Evaluation and Treatment of Sports Related Concussions

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- President/co-founder of MindWorks: Comprehensive Neuropsychological Services
Concussion
An Epidemic

Concussion Rates

- Estimated 3.8 million concussions occur each year, in the United States during a sporting event or practice.
- AND...it is estimated that 50% of concussions go unreported.
- Only 5-10% of sports related concussions are evaluated at the Emergency Room.
- Each year, U.S. emergency departments (EDs) treat an estimated 173,285 sports and recreation TBI's, including concussions, among children and adolescents, from birth to 19 years.
- During the last decade, ED visits for sports- and recreation-related TBIs, including concussions, among children and adolescents increased by 60%.
- Overall, the activities associated with the greatest number of TBI-related ED visits included bicycling, football, playground activities, basketball, and soccer.
Getting the Terminology
A quick study of vocabulary
Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:

- Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an ‘impulsive’ force transmitted to the head.

- Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, symptoms and signs may evolve over a number of minutes to hours.
Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard neuroimaging studies.

Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that in some cases symptoms may be prolonged.

**Concussion vs mTBI**

**Concussion**
- Most often used in the athletic realm
- No single definition used across the board
- As time has progressed, now used by medical professionals as a subset of mTBI

**mTBI**
- Term most likely used in the scientific literature
- Can describe other types of mild head trauma, such as those sustained in car accidents
Concussion, continued:

**Simple**
Post-traumatic symptoms resolve within 10 days

**Complex**
Posttraumatic symptoms continue after 10 days, and possibly include:
- Exertional Headache
- Cognitive Impairment
- Seizures
Ommaya and Gennarelli Classification for Grading Severity of Concussion

<table>
<thead>
<tr>
<th>Severity Grade</th>
<th>Alteration in Mental Status</th>
<th>Characteristics</th>
<th>Hypothesized Pathophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Confusion</td>
<td>Normal consciousness without amnesia</td>
<td>Cortical-subcortical disconnection (SCD)</td>
</tr>
<tr>
<td>II</td>
<td>Confusion and amnesia</td>
<td>NC and PTA</td>
<td>SCD, possible diencephalic disconnection</td>
</tr>
<tr>
<td>III</td>
<td>Confusion and amnesia</td>
<td>NC, confusion, PTA and RGA</td>
<td>SCD and diencephalic disconnection (SCDD)</td>
</tr>
<tr>
<td>IV</td>
<td>Coma (paralytic)</td>
<td>Confusion with PTA and RGA</td>
<td>CSDD and mesencephalic disconnection (CSMD)</td>
</tr>
<tr>
<td>V</td>
<td>Coma</td>
<td>Persistent Vegetative State</td>
<td>CSMD</td>
</tr>
<tr>
<td>VI</td>
<td>Death</td>
<td>Fatal Injury</td>
<td>CSMD</td>
</tr>
</tbody>
</table>

Post concussive Syndrome (PCS)

- PCS is defined as a set of symptoms following mTBI.
- A complex of symptoms may include headache, dizziness, irritability, decreased memory functions and attention difficulties
- PCS-acute (1-7 days). PCS-subacute (8-90 days).
- Persistent Post-Concussive Syndrome is often used when symptoms persist more than 90 days, as people are likely to recover from a single, uncomplicated mTBI within that time.
Second Impact Syndrome

- aka: Delayed Cerebral Edema
- SIS involves an athlete suffering post-concussive symptoms following a head injury sustains a second head trauma, prior to having complete recovery from the first.
- The subsequent trauma is then associated with diffuse cerebral swelling, brain herniation, and, possibly, death can occur.
- Documented case studies indicate a course of rapid deterioration after the second injury, most typically when they are still symptomatic of the first.
- In many instances, the athlete collapses and enters a coma and respiratory failure due to the increased intracranial pressure from severe vascular congestion and brainstem herniation
- The end result is permanent disability or death

Chronic neurocognitive impairment

◆ May present as PCS OR years later following a period of no symptoms
◆ Symptoms and Behaviors are assessed through Neuropsychological Testing
◆ Some evidence supports an relationship between risk of NCI and multiple concussions or repeated blows to the head
Chronic Traumatic Encephalopathy

- Associated with repetitive brain trauma
- Neurodegenerative
- Increased tau protein
- Diagnosed post-mortem with histopathological findings

- Associated with executive and memory dysfunction and poor impulse control
- Develops decades after exposure (not due to post-concussive syndrome)
- The diagnosis can be made without diagnosis of frank concussion
Stages of CTE

- Recently released: CTE was found in 87 of 91 NFL (96%) players who had donated their brains to the study prior to their deaths.
- Additionally, CTE has been identified in the brain tissue of a total of 131 out of 165 individuals who played football either professionally, semi-professionally, in college or in high school before their deaths.
- Forty percent of those who tested positive were offensive and defensive linemen, players who come into contact with one another on every play of a game.

Boston University with VA ongoing research
Neurophysiological Changes

Biomechanics in Concussion

Sport Science: NFL Concussions and helmet to helmet collisions

Helmet to Helmet video.html
Primary Effects of Concussion

- Rotational/Sheering
- Diffuse Axonal Injury

Secondary Changes to Head Trauma

- Hemorrhages
- Raised ICP/Hydrocephalus
- Wallerian Degeneration
- Edema
- Brain Shift/Herniation
- Biochemical/Neurochemical changes
Neuromembrane events in TBI

Memory and behavior changes

Neuroinflammation and Cytoskeletal derangement

Axonal transport causes

Glutamate uptake

Brain edema, high ICP

GLU, ACh Neurotransmitter release

Open ion channels

K+ Neuronal activity

Diffuse axonal injury

Second messenger deranged

Ca2+ GABA channel

Calcium

Distorted ion channels

Ca2+ entry

Mitochondrial swelling and impaired function

Direct activating effect on mitochondria

Free radicals

Cytoskeletal reorganization

Cytoskeleton

Cytochrome c impaired

Cytochrome c Leakage

Cardiac arrest

Openning of BBB

Secondary Brain injury: Edema, Brain dysfunction

Secondary Brain injury: Edema, Brain dysfunction

Assessment of intraabdominal indices of injury

Neuroinflammation

Glucose, Lactate

Reduced O2 delivery

Increased intracranial fluid and tissue pressure

Vascular failure

K+ Glial swelling

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<table>
<thead>
<tr>
<th>Brain areas vulnerable to TBI</th>
<th>Relevant structures/systems</th>
<th>Neuropsychiatric function(s) supported</th>
<th>Effects neurotrauma-induced injury or dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper brain stem and brain stem-diencephalic junction</td>
<td>Reticulothalamic system, including pedunculopontine and laterodorsal tegmental nuclei (CH5 and CH6); their efferent projections and their thalamic, subcortical, and cortical targets; thalamic and reticular thalamic nuclei as well as their glutamatergic and GABAergic projections</td>
<td>Arousal (wakefulness)</td>
<td>Impaired or absent arousal, including coma</td>
</tr>
<tr>
<td>Ventral forebrain</td>
<td>Reticulocortical system, including ventral tegmental area (DA), locus ceruleus (NE), median and dorsal raphe nuclei (5HT), ventral forebrain cholinergic nuclei (Ch1-4) (ACH)</td>
<td>Arousal, cortical orientation to novel sensory events, elementary selective attention</td>
<td>Diminished arousal, reduced clarity of awareness of the environment, ineffective neural engagement in information processing</td>
</tr>
<tr>
<td></td>
<td>Septal nucleus [Ch1], diagonal band of Broca [vertical limb [Ch2] and horizontal limb [Ch3]], nucleus basalis of Meynert [Ch4], and their efferent pathways to cortical and subcortical targets</td>
<td>Attention, memory, executive function [Ch1, Ch2, Ch4]</td>
<td>Impaired sensory gating, attention, declarative memory, and executive function</td>
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<tr>
<td></td>
<td></td>
<td>Offaction [Ch3]</td>
<td>Hyposmia or anosmia</td>
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</thead>
<tbody>
<tr>
<td>Hypothalamus</td>
<td>Anterior tuberal, and posterior (including mammillary) nuclei</td>
<td>Autonomic, neuroendocrine, circadian, memory, social, and appetitive functions</td>
<td>Autonomic dysfunction, impaired thermoregulation, altered feeding behaviors, endocrine abnormalities (including specific endocrine disturbances or parhypopituitarism), altered sleep-wake and other circadian cycles, pathological laughter or anger</td>
</tr>
<tr>
<td>Cerebral white matter</td>
<td>Upper brain stem (ie, pontine, midbrain, and mesencephalic white matter), parasagittal white matter, corpus callosum, and superficial (cortical) gray-white matter junctions</td>
<td>Connects cerebral, cerebellar, and brain stem structures involved in all manner of information processing; myelination facilitates speed of information transfer</td>
<td>Slowed and inefficient information processing; lesions to discrete pathways or tracts impair information processing in the networks to which they contribute</td>
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<tr>
<td></td>
<td>Uncinate fasciculus (white matter linking anterior temporal lobe with inferior frontal gyrus and ventral frontal lobe)</td>
<td>Dominant hemisphere: auditory-verb memory proficiency</td>
<td>Impaired verbal memory</td>
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<tr>
<td></td>
<td></td>
<td>Nondominant hemisphere: automatic consciousness (experiencing self as continuous over time)</td>
<td>Impaired self-awareness, particularly as regards experience of continuous self over time</td>
</tr>
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</table>
### Recommended neuroimaging studies in the current clinical management of concussion/mild traumatic brain injury

**ACUTE MILD TBI:**
- Noncontrast CT most appropriate initial exam
- MRI may be appropriate for problem solving (e.g., to characterize axonal injury or hypoxic or ischemic injury)

**SUBACUTE OR CHRONIC MILD TBI WITH PERSISTENT SYMPTOMS/DEFICITS:**
- MRI preferable to CT for detection and characterization of non-surgical lesions in the subacute or chronic stage
- MRI may also have a role in prognosis

**ADVANCED NEUROI MAGING:**
- DTI, fMRI, PET, SPECT, perfusion CT/MRI, MR spectroscopy may have utility in better understanding selected patients, but are not yet considered routine in clinical management of TBI

### Indications for noncontrast head CT in nonpenetrating head trauma for patients 16 years of age presenting to Emergency Department within 24 hours of injury with admission GCS of 14 or 15, without multisystem trauma (ACEP/CDC joint practice guidelines)

<table>
<thead>
<tr>
<th>Loss of consciousness or posttraumatic amnesia?</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

### Noncontrast head CT is indicated for:
- Headache
- Vomiting
- >60 years of age
- Drug or alcohol intoxication
- Deficits in short-term memory
- Physical evidence of trauma above clavicle
- Posttraumatic seizure
- GCS<15
- Focal neurologic deficit
- Coagulopathy

### Noncontrast head CT should be considered for:
- Focal neurologic deficit
- Vomiting
- Severe headache
- >65 years of age
- Physical signs of basilar skull fracture
- GCS<15
- Coagulopathy
- Dangerous mechanism of injury (ejection from motor vehicle, pedestrian struck by motor vehicle, fall from >3 feet or >5 stories)
Computed Tomography

- Most major practice guidelines indicate that head CT should be performed for LOC .30 seconds to 1 minute, prolonged altered or deteriorating level of consciousness, severe headache, focal neurologic deficit or seizure, or worsening symptoms.

- CT is the initial imaging study of choice in acute mTBI for many reasons, including availability, speed, excellent depiction of bony fractures, and high sensitivity for acute intracranial hemorrhage.

- Estimated 5% to 30% of mTBI patients have intracranial hemorrhage on initial head CT.

Structural Magnetic Resonance Imaging

- MRI has superior sensitivity to CT for identification of hemorrhagic axonal injury, small contusions, and small extra-axial collections.

- Despite its higher sensitivity, brain MRI is not currently recommended in most guidelines for the routine management of acute concussion/mTBI.

- MRI does have a role in the clinical management of subacute or chronic mTBI with persistent symptoms or deficits, and studies have shown it has prognostic value in this setting.
Functional MRI

- fMRI is based on the blood oxygen level-dependent (BOLD) effect, in which increased regional neuronal activity draws oxygen-rich blood whose presence can be detected with specialized MRI sequences.

- fMRI consists of 2 main types: task-based fMRI and resting state fMRI (rs-fMRI).
  - Several task-based fMRI studies of mTBI have demonstrated increased activation without significantly worse performance, suggesting that some mTBI patients “work harder” to perform a simple task at a satisfactory level.

- rs-fMRI, the study of spontaneous fluctuations in the BOLD signal, in resting patients, reveals the intrinsic functional connectivity of different brain regions. The few rs-fMRI studies of strictly mTBI to date have shown variable results (both reduced and increased connectivity within several networks). This may be due to small sample sizes and evaluation at variable times points after injury.
Acute and Sub-acute changes in Neural Activation during the recovery from Sport related concussion.

- **Objective:** To investigate the natural recovery from sports concussion.
- **Subjects:** 12 concussed athletes and 12 age-matched controls
- **Measures:** Balance testing, symptom check lists, and neuropsychological testing and event-related fMRI at 13 hours and 7 weeks post injury.
Outcomes:

- Injured athletes showed PCS and cognitive decline with decreased reaction time and increased reaction time variability on a working memory test acutely, but resolved by 7 weeks.
- fMRI data revealed decreased activation in the right hemisphere in injured athletes, compared to controls in the acute phase, but a reversal 7 weeks later.
- These findings suggest decreased right hemisphere activation coincides with decreased attentional networks.

Diffusion Tensor Imaging

- Diffusion tensor imaging (DTI) can be used to quantify white matter integrity throughout the brain.
- Each of the 4 major DTI analysis methods, histogram analysis, voxelwise analysis, region-of-interest analysis, and tractography, has strengths and weaknesses.
- Many studies to date have demonstrated group differences in DTI parameters between mTBI patients and controls. The current challenge is to demonstrate the use of DTI parameters as prognostic biomarkers in the individual mTBI patient, but no strong consensus yet exists on the best approach for this.

- Questions: What are long term consequences in older individuals with a history of concussion?
- Ss: 15, clinically normal, formally football and hockey players. Average of 2 concussion in youth. Control group was similar age/ed level and no concussion.
- Each subject was administered an exhaustive neuropsychological battery and MRI and DTI. Authors utilized tract-based spatial statistics (novel technique)
Results

- NPE demonstrated cognitive dysfunction in memory, executive functioning
- MRI revealed typical alterations associated with aging, but not between groups
- Structural imaging revealed that older concussed athletes demonstrated significantly enlarged lateral ventricles when compared to the non-concussed group. (and correlated with memory issues).
- No differences between gray matter
- In the case of white matter tracts, using DTI revealed damage including interhemispheric fibers, anterior limb of the internal capsule, the corona radiate involving the corticospinal tracts, and the superior and inferior longitudinal fasciculi.
- These findings, where specifically correlated with NPE for recall, executive functions memory and sequential motor learning
Figure 2. Representative fiber tractography results from a control subject (left) and a patient with traumatic brain injury (TBI) (right). The corpus callosum (top) is divided into areas 1 through 4 as shown by the corresponding colors: yellow, orange, green, or blue. The fornix body and inferior crus are yellow (middle). The posterior projections (bottom) are divided into posterior projections to the ventral frontal cortex (yellow), posterior projections to the dorsal frontal cortex (orange), posterior projections to the parietal cortex (green), and posterior projections to the occipital cortex (blue). The patient did not have cortical contusions on computed tomography, but some shear hemorrhages were noted.
Proton Magnetic Resonance Spectroscopy (1H MRS)

- A method of probing the molecular content within regions of the brain.
- Protons resonate with different frequencies, based on their chemical environment.
- A relative content will be recognized for different metabolites within the characteristic spectra for a particular molecule.
- Several 1H MR spectroscopy studies of the brain in TBI, ranging from mild to severe TBI, have demonstrated reduced N-acetylaspartate (NAA), a marker of neuronal integrity, in the splenium.
- Another study revealed reduced choline-to-creatine ratios in the thalamus and centrum semiovale in the subacute stage of head injury.
- A small number of studies have suggested a correlation between these metabolic changes and outcome.

Metabolic alterations in corpus callosum may compromise brain functional connectivity in mTBI patients: An 1H-MRS study

- 15 student athletes with age-matched controls
- No prior history of mTBI/concussion
- Hypotheses: Given that reduced interhemispheric functional connectivity may result from compromised integrity of the corpus callosum; the aim of this study was to evaluate the metabolic profile of the corpus callosum with magnetic resonance spectroscopy (1H-MRS) in the subacute phase of mTBI.
- Differences for metabolites were determined at the genu and splenium, even after PCS symptoms were resolved.
- Conclusions: Metabolite changes in the corpus callosum correlation between structural and functional connectivity.
Positron emission tomography (PET) provides information on the distribution and concentration of biological molecules into which specific radionucleotides are introduced.

- PET has high spatial resolution and greater functionality than SPECT but is dependent upon ready supply of radionucleotides that have short half-lives.

- *PET studies in (mostly severe) TBI patients to date have most often reported abnormalities in the frontal and temporal lobes that correlate with outcome.*

- At this time, no PET technique is considered diagnostic for concussion.
Single-Photon Emission Computed Tomography (SPECT)

- Reduced blood flow can be seen in and around acute/subacute brain contusions.
- A more surprising and subtle effect that has been reported is reduced blood flow and blood volume, mostly frontal and temporal lobes in some mTBI patients with no visible intracranial injury on conventional neuroimaging studies. Some studies have shown a relationship of these findings with outcome.
- SPECT is not currently widely accepted for routine clinical use, but may be valid as supporting information to supplement structural brain imaging, clinical history and neuropsychiatric testing for some patients.

The Impact of Playing American Football on Long Term Brain Functioning (Amen et al 2011)

- 100 active and retired players (27 teams; numerous positions)
- Each subject was an active player for at least three years
- Athletes taking a prescribed psychopharmological agent were excluded
- Each subject was administered three computerized NP tests:
  - Microcog
  - Conner’s CPT
  - Mild Cognitive Impairment Screen
- Each subject underwent an SPECT and QEEG
TABLE 1. Demographic Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>57.27 (range 25–82) [SD=12.37]</td>
</tr>
<tr>
<td>LOC Episodes</td>
<td>3.693</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
<th>84 right, 16 left or ambidextrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity</td>
<td></td>
<td>African American 33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caucasian 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hispanic 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed 6</td>
</tr>
<tr>
<td>Positions (N=100)</td>
<td></td>
<td>Quarterback 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Running back 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wide receivers 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tight ends 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Offensive lineman 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defensive lineman 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linebackers 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defensive backs 19</td>
</tr>
<tr>
<td>Reported Episodes of LOC</td>
<td>n</td>
<td>0 37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 15</td>
</tr>
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<td>2 15</td>
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<tr>
<td></td>
<td></td>
<td>35 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 14</td>
</tr>
<tr>
<td>Minimum/Maximum Episodes of Loss of Consciousness</td>
<td>0/20</td>
<td></td>
</tr>
</tbody>
</table>

Diagnosed Depression (DSM-IV Criteria) Currently or Under Treatment for Depression 28

Waist-to-height ratio

<53%; overweight or obese 48
<53%; normal weight 52

LOC: loss of consciousness. For number of concussions, four players report “multiple times” or “too many to count” but could not be more specific.

TABLE 2. Neuropsychological Assessment Results of 97 Retired Players*

<table>
<thead>
<tr>
<th>Conners’s Continuous Performance Test II (CCPT II)</th>
<th>81</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% greater chance of having ADHD based on CCPT II</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mild Cognitive Impairment Screen by Age-Group</th>
<th>Abnormal/Total N</th>
</tr>
</thead>
<tbody>
<tr>
<td>75-82</td>
<td>4/7</td>
</tr>
<tr>
<td>65-74</td>
<td>5/22</td>
</tr>
<tr>
<td>50-65</td>
<td>5/52</td>
</tr>
<tr>
<td>25-49</td>
<td>1/22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MicroCog Percentile Scores</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>General cognitive functioning</td>
<td>33.3</td>
<td>25.5</td>
</tr>
<tr>
<td>General cognitive proficiency</td>
<td>27.6</td>
<td>23.2</td>
</tr>
<tr>
<td>Processing speed</td>
<td>33.3</td>
<td>26.0</td>
</tr>
<tr>
<td>Processing accuracy</td>
<td>41.2</td>
<td>26.8</td>
</tr>
<tr>
<td>Attention</td>
<td>40.8</td>
<td>26.3</td>
</tr>
<tr>
<td>Reasoning</td>
<td>34.4</td>
<td>27.5</td>
</tr>
<tr>
<td>Memory</td>
<td>36.5</td>
<td>28.7</td>
</tr>
<tr>
<td>Spatial processing</td>
<td>68.0</td>
<td>21.9</td>
</tr>
<tr>
<td>Reaction time</td>
<td>70.2</td>
<td>24.5</td>
</tr>
</tbody>
</table>

*Because of physical ailments or advanced dementia, three players were unable to complete the tests. ADHD: attention-deficit hyperactivity disorder.
Summary of Results

- SPECT: Significant decreases in rCBF throughout brain, especially prefrontal poles, temporal poles, occipital lobes, anterior cingulate gyrus and cerebellum.

- Significant decreases in posterior cingulate gyrus and hippocampus (possibly precursors to dementia)

- MCI= was recognized at a higher rate across all age groups

- 80% had “higher incidence of “ADHD”

- 28% (v. 9.5%) had higher incidence of depression

- QEEG revealed frontal and temporal deviations
Seizures in TBI
Population Based Study of Seizures after TBI

Annegers, J. et al

![Graph showing probability of seizures over time after brain injury]

<table>
<thead>
<tr>
<th>Year after Brain Injury</th>
<th>Mild injury</th>
<th>Moderate injury</th>
<th>Severe injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>15</td>
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<td>25</td>
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<td>20</td>
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<tr>
<td></td>
<td>30</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of Patients</th>
<th>Mild injury</th>
<th>Moderate injury</th>
<th>Severe injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2758</td>
<td>1751</td>
<td>1191</td>
</tr>
<tr>
<td></td>
<td>1455</td>
<td>934</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>933</td>
<td>141</td>
<td>132</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incidence Ratio</th>
<th>Mild injury</th>
<th>Moderate injury</th>
<th>Severe injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.1 (1.0–7.2)</td>
<td>2.1 (1.1–3.8)</td>
<td>3.1 (1.4–6.0)</td>
</tr>
<tr>
<td></td>
<td>0.9 (0.3–2.6)</td>
<td>1.1 (0.5–2.1)</td>
<td>1.1 (0.8–3.6)</td>
</tr>
</tbody>
</table>

Table 2. Standardized Incidence Ratios for Seizures according to the Severity of Traumatic Brain Injury and the Interval after the Injury.

<table>
<thead>
<tr>
<th>Interval after Injury (yr)</th>
<th>No. of Patients*</th>
<th>No. of Cases</th>
<th>Standardized Incidence Ratio (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild injury</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td>2758</td>
<td>5</td>
<td>1.6 (1.0–7.2)</td>
</tr>
<tr>
<td>1–4</td>
<td>2483</td>
<td>11</td>
<td>5.2 (1.1–3.8)</td>
</tr>
<tr>
<td>5–9</td>
<td>1751</td>
<td>4</td>
<td>4.3 (0.3–2.6)</td>
</tr>
<tr>
<td>10–14</td>
<td>1191</td>
<td>8</td>
<td>7.4 (0.5–2.1)</td>
</tr>
<tr>
<td>Moderate injury</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td>1455</td>
<td>6</td>
<td>0.9 (2.4–14.1)</td>
</tr>
<tr>
<td>1–4</td>
<td>1307</td>
<td>9</td>
<td>2.9 (1.4–6.0)</td>
</tr>
<tr>
<td>5–9</td>
<td>934</td>
<td>7</td>
<td>2.3 (1.2–6.2)</td>
</tr>
<tr>
<td>10–14</td>
<td>660</td>
<td>8</td>
<td>4.4 (0.8–3.6)</td>
</tr>
<tr>
<td>Severe injury</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
<td>328</td>
<td>19</td>
<td>0.2 (58.4–151.2)</td>
</tr>
<tr>
<td>1–4</td>
<td>275</td>
<td>10</td>
<td>0.6 (8.4–32.0)</td>
</tr>
<tr>
<td>5–9</td>
<td>181</td>
<td>6</td>
<td>0.5 (4.5–26.6)</td>
</tr>
<tr>
<td>10–14</td>
<td>136</td>
<td>4</td>
<td>1.0 (1.1–10.2)</td>
</tr>
</tbody>
</table>
EEG and Quantitative EEG Assessment

QEEG Findings in concussion

**Previous research supports:**
- Reduced mean frequency in alpha
- Increased theta activity
- Reduced power in alpha and beta
- Increased frontal coherence
- Slowing in frontal and temporal regions

- Increased vulnerability in fronto-temporal regions
- Abnormality may last in excess of one year with persistent symptoms
- Decreased frontal to temporal coherence

- EEG may be more sensitive than a neurological exam in detecting head trauma.
- Post-concussion, 86% of patients will have an abnormal EEG.
- Only 23% of those will have an abnormal neurological examination.
- On occasion, resolution of EEG abnormalities may occur within 15 minutes.
- PTA and unconsciousness predict longer EEG abnormalities.

EEG Changes following mTBI (hours to weeks)

- Animal studies suggest that immediately following the event, epileptiform activity (high amplitude sharp waves/high frequency discharges).
- This is followed by diffuse suppression of cortical activity, usually lasting 1-2 minutes.
- Followed by diffuse slowing of the EEG which returns to base line within 10 minutes to 1 hours.
- Half of a sample of 31 patients with mTBI did not demonstrate EEG changes within 24 hours.
- Within hours, there is attenuation of posterior alpha along with generalized/focal slowing, particularly noted over the temporal regions.
EEG Changes following mTBI, weeks to months

- Majority of EEG abnormalities resolve by 3 months and 90% by one year
- Within the first weeks, there is often a 1-2 Hz increase in posterior alpha activity
- Some suggestion that on going PCS, for more than a year, increase likelihood of epileptiform activity.

QEEG changes following mTBI, hours to weeks

- Immediate reduction of mean alpha frequency, along with increased theta or increased theta: alpha ratio
- Increased delta over the posterior regions
- Within 3-10 days, increased power of slow alpha and reduction of fast alpha
- Belfast Studies: 24 hours and 6 weeks: 1) diffuse slowing; 2) PTA was correlated with brainstem auditory evoked potential; 3) cortical changes were transient, while BAEP were found to more long term (>6 months)
Changes in QEEG, weeks to months

- Continued reduced alpha and increased delta activity
- Follow-up in Belfast studies: continued to note slowing in the left temporal region, which was correlated to PCS symptoms

Acute Effects and Recovery after sports-related concussion: A Neurocognitive and Quantitative Brain Electrical Activity Study

Objective: Exam the utility and sensitivity of a portable, automatic, frontal QEEG acquisition
- Design: 396, non-randomized high school and college football players, including 28 athletes with concussions and 28 age-matched controls.
- All subjects underwent preseason baseline cognitive, balance and post-concussive symptoms rating scales.

Outcomes:
- Injured group experienced more symptoms at day 3, resolving by day 8
- Injured group did poor on cognitive measures on day of injury, but not at day 8/45
- QEEG showed greater abnormality on day 3, 8, but not on 45.

Conclusions:
- Results of physiological disturbance, likely to be longer than cognitive or symptoms reporting after concussion
Neuropsychological Changes
How many fingers?

Concussion Symptoms and Signs

Physical & Postural
- Headache
- Nausea/vomiting
- Sensitivity to light/noise
- Visual problems
- Fatigue
- Dazed, stunned
- Dizzy, balance problems

Cognitive
- Feeling mentally "foggy"
- Feeling slowed down
- Answers questions slowly
- Difficulty concentrating
- Forgetful of recent events
- Repeats questions
- Drop academic performance

Emotional
- Irritability
- Sadness/Depression
- Personality change
- Anxiety/panic
- More emotional
- Less emotion (apathy)

Sleep
- Drowsy
- Sleeping more
- Sleeping less
- Difficulty falling or staying asleep
Concussive Symptoms associated with neuroanatomical locations

- Frontal Lobe
  - Cognition
- Temporal Lobe
  - Memory
- Parietal Lobe
  - Complex Functions

Concussion

Subcortical Systems

- Hypothalamus
  - Thermoregulation
  - BP Control
  - Sleep Patterns
  - Sexual Function
- Trigeminal System
  - Headache
  - Facial Pain
- Basal Ganglia
  - Sensory-Motor
- Cerebellum
  - Balance/Posture

Neuropsychological Assessment

- Reasoning
- Attention
- Concentration
- Memory
- Executive Functions
- Language
- Visuo-spatial
- Sensory-Perceptual
- Psycho-motor
- Academic Skills
- Mood/personality
Options of Assessment

- Full-NP Battery
- 5-7 hours
- More costly; requires a neuropsychologist
- More sensitive and specific for cognitive, functional and psychological deficits
- Computerized Assessment
- ImPact
- CNS-VS
- 20-30 minutes
- Symptom checklist
- Repeatable

Reliability and Validity of conventional, Computerized and CNS VS

Table 5
Test-retest reliability of conventional tests, computerized tests, and CNS Vital Signs

<table>
<thead>
<tr>
<th>Tests/domains</th>
<th>Conventional</th>
<th>Computerized</th>
<th>CNSVS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>r</td>
<td>N</td>
</tr>
<tr>
<td>Memory</td>
<td>713</td>
<td>0.67-0.71</td>
<td>1801</td>
</tr>
<tr>
<td>Psychomotor speed</td>
<td>1159</td>
<td>0.78-0.65</td>
<td>2228</td>
</tr>
<tr>
<td>Finger tapping</td>
<td>596</td>
<td>0.75-0.83</td>
<td>310</td>
</tr>
<tr>
<td>Coding</td>
<td>563</td>
<td>0.87-0.88</td>
<td>629</td>
</tr>
<tr>
<td>Stroop Test</td>
<td>224</td>
<td>0.64</td>
<td>471</td>
</tr>
<tr>
<td>Cognitive flexibility</td>
<td>139</td>
<td>0.68-0.74</td>
<td>746</td>
</tr>
<tr>
<td>Attention</td>
<td>554</td>
<td>0.70-0.73</td>
<td>1578</td>
</tr>
<tr>
<td>Reaction time</td>
<td>78</td>
<td>0.82</td>
<td>621</td>
</tr>
</tbody>
</table>
Concussion in Women and youth
Special Considerations

PREDICTORS OF INCREASED MORBIDITY

Age
Previous Concussion(s)
Migraines
ADHD/LD
Mood disorder
Sex

Concussion in Women and youth
Special Considerations
Differences in Concussion for Women

- Previous research suggested that women may experience greater symptoms and cognitive consequences after concussion.

- AAN presented a paper at the Sports Concussion Conference (7/2015):
  - 148 college athletes, 11 sports
  - 45% female; 51% contact sport; 24% experienced a concussion; averaged .3 concussion (1-4 events)
  - Men and women were equally likely to have a concussion

- All women, regardless of concussion, experienced greater symptoms and scored lower on baseline cognitive testing (this translated to 1.5 more symptoms; 3 points higher on symptom severity, 19 milliseconds slower on a reaction time test, and on tasks of processing speed, attention and working memory ave. 7% slower).

Sex-Based Differences as a Predictor of Recovery Trajectories Using ImPACT

- Thomas G. Burns, Psy.D., ABPP & Kim E. Ono, Ph.D.

- The purpose of the study was to assess whether female athletes displayed more symptoms at baseline and prolonged recovery following a SRC, compared to male athletes.

- 135 male and 41 female athletes (10–18 years in age) who participated in high impact sports

- All athletes completed baseline assessment and at least one post-concussion assessment from the Immediate Post-Concussive Assessment and Cognitive Testing (ImPACT) battery.

- Longitudinal hierarchical linear modeling was employed to examine individual-level variables and their associations with adolescents’ rates of recovery in concussive symptoms, after controlling for age and number of prior concussions.
**Sex differences, cont...**

- Aggregate symptoms were rated as higher in female athletes compared to male athletes at base-line and immediately following a concussion (p<.01).
- There were no group differences in slope of recovery between male and female athletes, indicating generally similar trajectories of change for both groups.
- Post-hoc analyses revealed higher levels of migraine and neuropsychological symptoms in females at baseline.
- The latter finding is consistent with results from previous research, which has demonstrated elevated symptom severity and poorer cognitive performance at baseline in female athletes when compared to male athletes.

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**Institute of Medicine and National Research Council; Committee on Sports-Related Concussions in Youth (Oct. 2012)**

- Commissioned to review the science of sports-related concussions in youth from elementary school through young adulthood.
- Charged with reviewing the literature within the context of neurobiology, concussions, relationships to impacts to head or body during sport, effectiveness of protective devices, screenings and diagnosis, treatment and management, and long-term consequences and then to make recommendations for future funding/research/practice, etc.
- Funded by Centers for Disease Control with the NFL Department of Defense, Department of Education, National Athletic Trainers’ Association Research and Education Foundation, the Health Resources and Resources Service Administration, National Institutes of Health.
- In their conclusion, the Committee recognized that the culture surrounding youth concussions does not appreciate the serious threat to the health of the athlete, both short term and long term.
Epidemiology

- High School Reporting Information Online High School ROI, NCAA Injury Surveillance System (NCAA ISS), National Electronic Injury Surveillance System – All Injury Program (NEISS AIP) are the reporting system for youth
  - Relatively new
  - Each have inherent problems
- In 2009, approximately 30-45 million children participate in recreational sports programs
- Among youth, under 19, TBI's (sports/recreational) increased from 150,000 to 250,000 between 2001 and 2009
- ER visits for brain injury increased 57% during the same time
- 70.5% of sports- and recreation-related TBI emergency department visits were among persons aged 10-19 years.
- 71.0% of all sports- and recreation-related TBI emergency department visits were among males.

Factors Associated with Increased Incidence Rates of Reported Concussions (as of 2012)

- College athletes had a higher overall rate of concussion than HS (4.3 vs 2.3 per 10,000 AEs)
- Youth football (1 of 2 year study) was consistent with HS football rates (11.3 per 10,000 AEs)
  - A smaller study rates were 17.6/10,000 AE during 2011 season AND 11-12yo players were 2.5x more likely to sustain a concussion than 8-10yo (25.3 vs 9.3 per 1000AEs)
  - Multiple studies have shown that HS athletes often return to baseline within 30 days, whereas college athletes normalized to baseline in 7-14 days
- Most studies consistently show concussions are more likely occur in competition vs practice, save for Cheerleading and Volleyball
- Studies comparing incident rates of male vs. female in same sport, found a higher incident rates for female athletes (as high as 60% greater: soccer, basketball, base/soft ball, lacrosse)
Concussion Rates in youth Football

- 1 in 20 high school players (6.3%) will be concussed during a season—and this is thought much less than actual incidence, given reporting practices.

- After season questionnaires have the incidence closer to 25%.

- This is still likely to be low, as it has been estimated that only 1 of 3 athletes may acknowledge or recognize concussive symptoms.
Other Noteworthy Trends Regarding Youth Concussions:

- It is well accepted that children who suffer a concussion take a longer time recovering than adults.
- Animal models suggest that the developing brain may be more sensitive to the pathological release of excitatory amino acid neurotransmitters (glutamate and aspartate) than adult brains.
- The length of time for recovery is for high school athletes are estimated to be as long as four times as long as an adult professional athlete (3-5 days to 10-14 days). Younger athletes perhaps take longer.
- High school football players, 10% of concussed players still take longer than three weeks, as high as 6% taking as long as 6 months.
- 10-20% of concussed high school athletes complain of symptoms longer than one month.


- Purpose: A comprehensive review of the literature examining the incidence, mechanisms, biomarkers of injury and neurocognitive outcomes of concussions and heading in soccer
- Methods: 7 databases; 1806-2013; 229 articles selected for review; 49 were included
- Results: Female soccer players have a higher incidence of concussion than males
- The most frequent injury is from player to player contact for both genders; 58% due to a heading dual; 60% of all injuries were while heading the ball; 2nd most frequent were due to player-to-structure contact
- Defensive players and goalkeepers were at greatest risk
- 4 studies revealed cognitive deficits; including memory, reaction time and visual-processing speed
- Gender (women) and previous concussions were associated with greater impairment and post concussive symptoms
Soccer, cont...

- Cognitive performance during a season or after a game did not demonstrate differences from baseline performance.

- Over time, long term effects of heading were associated with poor memory, executive functions, and perceptual deficits in player positions known to head the ball more frequently. (Collegiate and professional players)

- Specific biomarkers were shown to be frequently found after heading exercises.

- MRI changes of professional players revealed decreased grey matter density over anterior temporal region; CT changes of professional players revealed enlargement of verticals and cerebral atrophy; recent DTI of professional players revealed myelin pathology and decreased white matter integrity.

- EEG of former National team players in Norway, revealed 12 of 37 players had abnormal EEG findings.

5 women Soccer players z-scored, absolute power analysis.
Neurofeedback and the Treatment of Concussion

EEG Neurofeedback Therapy: Can it attenuate brain changes in TBI? (munivenkatappa, et al., 2014)

- Case study of 2 patients; moderate head injury
  - LOC: 1 hour; 1 week
  - CT displayed diffuse axonal injury, blood in ears
  - Moderately disabled according to Glasgow outcome score
  - PCS
  - <5th percentile on motor speed, mental speed, category fluency, visuospatial working memory, set shift, visual and verbal memory
  - NFB and MRI completed one week before and one week after treatment

- 20 sessions of EEG NFB; 40 min/day; 3 days/week; protocol dependent on slow activity
EEG Neurofeedback Therapy: Can it attenuate brain changes in TBI?, cont..

- Outcomes: Improvement in symptom reporting, NPE and MRI
  - Improvement in motor speed, metal speed, category fluency, working memory, mental shifting, encoding and memory.
  - Concussion symptoms
  - Significant decreased in theta, but not alpha excesses
  - Increased in cortical volume
  - Structural WM changes thalamocerebral connections, in WM tracts and cortical structures,
  - Improvement in functional connectivity-global and local efficiency

Neurofeedback and TBI

A review of the literature
Geoffrey May, MD Randall Benson, MD Richard Balon, MD Nash Boutros, MD. 2013
Authors used Google Scholar, as it provided more citations than other search engines, such as Pub Med.

999 articles were identified, but after review only 22 were deemed worthy to be a part of the study.

Of those, 8 were cohort designs, while the remaining

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**TABLE 1: Classification rubric for levels of evidence**

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anecdotal evidence</td>
</tr>
<tr>
<td>2</td>
<td>Uncontrolled case study</td>
</tr>
<tr>
<td>3</td>
<td>Historical control</td>
</tr>
<tr>
<td>4</td>
<td>Observational studies without randomization</td>
</tr>
<tr>
<td>5</td>
<td>Randomized wait-list or “intention to treat” controls</td>
</tr>
<tr>
<td>6</td>
<td>Within-subject and intra-subject replication designs</td>
</tr>
<tr>
<td>7</td>
<td>Single-blind, random assignment control design, either sham or active (behavioral, psychological, or pharmacologic) treatment controls</td>
</tr>
<tr>
<td>8</td>
<td>Double-blind control studies, sham or active controls, random assignment</td>
</tr>
<tr>
<td>9</td>
<td>Treatment equivalence or treatment superiority designs with placebo control</td>
</tr>
<tr>
<td>10</td>
<td>Other designs, e.g., double dummy, Solomon four-group</td>
</tr>
</tbody>
</table>

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**TABLE 2: A summary of level 3 and 5 evidence**

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Citation</th>
<th>Number of subjects</th>
<th>Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Titules and Titules, 2000**</td>
<td>16 NF patients and 15 healthy controls</td>
<td>Psychological and neuropsychological testing was performed before and after NF treatment; controls did not receive treatment</td>
<td>Broad improvement in NF group, significant after Bonferroni correction</td>
</tr>
<tr>
<td>5</td>
<td>Keller, 2003**</td>
<td>21 patients with a history of TBI</td>
<td>12 patients received 10 sessions of NF; 9 patients received computer attention training</td>
<td>Patients improved significantly relative to controls in measures of attention; patients showed increased time spent in beta rhythm during NF</td>
</tr>
<tr>
<td>3</td>
<td>Bouras et al., 2001***</td>
<td>27, grouped into 5 clusters</td>
<td>Patients were clustered based on symptoms, and responses to NF were correlated with cluster type</td>
<td>More symptoms require more sessions; more sessions lead to greater improvement</td>
</tr>
<tr>
<td>3</td>
<td>Hoffman et al., 1995**</td>
<td>14 patients status post-mTBI from MVA</td>
<td>Unspecified</td>
<td>General improvement in symptoms, quality of life, and MicroLog™ assessment</td>
</tr>
<tr>
<td>3</td>
<td>Waller et al., 2003**</td>
<td>26 patients with a history of TBI</td>
<td>Coherence abnormalities on QEEG were corrected 1 by 1 until patients reported improvement</td>
<td>50% improvement or more by self-report in 86% of patients</td>
</tr>
<tr>
<td>3</td>
<td>Zevul, 2002**</td>
<td>10 patients with loss of consciousness of &gt;30 minutes</td>
<td>QEEG and PIBANS were given before and after 30 sessions of NF</td>
<td>PIBANS improvement, with coherence abnormalities as opposed to power abnormalities preceding successful treatment</td>
</tr>
<tr>
<td>3</td>
<td>Rezgami et al., 2011**</td>
<td>12 patients with a history of TBI</td>
<td>6 patients received NF and 6 were wait-listed controls</td>
<td>Statistically significant improvement in QEEG findings in the treatment group</td>
</tr>
<tr>
<td>3</td>
<td>Zoricz et al., 2011**</td>
<td>6 patients with a history of TBI</td>
<td>All 6 patients received NF training</td>
<td>Fewer perseverative errors in WOST; no reported change in the Stroop test</td>
</tr>
</tbody>
</table>

NF = traumatic brain injury, MVA = motor vehicle accident, NF = neuromodulation, PIBANS = Paced Auditory Serial Addition Test, QEEG = quantitative electroencephalography, TBI = traumatic brain injury, WOST = Wisconsin Card Sorting Test.
Hypothesis 1: TBI leads to large reductions in coherence

Hypothesis 2: Low frequency coherence anomalies near the regions of the corpus callosum (diffuse axonal injury)
Hypothesis 3: Beta coherence anomalies overly frontotemporal regions susceptible to shearing forces
Treatment Success

\[ \text{Intensity} = \frac{28 \times 3}{5} \times 25 = \frac{25}{2} \times 5 \] \( \text{Duration} = \frac{71}{5} \times 25 = \frac{25}{2} \times 2 \)

Results - Headaches

\[ A_{\text{pre}} | B_{\text{post}} \] 21 | 18
\[ Q_{\text{pre}} | B_{\text{post}} \] 6 | 4
\[ F_{\text{pre}} | K_{\text{post}} \] 3.33 | 2.67

\[ -1 \%\& \] K_4 p \text{Neel}
Results – Neuropsychological Testing

- Attention memory executive functioning

- $g(2) B = s & g(2), g(4)$
Summary of Findings

Evaluation and Management of the Concussed Athlete
Evaluation, Management
and Treatment

MindWorks: Concussion
Assessment and
Treatment Program
A working model

Pre-season Assessment
• Baseline NP,
• Balance test,
• QEEG and
• Symptom scale

Sideline Post-Head Trauma Assessment
• Often Per Athletic trainer
• Repeat SCAT, Baseline
• No normalization within 7-14 days, refer to specialist
• Rest

Further NP and Neurophysiological Assessment
• Neurologist
• Neuropsychologist
• Other specialists

Treatment
• Rest
• Neurofeedback
• Ongoing re-evaluation
• Gradual return to activities
1. No activity: Complete physical rest until asymptomatic. Once an athlete is asymptomatic at rest, progress through following stages. Each stage should take a minimum of 24 hours to complete. Progress to the next stage only if asymptomatic with the new activities. If the new stage provokes symptoms, return to the previous stage for at least 24 hours.

2. Low levels of physical exertion as tolerated (symptoms do not get worse or come back during or after the activity). This includes walking, light jogging, light stationary biking.

3. Moderate levels of physical exertion as tolerated. This includes sport-specific exercises such as skating drills in ice hockey, running drills in soccer, but no head impact activities.

4. Noncontact sport specific-training drills including passing drills in football and ice hockey; may start progressive weight training.

5. Full contact practice following medical clearance, participate in normal training activities.


---

**Table 5.1 Zurich Consensus Conference Graduated Return to Play Protocol**

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Functional Exercise at Each Stage of Rehabilitation</th>
<th>Objective of Each Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No activity</td>
<td>Symptom-limited physical and cognitive rest</td>
<td>Recovery</td>
</tr>
<tr>
<td>2. Light aerobic</td>
<td>Walking, swimming, or stationary</td>
<td>Increase heart rate</td>
</tr>
<tr>
<td>exercise</td>
<td>cycling keeping intensity &lt;70%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maximum permitted heart rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No resistance training</td>
<td></td>
</tr>
<tr>
<td>3. Sport-specific</td>
<td>Skating drills in ice hockey, running drills in</td>
<td>Add movement</td>
</tr>
<tr>
<td>exercise</td>
<td>soccer. No head impact activities</td>
<td></td>
</tr>
<tr>
<td>4. Noncontact</td>
<td>Progression to more complex training drills (e.g.,</td>
<td>Exercise,</td>
</tr>
<tr>
<td>training drills</td>
<td>passing drills in football and ice hockey)</td>
<td>coordination, and</td>
</tr>
<tr>
<td></td>
<td>May start progressive resistance training</td>
<td>cognitive load</td>
</tr>
<tr>
<td>5. Full-contact</td>
<td>Following medical clearance participate in normal</td>
<td>Restore confidence</td>
</tr>
<tr>
<td>practice</td>
<td>training activities</td>
<td>and assess</td>
</tr>
<tr>
<td></td>
<td></td>
<td>functional skills by</td>
</tr>
<tr>
<td></td>
<td></td>
<td>coaching staff</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Adapted from McCrory, Meeuwisse, Aubry, et al. (2013)*
Graduated return to mental activity

1. No activity. Remain in darkened room. No TV, computer, reading, etc...until asymptomatic.

2. Begin to do small amounts of cognitive works, in restricted environments. Listening and making conversation, eventually, brief reading for content.

3. Increase tasks of cognitive demand, lasting closer to an hour. Start playing games, card games and/or those that require higher order thinking.

4. May return to school/work part time once can participate in more rigorous tasks without symptoms.

An Integrated model of assessment & Treatment

Blending observational, neuropsychological and neurophysiological information
Case Study #1
DI Football Player

- 18-year-old, right handed
- Presenting c/o: history of periods of amnesia following minor blows
- Lasting several hours, with headache
Neuropsychological Data

- Normalization of ImPact testing, via his athletic trainer
- NP Exam:
  - Impaired sensory motor (left)
  - Manual facility (bilateral)
  - Impaired memory/learning (auditory and visual)
  - Low visuomotor integration and planning/executive functions
Case Study #2
Soccer Player

• 19-year-old, right handed, woman
• Presenting c/o: pt headaches, sensitivity to light and noise.
• Many of these symptoms resolved during assessment process.
• 4 documented concussions had been experienced within a year.
• Hx of excellence in academic work
April 1, 2013. After her alarm sounded, she jumped off her loft to get it. As she lifted her head, she struck the back of her neck and head. She went to class and then presented to her trainer with headache. She scored 80 points, out of 100, on the SCAT2 and subsequently performed below expectation on the Visual Motor Speed Composite on the ImPact. She completed the most recent SCAT-2 on 4/8/2013 and she obtained a perfect score. ImPact testing at that time also revealed a slight decline in verbal memory and visuo-motor speed was appreciated, with all other scores meeting or exceeding her baseline score.

February 19, 2013. While in soccer practice, XX sustained a concussion when her teammate struck her in the right temporal area. She described being a little dazed, but continued practicing. She experienced fatigue and difficulty studying. The next morning, she continued to experience headache and “didn’t feel right.” She presented to her trainer. After concussion testing normalized, she returned to play on 3/6/13.

October 2, 2012. XX sustained a concussion from having a ball hit her in the chin after being kicked upwards.

October 13, 2012. XX fell in her dorm room and the curtain rod fell on the head. She experienced an increase in headaches. Prior to returning to play, on October 18th, her ImPact score and her ability to withstand exertional tests without symptoms occurred.
**Summary of Neuropsychological Findings:** The sensory-perceptual examination revealed below average sensory functions for the left upper extremity. Psychomotor and sensorimotor functions fell within normal limits.

Neuropsychological testing data revealed that general intellectual functions fell in the Superior range. However, a relative difference was revealed between the Superior, Verbal Comprehension and the high average, Perceptual Reasoning Indices. Performance on other tasks revealed an impaired score for a complex language comprehension tasks. Otherwise, relative differences were measured with executive functions of visual organization and planning, as well as, word reading, confrontation naming and visuo-spatial abilities.
Z-scored, Absolute Power Analysis
Eyes Open

Multivariate Coherence Analysis Horizontal EigenImages
Eyes Open

Z-Scored Intra- and Inter-Hemispheric Shared Variance Statistics
Eyes Open
Case #3
BH, HS football player

- 18 year old
- Experienced three concussions during the previous football season
- Most recent, head-to-ground injury, 8th game of the season
- After last concussion, two weeks of headaches; several months of feeling in a fog.
- As of July (8 months later) continued to issues with significant memory, anxiety, stress and emotional liability, which worsened due to the stress of his difficult academic schedule.
- He was unable to complete the ACT examination in December
Case History, cont...

- "A-student;" mother described as a driven student often taking AP classes in all areas
- Normal neurodevelopmental history
- Youngest of two children; healthy, intact family
- Previous concussions:
  - 4/2008: playing football, LOC<1 minute, several minutes of confusion; post-traumatic headaches for several days
  - 10/2010: Brief LOC, and confusion, followed by several days of post-traumatic headache
- Psychological history: underwent evaluation by a mental health professional for depression but has not received any treatment. Brett reported struggling with depression, anger, low frustration tolerance, decreased range of interest, intense anxiety, and ruminative thoughts that won’t leave his head for the last 6-8 months. Brett denied experiencing a psychological trauma.
### Neuropsychological Test Data:

<table>
<thead>
<tr>
<th>Date</th>
<th>Sensory Perceptual Abilities</th>
<th>Spatial Abilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/30/2015</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>07/20/2015</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>08/25/2015</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

#### Sensory Perceptual Abilities

- **Sensory Perceptual (right)**
  - Mild-Moderate Impairment (T=34)
  - Below Average (T=42)
- **Sensory Perceptual (left)**
  - Mild Impairment (T=37)
  - Average (T=49)

#### Attention/Concentration:

- **Sustained Auditory Attention**
  - Severely Impaired (SS=40)
  - Average (SS=89)
- **Sustained Visual Attention**
  - Severely Impaired (SS=6)
  - Average (SS=105)
- **Focus/Execute Attention**
  - Low Average (ss=8)
  - Average (ss=9)

#### Spatial Abilities:

- **VIII**
  - Mildly Impaired (SS=79)
  - Low Average (SS=83)

*Indicates qualitative descriptors and T scores are demographically adjusted. Standard Scores (SS) and scaled scores (ss) are age based.

*Please note: A SS mean=100; s.d. +/-15. A ss mean=10; s.d. +/-3. A T score mean=50; s.d. +/-10.

*Bold print denotes a significant limitation; italics denotes a relative limitation.
Case #4

- 19-years-old, right-handed, Caucasian woman

- Presenting symptoms: headaches, short term memory, focusing, light sensitivity and waking in the morning

- 2 concussions within 3 months:
  1) 5/2014 - soccer
  2) 7/2014 - mva

Case #4: Relevant History

- May 9th: head-to-head contact, struck left eye orbit, nose fracture, maxillary fracture; dazed and disoriented for several minutes. Released to return to game with helmet and face mask. Played the rest of the game. Since then has continued to experience sensitivity to light and frequent headaches

- June, struck by car on her side of vehicle. Struck the right side of the head on the window. Continued issues with irritability, headaches, lability, fatigue and cognitive limitations when returned to classwork in the fall.

- Academic and developmental history were unremarkable, save for pt has been an above average student, save for math, for which she struggled both in the academic environment and on the ACT
Ratings on the Head Injury Questionnaire revealed moderate to severe exacerbations for headache, memory, forgetfulness, distractibility, extreme emotional reaction, crying spells, short attention span, mood swings, irritability, and mistrust of others. The Frontal Systems Behavioral Scale revealed elevations for apathy, disinhibition and executive dysfunctions after the head injuries, when compared to before.
### Absolute Power Analysis, Eyes Open

![Absolute Power Analysis, Eyes Open](image)

### Attention/Concentration:

<table>
<thead>
<tr>
<th></th>
<th>2/29/2015</th>
<th>05/29/2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sustained Attention</strong></td>
<td>Average (SS=93)</td>
<td>Average (SS=112)</td>
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<tr>
<td>Sustained Auditory Attention</td>
<td>Average (SS=102)</td>
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</tr>
<tr>
<td><strong>Sustained Visual Attention</strong></td>
<td><strong>Severely Impaired</strong> (SS=0)</td>
<td>Average (SS=102)</td>
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<tr>
<td><strong>Focus/Execute Attention</strong></td>
<td>Coding Average (ss=10)</td>
<td>High Average (ss=13)</td>
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### Motor Abilities:

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<tr>
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<th>05/29/2015</th>
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</thead>
<tbody>
<tr>
<td>Grooved Pegboard (dominant)</td>
<td>Average (T=45)</td>
<td>Above Average (T=57)</td>
</tr>
<tr>
<td>Grooved Pegboard (non-dominant)</td>
<td>Low Average (T=41)</td>
<td>Average (T=41)</td>
</tr>
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</table>

### Spatial Abilities:

<table>
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<tr>
<th></th>
<th>2/29/2015</th>
<th>05/29/2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMI</td>
<td>Average (SS=87)</td>
<td>Average (SS=92)</td>
</tr>
</tbody>
</table>

* Indicates qualitative descriptors and T scores are demographically adjusted. Standard Scores (SS) and scaled scores (ss) are age based. Please note: A SS mean=100; s.d. +/- 15. A ss mean=10; s.d. +/-3. A T score mean=50; s.d. +/-10. Bold print denotes a significant limitation. Italic denotes a relative limitation.
Concussion Education in Youth Sports

Education of Concussion to youth
Concussion Legislation, K-12

MOST STATES REQUIRE:

- Parents to sign informed consent to allow their child to play a sport that has a concussive risk.
- Removal of play if the athlete is suspected of head trauma
- A qualifying clinician’s signature to return to play
- Some states’ legislation extends to private schools
- Some states’ legislation requires increased education for trainers and coaches
- Other states also require baseline testing for all K-12 athletes in contact sports