The Role of Neuropsychological Testing in Concussion

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“When it comes to concussion, don’t believe me when I tell you that I’m OK”

NFL Athlete, 2010
League of Denial: The NFL’s Concussion Crisis

COMING OCTOBER 8, 2013

FRONTLINE reveals the hidden story of the NFL and brain injuries.

The National Football League, a multibillion-dollar commercial juggernaut, presides over America’s indisputable national pastime. But the NFL is under assault: thousands of former players and a host of scientists have claimed the league tried to cover up how football inflicted long-term brain injuries on many players. What did the NFL know, and when did it know it? In a special two-hour investigation, FRONTLINE reveals the hidden story of the NFL and brain injuries.
Sports Concussion Facts

• ~1.6 million to 3.8 million concussions / year per CDC
• 5-10% of athletes will experience a concussion per season
• <10% of sport related concussions have LOC
• Football - most common sport concussion risk for males (75% chance for concussion)
• Soccer - most common sport concussion risk for females (50% chance for concussion)
• 78% of concussions occur during games (as opposed to practices)
Sports Concussion Facts

- Females are twice as likely to sustain a concussion as males
- Headache (85%) and Dizziness (70-80%) most commonly symptoms
- ~ 47% of athletes do not report feeling any symptoms after a concussive blow
- Professional football player will receive ~ 900 to 1500 blows to the head per season
- Impact speed professional boxers punch: 20mph
- Impact speed football player tackling a stationary player: 25mph
- Impact speed soccer ball being headed by a player: 70mph
Sports Concussion Facts

- Concussion history of **has higher risk** of sustaining another
- Greater #, severity and duration of symptoms predictor of **prolonged recovery**
- Youth athletes have a more **prolonged recovery** and more susceptible to a concussion accompanied by a catastrophic injury
- **Pre-injury** mood disorders, learning disorders, (ADD/ADHD) and **migraine headaches** complicate diagnosis and management of a concussion.
## Comparison of mTBI (Concussions)

* Approximation

<table>
<thead>
<tr>
<th></th>
<th>NFL*</th>
<th>NHL*</th>
<th>High School*</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Participants</td>
<td>1,696</td>
<td>690</td>
<td>1,050,000</td>
</tr>
<tr>
<td>Ave Concussions per year</td>
<td>144</td>
<td>71</td>
<td>63,750</td>
</tr>
<tr>
<td>Annual % per year</td>
<td>8.5%</td>
<td>10.3%</td>
<td>5.75%</td>
</tr>
</tbody>
</table>

**US Military**

| Total # Deployed up until Oct 2007 | 1.6¹ million |
| Estimated # of Concussions        | 304,000      |
| Post Deployment Survey Results    | 19%¹         |


¹ RAND Corporation April 17, 2008 Invisible Wounds of War Psychological and Cognitive Injuries, Their Consequences, and Services to Assist Recovery
Consequences of Concussion?

Concussion

- Loss of Consciousness
- Post Concussion Syndrome
- Second Impact Syndrome
- Post Traumatic Stress Disorder
- Chronic Traumatic Encephalopathy

VS.

Complete Return to Normal
What is a Concussion?

Concussion is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process.
Pathophysiology

- Neurometabolic “Mismatch”
  - Initial Signs and Sx’s

- Excitotoxic
  - Extracellular Glutamate

- Immunologic
  - Activated Macrophages
  - Immune Inflammatory Factors
Review Article

Immunoexcitotoxicity as a central mechanism in chronic traumatic encephalopathy—A unifying hypothesis

Russell L. Blaylock, Joseph Maroon*

Theoretical Neurosciences, LLC Visiting Professor of Biology, Belhaven University, Jackson, MS 315 Rolling Meadows Rd, Ridgeland, MS 39157, *Department of Neurosurgery, Heindl Scholar in Neuroscience, University of Pittsburgh Medical Center, Team Neurosurgeon, The Pittsburgh Steelers

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Spectrum of Immunoexcitotoxicity

Degree of MicrogliA Activation

mTBI Concussion
Post-Concussion Syndrome
PTSD
CTE

Time
Immunoexcitotoxicity and CTE
Diagnosis of Concussion

- Concussion remains a clinical diagnosis
- Graded symptom checklists provide an objective tool for assessing a variety of symptoms related to concussions
- Standardized assessment tools (SAC) provide a helpful structure for the evaluation of concussion
Neuropsychological testing (NP)

- An objective measure - more sensitive for cognitive impairment than clinical exam.
- Computerized neuropsychological (CNP) testing should be interpreted by healthcare
- NP testing used not in isolation but as added value to assess cognitive function and recovery in the management of sports concussions
Return to play - RTP

- Concussion **symptoms** should be **resolved** before exercise
- A RTP **step-wise progression** increase in physical demands (sport-specific)
- If **symptoms** occur with activity, **progression should be halted**
- RTP by a licensed healthcare provider trained in the evaluation and management of concussions.

<table>
<thead>
<tr>
<th>Rehabilitation stage</th>
<th>Functional exercise at each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No activity</td>
<td>Complete physical and cognitive rest</td>
</tr>
<tr>
<td>2. Light aerobic activity</td>
<td>Walking, swimming, stationary cycling, keeping intensity less than 70% of maximum predicted heart rate; no resistance training</td>
</tr>
<tr>
<td>3. Sport-specific exercise</td>
<td>For example, skating drills in ice hockey, running drills in soccer; no head impact activities</td>
</tr>
<tr>
<td>4. Noncontact training drills</td>
<td>Progression to more complex training drills (eg, passing drills in football and ice hockey); may start resistance training</td>
</tr>
<tr>
<td>5. Full-contact practice</td>
<td>After medical clearance, participate in normal training activities</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
</tr>
</tbody>
</table>

Consequences of Concussion?

Concussion

- Loss of Consciousness
- Post Concussion Syndrome
- Second Impact Syndrome
- Post traumatic Stress Disorder
- Chronic Traumatic Encephalopathy

VS.

Complete Return to Normal
Post Concussion Syndrome (PCS)

- Symptoms may include:
  - Chronic headaches
  - Fatigue
  - Sleep difficulties
  - Personality changes (e.g. increased irritability, emotionality)
  - Sensitivity to light or noise
  - Dizziness when standing quickly
  - Deficits in short-term memory, problem solving and general academic functioning
### Most Commonly Reported Symptoms

**Athletes with Concussion — 1-7 days following concussion**

<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1  Headache</td>
<td>75%</td>
</tr>
<tr>
<td># 2  Difficulty Concentrating</td>
<td>57 %</td>
</tr>
<tr>
<td># 3  Fatigue</td>
<td>52 %</td>
</tr>
<tr>
<td># 4  Drowsiness</td>
<td>51 %</td>
</tr>
<tr>
<td># 5  Dizziness</td>
<td>49 %</td>
</tr>
<tr>
<td># 6  Foggy</td>
<td>47 %</td>
</tr>
<tr>
<td># 7  Feeling Slowed Down</td>
<td>46 %</td>
</tr>
<tr>
<td># 8  Light Sensitivity</td>
<td>45 %</td>
</tr>
<tr>
<td># 9  Balance Problems</td>
<td>39 %</td>
</tr>
<tr>
<td># 10 Difficulty with Memory</td>
<td>38 %</td>
</tr>
</tbody>
</table>

Kontos, Elbin, French Collins, Data Under Review; N = 1,438
Post-Concussion Symptom Groups

EMOTIONAL
- More emotional
- Sadness
- Nervousness
- Irritability

PHYSICAL-MIGRAINE
- Headaches
- Visual Problems
- Dizziness
- Noise/Light Sensitivity
- Nausea

COGNITIVE SYMPTOMS
- Attention Problems
- Memory dysfunction
- “Fogginess”
- Fatigue
- Cognitive slowing

SLEEP DISTURBANCE
- Difficulty falling asleep
- Sleeping less than usual

N=327, High School and University Athletes Within 7 Days of Concussion

Consequences of Concussion?

- Concussion
- Loss of Consciousness
- Post Concussion Syndrome
- Second Impact Syndrome
- Post Traumatic Stress Disorder
- Chronic Traumatic Encephalopathy

VS.

Complete Return to Normal
Acute Management
Rule out more serious intracranial pathology (CT, MRI, neurologic examination primary diagnostic tests)

Post Injury Management
Prevent against Second Impact Syndrome (SIS)
Prevent against cumulative effects of repeat injury causing extension of injury
Prevent presence of Post-Concussion Syndrome

(SIS) two events
1. athlete suffering post-concussive symptoms following a head injury.
2. If, within several mins, hrs, days or weeks, the athlete returns to play and sustains a second head injury, diffuse cerebral swelling, brain herniation, and death can occur.
Consequences of Concussion?

- Concussion
- Loss of Consciousness
- Post Concussion Syndrome
- Second Impact Syndrome
- Post Traumatic Stress Disorder
- Chronic Traumatic Encephalopathy

VS.

Complete Return to Normal
Post-Traumatic Stress Disorder

Symptom Complex:

- Traumatic Event
- “Flashbacks”
- Avoidance
- Hyper-responsiveness
- Emotional Liability
- Autonomic Reactivity
- Sleep Disturbance
Incidence of PTSD

- **Vietnam War** - 15% men / 9% of women, immediate (479,000) and ~30% men / 27% women lifetime (1 Mil)
- **Persian Gulf War** - veterans range from 9% to 24%
- **Iraq War and Afghanistan** - ~ 12.5% PTSD


MTBI(PCS) and PTSD – Overlapping Conditions?

M. Lovell

mTBI (PCS)
- Dizziness
- Balance Impairment
- Headaches
- Phonophobia
- Photophobia
- Visual blurring
- Nausea

Amnesia?
Sleep Issues
Irritability/Anger
Depression
Fatigue
COGNITIVE ISSUES

PTSD
- Traumatic Event
- “Flashbacks”
- Avoidance
- Hyper-responsiveness
- Emotional Liability
- Autonomic Reactivity
- Autonomic Reactivity
- Sleep Disturbance

Shared Symptoms
Inflammation by Immuno-excitotoxicity Pathway for PTSD

↑ Stress

Hypothalamic-Pituitary-Adrenal Axis

- ↑ Corticoids and Inflammatory Prostaglandins
- ↓ T&B Lymph
- ↓ NK Cell Activity
- ↓ Energy, ↓ Metabolism to Stress & DNA Repair
- ↓ SIRT1
- ↑ Inflammation & Impaired Immune Sys

↑ Depression

- ↑ Microglia, ↓ Astrocytes (BDNF)
- ↑ Pro-Inflammatory Cytokine (IL-1B, IL-2, IL-6, TNF-a, Interferon)
- ↑ Kynurenic Acid & Quinolinic Acid
- ↑ NMDA Receptor Damage
- ↑ NFk-B
- ↑ COX 1&3

Excitotoxic & Anti-neurogenic
Consequences of Concussion?

Concussion

- Loss of Consciousness
- Post Concussion Syndrome
- Second Impact Syndrome
- Post-Traumatic Stress Disorder
- Chronic Traumatic Encephalopathy

VS.

Complete Return to Normal
CHRONIC TRAUMATIC ENCEPHALOPATHY IN A NATIONAL FOOTBALL LEAGUE PLAYER

OBJECTIVE: We present the results of the autopsy of a retired professional football player that revealed neuropathological changes consistent with long-term repetitive concussive brain injury. This case draws attention to the need for further studies in the cohort of retired National Football League players to elucidate the neuropathological sequelae of repeated mild traumatic brain injury in professional football.

METHODS: The patient’s premortem medical history included symptoms of cognitive impairment, a mood disorder, and parkinsonian symptoms. There was no family history of Alzheimer’s disease or any other head trauma outside football. A complete autopsy with a comprehensive neuropathological examination was performed on the retired National Football League player approximately 12 years after retirement. He died suddenly as a result of coronary atherosclerotic disease. Studies included determination of apolipoprotein E genotype.

RESULTS: Autopsy confirmed the presence of coronary atherosclerotic disease with dilated cardiomyopathy. The brain demonstrated no cortical atrophy, cortical contusion, hemorrhage, or infarcts. The substantia nigra revealed mild pallor with mild dropout of pigmented neurons. There was mild neuronal dropout in the frontal, parietal, and temporal neocortex. Chronic traumatic encephalopathy was evident with many diffuse amyloid plaques as well as sparse neurofibrillary tangles and $\tau$-positive neuritic threads in neocortical areas. There were no neurofibrillary tangles or neuropil threads in the hippocampus, lateral geniculate body, or cerebellum.
Chronic Traumatic Encephalopathy in Athletes: Progressive Tauopathy following Repetitive Head Injury

Ann C. McKee, MD\textsuperscript{1,2,3,4}, Robert C. Cantu, MD\textsuperscript{3,5,6,7}, Christopher J. Nowinski, AB\textsuperscript{3,5}, E. Tessa Hedley-Whyte, MD\textsuperscript{8}, Brandon E. Gavett, PhD\textsuperscript{1}, Andrew E. Budson, MD\textsuperscript{1,4}, Veronica E. Santini, MD\textsuperscript{1}, Hyo-Soon Lee, MD\textsuperscript{1}, Caroline A. Kubiul\textsuperscript{1,3}, and Robert A. Stern, PhD\textsuperscript{1,3}

\textsuperscript{1} Department of Neurology, Boston University School of Medicine, Boston, Massachusetts
\textsuperscript{2} Department of Pathology, Boston University School of Medicine, Boston, Massachusetts
CTE- CHRONIC TRAUMATIC ENCEPHALOPATHY - ?New Agent Orange?

• Subconcussive blows
• Prolonged latent period
• Mean survival of 18 years after diagnosis
• Early behavioral personality changes with memory loss
• Progressive dementia, Parkinsonism, gait and speak disorders
CTE- Questions from Ann McKee – NFL Conference Jun 2010

- How to diagnose?
- How to treat?
- How to prevent?
- What is the actual prevalence?
  - (minimum—3.2% of retired NFL players?)
- What are the risk factors?
  - Genetic (Apo E4)
  - Severity of trauma
  - Type of trauma
  - Frequency and time interval between successive head injuries
  - Age of individual at time of injury
  - Positive played and type of sport

  » Ann McKee, June 2, 2010, TBI in Professional Football
CTE Questions?

• What are the Risk Factors?
  – Prior “Priming” of Microglia Cells?
  – Severity and Frequency of Trauma?
  – Age?
  – Genetics (ApoE4)?

• How to Diagnosis?
• How to Treat?
• How to Prevent?
• What is the True Incidence?
Neuropsychological Testing for Concussion Management
“The Challenge”

“I don’t want guesswork for my players. Give me objective data for return to play.”

Chuck Noll, Head Coach, Pittsburgh Steelers 1990
Computer-Based Neurocognitive Testing

CURRENTLY AVAILABLE PROGRAMS:

Cogsport (Axon)
Headminders (CRI)
ANAM
CNS Vital Signs
ImPACT
ImPACT
Immediate
Post-Concussion Assessment
and Cognitive Testing

Computerized Neurocognitive Testing

Joseph Maroon, MD - UPMC Dept. of Neurological Surgery
Mark Lovell, PhD, FACPN, Dsci, Software Developer, ImPACT
Micky Collins, PhD - UPMC Dept. of Orthopaedic Surgery
**ImPACT: Post-Concussion Evaluation**

- Demographic / Concussion History Questionnaire
- Concussion Symptom Scale
  - 21 Item Likert Scale (e.g. headache, dizziness, nausea, etc)
- **8 Neurocognitive Measures**
  - Verbal Memory, Visual Memory, Reaction Time, Processing Speed Summary Scores
- Detailed Clinical Report
  - Outlines Demographic, Symptom, Neurocognitive Data
  - Automatically Computer Scored
- **Internal baseline validity checks built into program**
- Desktop and On-Line Versions Available
  - Extensive normative data available from ages 11-60
- **Over 100 peer-reviewed research articles/books/chapters, published since 2000**
  - Extensive data published on reliability, validity, sensitivity/specificity of test
The Design of ImPACT

- Six challenging brief cognitive tests
- Online and Offline versions available
- 25 minutes in length
- Available in 14 languages
- Tests measure:
  - Reaction time
  - Visual and Verbal memory
  - Multitasking (working memory)
  - Motor speed
  - Symptoms as reported by Subject
Neurocognitive Testing: What it is and Isn’t

IS - **tool** to help determine recovery

IS - **tool** to help return to academics, to play

IS a **tool** to help communicate post-concussion status to coaches, parents, clinicians

IS **NOT** a substitute for medical evaluation / treatment
Concussion Evaluation Timeline

Pre-season

Baseline Testing
Supervised at School or Clinic

Concussion
Remove From Play

1-3 Days
First Follow-Up
Evaluation

Follow-up Testing as needed
Return to Play
Measuring Neurocognitive Concussion Recovery

How Long Does it Take?

Three-year prospective study in Western PA.

17 high school football teams (2,141 total sample)

134 athletes with diagnosed concussion (6.2%)

All athletes referred for evaluation at UPMC

Recovery determined by “Back to Baseline” on computer neurocognitive test scores & symptom inventory

Determined by Reliable Change Index Scores-RCI’s)

Individual Recovery From Sports MTBI: How Long Does it Take?

N=134 High School Male Football Athletes

40% RECOVERED

60% RECOVERED

80% RECOVERED

Collins et al., 2006, Neurosurgery
Functional MRI and Sports Concussion

Lovell, Collins, Eddy, Becker, Pardini, Maroon, Field, Marion, and Boada
(2001-2006) RO1 HD 42386-05
Brain Metabolism is Related to Recovery

- Over 200 High School Athletes Studied using fMRI
  
  *Tested in 7 days of concussion and at point of clinical recovery*

- Hyperactivation predicts **CLINICAL** recovery time

- Resolution of hyperactivation correlates with recovery on ImPACT

The Greater the Degree of
Hyperactivation the LONGER the
Recovery time!  

Lovell, Maroon et al.,
Neurosurgery, 2007
Recovery: fMRI Subsample (UPMC Program)

Mean Age: 16.2 yrs
Gender: 78% male

N = 208

Cumulative Percent Recovery
- 15 days: 25%
- 26 days: 50%
- 45 days: 75%
- 92 Days: 90%

Days to Recover
- Range: 4 – 211 days*
- Mean: 26.2 days

* End of study period

Cumulative Percent Recovery
- 15 days: 25%
- 26 days: 50%
- 45 days: 75%
- 92 Days: 90%
Which On-Field Symptoms Increase Risk of Post Concussion Syndrome in HS Football Players?

176 Male HS Football Players (Mean Age = 16.2 years)
Baseline ImPACT testing reevaluated within 3 days of injury
All followed until clinical recovery (Mean = 4.1 evaluations)

Results:
32% - “Rapid Recovery” < 7 days until recovery
39% - 7-14 days until recovery
17% - “Protracted Recovery” > 21 days until recovery
(Mean = 33.2 days)

Which On-Field Markers/Symptoms Predict 3 or More Weeks Recovery from MTBI In High School Football Players

<table>
<thead>
<tr>
<th>On-Field Marker</th>
<th>N</th>
<th>Chi²</th>
<th>P</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttraumatic Amnesia</td>
<td>92</td>
<td>1.29</td>
<td>0.257</td>
<td>1.721</td>
<td>0.67-4.42</td>
</tr>
<tr>
<td>Retrograde Amnesia</td>
<td>97</td>
<td>.120</td>
<td>0.729</td>
<td>1.179</td>
<td>0.46-3.00</td>
</tr>
<tr>
<td>Confusion</td>
<td>98</td>
<td>.114</td>
<td>0.736</td>
<td>1.164</td>
<td>0.48-2.82</td>
</tr>
<tr>
<td>LOC</td>
<td>95</td>
<td>2.73</td>
<td>0.100</td>
<td>0.284</td>
<td>0.06-1.37</td>
</tr>
</tbody>
</table>

**p<.01

<table>
<thead>
<tr>
<th>On-Field Symptom</th>
<th>N</th>
<th>Chi²</th>
<th>P</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dizziness**</td>
<td>98</td>
<td>6.97</td>
<td>0.008</td>
<td>6.422</td>
<td>1.39-29.7</td>
</tr>
<tr>
<td>Headache</td>
<td>98</td>
<td>0.64</td>
<td>0.43</td>
<td>2.422</td>
<td>0.26-22.4</td>
</tr>
<tr>
<td>Sensitivity LT/Noise</td>
<td>98</td>
<td>1.19</td>
<td>0.28</td>
<td>1.580</td>
<td>0.70-3.63</td>
</tr>
<tr>
<td>Visual Problems</td>
<td>97</td>
<td>0.62</td>
<td>0.43</td>
<td>1.400</td>
<td>0.61-3.22</td>
</tr>
<tr>
<td>Fatigue</td>
<td>97</td>
<td>0.04</td>
<td>0.85</td>
<td>1.080</td>
<td>0.48-2.47</td>
</tr>
<tr>
<td>Balance Problems</td>
<td>98</td>
<td>0.28</td>
<td>0.59</td>
<td>0.800</td>
<td>0.35-1.83</td>
</tr>
<tr>
<td>Personality Change</td>
<td>8</td>
<td>0.86</td>
<td>0.35</td>
<td>0.630</td>
<td>.023-1.69</td>
</tr>
<tr>
<td>Vomiting</td>
<td>97</td>
<td>0.68</td>
<td>0.41</td>
<td>0.600</td>
<td>0.18-2.04</td>
</tr>
</tbody>
</table>

The total sample was 107. Due to the normal difficulties with collecting on-field markers, there were varying degrees of missing data. The number of subjects who had each coded ranged from 92-98. The N column represents the number of subjects for whom data were available for each category. Markers of injury are not mutually exclusive.
On-Field Symptom Summary

Brief LOC (<30 sec) *not predictive* of subacute or protracted outcomes following sports-concussion.

Amnesia important for sub-acute presentation, but *may not be as predictive* of protracted recovery.

On-Field dizziness best predictor of protracted recovery and “post concussion syndrome”

Etiology of dizziness?
- Migraine variant?
- Central Vestibular Dysfunction?
- Peripheral Vestibular Dysfunction?
- Cervico-genic?
- Psychiatric?
Factor Analysis, Post-Concussion Symptom Scale
(Pardini, Lovell, Collins et al. 2004)

NEUROPSYCHIATRIC
- More emotional
- Sadness
- Nervousness
- Irritability

MIGRAINE (PHYSICAL SX)
- Headaches
- Visual Problems
- Dizziness
- Noise/Light Sensitivity
- Nausea

COGNITIVE SYMPTOMS
- Attention Problems
- Memory dysfunction
- “Fogginess”
- Fatigue
- Cognitive slowing

SLEEP DISTURBANCE
- Difficulty falling asleep
- Sleeping less than usual

N=327, High School and University Athletes Within 7 Days of Concussion
## Rank Order of Most Predictive Symptoms of Outcome

<table>
<thead>
<tr>
<th>Variables</th>
<th>Classification</th>
<th>Z-Score (Simple vs. Complex)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fogginess</strong></td>
<td>Cognitive</td>
<td>4.3*</td>
</tr>
<tr>
<td>Difficulty Concentrating</td>
<td>Cognitive</td>
<td>2.46</td>
</tr>
<tr>
<td>Vomit</td>
<td>Migraine</td>
<td>2.391*</td>
</tr>
<tr>
<td>Dizziness</td>
<td>Migraine</td>
<td>2.09</td>
</tr>
<tr>
<td>Nausea</td>
<td>Migraine</td>
<td>1.96</td>
</tr>
<tr>
<td>Headache</td>
<td>Migraine</td>
<td>1.71</td>
</tr>
<tr>
<td>Slowness</td>
<td>Cognitive</td>
<td>1.53</td>
</tr>
<tr>
<td>Balance</td>
<td>Migraine</td>
<td>1.53</td>
</tr>
<tr>
<td>Light Sensitivity</td>
<td>Migraine</td>
<td>1.52</td>
</tr>
<tr>
<td>Noise Sensitivity</td>
<td>Migraine</td>
<td>1.52</td>
</tr>
<tr>
<td>Numbness</td>
<td>Migraine</td>
<td>1.46</td>
</tr>
<tr>
<td><strong>Trouble Sleeping</strong></td>
<td><strong>Sleep</strong></td>
<td><strong>1.231</strong>*</td>
</tr>
<tr>
<td>Visual Problems</td>
<td>Migraine</td>
<td>0.97</td>
</tr>
<tr>
<td>Difficulty Remembering</td>
<td>Cognitive</td>
<td>0.93</td>
</tr>
<tr>
<td>Sleeping Less</td>
<td>Sleep</td>
<td>.52</td>
</tr>
<tr>
<td>Drowsiness</td>
<td>Cognitive</td>
<td>0.5</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Cognitive</td>
<td>0.48</td>
</tr>
<tr>
<td>Emotional</td>
<td>Neuropsychiatric</td>
<td>0.37*</td>
</tr>
<tr>
<td>Irritability</td>
<td>Neuropsychiatric</td>
<td>0.3</td>
</tr>
<tr>
<td>Sadness</td>
<td>Neuropsychiatric</td>
<td>0.09</td>
</tr>
<tr>
<td>Nervousness</td>
<td>Neuropsychiatric</td>
<td>-0.03</td>
</tr>
<tr>
<td>Sleeping More</td>
<td>Cognitive</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

*Symptoms with the largest contributions to differences between “quick” and “protracted” recovery in each symptom factor.

Lau, Lovell, Collins et al. CJSMS, 2009
Post-Concussion Headache

“It’s more than just a headache”:

- Athletes with migraine-type symptoms (headache with nausea and/or light-noise sensitivity) exhibit more protracted recovery than with athletes with headache only

- 81% of post-traumatic migraine group also reported dizziness (post-traumatic vestibular migraine??)

- Important to assess for quality and type of headache in athletes with concussion
Sensitivity and Specificity of ImPACT in Classifying Athletes with Concussion

Discriminate Function Analysis
Statistical classification of Concussed (physician dx)/Control subjects
No Clinician Input
Testing completed within 3 days post injury

Positive Predictive Value (90%)
(Probability that that a concussion is present when test is positive)

Negative Predictive Value (82%)
(Probability that a concussion is not present when test is negative)

Predicting Quick versus Protracted Recovery from Sports mTBI

- At three days post-injury, if athlete exhibit three or more changes on ImPACT composite scores (relative to baseline), there is a 94% chance that recovery will require >10 days.

- Exhibiting a high symptom score did not improve classification accuracy over neurocognitive test scores in isolation.

- Athletes with prior history of concussion were not statistically more likely to have “protracted” recovery from concussion.

Iverson G. CJSM; 2008
## Risk Factors For More Complicated Concussion Recovery

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Pellman, Lovell et al. <em>Neurosurgery</em>, 2006</td>
</tr>
<tr>
<td></td>
<td>- Kontos, Elbin, Collins, Data submitted for publication</td>
</tr>
<tr>
<td></td>
<td>- Iverson et al, <em>CJSM</em>, 2004</td>
</tr>
<tr>
<td>Gender (?) Female</td>
<td>- Colvin, Lovell, Pardini, Mullin, Collins, <em>AJSM</em>, 2009</td>
</tr>
</tbody>
</table>
Concussion Summary

- Outcomes are highly variable
- Vestibular-related symptoms following injury predict more protracted recoveries
- Migraine-type symptoms (and potentially preexisting history of migraine) may place individuals at increased risk of injury and longer recovery
- Neurocognitive testing is valuable in determining prognosis and recovery in sports-related mTBI
- Clinical management key to preventing poor outcomes
- The “mild” injuries may become severe and the “severe” injuries may become mild
• CLINICAL EVALUATION
• IMPACT TESTING
• Vestibular Screening
Vestibular Screening: Physical Examination

- **Ocular-Motor:**
  - Smooth Pursuits ("H-Test")
  - Saccades (Vertical/Horizontal)
    - Any dizziness, blurriness, over/under shoots?

- **Vestibular-Ocular:**
  - Gaze Stability (focus on stationary object while moving head side to side/up and down)
    - Vertical/Horizontal
      - Any observable nystagmus, provocative dizziness/blurriness, slowed movements?
  - Convergence
    - In high school/college aged athletes, near point < 6-8 cm

- **Balance Examination**
  - Romberg, Compliant Foam-eyes open/eyes closed
Screen for Vestibular Abnormalities – Concussion Program

<table>
<thead>
<tr>
<th>Physical Exam:</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Ocular Motor/Vestibulo-Ocular</strong></td>
<td></td>
<td></td>
<td><strong>Possibly central vestibular disorder, particularly if a, b, or c abnormal</strong></td>
</tr>
<tr>
<td><strong>a.</strong> Abnormal Pursuits? ---------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>b.</strong> Abnormal Saccades? ---------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>c.</strong> Abnormal Convergence (&lt;6 cm)? --------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>d.</strong> Any observable nystagmus? ---------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>e.</strong> Blurring/dizziness with VOR (focus on stationary object while moving head side to side)?</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>B. Balance Screen:</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a.</strong> Romberg Eyes Open &lt; 30 sec or unsteady------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>b.</strong> Romberg Eyes Closed &lt; 30 sec or unsteady----</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>c.</strong> Tandem Romberg Eyes Open &lt; 30 sec or unsteady --------------------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>d.</strong> Tandem Romberg Eyes Closed &lt; 20 sec ------- (unless age &gt;50)</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>e.</strong> Compliant Foam Eyes Open &lt; 30 sec or unsteady ---------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>f.</strong> Compliant Foam Eyes Closed &lt; 30 sec or unsteady --------------------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>g.</strong> Tandem gait unsteady--------------------------</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Abnormality on any item suggests a balance disorder

Modified 10/04/10
Physical Exam – Balance Screen

**Tandem Stance**

- Eyes Open/Arms Crossed
  - Abnormal if <30 sec or unsteady
- Eyes Closed/Arms Crossed
  - Abnormal if <20 sec (unless 50+ years old)

**Tandem Walk**

- Abnormal if unsteady or unable
ImPACT Users (> 4.5 M Tests)

Professional Teams using ImPACT
- National Football League - All NFL Teams
- All NHL Teams
- Major League Baseball
- All Major League Umpires
- Major League Soccer
- All MLS Teams
- Chicago Fire
- National Basketball Association
- Professional Automobile Racing
  - Champ Car Racing
  - Deutsche Motor Sport
  - Formula 1
  - Formula BMW Race Series
  - Indy Racing Team
  - International Motor Sports Association
  - IRL
  - UK BMW Formula Racing
  - World Rally Championship
- Rugby
- Olympic Organizations
- Swedish World Cup Soccer Team
- US Olympic Training Center
- US Soccer
- USA Boxing
- USA Hockey
- USSA - US Ski Association
- Junior Hockey
- **US Army**
- **US Navy**
- Washington Wild Things
- World Wrestling Entertainment (WWE)
- ZSC Lions (Switzerland)

Over 5,000 HS and Colleges
Summary of ImPACT™

1. Independently validated with proven sensitivity and specificity
2. Correlated with fMRI
3. Can be scaled to test millions of people
4. Optimized and proven security
5. Positive response from military users
6. Customized to military specifications
“The Role of a Physician is to Amuse the Patient until Nature Cures Him.”

Jean-Baptiste Poquelin Molière
1622 – 1673
Current Rx for PCS

• **Pharmacological**
  – Anti-depressants
  – Hypnotics
  – Anxiolytics
  – ADHD meds

• **Rest the Brain** (no brain stimulation)
  – No work, school, TV, etc
Countering Immunoexcitotoxicity

Anti-Inflammatory
- Block COX 1-3
  - Aspirin
  - Ibuprofen
  - Celecoxib
  - Celecoxib
  - Naproxen
- Fish Oil
- Resveratrol
- Quercetin
- Curcumin
- Green Tea

Neurotrophic
- Block Cytokines/Suppress Microglia & ↓EAA
  - Minocycline
  - Progesterone
- Fish oil
- Resveratrol
- Curcumin
- Vitamin D
- Magnesium
- Luteolin

Immune
- ↑BDNF
  - SSRI’s
  - Tricyclics
  - ECT
  - Progesterone
- Fish oil
- Resveratrol
- Curcumin
- Exercise
- HBO

SIRT1
- Enhance Immune System
  - Probiotics
  - Vitamin D
  - b-Glucan
- Exercise
- HBO

Resveratrol
- Quercetin
- Fish oil
- Curcumin
- Green Tea
- HBO
Dietary Supplementation with the Omega-3 Fatty Acid Docosahexaenoic Acid in Traumatic Brain Injury?

Neurosurgery. 2011 Jan 5

DHA for the Brain

- Neurogenesis
- Anti-oxidant
- Membrane building
- Protect from
  - Excitotoxicity
  - Inflammation
US military may ‘shock and awe’ omega-3 market

By Mike Stones, Press Release 02-Feb-2010

A multi-million dollar omega-3 market could open up within two-to-three years if the US Department of Defense (DOD) orders its troops to take EPA and DHA omega 3 fatty acids.

The department is considering either supplementing or fortifying the rations of all active service personnel in order to enhance stress resilience and general wellness leading to improved military performance, to cut hospital bills and to speed recovery from traumatic brain injuries (TBI).

“There are discussions at many levels about the addition of the omega-3, especially in combat-feeding and/or clinical setting (eg TBI) but they are discussions at this point in time.”

Although the department has no official view about the benefits of omega-3s, its Dietary Supplements Committee is working with Samueli Institute based in Alexandria, Virginia, to explore the military benefits of their use.
“Omega-3 DHA and EPA shown to reduce oxidative damage, counteract learning disability and normalize BDNF”


“Omega-3 fatty acids that ameliorates protein oxidation the reduction of the energy status of cells. Hippocampal levels of total and phosphorylated AMPK were reduced after TBI and levels were normalized by omega-3 fatty acts supplements.”

“The present results demonstrate that Vitamin D₃ and D₂ inhibit TNFα expression in macrophages”


“Mg2+ therapy is effective in facilitating cognitive recovery of function following brain injury”

Resveratrol

The brain is highly susceptible to free radical damage, but Resveratrol (found in grape skins and seeds) acts as an anti-oxidant and neuroprotectant.

prevents apoptotic neuronal death and, by suppressing FOXO proteins promotes neuronal survival

Resveratrol activates SIRT1, which, via inhibition of NF-κB signaling
Resveratrol is Neuroprotective

Potential Mechanisms:

- Anti-oxidant → Blocks Free Radicals
- Anti-Inflammatory → Blocks NFkB
- Increases NO → Vasodilatation
- Anti-platelet → Decreased Clotting
- Anti-apoptosis → Decrease Infarct Size

H. ZHUANG Potential Mechanism by Which Resveratrol, a Red Wine Constituent, Protects Neurons Volume 993 Issue NEUROPROTECTIVE AGENTS Sixth International Conference, Pages 276 - 286, 2006
HBO – Hyperbaric Oxygen Therapy
Case report: Treatment of mild traumatic brain injury with hyperbaric oxygen

Colonel James K. Wright1, Eddie Zant2, Kevin Groom3, Robert E. Schlegel4, Kirby Gilliland4

1720th Special Tactics Group, Hurlburt Field, Florida, USA; 2Hyperbaric Medicine Inc., Fort Walton Beach, Florida, USA; 3The Anchor Clinic, Destin, Florida, USA; 4Center for the Study of Human Operator Performance, The University of Oklahoma, Norman, Oklahoma, USA

Abstract

Two United States Air Force Airmen were injured in a roadside improvised explosive device (IED) blast in Iraq in January 2008. Both airmen suffered concussive injuries and developed irritability, sleep disturbances, headaches, memory difficulties and cognitive difficulties as symptoms of mild traumatic brain injury (mTBI). Six months after injury, repeat Automated Neuropsychological Assessment Metrics (ANAM) testing showed deterioration, when compared to pre-injury baseline ANAM assessment, in all measured areas (simple reaction time, procedural reaction time, code substitution learning, code substitution delayed, mathematical processing, and matching to sample).

The airmen were treated with hyperbaric oxygen in treatments of 100% oxygen for one hour at 1.5 atmospheres absolute, resulting in rapid improvement of headaches and sleep disturbances, improvement in all symptoms and resolution of most symptoms. Repeat ANAM testing after completion of the hyperbaric treatments — nine months after initial injury — showed improvement in all areas, with most measures improving to pre-injury baseline levels. The airmen received no other treatment besides medical monitoring. Repeat neuropsychologic testing confirmed the improvement. We conclude that the improvement in symptoms and performance is most likely attributable to HBO treatment.

2009 Undersea and Hyperbaric Medical Society, Inc.
Hyperbaric Oxygen Therapy Treatment of Chronic Mild-Moderate Blast-Induced Traumatic Brain Injury/Post Concussion Syndrome with Post Traumatic Stress Disorder: Pilot Trial

Objectives
Mild-moderate blast-induced traumatic brain injury (TBI) and post-traumatic stress disorder (PTSD) affect 11-28% and 13-17%, respectively, of U.S. combat troops returning from Iraq and Afghanistan. Protracted treatment for PTSD exists, but there is no effective treatment for the post-concussion syndrome (PCS) of mild-moderate TBI nor the combined diagnoses of PCS and PTSD. We investigated hyperbaric oxygen therapy (HBOT 1.5) on symptoms, cognition, and SPECT brain blood flow in military veterans with blast TBI/PCS with/without PTSD.

Method
Fifteen symptomatic U.S. military veterans with blast-induced PCS (2) or PCS/PTSD (13), diagnosed by military neuropsychologists and neurologists, who were average: 29.7y (21-45); 2.6y (1.24-4.75) post injury, 1 minute (13 subjects; 2 subjects 4.5 & 9h) loss of consciousness, with 3 blast TBI's (1-8) completed the study. All subjects completed cognitive testing, symptom and quality of life questionnaires, and affective measures pre and immediately post a course of forty bid, 5d/week, 1.5ATA/60 minute hyperbaric oxygen therapy treatments (HBOT). Subjects underwent SPECT brain blood flow imaging (Picker Prism 3000, 25mCi Ethyl Cysteinate Dimer) pre and post a single HBOT and post 40 HBOT's. SPECT was analyzed with Osirix software; relative standard deviation of the mean on a histogram analysis of counts in left centrum semiovale region of interest was taken pre/post Rx. Paired Student t test and Wilcoxon Signed Ranks test (non-normally distributed data) were used for all measures.

Results
All subjects reported symptomatic improvement in the 35 day study period.

Conclusions
A thirty day course of forty 1.5 ATA HBOT’s demonstrated significant symptomatic, cognitive, and affective improvements in 15 U.S. military veterans with chronic blast-induced post-concussion syndrome and post-traumatic stress disorder. These findings were reinforced by quantitative and qualitative SPECT improvements.
### HBO for mTBI – 1.5 atm, 1-2 hr / Daily

<table>
<thead>
<tr>
<th>Subjects n=20</th>
<th>Concussions</th>
<th>Ave # of Sessions</th>
<th>Ave Length of PCS (months)</th>
<th>Improvement seen after # of Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number Completed</strong></td>
<td>9 (Ave Age = 18)</td>
<td>5 – 1</td>
<td>21 (5 – 60)</td>
<td>9 Sessions (3 – 15)</td>
</tr>
<tr>
<td><strong>Drop outs</strong></td>
<td>5 (Ave Age = 18.5)</td>
<td>3 – 1</td>
<td>12.6 (3 – 25)</td>
<td>5 (1) * (3 – 15)</td>
</tr>
<tr>
<td><strong>Currently being treated</strong></td>
<td>6 (Ave Age = 17.4)#</td>
<td>4 – 1</td>
<td>15.6 (3 – 34)</td>
<td>5 (2) * (3 –10)</td>
</tr>
</tbody>
</table>

# One subject 55 yr not included in Ave Age
* Not all subjects saw improvements
Thank You
Welcome to ImPACT

Immediate Post-concussion Assessment and Cognitive Testing

- Start a new test
- Print reports
- Submit your data

The Best Approach To Concussion Management
<table>
<thead>
<tr>
<th><strong>First Name</strong></th>
<th><strong>Last Name</strong></th>
<th><strong>Organization</strong></th>
<th><strong>Height</strong></th>
<th><strong>Weight</strong></th>
<th><strong>Gender</strong></th>
<th><strong>Handedness</strong></th>
<th><strong>Country</strong></th>
<th><strong>Native language</strong></th>
<th><strong>Second language</strong></th>
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<tbody>
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</tr>
</tbody>
</table>

**Identification**

Language/Lengua: **English/Inglés**

Enter the subject’s identification number and date of birth below. If available, use the social security or social insurance number as the identification number. Otherwise, assign a unique identification number to the subject.

SSN/Identification #: **---**

Date of Birth: **/ /** (MM/DD/YYYY)

**Language**

Native country/region: **United States of America**

Native language (or language group): **English**

Second language (or language group): **(None)**

Years speaking: **0**

Years in North America: **0**

**Current sport**

- Current position/event/class
- Current Level

**Years experience**
Number of times diagnosed with a concussion

Total number of concussions that resulted in loss of consciousness

Total number of concussions that resulted in confusion

Total number of concussions that resulted in difficulty with memory for events occurring immediately after injury

Total number of concussions that resulted in difficulty with memory for events occurring immediately before injury

Total games were missed as a direct result of all concussions combined.

List the 5 most recent concussions

Indicate whether you have experienced the following

- Treatment for headaches by physician
- Treatments for migraine headaches
- Treatment for epilepsy/seizures
- History of brain surgery
- History of meningitis
- Treatment for substance/alcohol abuse
- Treatment for psychiatric condition (depression, anxiety, etc.)
CURRENT SYMPTOMS

- Headache
- Nausea
- Vomiting
- Balance Problems
- Dizziness
- Fatigue
- Trouble falling asleep
- Sleeping more than usual
- Sleeping less than usual
- Drowsiness
- Sensitivity to light
- Sensitivity to noise
- Irritability
- Sadness
- Nervousness
- Feeling more emotional
- Numbness or tingling
- Feeling slowed down
- Feeling mentally foggy
- Difficulty concentrating
- Difficulty remembering
- Visual problems (blurry or double vision)
Module 1 (Word Discrimination)

- Evaluates attentional processes/verbal recognition memory
- Utilizes a word discrimination paradigm.
- Twelve target words are presented for 750 milliseconds (twice to facilitate learning of the list)
- The subject is then tested for recall via the presentation of the 24-word list that is:
  - comprised of 12 target words and 12 non-target words
  - Words chosen from the same semantic category as the target word.
  - EX: the word “ice” is a target word, while the word “snow” represents the non-target word.
  - The subject responds by mouse-clicking the “yes” or “no” buttons
  - Individual scores are provided both for correct “yes” and “no” responses - In addition, a total percent correct score is provided.
- There are five different forms of the word list.

Delay Condition: Following the administration of all other test modules (approximately 20 minutes), the subject is again tested for recall via the same method described above. The same scores that are described above are provided for the delay condition.
Module 2 (Design Memory)

- Evaluates attentional processes and visual recognition memory
- Utilizes a design discrimination paradigm.
- Twelve target designs are presented for 750 milliseconds (twice to facilitate learning)
- The subject is then tested for recall via the presentation of the 24-designs

✓ comprised of 12 target designs and 12 non-target designs

✓ EX: target designs that have been rotated in space

✓ The subject responds by mouse-clicking the “yes” or “no” buttons

✓ Individual scores are provided both for correct “yes” and “no” responses

✓ In addition, a total percent correct score is provided

There are five different forms of this task
Module 3 (X’s and O’s)

- Measures visual working memory, visual processing speed, and visual memory paradigm
- Encorporates a distractor task.
- The subject can practice the distractor task prior to presentation of the memory task.
- The distractor is a choice reaction time test: the subject is asked to click the left mouse button if a blue square is presented and the right mouse button if a red circle is presented.
- Once the subject has completed this task, the memory task is presented.

- Memory task: a random assortment of X’s and O’s is displayed for 1.5 seconds.
- For each trial: three of the X’s or O’s are illuminated in YELLOW (the subject has to remember the location of the illuminated objects).
- Immediately after the presentation of the 3 X’s or O’s, the distractor task re-appears on the screen.
- Following the distractor task, the memory screen (X’s and O’s) re-appears and the subject is asked to click on the previously illuminated X’s and O’s.
- Scores are provided for correct identification of the X’s and O’s (memory), reaction time for the distractor task, and number of errors on the distractor task.

- For each administration of ImPACT, the subject completes 4 trials.
Module 4 (Symbol Matching)

- Evaluates **visual processing speed, learning and memory**
- Initially, the subject is presented with a screen that displays 9 common symbols (triangle, square, arrow, etc).
- Directly under each symbol is a number button from 1 to 9.
- Below this grid, a symbol is presented.

- The subject is required to click the matching number as quickly as possible and to remember the symbol/number pairings.
- Correct performance is reinforced through the illumination of a correctly clicked number in GREEN. Incorrect performance illuminates the number button in RED.
- Following the completion of 27 trials, the symbols disappear from the top grid.
- The symbols again appear below the grid and the subject is asked to recall the correct symbol/number pairing by clicking the appropriate number button.

- This module provides an average **reaction time score** and a score for the **memory condition**.
Module 5 (Color Match)

- Represents a choice reaction time task and measures impulse control/response inhibition
- First, the subject is required to respond by clicking a red, blue or green button as they are presented on the screen. This procedure is completed to assure that subsequent trials would not be affected by color blindness
- Next, a word is displayed on the screen in the same colored ink as the word (e.g. RED), or in a different colored ink (GREEN or BLUE)

✓ The subject is instructed to click in the box as quickly as possible only if the word is presented in the matching ink.

- In addition to providing a reaction time score, this task also provides an error score.
Module 6 (Three letters)

- Measures **working memory** and **visual-motor response speed**
- First, the subject is allowed to practice a distractor task
  - Consists of 25 numbered buttons (5 x 5 grid).
  - The subject is instructed to click as quickly as possible on the numbered buttons in backward order starting with “25.” (has an initial practice task)
  - Then they are presented with three consonant letters displayed on the screen.
  - Immediately following display of the 3 letters, the numbered grid re-appears and the subject is instructed to click the numbered buttons in backward order, again
  - After a period of 18 seconds, the numbered grid disappears and the subject is asked to recall the three letters by typing them from the keyboard.
  - Both the number placement on the grid and letters displayed are randomized for each trial.
- Yields a **memory score** (total number of correctly identified letters) and a score for the average number of correctly clicked numbers per trial from the distractor test.
- Five trials of this task are presented for each administration of the test.
Injury Description

- Following the first evaluation of the athlete following a concussion, the professional who is conducting the evaluation is asked to describe the characteristics of the injury and treatment undertaken, if any.

- The mouse is used to identify appropriate descriptors of the injury (e.g. duration of loss of consciousness, retrograde amnesia, on-field symptoms) as well as a description of evaluation and treatment, if any (e.g. CT, MRI, emergency room visit, etc.).

- This section also tracks other potentially important information such as whether or not a dental protection device (mouth guard) was utilized.
**Composite Summary of Results**

In addition to the individual scores for each module described, ImPACT 2.0 also yields summary composite scores for Verbal Memory, Visual Memory, Reaction Time, Processing Speed and Impulse Control.

**Numeric Display of all Composites over Time**

<table>
<thead>
<tr>
<th>Exam Type:</th>
<th>Baseline</th>
<th>Post-concussion</th>
<th>Post-concussion</th>
<th>Post-concussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Tested:</td>
<td>09/04/02</td>
<td>01/28/03</td>
<td>02/03/03</td>
<td>02/06/03</td>
</tr>
<tr>
<td>Last Concussion:</td>
<td>01/27/03</td>
<td>01/27/03</td>
<td>01/27/03</td>
<td>01/27/03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composite Scores</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory composite (Verbal)</td>
<td>96 %</td>
<td>66 %</td>
<td>84 %</td>
<td>90 %</td>
</tr>
<tr>
<td>Memory composite (Visual)*</td>
<td>78 %</td>
<td>65 %</td>
<td>61 %</td>
<td>84 %</td>
</tr>
<tr>
<td>Visual motor speed composite</td>
<td>32.85</td>
<td>16.05</td>
<td>15.25</td>
<td>32.55</td>
</tr>
<tr>
<td>Reaction time composite</td>
<td>0.50</td>
<td>0.63</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>Impulse control composite</td>
<td>7</td>
<td>120</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>
**Verbal Memory Composite**

Is comprised of the average of the following scores:

1) Total percent correct score from Module 1 (Word Discrimination)
2) Total correct hidden symbols from Module 4 (Symbol Matching)
3) Percent of total letters correct from Module 6 (3 Letters)

**Graphic Display of Verbal Memory Composite over time**

![Graphic Display of Verbal Memory Composite](image)
**Reaction Time Composite**

Is comprised of the average of the following scores:
1) Average Correct RT of interference stage of module 3 (X’s & O’s)
2) Average Correct RT /3 of module 4 (Symbol Match)
3) Average Correct RT of module 5 (Color Match)

**Graphic Display of Reaction Time Composite over time**
**Processing/Visual Motor Speed Composite**

Is comprised of the average of following scores:
1) Total number correct /4 during interference of module 3 (X’s & O’s)
2) Average counted correctly x3 from countdown phase of module 6 (3 Letters)

**Graphic Display of Processing/Visual Motor Speed Composite over time**

![Graph showing visual motor speed composite over time]
Total Symptom Composite
Is also displayed graphically. This score represents the total for all 22-symptom descriptors.

Graphic Display of Total Symptom Composite over time
**Visual Memory Composite**

This score represents a new composite score for ImPACT 2.0, which is currently undergoing field-testing. **Clinical decisions should not be based on this composite score until data is available.** This score in its current form is comprised of the average of:

1) Total percent correct score from module 2 (Design Memory)
2) Total correct-memory score from module 3 (X’s & O’s)

**Graphic Display of Visual Memory Composite over time**

![Memory Composite Graph](image-url)
**Impulse Control Composite**

This score indicates the sum of errors committed during different phases of the test and while it clinical decisions should not be based on this composite, its inclusion may help in the interpretation of other composites. This score is obtained by adding:
1) Total errors on the interference phase of module 3 (X’s & O’s)
2) Total commissions from module 5 (Color Match)

**Graphic Display of Impulse Control Composite over time**

![Chart showing Impulse Control Composite scores over time](chart_image.png)
Developed following years of university-based research:

- Valid and Reliable
- Sensitive to Subtle Changes in Brain Function
- Easy to Administer
- Baseline and Post-Injury Testing
- Comprehensive Clinical Report
- Utilized Throughout Professional and Amateur Sports:
  - 24 NFL Teams
  - IRL, CHAMP CAR & Formula One
  - USA Women’s Olympic Hockey
  - USA Women’s Hockey
  - 1000 + High Schools
  - 250 + Sports Medicine Centers
  - Professional Hockey
  - Professional Baseball
  - International Rugby
  - Swedish World Cup Soccer
  - 300 + Universities
  - 150 + Neuropsychology Clinics
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