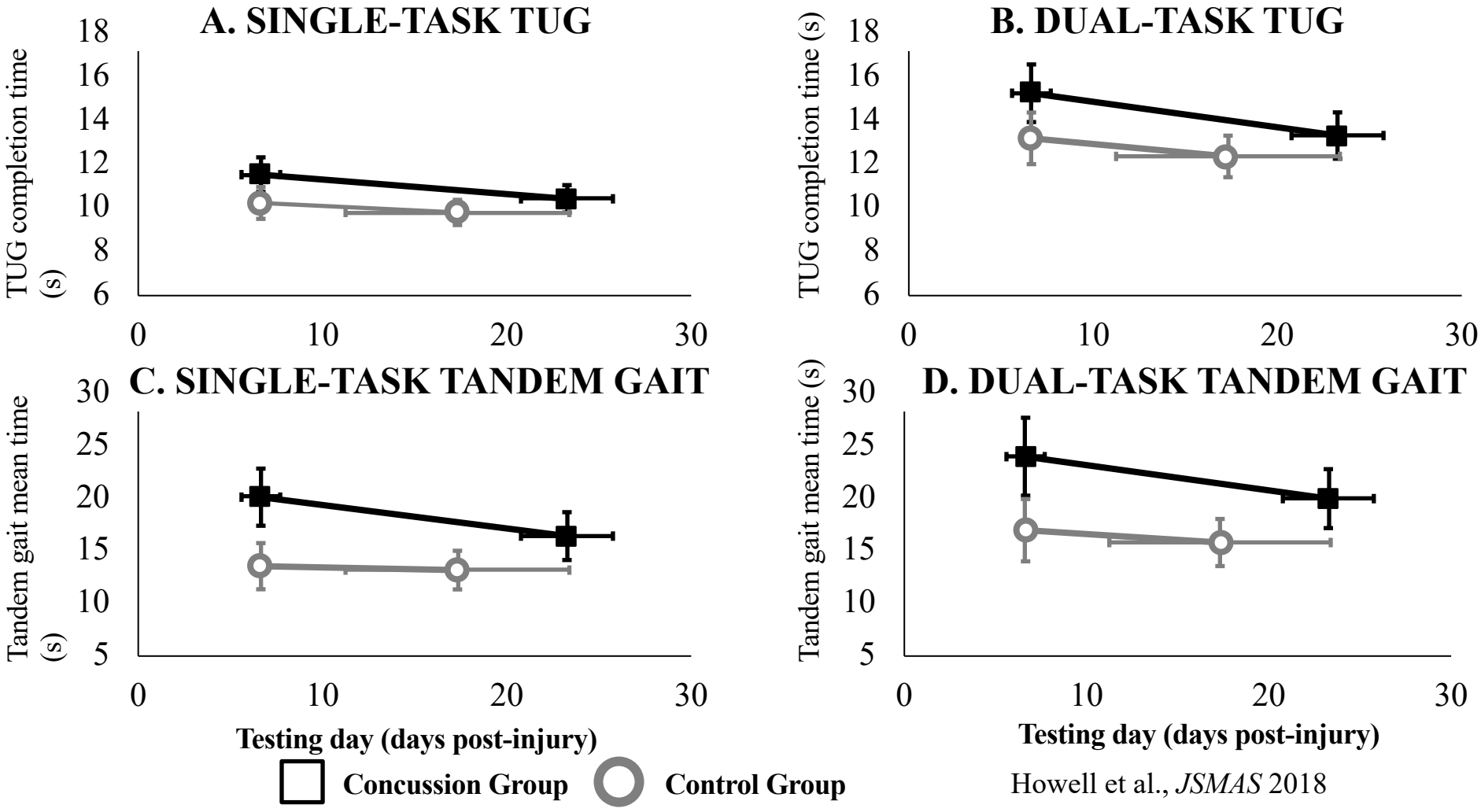
**Reflection of on-field demands**

# Tandem Gait Time




Adolescents with concussion completed the TG test slower than controls at the initial time point during single-task ($p$ = .006) and for the first 2 weeks post-injury during dual-task conditions (p = 0.005, 0.006, and 0.008, respectively)

Howell et al., J Sci Med Sport, 2017




Howell et al., *JSMAS* 2018

# Static/Dynamic Cognitive Evaluation

- Evaluate performance on serial 7s, spelling words backwards, saying months backwards while still vs. walking
- Post-concussion deficits can be identified when assessing cognitive task performance while standing and while walking
- Assessment of cognitive performance during dynamic tasks may be a clinically viable method to evaluate post-concussion deficits.

Brilliant et al., Clin J Sports Med, 2019

# Monitoring Recovery:

## Dual-task deficits outlast…

*Journal of Athletic Training* 2017;52(11):000–000
doi: 10.4085/1062-6050-52.11.23

www.natajournals.org

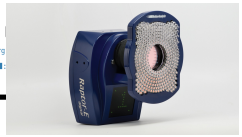
### Gait and Quiet-Stance Performance Among Adolescents After Concussion Symptom Resolution

**Justin Berkner, BS*; William P. Meehan III, MD†; Christina L. Master, MD‡; David R. Howell, PhD, ATC†§**

*University of New England, Biddeford, ME; †The Micheli Center for Sports Injury Prevention, Division of Sports Medicine, Boston Children's Hospital, Waltham, MA; ‡Sports Medicine and Performance Center, The Children's Hospital of Philadelphia, University of Pennsylvania Perelman School of Medicine; §Sports Medicine Center, Department of Orthopedics, Children's Hospital Colorado, University of Colorado School of Medicine, Aurora

**Single-task deficits**

ACRM AMERICAN CONGRESS OF REHABILITATION MEDICINE
Archives of Physical Medicine and
journal homepage: www.archives-pmr.org
Archives of Physical Medicine and Rehabilitation 2018;■:■–■



ORIGINAL RESEARCH

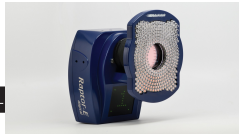
### Detection of Acute and Long-Term Effects of Concussion: Dual-Task Gait Balance Control Versus Computerized Neurocognitive Test

David R. Howell, PhD,[a,b,c] Louis R. Osternig, PhD,[d] Li-Shan Chou, PhD[d]

*From the [a]Sports Medicine Center, Children's Hospital Colorado, Aurora, CO; [b]Department of Orthopedics, University of Colorado School of Medicine, Aurora, CO; [c]The Micheli Center for Sports Injury Prevention, Waltham, MA; and the [d]Department of Human Physiology, University of Oregon, Eugene, OR.*

**Computerized neurocognitive deficits**

CLINICAL



### Return to Activity after Concussion Affects Dual-Task Gait Balance Control Recovery

DAVID R. HOWELL, LOUIS R. OSTERNIG, and LI-SHAN CHOU
*Department of Human Physiology, University of Oregon, Eugene, OR*

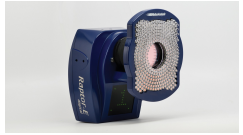
**Return to Play Time**

Exp Brain Res (2014) 232:1773–1782
DOI 10.1007/s00221-014-3869-1

RESEARCH ARTICLE

### The effect of cognitive task complexity on gait stability in adolescents following concussion

David R. Howell · Louis R. Osternig · Michael C. Koester · Li-Shan Chou



**Self-reported symptoms**

Original Research

### Quantitative Multimodal Assessment of Concussion Recovery in Youth Athletes

David R. Howell, PhD, ATC,*†‡ Gregory D. Myer, PhD,§ Anna Brilliant, BS,‡¶ Kim Barber Foss, MS, ATC,§ and William P. Meehan III, MD‡¶‖

**Electrophysiologic deficits**

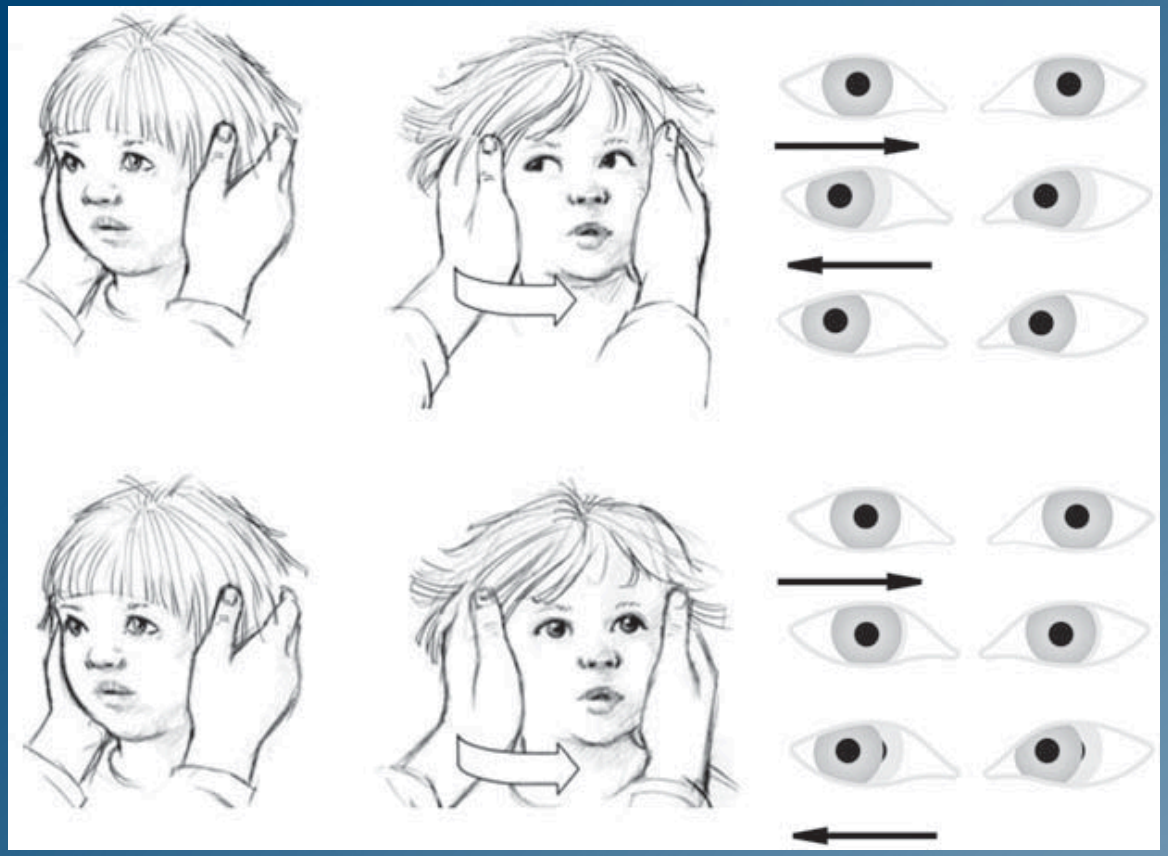
# Oculomotor Testing

| OM Test | Central vs. Per. | Normal | Abnormal |
|---|---|---|---|
| Spontaneous Nystagmus | Central | Normal eye alignment, no nystagmus | Nystagmus, note the direction |
| Gaze Holding Nystagmus | Central or Peripheral | No nystagmus, able to maintain gaze | Peripheral: non direction changing nystagmus<br><br>Central: direction changing nystagmus |
| Smooth Pursuit | Central | patient is able to maintain gaze on finger | nystagmus, jerky or saccadic eye movements |

# Oculomotor Testing, Cont.

| OM Test | Central vs. Per. | Normal | Abnormal |
|---|---|---|---|
| Saccades | Central | patient is able to switch gaze from finger to nose with no difficulty. One eye correction or corrective saccade can be normal | over and/or undershooting the target, nystagmus, jerky eye movements. More than one eye correction |
| Convergence | Central | patient is able to adduct both eyes and reports double vision within 5 cm from the nose. | Patient is unable to adduct one or both eyes as target moves toward the nose.<br>-Patient reports double vision >5cm from the nose (measure from the bridge of the nose) |

| Special Test | Testing | Sens/Spec. | Normal | Abnormal |
|---|---|---|---|---|
| Head Thrust Test/Head Impulse Test | -VOR function<br>-peripheral hypofunction (SCC)<br>-peripheral | Sensitivity: 75%<br>Specificity:77%<br>Reliability: ICC .73 | patient is able to maintain gaze on the nose. | corrective saccade. 2/3 trials are positive. Name to the side the head was thrusted to. |
| Dynamic Visual Acuity (DVA) | -VOR function<br>-peripheral hypofunction (SCC)<br>-peripheral | Sensitivity: 88%<br>Specificity: 69%<br>Reliability: ICC .81 | able to read up to 2 lines of dynamic visual acuity as related to static visual acuity. | > 2 lines of dynamic visual acuity as related to static visual acuity |
| Bucket Test | -Otolith function<br>-subjective visual vertical<br>-Peripheral | Reliability ICC .74<br>Sensitivity: 77%<br>Specificity: 72% | <2 degrees off vertical | >2 degrees off vertical |
| Head shake test | VOR<br>-central vs. peripheral | Sensitivity: 56%<br>Sensitivity:71% | No nystagmus | Unidirectional horizontal nystagmus – peripheral<br><br>Vertical nystagmus – central<br><br>*Christy 2014* |



# Outcome Measures

- Vanderbilt Pediatric Dizziness Handicap Inventory (p-DHI): 4-12 yrs old. Caregiver completes
- Dizziness Handicap Inventory (Adult)
  - MCID: 18 pts
- Dynamic Gait Index (DGI)
  - MDC = 3.2 pts (vestibular disorders)
- Functional Gait Assessment (FGA)
- BESS
- Modified Clinical Test of Sensory Integration of Balance (m-CSTIB)
- Developmental:
  - BOT II
  - PDMS

Children's Hospital Colorado
Orthopedics Institute

ORTHOPEDICS
INSTITUTE

# VESTIBULAR REHABILITATION

*Margot Gray  PT, DPT*
*PT Vestibular Program Lead*
*Children's Hospital Colorado*

Affiliated with
School of Medicine
UNIVERSITY OF COLORADO
ANSCHUTZ MEDICAL CAMPUS

# Vestibular Rehabilitation

- Vestibular rehabilitation reduces dizziness and improves balance in individuals with head injury (*Herdman, Gizzi, Hoffer et al., Alsalaheen et al.)*
- Vestibular rehabilitation is a key component to management of dizziness and balance disorders from vestibular system dysfunction both peripheral or central *(Horak et al., Herdman et al., Krebs et al., Enticott et. al)*
- Clinical practice guideline for concussion/mTBI and persistent symptoms 2015 – recommendation of VRT for persistent vestibular symptoms or dysfunction *(Marshall et.al.)*

# VRT and Concussion

- Systematic review looking at rest and treatment following SRC: Data supports cervical and vestibular rehab and multifaceted collaborative care. *(Scheider et al. 2017)*
- Systematic review showed current level of evidence supporting VRT in concussions is considered low (*Murray et. al.* 2017)
  - Patients with dizziness imbalance symptoms respond more effectively to treatment.

# Hall et. Al. 2016 CPG for Peripheral Vestibular Hypofunction

- Current vestibular rehab is an exercise based approach that typically includes a combo of 4 exercise components

1. Exercises to promote gaze stability
2. Exercises to habituate symptoms
3. Exercises to improve balance and gait
4. Walking for endurance

# Settling techniques

- Use  proprioception and visual input to compensate for vestibular dysfunction
- Visual: look at a stationary object
- Proprioception: push hands and/or feet into a firm surface (floor or chair)

# Adaptation

- An image motion on the retina associated with head movement helps to drive VOR adaptation. *(Zee D. 2000)*
- Velocity dependent
- Context specific

# Adaptation for gaze stability

- X1 and X2 viewing
- Repetition (3x/day for 6-12 weeks)
- Error signal
- Voluntary head movement
  - Yaw and pitch plane
  - Small amplitude
- Goal oriented and specific


*Hall 2016, HEP2GO.com*

# Exercise RX for Gaze Stability

- Daily
- 3x/day for 2-3 exercises
- At least 12 min/day = acute/ subacute vestibular hypofunction
- At least 20 min/day = chronic vestibular hypofunction
- Symptoms should return to baseline within 15-20 minutes or it is too much
- Be patient, it takes time

*Hall 2016*

# Variables to Change

- Background complexity
- Speed of head movement- go to the edge of blurry (smooth pursuits work at <2Hz)
- BOS and surface
- Distance of target
- Optotype size
- Optotype form
- Only change 1 variable at a time!!!

# Substitution for Gaze Stability

- Give alternative strategies to replace the lost or compromised function
- Vision- teach to anticipate, strengthen use of  OM to stabilize
  - Limited, can only go to 100 Hz
- Balance- allow vision and proprioception

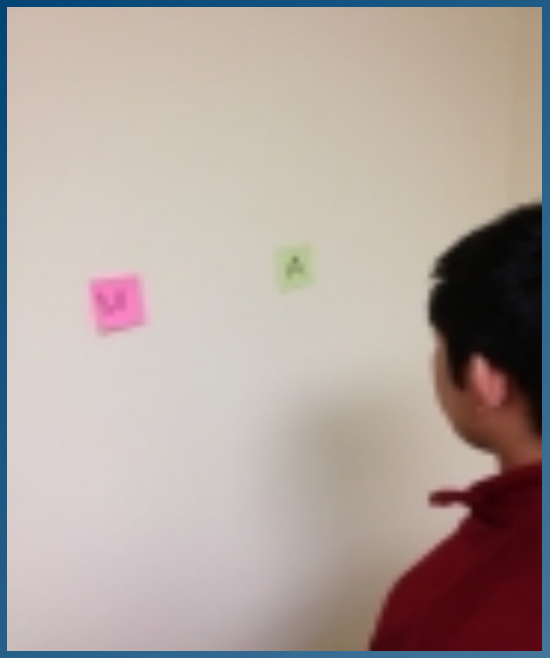
# Train OM

- Do X1 exercise but move card instead of head
  - Strengthening smooth pursuit and saccades
  - Optotype must be small enough to challenge acuity
  - Same progression as with adaptation

- Convergence- Strongest evidence
  - Brock String
  - Pencil Push Ups

# Oculomotor Exercises

Saccades (horizontal)




Saccades (Vertical)

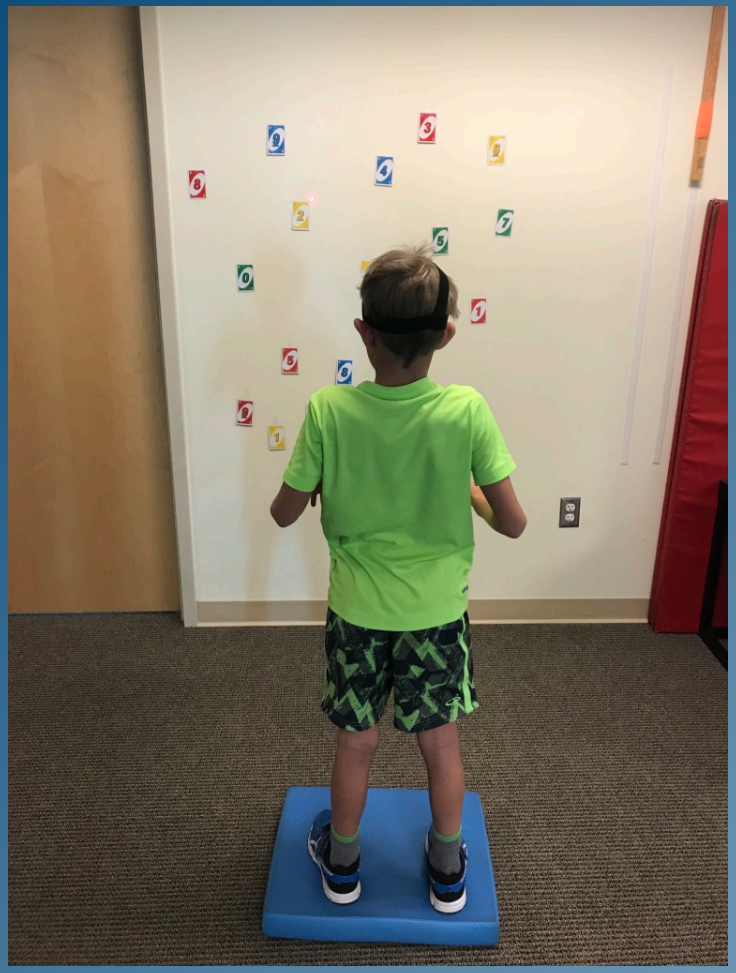
# Habituation

- Reduction in a behavioral response to repeated exposure to a provoking stimulus with the goal of reducing symptoms
  - Learning to tolerate movement
- Must replicate what provokes the symptoms

# Habituation Activities

- Determine what motion causes symptoms - mild to moderate symptoms
- Do this motion with them 3 X/day, 3-5 reps
  - Start with only 1 exercise and increase to 4
  - Should return to baseline within 15-20 minutes

# Balance Activities



# Balance Progression Ideas?

# Adaptation for Balance

- Change BOS
- Moving support
- Head movements
- Visual challenges
- Moving visual stimulation

# Substitution for Balance

- Train to use vision and somatosensory to compensate
  - Vision:
    - Target fixation
    - Night lights
  - Proprioception:
    - Hold onto railing or wall

# Summary
# Treatment Strategies

- Oculomotor exercises: saccades, pursuits, vergence (convergence/divergence)
- Adaptation: VOR X1 and X2 exercises (Herdman, 2007. Schubert, Rine and Brasswell)
- Habituation: repeated exposure to noxious stimulus to habituate the nervous system.
- Substitution/Compensation: Only in instances of complete or bilateral loss.
- Balance training: specific to vestibulospinal system

# Modified Table 27-1 Diagnosis Driven Tx- Herdman and Rine

| Diagnosis | Treatment Options |
|---|---|
| BPPV | Canalith repositioning, Liberatory, Appiani, Gufoni, Brandt-Daroff; maybe habituation, maybe balance |
| Unilateral vestibular hypofunction | Gaze stabilization (more adaptation), habituation and postural stabilizations exercises (balance) |
| Bilateral vestibular hypofunction | Gaze stabilization (more substitution), maybe habituation and balance |
| Motion sensitivity | Habituation, maybe substitution, maybe balance |
| Central Vestibular | Train OM (mainly vergence), gaze stabilization (both substitution and adaptation), Habituation, and balance |

Children's Hospital Colorado
Orthopedics Institute

ORTHOPEDICS
INSTITUTE

# Case Studies

Affiliated with
University of Colorado
Anschutz Medical Campus

# Case # 1

- 12 year old female
- c/o headache (HA) and neck pain seen 2 days after a concussive event
- Was playing in a soccer game and fell twice near the end of the game. The first time she was hit in the back of her knee and she fell forward, landed and rolled and hit the front of her head on the ground. She was slow to get up but did and ran to stop a goal. She was then knocked over by another player that was going for the same ball. She fell backwards and hit the back of her head on the ground. She had a bad and sudden HA and was dizzy. She was emotional and sleepy. She complained that the light bothered her. They went home and she was laughing at things that weren't really funny but answering questions fine.
- No significant medical history
- Family medical history is significant for 2 sisters with migraines and 1 sister with a possible anxiety disorder

# Subjective Symptoms

Headache

- 7/10 currently, 9/10 worst, 5-6/10 best constant
- “feels like someone is punching her in the middle of the back of her head
- Light, smells and loud noises make it worse, laying down and resting make it better

Dizziness

- 0/10 currently, 5/10 worse
- Described as ”lightheaded”
- Smelling lotion and position changes make it worse, rest makes it better

Neck pain

- 7/10 currently, 9/10 worst, 5-6/10 best
- Feels like someone is “pulling on your skin and punching the back of my neck”
- Moving head makes it worse, had to whisper because talking made it worse, laying down makes it better

Vison and auditory complaints- no

# PT Exam

- Ligamentous tests -normal
- Cranial nerves- normal
- Upper quarter screen- normal
- Cervical ROM: rotation (L= 40, R= 75), sidebend (L= 35, R= 30), flexion= 40, extension= 10 with pain all directions but esp. extension
- Thoracic ROM: rotation and sidebend= 50%, flexion= 25% and unable to do extension due to pain (pain all motions)
- Joint mobility: restricted in all directions, difficult to fully assess because she was so tender to palpation
- Soft tissue mobility: severe tenderness with moderate restriction in all muscles
- Oculomotor: smooth pursuits and convergence were normal, saccades were slowed but normal
- Vestibular: + sensation of movement at rest, negative gaze holding nystagmus, deferred other testing secondary to neck pain
- BESS:
  - firm surface double leg= 2 errors, Tandem= 5 errors, SLS= 10 errors
  - Foam surface double leg= 3 errors, Tandem= 10 errors, SLS= 10 errors

| | |
|---|---|
| Baseline VAS | 5/10 neck pain |
| Baseline HR | 97 bpm |
| HRR | 111 bpm |
| 70% HRR | 174.7 bpm |
| 80% HRR | 191.35 bpm |
| Test ended | 8 minutes |
| RPE | 17 |
| Ending HR | 121 bpm |
| Ending VAS | 6/10 |

- Tested at 3rd visit when symptoms were less than 7/10

# CASE #2

J.M is a 13 year old female presenting to physical therapy after sustaining a concussion approximately 1 month ago when she was in a motor vehicle accident. J.M was in the back passenger side when the car was hit on the passenger side. J.M. demonstrated no LOC or PTA. J.M went to the ED after the accident with a severe headache, dizziness, nausea, vomiting and neck pain. She received a cervical x-ray and MRI that were both normal.

J.M reports continued dizziness, headaches and neck pain since the accident. She states the dizziness is sporadic lasting "seconds to minutes". She describes it as "spinning" and "feeling like I could fall". Dizziness can occur with and without a headache. J.M experiences headaches daily along the back to the left side of her head. J.M also states that she has difficulty with reading in school with eye pain and fatigue. Specifically, she has blurry vision with looking from the white board and back to her paper. She reports neck pain approximately 2-3 times a week along the back of her head extending down the posterior cervical region with sitting for prolonged periods of time.

+ h/o anxiety and ear infections with tubes, + family h/o migraines (MOC)

# PT Exam

- Ligamentous tests: WNL
- Cranial nerves: WNL
- Upper quarter screen: WNL
- Cervical ROM: rotation (L= 80, R= 80), sidebend + pain (L= 30, R= 25), flexion= 50 +pain, extension= 50 + pain
- Thoracic ROM: WNL with no pain
- Joint mobility: dec rot to L at AA with pain, dec. lat mobility C3-5 L to R
- Soft tissue mobility: severe tenderness with moderate restriction in suboccipitals, upper traps, levators and cerv paraspinals
- Oculomotor: smooth pursuit and saccades WNL, conv: + ~10cm
- Vestibular: + head thrust L, gaze holding: + right beating nystagmus with frenzels, DVA + loss of 4 lines and dizziness
- BESS:
  - firm surface double leg= 4 errors, Tandem= 5 errors, SLS= 4 errors
  - Foam surface double leg= 10 errors, Tandem= 10 errors, SLS= 10 errors

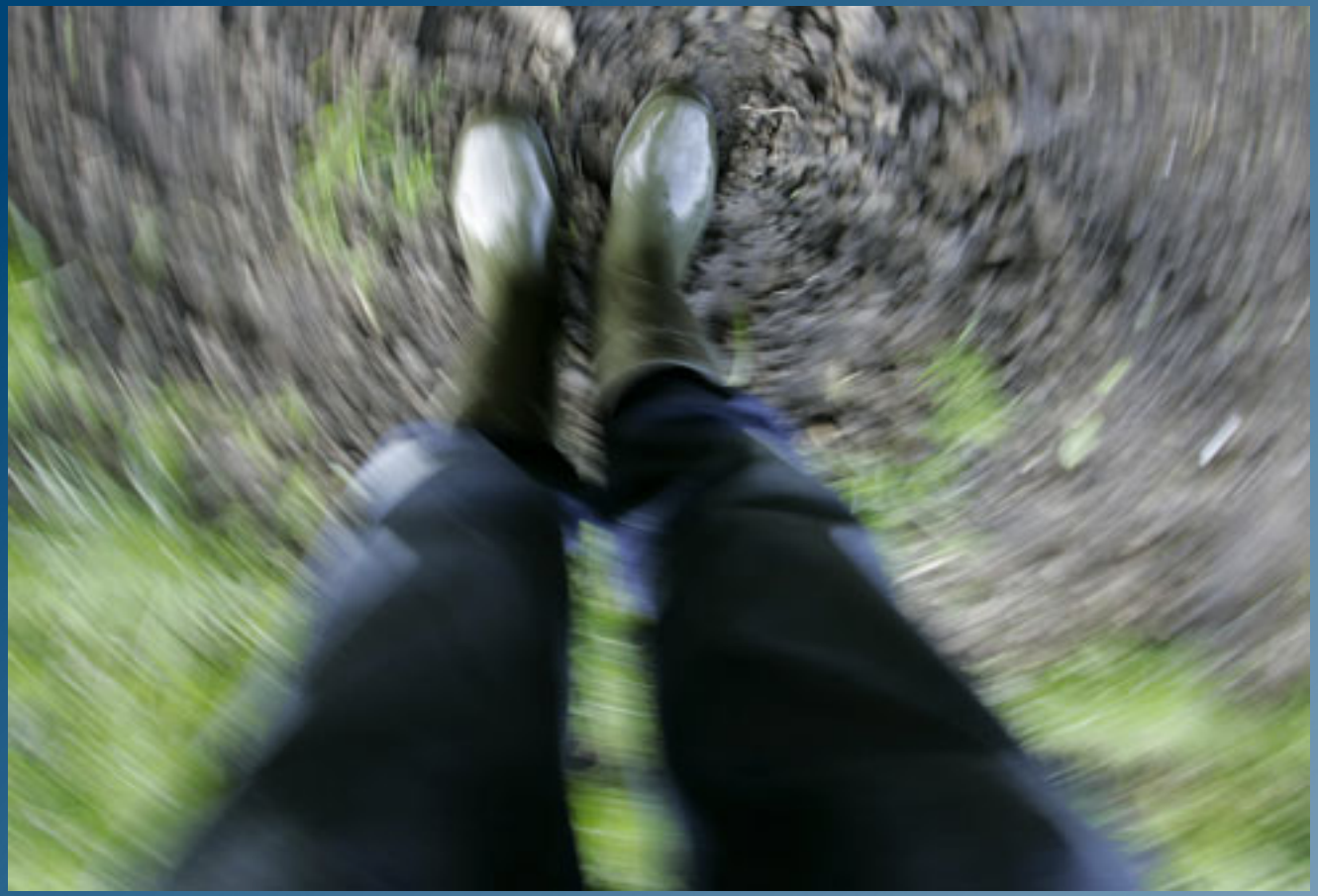
| | |
|---|---|
| Baseline VAS | 3/10 neck pain and dizziness |
| Baseline HR | 91 bpm |
| HRR | 115 bpm |
| 70% HRR | 171.5 bpm |
| 80% HRR | 188.75 bpm |
| Test ended | 16 minutes |
| RPE | 17 |
| Ending HR | 185 bpm |
| Ending VAS | 5/10 neck pain and dizziness |

# Balance Disorders Clinic

- Children's Hospital Colorado Balance Disorders Clinic (BDC)
  - Multidisciplinary clinic : ENT, Neurology, Audiology, PT
    - ENT: Dr. Melissa Scholes, MD
    - Neurologist: Dr. Carolyn Green, MD
    - Audiologists: Karen Harris Au.D., Dani Stern Au.D., Alyssa Schoeborn Au.D., Amanda Baker Au.D., Karen Harris Au.D.
    - Vestibular Testing prior to MDC clinic appt.
    - VNG, VEMPS, and vHIT
  - 4th Tuesday and 3rd Friday of every month
  - referral: send email to margot.gray@childrenscolorado.org

# Questions?

# THANK YOU



- Margot Gray PT, DPT
  - Children's Hospital Colorado
  - PT Vestibular Program Lead
  - Margot.gray@childrenscolorado.org



*References are available upon request


TEST

1. Which vestibular end organs sense linear movements:
   a. cochlea
   b. semicircular canals
   c. otoliths
   d. vestibular aqueducts

2. Which of the below are tested during an ocular –motor exam?
   a. Saccades
   b. VOR
   c. Smooth pursuit
   d. Both a and c

3. Which of the following is the best way to introduce exercise back to an athlete after a concussion?

a. Allow them to fully return to sport
b. Perform an exertional test, take 80% of their max heart rate at time of symptom exacerbation and have them exercise at that heart rate.
c. Don't let them exercise until their symptoms have fully resolved
d. All of the above

4. True/False The vestibular-ocular reflex looks at the ability of the eyes to main gaze during head rotations.

5. True or False, Females are more likely to present with prolonged recovery after a concussion as compared to male.

6. True or False, Concussions are a homogenous injury with most patients presenting with very similar symptoms and recovery.

7. True or False, Early subsymptom threshold aerobic exercise has been shown to help decrease persistent symptoms.

8. True or False, You should only address one system at a time when treating a patient with post concussion symptoms.

9. True or False, Whiplash symptoms can mimic concussion symptoms.

10. The physical therapy evaluation for a patient with persistent post concussion symptoms should include the following…

a. Oculomotor- Vestibular exam
b. Cervical spine exam
c. Exertional tests
d. Neuroscreen
e. All the above

# References


- Howell DR, Potter MN, Kirkwood MW, Wilson PE, Provance AJ, Wilson JC. Clinical predictors of symptom resolution for children and adolescents with sport-related concussion. *Journal of Neurosurgery Pediatrics*. 2019
- Howell DR, Wilson JC, Brilliant AN, Gardner AJ, Iverson GL, Meehan WP. Objective clinical tests of dual-task dynamic postural control in youth athletes with concussion. *J Sci Med Sport*. 2019;22(5):521-525.
- Sufrinko AM, Mucha A, Covassin T, et al. Sex Differences in Vestibular/Ocular and Neurocognitive Outcomes After Sport-Related Concussion. *Clin J Sport Med*. 2017;27(2):133-138.
- Iverson GL, Gardner AJ, Terry DP, et al. Predictors of clinical recovery from concussion: a systematic review. *Br J Sports Med*. 2017;51(12):941-948.
- Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther*. 2010;34(2):87-93.
- Herdman S, Clendaniel R. *Vestibular Rehabilitation*. 4 edition. Philadelphia: F.A. Davis Company; 2014
- Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomised controlled trial. *Br J Sports Med*. 2014;48(17):1294-1298.
- Murray DA, Meldrum D, Lennon O. Can vestibular rehabilitation exercises help patients with concussion? A systematic review of efficacy, prescription and progression patterns. *Br J Sports Med*. 2017;51(5):442-451.
- Master CL, Master SR, Wiebe DJ, et al. Vision and Vestibular System Dysfunction Predicts Prolonged Concussion Recovery in Children. *Clin J Sport Med*. October 2017.
- Christy JB, Payne J, Azuero A, Formby C. Reliability and diagnostic accuracy of clinical tests of vestibular function for children. Pediatr Phys Ther. 2014 Summer;26(2):180-9.