MTBI/CONCUSSION AND THE VISUAL SYSTEM: ASSESSMENT & REHABILITATION

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DISCLOSURES

• Consultant: Diopsys Corporation; RightEye Corporation; Vision Assessment Corporation

• Grant/Research Support: North Dakota Department of Commerce, Research ND 15-02-G-88 Grant, Evaluation of the effectiveness of Sports Vision programs in improving performance and health in ND youth athletes, in partnership with UND’s Dept. of Psychology, Dr. Dmitri Poltavski, PI.
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).
- Several of the major post-concussive symptoms are visual symptoms.
- The brain accounts for 20% of the resting body’s total energy requirement. Visual processing accounts for 44% of the brain’s energy consumption. So, almost 9% of the resting body’s energy consumption is taken up by the visual system alone.
- A growing number of subjective and objective ocular and vision tests are now being investigated as “visual biomarkers” of concussion and for RTP/RTL decision-making.
- Neuro-cognitive testing alone may miss vision problems.
- Hidden vision problems frequently persist beyond 6-9 month post-concussive period, so one cannot assume that the absence of symptoms means vision is just fine!
- Vision tests are valuable tools when investigating other neurological impairments (e.g. Roadside Field Sobriety Tests), why not concussion?
- The literature supports vision therapy for mTBI vision problems with resulting improvement/resolution of symptoms, improved performance and improved QOL.
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

Diagram of brain pathways with labels such as Frontal Eye Fields, Posterior Parietal Cortex, Striate Cortex (V1), Medial Superior Temporal Cortex (MST), Middle Temporal Cortex (MT), and Inferior Temporal Cortex (IT).
DORSAL (MAGNO) AND VENTRAL (PARVO) PATHWAYS
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

Finding clothes in a pile

objects in clutter

Finding an object on a patterned background

Crowding of text

Recognizing facial expressions

Route finding in crowded scenes

Innate ability to route find

Visual guidance of movement of the

arms and hands

legs and feet

body

Recognizing objects

shapes

Recognizing words

letters

numbers

Naming colors

Temporal lobes

Occipital lobes

Clarity/Acuity

Color vision

Contrast sensitivity

Visual fields

Optic radiations

Lateral geniculate bodies

Posterior parietal lobes

Middle temporal lobes (MT)

for the accurate perception of movement

Reflex vision in the upper mid-brain

(Superior colliculi)

Optic tracts

Optic chiasm

Optic nerves

Retina

Left eye

Visual Scene

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 Infacility)
  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)

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): 30%


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 SACCADE 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 DISPARITY (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. . .
POLTAVSKI D, BIBERDORF D. SCREENING FOR LIFETIME CONCUSSION IN ATHLETES: IMPORTANCE OF OCULOMOTOR MEASURES. BRAIN INJ 2014; 28(4) 475-485.

• Forty-two Division I collegiate male and female hockey players were evaluated w/oculomotor-based clinical tests, including the NPFD.

• Athletes were 10.72X more likely to suffered 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!
PUPILLARY RESPONSES

NeurOptics PLR-200 Pupillometer

- Automated 8-parameter analysis

FIG. 3

Right Eye
1900W @ 657ms
2000/11/11 01:11:39
MAX MIN
-1.56 -2.70
-0.42 -1.9
LAT
Average Dilation Velocity
Max and Min Pupil Diameter
Duration of Light Stimulation
Latency of the Pupil Constriction Onset

FIG. 4A
Hold down the LEFT Button

FIG. 4B
Release the LEFT Button when ready

FIG. 4C
Keep the Pupilometer in position. Press LEFT again to abort
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 (POLTAVSKI 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
• 43.5% of athletes RTP too soon
• 44.7% of athletes RTL too soon
• If Hx of previous concussion, more days of rest will be needed before RTP compared to those with no prior Hx of concussion.
RETURN-TO-LEARN: MIXED MESSAGES!

• “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

• “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
• RTL should be managed by a multi-disciplinary team in a stepwise program that fits the needs of the individual.

• RTL assumes brain energy is not available for physical and cognitive exertion because of a concussion-induced brain energy crisis.

• RTL recommendations are based on consensus, with little evidence-based data.

• RTL recommendations are difficult to prescribe because contributors to reduced academic performance remain hidden.
NCAA WEBSITE: RTL GUIDELINES

• Cognitive rest
• If 30 minutes of light cognitive activity not tolerated, remain at home or in the residence hall
• If asymptomatic with 30-45 minutes of cognitive activity, return to the classroom in a step-wise manner: no more than 30-45 minutes of cognitive activity at one time, followed by at least 15 minutes of rest
• Academic adjustment; academic accommodation; academic modification
• Multi-disciplinary involvement should be made on a case-by-case basis
RATIONALE FOR INTERVENTION: NEUROPLASTICITY

- Brain will continuously modify both structure and function per its range of dynamic multi-sensory experiences (constantly active).
- Brain will form new synapses, strengthen or alter existing synapses, alter firing, etc.
- Repeated stimulation 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 TRAINING (VISUAL HARDWARE)
PURSUIT TRAINING
SACCADIC TRAINING
ACCOMMODATIVE TRAINING
VERGENCE TRAINING
USING THE CISS FOR RTL 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 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)
Midway through the Civil War, Lincoln decided that the country needed to be tied together by a railroad. At the time, it took four 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 railroads 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 the 1,086 miles of track. Many died in the effort. In 1869 in Utah, the last spike driven in was a gold one.
VISAGRAPH 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) increase is less than 3 grades, 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 TRAINING (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 TRAINING

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 TRAINING: (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)
VIP/VMI TRAINING
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 (i.e. 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 VSAT 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.
SENSORY STATION & PREDICTION OF FUTURE BRAIN TRAUMA: COULD VISION TRAINING LESSEN THE SEVERITY OF HEAD IMPACTS?

38 UNC football players wore helmet sensors to gauge impact biomechanics during games and practices.

Low Performers on Perception Span (visual memory to expanding flashed patterns) Target Capture (involuntary saccades); Go/No-Go (visual-motor response and decision making) and Depth Perception (distance stereopsis) sustained more than twice as many severe head injuries as high performers on these measures.

Athlete visual performance may be related to their ability to anticipate and react to impending head impacts on the field.

Sports vision enhancement training may decrease the risk of sustaining injurious head impacts.

COULD VISION TRAINING HELP MITIGATE CONCUSSIONS?

• U of Cincinatti Football Team instituted a vision training program beginning in 2010.

• The average number of diagnosed concussions per season for the four years prior to vision training was 8.75 ± 1.7. This compares to 1.5 ± 1.0 concussions per season over the four years after initiation of vision training (p<0.001).

POLTAVSKI D, BIBERDORF D, RESEARCH ND GRANT # 15-02-G88: EVALUATION OF THE EFFECTIVENESS OF SPORTS VISION PROGRAMS IN IMPROVING PERFORMANCE AND HEALTH IN NORTH DAKOTA YOUTH ATHLETES (2014)

Prevalence of concussion in youth hockey players (11-19 years old): 20-36% (Williamson and Goodman, 2006)

Prevalence of oculomotor problems in youth not related to head trauma – up to 40% according to Marran et al. (2006) with 34% showing convergence insufficiency.

Even if visual hardware is intact, combined oculomotor training + VIP/VMI training can thus be rehabilitative, preventative and augmenting for athletes
STUDY DESIGN

• 120 youth hockey players between 13 and 18 in Grand Forks, East Grand Forks and Crookston.
• Athletes tested and trained over a two-year period (60 per year)
• Roughly 12-15 athletes with a history of concussion assigned to each of 4 training regimens: Hardware only; Software only; Hardware, then Software; Software then Hardware (Cross-over)
STUDY METHODS

• Short-term Outcomes: Baseline, 5 weeks, 10 weeks; Oculomotor measures, Senaptec SS, NeuroTracker, VEP, EEG

• Long-term Outcomes:
  • Athletic outcomes: Performance statistics in the season prior to and following visual training co-varied by age, position type, and number of practice hours
  • Clinical Outcomes: Concussion rates (incidence per AE and PGH) 1 year before and 1 year after visual training co-varied by age; cross-sectionally with the age-matched cohort not receiving visual training.
STUDY IMPLICATIONS

• Contribution to scientific knowledge about sport-related concussion and rehabilitation in youth.
• Development of oculomotor concussion rehabilitation protocols and sideline screening tools for mTBI diagnosis.
• Improved athletic performance of youth hockey players.
• Possible prevention of concussion occurrence and re-occurrence in ND youth athletes.
• Although not directly targeted – possible improvement in academic performance of youth athletes through (e.g. oculomotor problems misdiagnosed as ADHD).
THANK YOU!

www.COVD.org
www.NORA.cc