Dynamic Aspects of accommodation and vergence in mild traumatic brain injury

A retrospective analysis of a clinical population conducted by the Brain Injury Group at SUNY College of Optometry
Brain Injury Group at
SUNY, College of Optometry

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Four Components of Accommodation

- Blur-driven accommodation
  - Response to defocus blur

- Vergence accommodation
  - Response to disparity (fusional) vergence

- Proximal accommodation
  - Response to apparent/perceived nearness

- Tonic accommodation
  - Results from baseline autonomic neural inervation (elicited in the absence of blur, disparity, and proximal cues)
Brain Injury Definitions

• **Acquired Brain Injury (ABI)**
  – Occurs after birth
  – Sudden-Onset
  – Non-Progressive
  – TBI is a subgroup of ABI
Brain Injury Definitions

- **Traumatic Brain Injury (TBI)**
  - Often due to an external force
  - Either open or closed-head
  - In coup-contrecoup injury there is diffuse axonal injury, shearing, and swelling
  - Typically more global, less localized
Epidemiology of TBI in the U.S.

- Approximately 1.5 million TBI injuries each year of which 95% require hospitalization or emergency room treatment
- Many require subsequent medical and rehabilitative services (e.g., vision, physical, occupational, cognitive therapy)
- Motor vehicle accidents are the primary cause of TBI for people aged 5 to 75 years
- The highest rates of TBI occur in the young (<5 years) and elderly (>75 years) populations, owing primarily to falls
- There is a higher incidence of TBI among males across all age groups
Iraq and Afghanistan War Fighters

- Estimates are 23-32% of injured war fighters experience TBI

- Over 90% of combat-related TBI’s are closed-head injuries that may be either mild or occur in conjunction with more visually obvious injuries

- It is likely that many injured war fighters with TBI go undiagnosed and potentially continue active duty

- Blast injuries have caused the most war-related TBI’s
Visual Symptoms in TBI

Accommodatively-based symptoms

• Eye focusing problems
• Blur
• Eyestrain and visual fatigue
• Avoidance of near tasks
• Oculomotor-based reading difficulties
• Headache
• Intermittent diplopia
Visual Signs in TBI

- **Accommodatively-based**
  - Reduced amplitude of accommodation
  - Increased lag of accommodation
  - Slowed Accommodative Facility
  - Reduced relative accommodation
  - Uncorrected hyperopia/astigmatism (due to an inability to compensate accommodatively)
  - Restricted fusional vergence ranges at near related to accommodative interactive problems
Previous Literature Findings

• Three reported accommodative diagnoses related to mTBI
  
  – Accommodative insufficiency (most prominent)
  
  – Accommodative excess or "pseudomyopia"
  
  – Accommodative infacility
Accommodative Insufficiency (AI)

- Several studies reported AI in 10-33% of subjects when comparing measured accommodative amplitude with normative literature values.

- A retrospective study reported 22% of returning veterans seen at a VA clinic manifested decreased accommodative amplitude.

- One study reported 16% of mTBI patients exhibited “poor accommodation” when using accommodative amplitude and/or PRA as the diagnostic parameter.
Pseudomyopia

• Researched less often than AI.

• One study reported 19% of the mTBI subjects exhibited pseudomyopia
  – No history of prescription for myopia
  – Patient reports blur at distance, correctible with minus lenses
  – Cycloplegic refraction in emmetropia, low hyperopia
Accommodative Infacility

• Ohtsuka and Sawa (1997) reported on a 29-year-old male patient with agenesis of the posterior vermis of the cerebellum

• Objective, dynamic accommodative responses of the patient and a visually-normal control subject were compared when tracking a sinusoidally-modulated blur stimulus

• The patient exhibited significantly less accuracy, including an increased lag (i.e., error) and a decreased response amplitude (i.e., gain) at all three of the relatively slow temporal stimulus frequencies, than found in the control subject
Accommodative Infacility

(Adapted from Ohtsuka and Sawa, 1997)
Accommodative Infacility


- This patient exhibited normal dynamic accommodative responses to a slowly modulated ramp stimulus, but manifested significantly abnormal dynamic accommodative responses, including reduced and variable response amplitude, to repetitive predictable step stimuli.

- After surgical removal of the cyst, however, the patient regained normal accommodative responsivity to the predictable step stimuli.
Accommodative Infacility

(Adapted from Kawasaki et al, 1993)
Accommodative Infacility

Preoperation

Step stimuli
Right eye
Left eye

4D 10 s

Postoperation

Step stimuli
Right eye
Left eye

4D 10 s

(Adapted from Kawasaki et al, 1993)
Recent Retrospective Findings from our Research Group

- We investigated several accommodative parameters in a large mTBI population from our clinic.

- We also determined the functional outcome of mTBI patients after conventional optometric vision therapy.

- A computer-based query of the medical records over a three-year period uncovered 160 individuals with mTBI, 51 of these being under 40 years of age (i.e., prepresbyopic), and therefore having received extensive accommodative testing.
Recent Retrospective Findings from our Research Group

Percentage of individuals with TBI (n=160) with a specific category of ocular motor dysfunction and the most common anomaly

<table>
<thead>
<tr>
<th>Ocular motor dysfunction</th>
<th>Percentage (%)</th>
<th>Most common anomaly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accommodation</td>
<td>41.1</td>
<td>Accommodative insufficiency</td>
</tr>
<tr>
<td>Versional</td>
<td>51.3</td>
<td>Deficits of saccades</td>
</tr>
<tr>
<td>Vergence</td>
<td>56.3</td>
<td>Convergence insufficiency</td>
</tr>
<tr>
<td>Strabismus</td>
<td>25.6</td>
<td>Strabismus at near</td>
</tr>
<tr>
<td>CN palsy</td>
<td>6.9</td>
<td>CN III palsy</td>
</tr>
</tbody>
</table>

**Note:** The "n" representing the number of persons tested for accommodation only includes those under the age of 40 years (i.e., prepresbyopic), "n" = 51. (Adapted from Ciuffreda et al, 2007)
Recent Retrospective Findings from our Research Group

Number of individuals (n = 51) with a specific category of accommodative dysfunction

<table>
<thead>
<tr>
<th>Accommodative insufficiency</th>
<th>Accommodative infacility</th>
<th>Accommodative excess</th>
<th>Ill-sustained accommodation</th>
<th>Total with accommodative dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>21</td>
</tr>
</tbody>
</table>

Note: Some persons presented with more than one accommodative dysfunction. The "n" represents the number of persons tested for accommodation, which only included those under the age of 40 years (i.e., prepresbyopic). 21/51 = 41.1% of persons with TBI presented with an accommodative dysfunction. (Adapted from Ciuffreda et al, 2007)
Recent Retrospective Findings from our Research Group

- Thirty-three of the 160 mTBI patients completed a conventional optometric vision therapy program

- Thirty of the thirty-three (90%) improved markedly in at least one sign and one symptom, which represented “successful treatment”

- This suggests that accommodative deficits, along with other oculomotor problems, in mTBI patients can be fully/partially remediated using relatively simple therapeutic procedures

(Ciuffreda et al, 2008)
Recent Prospective Findings from our Research Group

• Using both subjective and objective techniques, we investigated numerous static and dynamic aspects of accommodation in both clinical and laboratory settings.

• The findings were compared to either a visually-normal control group or normative literature values.
Static Measurement Findings

Mean Push-up Accommodative Amplitude
(TBI vs Age-Matched Duane's Values)

(Green et al, 2010)
### Static Measurement Findings

Accommodative amplitude characteristics and deviation from Duane's mean normative values in 12 subjects with mTBI.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yrs)</th>
<th>PU amplitude OD (D)</th>
<th>PU amplitude OS (D)</th>
<th>PU amplitude OU (D)</th>
<th>ML amplitude OD (D)</th>
<th>ML amplitude OS (D)</th>
<th>Absolute Deviation from Duane's Mean Norms (D)</th>
<th>Percentage Deviation from Duane's Mean Norms (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBI-A1</td>
<td>26</td>
<td>6.50</td>
<td>8.00</td>
<td>6.50</td>
<td>3.50</td>
<td>7.50</td>
<td>-3.70</td>
<td>-36.3</td>
</tr>
<tr>
<td>TBI-A3</td>
<td>34</td>
<td>9.00</td>
<td>7.12</td>
<td>8.37</td>
<td>4.00</td>
<td>3.50</td>
<td>0.37</td>
<td>4.6</td>
</tr>
<tr>
<td>TBI-A4</td>
<td>36</td>
<td>5.00</td>
<td>5.00</td>
<td>5.50</td>
<td>1.25</td>
<td>1.25</td>
<td>-1.90</td>
<td>-25.7</td>
</tr>
<tr>
<td>TBI-A5</td>
<td>28</td>
<td>4.00</td>
<td>5.25</td>
<td>5.00</td>
<td>3.75</td>
<td>4.00</td>
<td>-4.70</td>
<td>-48.5</td>
</tr>
<tr>
<td>TBI-A6</td>
<td>25</td>
<td>8.25</td>
<td>7.12</td>
<td>10.00</td>
<td>6.00</td>
<td>6.25</td>
<td>-0.40</td>
<td>-3.8</td>
</tr>
<tr>
<td>TBI-A7</td>
<td>27</td>
<td>7.12</td>
<td>6.00</td>
<td>8.37</td>
<td>6.50</td>
<td>5.00</td>
<td>-1.63</td>
<td>-16.3</td>
</tr>
<tr>
<td>TBI-A8</td>
<td>40</td>
<td>3.62</td>
<td>3.75</td>
<td>3.87</td>
<td>3.00</td>
<td>4.75</td>
<td>-2.33</td>
<td>-37.6</td>
</tr>
<tr>
<td>TBI-A9</td>
<td>28</td>
<td>5.75</td>
<td>7.37</td>
<td>6.87</td>
<td>3.25</td>
<td>4.25</td>
<td>-2.83</td>
<td>-29.2</td>
</tr>
<tr>
<td>TBI-A10</td>
<td>37</td>
<td>5.87</td>
<td>5.37</td>
<td>7.12</td>
<td>3.00</td>
<td>3.50</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>TBI-A11</td>
<td>37</td>
<td>6.00</td>
<td>3.50</td>
<td>6.25</td>
<td>5.25</td>
<td>3.75</td>
<td>-0.85</td>
<td>-13.6</td>
</tr>
<tr>
<td>TBI-A12</td>
<td>18</td>
<td>14.25</td>
<td>14.25</td>
<td>14.25</td>
<td>9.00</td>
<td>8.75</td>
<td>2.15</td>
<td>17.8</td>
</tr>
</tbody>
</table>

**Mean:**
- 31.33
- 6.63
- 6.38
- 7.15
- 4.31
- 4.65
- 1.52
- 19.0

**Std Dev:**
- 6.95
- 2.90
- 2.90
- 2.90
- 2.06
- 2.03
- 1.89
- 20.5

**SEM:**
- 2.01
- 0.87
- 0.87
- 0.87
- 0.59
- 0.59
- 0.57
- 6.2

(Green et al, 2010)
Static Measurement Findings

Accommodative Amplitude in Mild Traumatic Brain Injury Patients

Age (years)

Accommodative Amplitude (D)

- Push-up OU
- Push-up OD
- Push-up OS
- Poly. (Duane's Mean Norms)
- Poly. (Duane's Max Norms)
- Poly. (Duane's Min Norms)

(Green et al, 2010)
Static Measurement Findings

Comparison of accommodative amplitude mean values between the mTBI group and normative literature values (p<0.05)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direction of change in mTBI group</th>
<th>Normal vs. mTBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocular push-up accommodative amplitude</td>
<td>Decrease</td>
<td>8.23D vs. 6.51D</td>
</tr>
<tr>
<td>Binocular push-up accommodative amplitude</td>
<td>Decrease</td>
<td>8.68D vs. 7.15D</td>
</tr>
</tbody>
</table>

(Adapted from Green et al, 2010)
Static Measurement Findings

Mean Accommodative Stimulus/Response Slope Values

(Green et al, 2010)
Static Measurement Findings

Monocular Accommodative Stimulus/Response

\[ y = 0.872x - 0.281 \]
\[ R^2 = 0.9999 \]
(Normal)

\[ y = 0.7779x - 0.0973 \]
\[ R^2 = 0.9974 \]
(TBI)

(Green et al, 2010)
Static Measurement Findings

Binocular Accommodative Stimulus/Response Curve

- Linear (Normal):
  \[ y = 0.8117x - 0.1576 \]
  \[ R^2 = 0.9985 \]
  
- Linear (TBI):
  \[ y = 0.8092x - 0.1762 \]
  \[ R^2 = 0.9994 \]

(Green et al, 2010)
Static Measurement Findings

Mean Tonic Accommodation

Accommodative Response (D)

Normal  
TBI

(Green et al, 2010)
### Static Measurement Findings

Measurements of AC/A ratio, PRA/NRA, and heterophoria in twelve subjects with mTBI.

<table>
<thead>
<tr>
<th>Subject</th>
<th>AC/A ratio (PD/D)</th>
<th>PRA (D)</th>
<th>NRA (D)</th>
<th>Horizontal near phoria (PD)</th>
<th>Vertical near phoria (PD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBI-A1</td>
<td>4.20</td>
<td>-3.75</td>
<td>3.00</td>
<td>5 eso</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A2</td>
<td>2.75</td>
<td>-1.25</td>
<td>1.25</td>
<td>8.5 exo</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A3</td>
<td>5.50</td>
<td>-0.75</td>
<td>0.50</td>
<td>3.25 eso</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A4</td>
<td>6.00</td>
<td>-1.00</td>
<td>1.00</td>
<td>11 eso</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A5*</td>
<td>6.65</td>
<td>-2.50</td>
<td>1.50</td>
<td>4 exo</td>
<td>2 L. Hyper</td>
</tr>
<tr>
<td>TBI-A6</td>
<td>2.70</td>
<td>-0.75</td>
<td>2.75</td>
<td>3.5 exo</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A7</td>
<td>4.30</td>
<td>-2.00</td>
<td>3.75</td>
<td>5.5 eso</td>
<td>1 L. Hyper</td>
</tr>
<tr>
<td>TBI-A8**</td>
<td>n/a</td>
<td>-1.25</td>
<td>2.50</td>
<td>14 eso</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A9</td>
<td>-0.53</td>
<td>-2.00</td>
<td>2.75</td>
<td>2.75 exo</td>
<td>0.5 L. Hyper</td>
</tr>
<tr>
<td>TBI-A10</td>
<td>0</td>
<td>-2.50</td>
<td>2.75</td>
<td>6 exo</td>
<td>2 R. Hyper</td>
</tr>
<tr>
<td>TBI-A11</td>
<td>3.00</td>
<td>-1.75</td>
<td>2.50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TBI-A12</td>
<td>2.00</td>
<td>-7.25</td>
<td>2.50</td>
<td>7.25 exo</td>
<td>1 R. Hyper</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Eso (N=5)</th>
<th>Exo (N=6)</th>
<th>Ortho (N=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean:</td>
<td>3.32</td>
<td>-2.23</td>
<td>2.23</td>
</tr>
<tr>
<td>Std Dev:</td>
<td>2.31</td>
<td>1.80</td>
<td>0.95</td>
</tr>
<tr>
<td>SEM:</td>
<td>0.70</td>
<td>0.52</td>
<td>0.27</td>
</tr>
</tbody>
</table>

* Patient manifested a dramatic increase is esophoria with the 3.50D and 4.50D stimuli (AC/A)

** Patient was not able to perform task due to excessive tearing (AC/A)

(Green et al, 2010)
Static Measurement Findings

• AC/A ratio
  – *Two* subjects manifested ratios at or above 6 PD/D, which is considered abnormally high
  – *Three* exhibited ratios at or below 2 PD/D, which is considered abnormally low
  – *One* subject was unable to perform the task due to highly excessive tearing that frequently resulted when the patient became overly fatigued
  – Therefore, 50% (6/12) of the individuals with mTBI exhibited abnormality in the stimulus AC/A ratio

• PRA/NRA
  – 50% (6/12) exhibited either reduced values for both PRA and NRA or an NRA value exceeding the PRA value by 1.00D or more

• Heterophoria
  – *Five* exhibited esophoria
  – *Two* exhibited exophoria of greater than six prism diopters
  – Therefore, 64% (7/12) manifested values outside of the normal near range
Dynamic Measurement Findings

Dynamic Step Response (Normal-3)

Dynamic Step Response (TBI-A8)

Dynamic Step Response (TBI-A9)

Dynamic Step Response (TBI-A10)

(Green et al, 2010)
Dynamic Measurement Findings

**Dynamic Step Response (Normal-2)**

![Graph of Dynamic Step Response (Normal-2)]

**Dynamic Step Response (TBI-A9)**

![Graph of Dynamic Step Response (TBI-A9)]

(Green et al, 2010)
Dynamic Measurement Findings

Normal-5

TBI-10

(Tau = 0.243 s
Ampl. = 1.73 D
PV = 7.1 D/s)

TBI-10

(Tau = 0.251 s
Ampl. = 1.75 D
PV = 7.0 D/s)

(Tau = 0.838 s
Ampl. = 2.07 D
PV = 2.5 D/s)

(Tau = 0.459 s
Ampl. = 1.36 D
PV = 3.0 D/s)

(Green et al., 2010)
Dynamic Measurement Findings

Mean Time Constant

(Time Constant (s))

- Normal Inc.
- TBI Inc.
- Normal Dec.
- TBI Dec.

(Green et al, 2010)
Dynamic Measurement Findings

Mean Peak Velocity

![Bar graph showing peak velocity (D/s) for normal and TBI conditions with increases (Inc.) and decreases (Dec.).]

(Green et al, submitted)
Dynamic Measurement Findings

Comparison of time constant and peak velocity mean values between the mTBI and normal groups (p<0.05)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Direction of change in mTBI group</th>
<th>Normal vs. mTBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Constant</td>
<td>Increase</td>
<td>259ms vs. 384ms</td>
</tr>
<tr>
<td>Peak Velocity</td>
<td>Decrease</td>
<td>8.0D/s vs. 5.6D/s</td>
</tr>
</tbody>
</table>

(Adapted from Green et al, 2010)
Dynamic Measurement Findings

Mean Accommodative Response Level

- Normal 4D: 4.0
- TBI 4D: 3.5
- Normal 2D: 2.0
- TBI 2D: 1.5

Mean Initial Response Gain

- Normal Inc.: 1.0
- TBI Inc.: 0.9
- Normal Dec.: 1.0
- TBI Dec.: 0.9

(Green et al, 2010)
Dynamic Measurement Findings

Mean Response Variability

Variability (D)

Normal 4D  TBI 4D  Normal 2D  TBI 2D

(Green et al, 2010)
Dynamic Measurement Findings

![Bar chart showing mean monocular and binocular accommodative flipper facility](chart)

- Normal OD
- Normal OS
- TBI OD
- TBI OS
- Normal OU
- TBI OU

(Green et al, 2010)
Dynamic Measurement Findings

Mean Pre- and Post-Fatigue Binocular Accommodative Flipper Facility

(Green et al, 2010)
Summary of Abnormal Findings from the SUNY Research Group

• **Static**
  – Reduced amplitude of accommodation (66%)
  – Abnormally large phoria (64%)
  – Abnormal NRA/PRA (50%)
  – Abnormal AC/A ratio (50%)

• **Dynamic**
  – Reduced peak velocity (100%)
  – Increased time constant (100%)
  – Exhibited accommodative fatigue (75%)
Clinical Implications

• 5 of the 7 significant findings can be implemented routinely in a clinic setting

• These abnormal findings are consistent with patient symptoms

• Remediation can be performed with vision therapy, lenses, and/or prisms

• Provides insight into the affected neurological pathways

• Confirms the crucial role of the optometrist in the diagnosis and treatment of such patients
Future Directions

• Assess accommodative latency

• Testing with a ramp stimulus

• Assess steady-state accommodative response variability with power spectrum analysis

• Use age-adjusted lens flipper powers

• Assess effects of therapeutic interventions such as vision therapy, lenses, and/or prisms
  – Clinical parameters
  – Laboratory static and dynamic parameters
  – Brain imaging (e.g., DTI, fMRI)
  – Electrophysiological testing (e.g., VER)
Future Directions

- Modeling using bioengineering control systems and neurophysiological approaches (MATLAB)
- Test other ABI groups such as CVA
- Test pediatric populations
Acknowledgments

• We thank Drs. J. Choi-Lee, J. Cohen, L. Lowell, V. Wren, and Ms. I. Rosen for providing study patients

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