MTBI/CONCUSSION AND THE VISUAL SYSTEM: ASSESSMENT & REHABILITATION

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DISCLOSURES

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CONCUSSION: WHY VISION?

• 80-90% of all information entering the brain is visual
• Over 50% of the neural tissue is directly or indirectly related to vision (over 30 brain regions and 8 cranial nerves involved)
• The brain accounts for 20% of the resting body’s total energy requirement. Visual processing accounts for 44% of the brain’s energy consumption
• 90% of all concussed individuals will have 1 or more ocular problems
• 40% of individuals will have ocular problems lasting longer than 3 months
• If not addressed these ocular difficulties can result in a delayed recovery
• Intervention is helpful in ensuring resolution of ocular complaints and meeting the other trajectories as well
TYPICAL SYMPTOMS OF CONCUSSION

• Blurred vision
• Double vision
• Loss of place when reading
• Light sensitivity
• Motion sensitivity
• Headaches
• Dizziness
• Post-trauma amnesia
• Confusion
• Disorientation
• Vomiting and/or nausea
• Unsteadiness
TWO MODELS OF VISION

1.) Parallel Processing Model: Magnocellular and Parvocellular Functions

2.) Clinical Model: Oculomotor and Non-oculomotor Functions
MAGNOCELLULAR & PARVOCELLULAR VISUAL SYSTEMS

• Magnocellular System: “Where is it?” System; philogenetically older; fast conducting, responds to motion (fast temporal frequency) of coarse detail (low spatial frequency) and low contrast. Weighted in the peripheral retina and projects to the visuomotor dorsal stream to direct visual attention and eye movements. (10% of neurons)

• Parvocellular System: “What is it?” System; phylogenetically younger; slower conducting, responds to static stimuli (slow temporal frequency) of fine detail (small spatial frequency) and high contrast. Weighted in the central retina, responds to color and projects to the ventral stream.
MAGNOCELLULAR & PARVOCELLULAR SYSTEMS
M-PATHWAY AND P-PATHWAY
The Tree of Vision

Central visual processing to serve:
- Conscious recognition
- Search, attention & guidance of movement

- Recognizing people
  - Finding a person in a group of people
  - Spotting a distant target
- Recognizing animals
- Recognizing objects
  - Finding clothes in a pile
  - Objects in clutter
- Recognizing shapes
  - Finding an object on a patterned background
- Recognizing facial expressions
  - Crowding of text
- Route finding in crowded scenes

- Innate ability to route find

- Visual guidance of movement of the
  - Arms and hands
  - Legs and feet
  - Body

Temporal lobes

Occipital lobes
- Clarity/Acuity
- Contrast sensitivity
- Color vision
- Visual fields
- Optic radiations
- Lateral geniculate bodies

Middle temporal lobes (MT)
- Reflex vision in the upper mid-brain (Superior colliculi)

Posterior parietal lobes

Optic tracts
- Optic chiasm
- Optic nerves
- Retina

Optic nerves

Visual Scene

- Left eye
- Right eye
OCULOMOTOR AND NON-OCULOMOTOR-BASED DEFICITS FOLLOWING MTBI

Oculomotor-based vision problems:
  a.) Versions (Pursuit Dysfunction; Saccadic Dysmetria)
  b.) Accommodation (Accommodative Insufficiency; Accommodative Infacity)
  c.) Vergences (Convergence Insufficiency)

Non-oculomotor-based vision problems:
  a.) Refractive status/Ocular health
  b.) Vestibular (Vestibulo-ocular reflex/VOR)
  c.) Pupillary function (reduced pupillary dynamics)
  d.) Visual field defects (generalized reduced sensitivity on mean deviation)
  e.) Visual information processing/Visual-motor-perception
  f.) Hypersensitivity: Motion sensitivity; Photosensitivity
  g.) Abnormal spatial localization (midline shift)

### Ocular Motor Dysfunction Following MTBI

**Capó-Aponte et al. Military Medicine 2012**

<table>
<thead>
<tr>
<th>Type of visual Impairment</th>
<th>%mTBI</th>
<th>%controls</th>
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<tr>
<td>Convergence Insufficiency</td>
<td>55%</td>
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<td>Saccadic Impairment</td>
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<td>5%</td>
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<td>Accommodative Dysfunction</td>
<td>65%</td>
<td>15%</td>
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PURSUIT DYSFUNCTIONS

Pursuits: Smooth Eye Movements associated with following a moving target; Targets moving with velocities of greater than 30°/sec require catch-up saccades.

• Goodrich (2013): 34%
• Capo-Aponte (2012): 60%


RIGHT EYE SMOOTH PURSUIT METRICS

- Eye-Target Velocity Error (if speed is off, by how much)
- Smooth Pursuit Percentage (amount of time eyes were acceptably close to target speed)
- Predictive Smooth Pursuits (percent of time eyes ahead of the target)
- Latent Smooth Pursuits (percent of time eyes behind the target)
SACCADIC DYSFUNCTIONS (DYSMETRIA)

Saccades: Quick, simultaneous movement of both eyes in the same direction to targets of interest: voluntary and involuntary

• Capo-Aponte (2012): 30%
• Masters (2015): 29%
• Tannen (2015): 68%

OBJECTIVE INFRARED EYE TRACKING SACCade TESTS FOR CONCUSSION ASSESSMENT

• Measures saccade accuracy and timing of eye movements to various target demands

• **Delayed saccadic latency:** Immediately after concussion, Recovers 75% of time within 12 days; common in acute mTBI

• **Saccadic dysmetria** (i.e., saccadic inaccuracy): More eye movements to fixate a set number of targets; common in chronic mTBI

• Impaired **Anti-Saccades, Memory Guided Saccades** and **Self-paced Saccades:** First 10 days and in post-concussive syndrome (3-5 months after injury).

RIGHT EYE SACCADIC METRICS

- Voluntary (purposeful) horizontal saccadic speed and accuracy
- Voluntary vertical saccadic speed and accuracy
SUBJECTIVE SACCADe TEST: KING-DEVICK TEST

- Subjective “remove-from-play” tool: Speed of Rapid Number Naming; total of three test cards compared to baseline
- Includes language & attention
ACCOMMODATIVE DYSFUNCTION

Accommodation: Ability of ciliary muscle to change the shape of the lens to adjust focus for variable distances.

Alvarez et al. 2012: 24%
Ciuffreda et al. 2007: 41%
Stelmack et al. 2009: 47%
Master et al. 2015: 51%
Tannen et al. 2015: 76%

Alvarez TL et al. Optom Vis Sci 2013
Ciuffreda KJet al. Optometry 2007
Stelmack JA et al. Optometry 2009
Tannen B et al. Vis Dev & Reh 2015
ACCOMMODATIVE DYSFUNCTION

• Reduced peak velocity (maximum velocity): *Accommodative Infacility*

• Receded amplitude of accommodation (maximum amount of accommodation): *Accommodative Insufficiency*
SUBJECTIVE & OBJECTIVE ACCOMMODATION TESTS
VERGENCE DYSFUNCTION: CONVERGENCE INSUFFICIENCY

Vergences: Simultaneous, dysconjugate eye movements to maintain single vision (fusion) on targets at various distances

Alvarez et al. (2012): 23%
Ciuffreda et al. (2007): 42%
Lew et al. (2007): 46%
Brahm et al. (2009): 46%
Capo-Aponte (2012): 65%
Master et al (2015): 48%
Tannen (2015): 64%


VERGENCE DYSFUNCTIONS

• Reduced peak velocity: Maximum velocity to a change in vergence; **Vergence Infacility**; response time slowed by up to 3X (3 seconds).

• Receded Nearpoint of Convergence (NPC): Distance where fusion is lost after maximal effort, **Convergence Insufficiency** is NPC > 5 cm.
NEW MEASURE OF CONVERGENCE: NEARPOINT OF FIXATION DISPARRITY (NPFD)

- Distance at which bifixation is lost when attempting to converge to a slow (1-2 cm/sec) incoming target; more sensitive than NPC (loss of bifixation precedes breakdown of fusion.)
- Measure of how fragile the binocular system is. . .
Forty-two Division I collegiate male and female hockey players were evaluated with oculomotor-based clinical tests, including the NPFD.

Athletes were 10.72X more likely to suffer a past concussion if NPFD > 15 cm; longer duration of fixation and comprehension lower than 85% on Visagraph; lower values on ADHD questionnaire part A.

None of the IMPACT baseline assessment measures were significantly predictive of the individual’s concussion history.
60 pediatric patients with binocular disorders: 35 asymptomatic; 25 symptomatic

A receded NPC (>5 cm) was not sensitive to symptoms of CI (e.g. blur, eyestrain, visual fatigue, headaches)

NPC showed only 19% sensitivity to CI (81% of patients with CI were classified as having no CI)

NPFD showed 95% sensitivity and 100% specificity to CI

CI likely underdiagnosed if NPC alone is used to diagnose CI!
OCULOMOTOR DYSCONJUGACY: EYEBOXCNS (OCULLOGICA)

PUPILLARY RESPONSES

• NeurOptics PLR Pupillometer
• Automated 8-parameter analysis
ABNORMAL PUPILLARY DYNAMICS

• Reduced Peak Velocity: Slowed maximum constriction response to a brief increase in the light stimulus level and slowed average dilation response after stimulus constriction.

• Reduced Constriction Amplitude: Significantly reduced maximum response amplitude to a brief, stepwise increase in the light intensity level.

• Reduced Latency: Reduced time between stimulus onset and initiation of pupil constriction response.

• Suggests both sympathetic/parasympathetic involvement

FDT VISUAL FIELD DEFICITS

- Magnocellular-sensitive test based on the Frequency Doubling Illusion
  
  FDT visual fields often show overall diffuse loss of sensitivity, reduced mean deviation

- Recovery variable

Patel N, The Use of Frequency Doubling Technology to Determine Magnocellular Pathway Deficiencies J Beh Opt 2004:15(2); 30-33.
VESTIBULAR (VESTIBULO-OCULAR REFLEX/VOR)

• VOR Test (Dynamic Visual Acuity Test)
• Acuity drops 3 lines or more when moving head at 2 Hz
VISUAL INFORMATION PROCESSING/VISUAL-MOTOR-INTEGRATION TESTING (VIP/VMI)

• Senaptec Sensory Station (6/10 tests are VIP/VMI: Target capture; Visual-Motor Reaction Time; Go/No-Go; Reaction Time; Multiple Object Tracking; Perception Span)
HYPERSENSITIVITY: MOTION SENSITIVITY; PHOTOSENSITIVITY (MAGNOCELLULAR DEFICIT?)

- Elevated Critical Flicker Frequency Thresholds (CFF)
- Elevated Coherent Motion Thresholds (CMT)
- Visual Evoked Potential (VEP)


MAGNOCELLULAR DEFICITS IN PATIENTS WITH CONVERGENCE INSUFFICIENCY AS REVEALED BY VEP ARE ASSOCIATED WITH A HISTORY OF CONCUSSION (POLTAVKI D, ET AL. 2016, IN PRESS)

• N = 75 with CI; 35 had history of 1 or more concussions

• Latency delay AND reduced amplitude to magnocellular-weighted stimuli was able to discriminate between CI subjects with and without a history of concussion.

• Parvo-weighted stimuli: high contrast; slow; fine detail

• Magno-weighted stimuli: low contrast; fast; large
PREDICTION OF CI WITH CONCUSSION HX USING VEP

AUC=0.86 (p <0.01); Sensitivity – 0.92; Specificity – 0.80
ABNORMAL EGOCENTRIC SPATIAL LOCALIZATION

• Visual Midline Shift Syndrome: Dysfunction of magnocellular processing; right parietal lobe particularly vulnerable
RETURN-TO-LEARN: MIXED MESSAGES!

• “The majority of student-athletes who are concussed do not need a detailed return-to-learn program because *full recovery occurs within two weeks.*” NCAA website regarding concussion recovery

• “A concussion is an academic injury, in the sense that it affects the capacity for learning. There are *rarely times in school when these concussion issues do not have some potential effect on a kid’s grades and academic pursuits.*” Gerard Gioia, MD, Neuropsychologist at the Children’s National Medical Center, Washington, DC
RATIONALE FOR INTERVENTION: NEUROPLASTICITY

• Brain will continuously modify both structure and function per its range of dynamic multi-sensory experiences (constantly active).

• Brain will continue to form new synapses, strengthen or alter existing synapses, alter firing, etc.

• Repeated stimulation through intervention induces long-term potentiation by activation of N-methyl-D-aspartate (NMDA) receptors that trigger a cascade of cellular mechanisms resulting in learning and memory.

• Motor & perceptual learning can help one acquire new skill or recover a lost skill. Requires: 1.) trial and error with constant feedback; 2.) repetition of newly learned task; 3.) motor/perceptual skill becomes automatic without feedback control
Vision therapy is a sequence of activities individually prescribed and monitored by an optometrist to develop efficient visual skills and processing. It is prescribed after a comprehensive eye examination has been performed and has indicated that vision therapy is an appropriate treatment option. The vision therapy program is based on the results of standardized tests, the needs of the patient, and the patient's signs and symptoms. The use of lenses, prisms, filters, occluders, specialized instruments, and computer programs is an integral part of vision therapy. Most effective vision therapy programs in the U.S. are provided by a Certified Optometric Vision Therapist (COVT) under the direction and supervision of a Fellow of the College of Optometrists in Vision Development (FCOVD).
5 COMPONENTS OF EFFECTIVE NEURO-OPTOMETRIC REHABILITATION

1.) Motivation
2.) Feedback
3.) Repetition
4.) Sensory-motor mismatch
5.) Intermodal integration
OCULOMOTOR REHABILITATION (VISUAL HARDWARE)
SACCADIC REHABILITATION
ACCOMMODATIVE REHABILITATION
VERGENCE REHABILITATION
NEUROLENSES (EYEBRAIN MEDICAL)

- Symptoms of Headaches, Neck/shoulder stiffness, Visual discomfort, Dry eyes
- Mild binocular misalignment (fixation disparity) at far and near thought to trigger trigeminal nerve, causing symptoms
- Progressive prism lenses reduce the binocular mismatch of peripheral/distance and central/near vision to alleviate discomfort and better integrate magno/parvo systems
- May also be effective for chronic migraine sufferers and other conditions

http://eyebrainmedical.com/
USING THE CISS FOR RTL/RTW DECISION-MAKING

- Weighted in nearpoint related activities
- Well-researched
- Correlates with Reading Comprehension
- Correlates with Attention
- Helps to monitor vision rehabilitation
- Helps to guide RTL/RTW decision-making

DO REDUCED OCULOMOTOR SKILLS CONTRIBUTE TO CONCUSSION-RELATED READING DIFFICULTIES?

- Precise (1-3 degree) rhythmical (30-60 ms duration) and automatically-executed sequences of forward (left to right) **saccadic fixations**.

- Fixation pauses (about 250 msec), processing (about 75 msec), followed by programing of subsequent saccade (about 175 msec): **Fixation duration**.

- Right to left saccadic eye movements to review information or as an attentional pause: **Regressions**.

- Small dynamic changes (<0.10 deg) of binocular vergence angle (fixation disparity) must be precisely aligned when processing the subsequent word: **Vergences**.

- Lastly, text clarity is critical for efficient visual information processing, so accommodation must function in a time-optimal manner to obtain and maintain an accurate focusing response: **Accommodation**.

- Version, vergence, and accommodative functions must perform in an interactive and integrated manner with precise synchronization for optimal reading performance to occur. In addition, this must be accomplished for a sustained period of time with a high level of attention, comprehension, and visual comfort (Taylor, 1966; Ciuffreda & Tannen, 1995)
USING THE VISAGRAPHER FOR RTL/RTW DECISION-MAKING

Midway through the Civil War, Lincoln decided that the country needed to be tied together by a railroad. At the time, it took months to sail from one coast to the other and more than a month to go by stagecoach. Many people thought that the railroad companies should pay for the construction of the roads themselves. Lincoln felt that it would help the country recover from the war if a railroad were built. After Lincoln died, the government continued the project. Free land and payments for each mile of construction were given to the railroad companies. It took 20,000 workers six years and millions of private dollars to lay 1,886 miles of track. Many died in the effort. In 1869 in Utah, the last spike driven in was a gold one.
VISAGRAPHER PROTOCOL FOR MTBI/CONCUSSION

1.) Pt reads **grade level text** (e.g. grade level 10; comprehension at least 70%)

2.) Pt reads **5 levels below grade level text** (e.g. grade level 5; comprehension at least 70%)

3.) If Grade Level Equivalent (GLE) improves by **3 grades or less**, **suspect oculomotor dysfunction** (e.g. if initial GLE of 8.5 only goes up to GLE of 10.0 when text difficulty is “dummied down” by 5 grade levels)

4.) **Longer duration of fixation** also found in concussed and those with past history of concussion >12 months (e.g. for a college reader, 0.29 sec rather than 0.24 sec)

5.) **Cross-correlation** (symmetry) and **Anomalies** (opposite eye movements) indicators of poor eye teaming

5.) **Normative Data; Good sensitivity; Lacks specificity**

6.) Good for monitoring student-athletes’ vision recovery/rehabilitation for return-to-learn


NON-OCULOMOTOR REHABILITATION (VISUAL SOFTWARE)
DYNAMIC VISUAL ACUITY TRAINING (VOR)

- Often the only therapy done for concussions
- Done mainly by Physical Therapists and Optometric Vision Therapists
- Since accommodation and vergence are involved in binocular VOR, should these oculomotor skills be trained first?
SPATIAL LOCALIZATION REHABILITATION

Yoked Prism Therapy: Base is in the same direction in each eye to counter the expansion and compression of space in one’s ambient (magnocellular) vision process: shifts space into a more or less centered position.

Visual localization in space: saccades, fixation accuracy, visually guided reaching of stationary targets and visual interception of moving targets; Space Fixator
HYPERSENSITIVITY REHABILITATION: (PHOTOSENSITIVITY/MOTION SENSITIVITY)

• Magnocellular-parvocellular imbalance
  - Binocular vision therapy
  - Colored tints (20-30%)
  - Binasal occluders
  - Base-in prisms
  - Hand motion in peripheral field
  - Optokinetic stimuli in periphery (Gibsonian optic flow)
USING THE SENAPTEC SENSORY STATION FOR RTP DECISION-MAKING

• Ongoing norms: gender, sport, position and skill-level specific
• If baseline not available, norms can help guide RTP decision-making
• Goal is to rehabilitate up to the 50th percentile on all skills
• Vision rehabilitation beyond this point becomes vision enhancement training, (Patient ➔ Client); a.k.a. “preventative medicine”
USING THE NEUROTRACKER FOR RTP DECISION-MAKING

• Training multiple object tracking: heightens concentration and focus, improves response times and enhances situational awareness
• If no baseline, normed data can help guide decision making
• The more dynamic the sport, the more important the results
EFFECTIVENESS OF NEURO-OPTOMETRIC REHABILITATION

• Ciuffreda et al. (2008): Oculomotor Vision Therapy yielded 90% improvement in 160 post-concussion patients, as well as improved reading and QOL

• Yadav et al. (2014): Improved VEP amplitude; EEG alpha band power and measures of attention in 7 mTBI adults after just 9 hours of OVT

• Orsillo & Derr (2013): Improved VEP latency in 48% of Florida State Football Players after 8 weeks of visual-perceptual-motor training
THANK YOU!

www.COVD.org
www.NORA.cc