Assessing Vision, Balance, and Vestibular Function as Potential Biomarkers for Concussion

Drew Davis, MD
Erin Swanson, MD
Katherine K. Weise, OD, MBA, FAAO
Jennifer B. Christy, PT, PhD
Learning Objectives

• Understand the importance of identifying biomarkers for individuals with concussion.

• Learn to select clinical tests to screen for visual, vestibular, oculomotor, and balance function.

• Demonstrate use of clinical tests to screen for visual, vestibular, oculomotor, and balance function.

• Identify evidence-based intervention techniques to potentially improve impairments of vision, balance, and vestibular function in individuals with concussion.

• Demonstrate intervention techniques to potentially improve impairments of vision, balance, and vestibular function in individuals with concussion.

• Discuss elements of the visual, vestibular, oculomotor, and balance examination that show promise for development as biomarkers for concussion.
Erin Swanson, MD
Assistant Professor
Division of Pediatric Rehabilitation Medicine
Departments of Pediatrics and Physical Medicine and Rehabilitation
UAB/Children’s of Alabama
• Understand the importance of identifying biomarkers for individuals with concussion.
  • How do we define concussion?
    • Depends on who you ask
    • Some suggest we should not define but drop
  • How do we diagnose concussion?
    • Combination of history and examination
    • Do not always have objective findings
  • How do we define a biomarker?
    • Depends on who you ask
    • Generally agreed upon principles
How do we define concussion?

2012 - Zurich Consensus Statement on Concussion in Sport proposed that concussion and mild TBI should be viewed as distinct entities.

- "complex pathophysiological process affecting the brain"

2013 - American Academy of Neurology guidelines for sports concussion do not separate concussion from mild TBI.

- "a clinical syndrome of biomechanically induced alteration of brain function, typically affecting memory and orientation, which may involve loss of consciousness"

A lack of consensus in the use of the term and an overlap in the use of concussion and mild TBI.

• How do we diagnose concussion?
  • Take history to understand potential mechanism of injury.
  • Assess symptom report including somatic, cognitive, and/or emotional symptoms.
  • Perform exam including assessment of mental status, cognitive function, gait, and balance.
  • Make a diagnosis based on a mechanism of injury that explains the onset of symptoms, with or without specific physical examination findings.
• How do we follow the diagnosed concussion?
  • Reassess symptom report including somatic, cognitive, and/or emotional symptoms.
  • Perform exam including assessment of mental status, cognitive function, gait, and balance.
  • Continue to manage recovery based upon report of symptoms, with or without specific physical examination findings.
  • When the patient is improving consistently this is often adequate.
• What do we do when the patient is not improving or has a few lingering complaints?
  • Make sure we understand context of injury, i.e. previous concussion, ADHD, mood disorder, etc.
  • Ensure that vision and balance have been thoroughly assessed.
  • Target recommendations or treatments to specific signs or symptoms.
  • Look for a biomarker.
How do we define a biomarker?

- 1998 - the National Institutes of Health Biomarkers Definitions Working Group defined a biomarker as:
  - “a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention.”

- A joint venture led by the World Health Organization (WHO) defined a biomarker as:
  - “any substance, structure, or process that can be measured in the body or its products and influence or predict the incidence of outcome or disease”

• How do we define a biomarkers in concussion?
  • Neuroimaging
  • Electrical Studies
  • Laboratory Studies
    • CSF
    • Serum
    • Saliva, urine, and tears
  • Objective Testing of Vision, Balance, and Vestibular Function

• Objective Testing of Vision, Balance, and Vestibular Function

• 30 areas of the brain and 8 of 12 cranial nerves deal with vision

• Balance is derived from multiple sensory inputs from vestibular end-organs, the visual system, and the somatosensory and proprioceptive systems


Brain Injury Medicine: Principles and Practice, 2nd Edition
Fulton, James T., Processes in Biological Vision {online} {Corona Del Mar, CA. USA} Vision Concepts,
euronresearch.net/vision/
Katherine K. Weise, OD, MBA, FAAO
Professor of Optometry
Director, Pediatric Optometry Services
Executive Committee, Vestibular and Oculomotor Research Clinic
UAB School of Optometry
9 year old: charged on basketball court and hit back of head on concrete floor (2013)

- 9 months later
  - Unable to attend school for more than 2 hours at a time for a maximum of 3 days a week.
  - Has a teacher come to his house 4 days a week
  - Neuropsychologist suggests brain rest
    - Hold off on everything else including eye exercises until he can attend school for 10 hours a week.
Concussion Clinical Research Facility
Dream Team – July 2013

Children’s of Alabama
Marshall Crowther, MD – orthopedics
Drew Davis, MD - Pediatric Rehab Medicine
Leon S. Dure, MD – Pediatrics Neurology,
Drew Ferguson, MEd, ATC - UAB Sports Medicine Director
James M. Johnston, MD - Pediatric Neurosurgery

Eye and Vestibular
Claudio Busettini, PhD, Dr. Eng. – Vestibulo-ocular reflex science
Jennifer Christy, PT, PhD - Vestibular science

Chris Girkin, MD – Dept Chair, Ophthalmology
Mark Swanson, OD, MS – Director, UAB Eye Care Ocular Disease Service
Katherine K. Weise, OD, MBA – Director, UAB Eye Care Pediatric and Binocular Vision Service

Athletics
Joseph Ackerson, PhD - Neuropsych, Chair for Alabama Statewide Sports Concussion Taskforce
Frank Messina, PhD - Asst Athletic Director, UAB

UAB Engineering and Biomedicine
Larry DeLucas, OD, PhD – Center for Biophysical Sciences and Engineering/NASA
Crawford Downs, PhD - Center for Ocular Biomechanics and Biotransport (COBB)
Cali Fidopiastis, PhD - Virtual Cognitive Rehabilitation
Dean Sicking, PhD – Helmet design/field analysis

Other Key Collaborators
Craig Formby, MA, PhD – UA(T) Communicative Disorders
Dennis Leonard – Legos of UAB
Marsha Snow, OD – VAMC

Neuroscience
Lori L. McMahon, PhD – Comprehensive Neuroscience Center

Candace Floyd, PhD – National Neurotrauma Society
Anti-Point RT (0.988)
Pro-Point RT (0.933)
SAC (0.849)
KD (0.536)

True-positive rate (Sensitivity)
False-positive rate (1 − Specificity)
Concussion and The Eye (mTBEye)

• Why the Eye in concussion
• The Evidence
  • Clinical exam findings
  • Testing methods
  • Research in non-concussed Applied to mTBI
• UAB VORClinic
  • Vision and Academics
  • King-Devick in Youth
  • Objective Pupil testing
• iPad
Why The Eye in Concussion?
It’s built from the brain.
Week 3 – 10 of pregnancy

Diencephalon (forebrain)
Why The Eye in Concussion?
It’s built From the brain.
Week 3 – 10 of pregnancy
Why The Eye in Concussion?
It’s built Like the brain.
Mechanism of Diffuse Axonal Injury
Why the Eye in Concussion?
It courses Through the brain.
Why the Eye?

• Cranial Nerves
  • I - Olfactory
  • II - Optic
  • III - Oculomotor
  • IV - Trochlear
  • V - Trigeminal
  • VI - Abducens
  • VII - Facial
  • VIII - Vestibulocochlear
  • IX - Glossopharyngeal
  • X - Vagus
  • XI - Accessory
  • XII - Hypoglossal
Why The Eye in Concussion?

• The Eye
  • is built from the brain,
  • is built like the brain,
  • courses through the brain.
## Concussion and Vision - Prevalence Literature (Scheiman M):

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Convergence Insufficiency</th>
<th>Accommodative Insufficiency</th>
<th>Eye Movement</th>
<th>Visual Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master C Scheiman M 2015</td>
<td>100</td>
<td>49%</td>
<td>51%</td>
<td>29%</td>
<td></td>
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<tr>
<td>Stelmack 2009</td>
<td>103</td>
<td>28%</td>
<td>47%</td>
<td>6%</td>
<td>14%</td>
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<tr>
<td>Brahm 2009</td>
<td>191</td>
<td>42%</td>
<td>42%</td>
<td>33%</td>
<td>32%</td>
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<tr>
<td>Goodrich 2007</td>
<td>50</td>
<td>30%</td>
<td>22%</td>
<td>20%</td>
<td>21%</td>
</tr>
<tr>
<td>Suchoff 1999</td>
<td>62</td>
<td>42%</td>
<td>10%</td>
<td>40%</td>
<td>32%</td>
</tr>
<tr>
<td>Normal population</td>
<td></td>
<td>BV = 5%</td>
<td>3%</td>
<td>2%</td>
<td></td>
</tr>
</tbody>
</table>
Concussion and Vision – Literature 2012-2013

- Slowed, variable, and delayed dynamic vergence system
- Photophobia (light sensitivity)
- Reduced near-point of convergence

- Consistent accommodative fatigue effects

- Perceived limited depth perception

- Photosensitivity
Concussion and Vision
“Is Vision Part of the Puzzle?”

- Ventura RE, Jancuska JM, Balcer LJ, Galetta SL
- Pubmed review of last 5 years +
- Concussion:
  - abnormal
    - Saccades, pursuit eye movements
    - Convergence and accommodation
    - VOR
Vision and Return to Learn: Vision rarely mentioned in some Return to Learn Protocols

- Council on Sports Medicine and Fitness
  - Halstead ME 2010, Pediatrics 2010
- Clin J Sports Medicine
  - Olympia RP 2015
- Healthy Active Living and Sports Medicine Committee
  - Purcell LK 2014; Paediatr Child Health
Vision and Return to Learn: Vision rarely mentioned in some Return to Learn Protocols

- 2014 National Athletic Trainers’ Position statement
  - Consider: smooth pursuits, nystagmus, pupil reflex;
  - No convergence, accommodation, eye tracking recommended

### Symptoms of MILD TBI –

**Children’s of Alabama Concussion Database**

M. Swanson, et al. 2015

<table>
<thead>
<tr>
<th>Symptom</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Difficulty</td>
<td>141</td>
<td>13.7</td>
</tr>
<tr>
<td>Amnestic Event</td>
<td>272</td>
<td>26.4</td>
</tr>
<tr>
<td>Balance</td>
<td>111</td>
<td>10.7</td>
</tr>
<tr>
<td>Concentration Difficulty</td>
<td>223</td>
<td>21.6</td>
</tr>
<tr>
<td>Confusion</td>
<td>318</td>
<td>30.8</td>
</tr>
<tr>
<td>Dizziness</td>
<td>576</td>
<td>55.9</td>
</tr>
<tr>
<td>Fatigue</td>
<td>329</td>
<td>31.9</td>
</tr>
<tr>
<td>Headache</td>
<td>962</td>
<td>93.2</td>
</tr>
<tr>
<td>Hearing Problem</td>
<td>145</td>
<td>14.1</td>
</tr>
<tr>
<td>Irritable</td>
<td>150</td>
<td>14.5</td>
</tr>
<tr>
<td>Nausea</td>
<td>352</td>
<td>34.1</td>
</tr>
<tr>
<td>Sleep Disturbance</td>
<td>107</td>
<td>10.4</td>
</tr>
<tr>
<td>Slurred Speech</td>
<td>28</td>
<td>2.7</td>
</tr>
<tr>
<td>Vision</td>
<td>397</td>
<td>38.5</td>
</tr>
<tr>
<td>Vomiting</td>
<td>174</td>
<td>16.9</td>
</tr>
</tbody>
</table>

Swanson M, Weise KK, Dreer LE, Johnston J, Davis RD, Ferguson D, Hale MH, Gould SJ, Swanson E, Christy JC, Busetlini C, Lee SD.

- N = 1,033 (2007-2013)
  - N = 276 aged 5 to 18 years with ≥ 3 symptoms
    - Average age: 13.8
    - Median time since concussive event: 21 days
    - 33% more than 30 days

- Academic Difficulty: 29%
- Vision Abnormality: 46%
- >30 days: Only vision and concentration remained statistically significantly associated with academic difficulty
COA REDCap Database: 2007-2013

• “Vision problems were commonly reported in children with concussions and were independently associated with those reporting academic difficulty. **Comprehensive vision assessment** should be considered in children reporting academic difficulty and in the development of **return-to-learn protocols**.”
Near Point of Convergence After Sport-Related Concussion: Measurement of Reliability and Relationship to Neurocognitive Impairment and Symptoms (Pearce KL, Dec. 2015)

1Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania, USA.
2Department of Orthopaedic Surgery, University of California, San Francisco, San Francisco, California, USA.
3Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania, USA akontos@pitt.edu

“CONCLUSION:
Ci was common (~42%) in athletes evaluated within 1 month after an SRC. Athletes with Ci had worse neurocognitive impairment and higher symptom scores than did those with normal NPC. Clinicians should consider routinely screening for NPC as part of a comprehensive concussion evaluation to help inform treatment recommendations, academic accommodations, and referrals for vision therapy.”
Consider referral to eye care professional in concussion and academic difficulty when returning to learn.
Concussion and Vision - Evidence-based Clinical Eye Testing for mTBI (Capo-Aponte JE 2012)

- Near lateral and vertical phorias
  - Eyes pointing to same place on page?
- Positive fusional vergence
  - Eyes work together to stay on same place on page?
- Stereoacuity (Randot Preschool, e.g.)
  - 3D vision
- Near point of convergence
  - Eyes cross to same place on page?
- Amplitude of accommodation
  - Strength of focusing system?
- Monocular accommodative facility
  - Flexibility switching from desk to chalkboard?
  - Saccades and pursuit eye movements
- Eye tracking
- DEM, King-Devick
  - Also consider
    - CISS
    - Visual Acuity
    - Visual Field (120-pt neuro screening)
    - Dynamic visual acuity
    - EOM range of motion
CISS is Increased in concussion (≥16)

<table>
<thead>
<tr>
<th><strong>CONVERGENCE INSUFFICIENCY SYMPTOM SURVEY (CISS)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>**</td>
</tr>
<tr>
<td><strong>1. Do your eyes feel tired when reading or doing close work?</strong></td>
</tr>
<tr>
<td><strong>2. Do your eyes feel uncomfortable when reading or doing close work?</strong></td>
</tr>
<tr>
<td><strong>3. Do you have headaches when reading or doing close work?</strong></td>
</tr>
<tr>
<td><strong>4. Do you feel sleepy when reading or doing close work?</strong></td>
</tr>
<tr>
<td><strong>5. Do you lose concentration when reading or doing close work?</strong></td>
</tr>
<tr>
<td><strong>6. Do you have trouble remembering what you have read?</strong></td>
</tr>
<tr>
<td><strong>7. Do you have double vision when reading or doing close work?</strong></td>
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<tr>
<td><strong>8. Do you see the words move, jump, swim or appear to float on the page when reading or doing close work?</strong></td>
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<tr>
<td><strong>9. Do you feel like you read slowly?</strong></td>
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<tr>
<td><strong>10. Do your eyes ever hurt when reading or doing close work?</strong></td>
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<td><strong>11. Do your eyes ever feel sore when reading or doing close work?</strong></td>
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<td><strong>12. Do you feel a &quot;pulling&quot; feeling around your eyes when reading or doing close work?</strong></td>
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<td><strong>13. Do you notice the words blurring or coming in and out of focus when reading or doing close work?</strong></td>
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For a score of 16 or greater, vision therapy may be indicated.\(^{1,2,3}\)
CISS is a valid, reliable instrument


Receded Near Point of Convergence (NPC)


Convergence Insufficiency Treatment Trial


• Most highly accessed article in 2008 for Archives of Ophthalmology
Convergence Insufficiency Treatment Trial

- Pennsylvania College of Optometry (25)
  - PI: Mitch Scheiman, OD
- Bascom Palmer Eye Institute (35)
- SUNY College of Optometry (28)
- UAB School of Optometry (28)
- NOVA Southeastern University (27)
- The Ohio State University College of Optometry (24)
- Southern California College of Optometry (23)
- University of CA San Diego: Ratner Children's Eye Center (17)
- Mayo Clinic (14)

- National Eye Institute, Bethesda, MD: Paivi Miskala, PhD.
- Data and Safety Monitoring Committee
Convergence Insufficiency Treatment Trial

- N = 221
- Age: 9 to 17 years
- RCT:
  - Office-based vision therapy (12 weeks) – 73%
  - Home-based pencil push-ups – 43%
  - Home-based computer therapy – 33%
  - Office-based placebo therapy – 35%
- Improved outcome = lower CISS (p < .001), improved NPC and PFV (p = or < 0.005)
- www.clinicaltrials.gov
CITT-ART

- Convergence Insufficiency Treatment Trial – Attention and Reading Trial
  - Southern California College of Optometry at Marshall B Ketchum University
  - Pennsylvania College of Optometry at Salus University
  - The Ohio State University College of Optometry
  - NOVA Southeastern University College of Optometry
  - University of Alabama at Birmingham School of Optometry
  - State University of New York College of Optometry
  - Akron Children’s Hospital
  - Bascom Palmer Eye Institute

- www.clinicaltrials.gov
CITT – Concussion (CICON) – UG1 proposal

- Salus University (PCO) and Children’s of Philadelphia
  - M. Scheiman, OD, PhD  C. Master, MD
  - T. Alavarez, PhD

- UAB and Children’s of Alabama
  - K. Weise, OD, MBA  M. Heath Hale, MD
  - C. Busettini, PhD
  - J. Christy, PT/PhD  L. Dreer, PhD

- SCCO and Children’s of Orange County
  - S. Cotter, OD

- Akron Children’s Hospital
  - R. Hertle, MD (ophthalmology)
  - Tawna Roberts, OD, PhD
UAB Children’s of Alabama
Active Collaborations

• Research
  • 100 in a row
    • Prevalence
    • Non-intervention outcome at 16 weeks
  • Sideline Testing with Auburn University and Samford University
  • VOR in College Athletes (football, women’s soccer…)

• Clinic
  • UAB Sports Medicine Concussion Clinic at COA
    • Acute concussion (Heath Hale, MD; Sara Gould, MD; Erin Swanson, MD)
  • Peds Rehab Medicine
    • Chronic Concussion (R. Drew Davis, MD)
When to refer for vision testing
<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>(not very often)</th>
<th>Sometimes</th>
<th>Fairly Often</th>
<th>Always</th>
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For a score of 16 or greater, vision therapy may be indicated.\textsuperscript{1,2,3}
Diplopia:
Convergence Insufficiency (primary)
Diplopia: Physiological (Normal)
Diplopia: acquired (secondary; not normal)
Diplopia: acquired: 4\textsuperscript{th} nerve paresis? (not normal) – abnormal head position
Diplopia: acquired or congenital: “never fix a brain problem with eye surgery”

- Acquired:
  - New-onset diplopia
  - Vertical component
  - Consider MRI
- Congenital
  - No diplopia
Concussion and Vision: “Is Vision Part of the Puzzle?”

- Ventura RE, Jancuska JM, Balcer LJ, Galetta SL
- Pubmed review of last 5 years +
- Concussion:
  - abnormal
    - Saccades, pursuit eye movements
    - Convergence and accommodation
    - VOR
King-Devick
King-Devick
King-Devick

- Vision Testing Is Additive to the Sideline Assessment of Sports-Related Concussion
- *Neurol Clin Pract* July 2014
- “Combining K-D and SAC captured abnormalities in 89%; adding the BESS identified 100% of concussions.”
King-Devick: Galetta KM, J Neurol Sci 2011

K-D Time Scores (seconds)

A

P=0.009 vs. baseline
Baseline: n = 10
Concussion: n = 10

B

P=0.0003 vs. baseline
Baseline: n = 18
Post-workout: n = 18

C

P<0.0001 vs. baseline
Baseline: n = 219
Post-season: n = 219
King-Devick and Pre-season Visual Function in Adolescent Athletes (Weise KK, 2016)

- Weise KK¹, Swanson MW, Penix K, Hale MH, Ferguson D.
- Optom Vis Sci. 2016 Jul 23. [Epub ahead of print]
- UAB/COA
True Difference = 10 seconds

Mean, fastest, Error-free time = 43.9 seconds (24s – 120s)

ICC = 0.92
n = 619

- KD is NOT associated with
  - Failed NPC (p = 0.63)
  - Modified Thorington (p = 0.55)
- Therefore,
  - Score is not slower because of poor convergence or eye coordination
  - Consider NPC + KD
- If less than 20/30, 4 to 6 seconds slower
  - Implications: pre-season with glasses vs. on-field without
King Devick

• Baseline data required
  • Repeat up to 4 times in high school and junior high kids

• Avoid using it as a single sideline test

• Step in the right direction
  • Identifies a need for objective testing!
NeurOptics Pupillometer

Introducing the NPi®-200 Pupillometer for Neurocritical Care
UAB/COA Pre-season Sports Physicals
Spring 2015 - Pupillometer

- N = 247 in one high school
- Repeatability of Pupillometer
  - ICC (interclass correlation) = 0.57958 for OD
    = 0.57963 for OS
- This is the interclass correlation coefficient for the RIGHT pupillometry and the repeat. This indicates there is Fair agreement between the two measures.
- Note the similarity between Right and Left ICC.
UAB/COA Pre-season Sports Physicals Spring 2015 - Pupillometer

• N = 247 in one high school
• Average NPi (from company)
  • $4.1 \pm 0.32$
• Average NPi (from UAB/COA)
  • $4.1 + 0.30$
• Bland-Altman Limits of Agreement (UAB/COA)
  • LOA (OD) = 0.49; LOA (OD) = 0.48
  • Repeat if two measures differ by 0.50 or more
  • A measure that is 0.50 different post concussion is a true difference
UAB/COA Pupillometer under Friday Night Lights

- Average NPi: Pre-Season
  - 4.1 + 0.30
UAB/COA Pupillometer under Friday Night Lights: RE vs. RE (repeatability)
UAB/COA Pupillometer under Friday Night Lights: LE vs. RE (consistency)
UAB/COA Pupillometer under Friday Night Lights: Pre-season vs. sidelines (RE)

P=.05
UAB/COA Pupillometer under Friday Night Lights: Pre-season vs. sidelines (LE)

P=.01
Top 10 Concussion Research Articles of 2015

Trichu Sahajpal, DVM/PhD senior principal scientist, and Dr. Donald Marie, DVM/PhD senior clinical consultant

As the Defense Department’s center of excellence for traumatic brain injury (TBI), one of the primary goals of the Defense and Veterans Brain Injury Center (DVBIC) is to stay up-to-date on the latest in brain injury research. A team of DVBIC experts with a variety of clinical backgrounds reviewed approximately 250 abstracts from the TBI clinical research literature published in 2015. Choosing the ten articles they felt advanced the field of TBI research the furthest.

Listed below and categorized by topic are the titles and summaries of these top 10 concussion research articles of 2015. Click on the links provided to access the complete abstract or article on PubMed, a service of the U.S. National Library of Medicine.

Prevention
1. Sports-Related Concussion in Helmeted vs. Unhelmeted Athletes: Who Fares Worse? Do helmets prevent concussions? The answer isn’t as clear as you might think. This article provides the results of a new study of 136 athletes competing in similar sports with and without helmets. The study found no difference in the number or severity of concussions associated with helmet use. The study also showed that helmet use was unrelated to the symptoms experienced by athletes after a sports-related concussion. (Until further study is completed, DVBIC still recommends helmets for contact sports.)

Diagnosis
2. Detection of Subtle Cognitive Changes After Mild TBI Using a Novel Tablet-Based Task

Citizens often struggle with the subjective nature of the diagnosis of concussion. If the injured service member or athlete chooses not to disclose their symptoms, it’s difficult, if not impossible, to make a definitive diagnosis. This article describes a new study that found that tablet-based technology can provide a more sensitive and objective diagnosis of some functional deficits typically associated with concussion.
Detection of Subtle Cognitive Changes after mTBI Using a Novel Tablet-Based Task
Fischer TD...Sereno AB, 2016
VESTIBULAR AND OCULOMOTOR RESEARCH CLINIC

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• www.emrl.uab.edu
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Objectives

- Describe the UAB VORC mTBI protocol
  - Present preliminary data from a cohort of athletes

- Discuss clinical screening tools and theories of treatment for athletes with chronic mTBI and vestibular related impairments
Impairments from sport related mTBI:

- Poor Static and Dynamic Balance
- Gaze Instability
  - Convergence insufficiency vs. VOR dysfunction
- Poor perception of vertical
- Symptoms
  - Vertigo (head mov’t induced vs. visual vertigo)
  - Off-balance
  - Motion sensitivity
  - Exacerbated with aerobic activity
- Headache - Migraine

Zhou 2015; Corwin 2015; Ellis 2015; Heinmiller 2016; Leddy 2016
PREDICTORS OF RECOVERY

• There is moderate evidence to suggest that DIZZINESS, DISORIENTATION or AMNESIA (retrograde or posttraumatic) identified on the field or sideline after concussion can PREDICT PROLONGED RECOVERY in high school and college athletes.

• Shim et al. 2015. Critically Appraised Topic. *Journal of Sport Rehabilitation*
LE MS Injury After Return to Play

• Higher incidence of acute LE MS injury compared to controls.
• Odds were 2.48 X’s higher in concussed athletes than controls during 90 days after return to play.
• Why?
  • Vision? Balance? Vestibular?
Peripheral Vestibular System:

- 3 semicircular canals and 2 otolith organs that detect head movement and gravity
- 8th cranial nerve that connects to the vestibular nuclei in the brainstem, and the vestibulocerebellum
- To test this system: you must perform rotary chair, caloric, Vestibular Evoked Myogenic Potential, Computerized Head Impulse Test
- Schubert 2004: Review of vestibular anatomy and physiology
Central Vestibular Pathways

- Vestibulo-Ocular Reflex (gaze stability)
- Vestibulo-Cerebellum (timing)
- Vestibulo-Spinal (postural control)
- Vestibulo-Thalamico-Cortical (perception of vertical)
- Vestibulo-Autonomic (symptoms)

Kim et al. 2015; Chandrasekhar 2013
VORC mTBI protocol – pure vestibular measures of the horizontal canal (superior vestibular nerve) – in complete darkness

• Sinusoidal Harmonic Acceleration:
  • Gain and phase of the VOR is measured with infrared high speed video goggles as the chair moves side to side at low, medium and high frequencies.

• Step Test:
  • Time Constant is measured during and following 100 deg/sec rotations to the right and left.
  • Using caution in acute concussion

• Controlled Rotation High Impulse Test (crHIT):
  • Gain of the VOR is measured to 1000 deg/sec^2 accelerations to the right and left
  • Not in acute concussion
VORC mTBI protocol – pure vestibular measures of the saccule (inferior vestibular nerve)

• Cervical Vestibular Evoked Myogenic Potential:
  • EMG of the sternocleidomastoid is measured as tone bursts (107dBNHL) are delivered into the ear.
  • The inhibitory response is analyzed for symmetry, latency and amplitude
  • Takes 10 minutes
  • Young children can easily complete
Objective Measures of Oculomotor Pathways

• Smooth Pursuit (Video-goggles)
• Saccades (Video goggles)
• Optokinetic Reflex (Video goggles)
• Pupillary Response (Pupillometer)
VORC mTBI oculomotor protocol:

• **Predictive Saccades:**
  - A target begins to move in a predictive pattern. We measure how many saccades were predicted.

• **Horizontal and Vertical Random Saccades:**
  - A target moves randomly right, left, up and down. We measure the latency, accuracy of the covert saccade, final accuracy of the overt saccade, and velocity.

• **Horizontal and Vertical Smooth Pursuit:**
  - A target moves horizontally and vertically at various frequencies. We measure the gain, velocity, accuracy and symmetry of the eye movements.
VORC mTBI oculomotor protocol (con’t)

• Anti-Saccades:
  • The target moves to the right or left of center and the athlete moves the eyes in the opposite direction, but the same amplitude. We measure the number of errors and accuracy.

• Optokinetic Nystagmus:
  • We measure gain and symmetry in response to an optokinetic stimulus at 20 and 60 deg/sec.
VORC: mTBI protocol to assess visual-vestibular interactions

- **Visual Enhancement:**
  - Sinusoidal Harmonic Accelerations at 0.64 Hz completed with light. We measure the gain of the VOR which is expected to be close to 1.

- **VOR Cancellation:**
  - Sinusoidal Harmonic Accelerations at 0.64 Hz with a target moving with the chair. We expect that the VOR gain will be close to 0.
VORC: mTBI protocol to assess reaction times

• Visual Reaction Time:
  • The athlete is asked to press a button with the dominant hand as quickly as possible after seeing a light appear. We measure average reaction time in ms and standard error.

• Auditory Reaction Time:
  • The athlete is asked to press a button with the dominant hand as quickly as possible after hearing a short beep. We measure average reaction time in ms and standard error.
Saccades and Reaction Time:

- A light target makes a rightward or leftward movement. The athlete is asked to look at the light and push the corresponding button (right or left). We measure errors, saccade latency and accuracy, and latency of motor response.
VORC: mTBI protocol to indirectly measure central vestibular pathway function

• Subjective Visual Vertical and Horizontal:
  • The athlete uses buttons to set a laser bar to perceived horizontal and vertical. We measure the degrees off center which should be <2.
  • This is mediated by the utricular pathways

• The clinical test is the bucket test of SVV
  • Zwergal, 2009; Christy, 2014
Sensory Organization Test
Findings from the VORC: Preliminary Data

- Test-Retest Reliability
- Normative Data
- Data from Athletes with Concussion

- This data will be presented at the talk.
CLINICAL IMPLICATIONS

1. What clinical tests are best to screen for vestibular related impairments?
2. When do I refer to PT?
3. What exercises are evidence based for patients with concussion?
PUBMED 09.02.2016: “CONCUSSION AND VESTIBULAR”

- N=155 articles
- Peripheral vestibular function was not tested using gold standard tests
- Measures focused on symptoms (VOMS), balance (SOT/BESS) and gaze stability (DVA or GST)
- No single test can be used

- [Heinmiller 2016; McDevitt 2016]
### Vestibular/Ocular Motor Screening

**VOMS SCORING SHEET**

Symptoms on a 0-10 point scale

<table>
<thead>
<tr>
<th>Vestibular/Oculomotor</th>
<th>Type</th>
<th>Not Tested</th>
<th>Headache</th>
<th>Dizziness</th>
<th>Nausea</th>
<th>Fogginess</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Symptoms</td>
<td></td>
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<tr>
<td>Smooth Pursuit</td>
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<tr>
<td>Saccades (Horizontal)</td>
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<tr>
<td>Saccades (Vertical)</td>
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<tr>
<td>Convergence (Near Point)</td>
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<td>Score#1 cm</td>
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<td>Score#2 cm</td>
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<td>Score#3 cm</td>
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<tr>
<td>VOR Horizontal</td>
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<tr>
<td>VOR Vertical</td>
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<tr>
<td>Visual Motion Sensitivity</td>
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</tbody>
</table>

A change from baseline of \( \geq 2 \) is considered abnormal

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*Mucha et al. 2014*
Computerized DVA & Gaze Stabilization Test

DVA: Looks at the difference in visual acuity during head movement versus stationary

GST: measures the most rapid head movement velocity at which the patient can maintain visual acuity

McDevitt 2016
Hansen, 2016:

N=373 healthy children aged 5-14 yrs
Interrater ICC = 0.93
Intrarater ICC=0.96
Test-retest ICC=0.90
MDCs = 9.6, 4.6, 7.3 based on ICC

Alsahaleen, 2015:
N=36 (aged 15.9 +/- 1.5 yrs)
ICC for instrumented or clinical test was 0.74
“Vestibular” & Oculomotor Testing in Athletes

• **McDevitt et al. 2016**
  - 72 college athletes (12 concussed)
  - SOT sensory ratios, near point of convergence, signs and symptoms following optokinetic stimulation discriminated concussed from healthy controls (98.6% accuracy)
  - Gaze stabilization test + Near Point of Convergence classified concussed with 94.4% accuracy.

• **Kontos et al. 2016**
  - 263 athletes tested at baseline
  - 89% of athletes scored normal on VOMS (>2)
    - Females and athletes with a h/o motion sickness were likely to score ≥1 on VOMS
• NOT APPEARING IN THE LITERATURE BUT CLINICALLY IMPORTANT:
NECK STRENGTH

• Muscular Strength
• ROM
• Proprioception
JOINT POSITION ERROR
VOR FUNCTION

• HEAD IMPULSE TEST
• CLINICAL DYNAMIC VISUAL ACUITY
• BUCKET TEST (SVV)
• BPPV
SYMPTOMS

• VVAS (vertigo visual analog scale)
Visual Vertigo Analogue Scale
(Adapted from Longridge et al., 2002)

Indicate the amount of dizziness you experience in the following situations by marking off the scales below.

0 represents no dizziness and 10 represents the most dizziness.

Walking through a supermarket aisle

0 | 10

Being a passenger in a car

0 | 10

Being under fluorescent lights

0 | 10

Watching traffic at a busy intersection

0 | 10
DYNAMIC BALANCE

• FUNCTIONAL GAIT ASSESSMENT
PUB MED SEARCH (09.02.2016): VESTIBULAR REHABILITATION AND CONCUSSION AND BALANCE THERAPY FOR ATHLETES WITH CONCUSSION

• 34 results

• **Hoffer, Schubert and Balaban, 2015**:  
  • Review article with conclusions drawn from the literature on the military and clinical experience

• **Alsaleh, et al. 2010**:  
  • Retrospective Chart Review  
  • VR improves outcomes and shortens disability times in patients with mTBI that did not improve with rest
Schneider et al. 2014:

- Randomized Controlled Trial
- 31 individuals with concussion aged 12-30 years
  - Treatment group (standard care + Vestibular PT and cervical spine PT)
  - Control group (standard care: rest until symptom free, followed by graded exertion)
- The treatment group returned to sport significantly faster than the control group (within 8 weeks of initiating treatment).
Gottshall et al. 2010

• Pre-test/Post-test design
• N=82 military participants with mTBI who received vestibular therapy
  • SOT and Motor Control Test.
  • Dynamic Gait Index.
  • Neurocom inVision Tunnel Standardized Test:
    • SVA. DVA. Perception Time. Target acquisition. Target Following. GST.

• **Vestibular therapy** was provided 2X/week for 1 hour, 4-8 weeks, home program.

• Most outcomes returned to normal after 4 weeks
Broglio et al. 2015:

- Concussion rehab: consensus based
- Controlled exercise and cognitive activity may stimulate recovery
- Vestibular, oculomotor and pharmacological therapies are promising if delivered by a trained professional
VESTIBULAR REHABILITATION IS BASED ON FUNDAMENTAL THEORIES OF RECOVERY

- Adaptation exercises
  - must get retinal slip and error signal
  - Requires some vestibular function (e.g. UVH)
- Substitution exercises
  - To promote central preprogramming
  - Does not require remaining function (e.g. BVH)
- Habituation exercises
  - To decrease symptoms (if present)
OVERALL GOALS OF VESTIBULAR REHABILITATION TO AUGMENT STANDARD CARE:

• DECREASE SYMPTOMS (VOMS, VAS OR VVAS)
• IMPROVE GAZE STABILITY WITH HEAD MOVEMENT (DVA)
• IMPROVE STATIC BALANCE (SOT, BESS)
• IMPROVE DYNAMIC BALANCE (FGA)
• DECREASE NECK STIFFNESS
• TO ENABLE RETURN TO SPORT!
Questions?

The Impact of Concussion on Vision, Balance, and Vestibular Function

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