The Role of Neuropsychological Testing in Sports Concussion

Michael McCrea, Ph.D., ABPP
Neuroscience Center, ProHealth Care
Department of Neurology, Medical College of Wisconsin
Role of Neuropsychological Testing

• That Was Then and This is Now: history & evolution of neuropsychological testing in sports concussion

• From Opinion to Evidence: Standardization and scientific movements

• Beyond “How many fingers?” Objectively measuring acute cognitive effects and early cognitive recovery

• The Next Frontier: Clinically-meaningful data at the individual case level

• I feel fine, can I go? Incremental value of neuropsychological testing in determining full “recovery”

• The How To’s: minimal standards and implementing the best plan for you
Neuropsychology of Sports Concussion

- Gronwall & Wrightson (1970’s): amnesia, cumulative injury
- Virginia/Ivy League Football Study- 1980’s (Barth)
- Boxing research – 1991: Heilbronner, Jordan, others
- 1990’s Movement: Macciocchi, Lovell, Echemendia
- Expanding Literature: Barr, Bleiberg, Collins, others
- NFL and NHL clinical protocols
- High School and College: Multiple Sports
- NCAA Study: 30 Division I Football Programs

Evolving role of neuropsychological testing...
Evolution of Neuropsychological Testing

• **1997:** “Development of a standardized neuropsychological test battery is recommended to detect impairment associated with concussion”
  (AAN Practice Parameter)

• **1999:** “The usefulness of neuropsychological assessment in clinical decision making should not be short-changed”
  (AOSSM Concussion Workshop Group)

• **2001:** “Neuropsychological Testing is one of the cornerstones of concussion evaluation”
  (CISG, Vienna Agreement Statement)
The Scientific & Standardization Movements

Sports Concussion Publications

- 1960's: 0
- 1970's: 25
- 1980's: 50
- 1990's: 75
- 2000's: 100

(PubMed: 1960-2005)

Benefit of Assessment Tools

- More Accurate: 85.2%
- No Effect: 14.8%
- Less Accurate: 0%

Compared to Clinical Exam Alone

Ferrara et al, JAT 2001
Multidimensional Approach
Brief Cognitive Assessment

Beyond “What’s Your Name, Bubba?”

• Feasible for sports sideline
• Beyond traditional means
• Minimal training required
• Objective injury assessment
• Reliable, Valid, Sens/Spec
• Quantify gradient of severity
• Measure, track acute recovery
• Alternate forms for f/u
• Complements neuropsych testing
• Not a substitute/stand alone
Neuropsychological Testing

Extended Follow-up

• Brief, Repeatable, Portable
• Established Norms
• Concussion Literature
• Multiple cognitive domains
• Reliable, valid, sens/spec
• Sensitive to recovery
• Alternate forms - serial testing
• Special Considerations (e.g., language)
Can we *measure* the acute cognitive effects...  

...Can tests *measure* early recovery?
Acute Effects and Recovery Time Following Concussion in Collegiate Football Players
The NCAA Concussion Study

Context Lack of empirical data on recovery time following sport-related concussion hampers clinical decision making about return to play after injury.

Objective To prospectively measure immediate effects and natural recovery course relating to symptoms, cognitive functioning, and postural stability following sport-related concussion.

Design, Setting, and Participants Prospective cohort study of 1631 football players from 15 US colleges. All players underwent preseason baseline testing on concussion assessment measures in 1999, 2000, and 2001. Ninety-four players with concussion (based on American Academy of Neurology criteria) and 56 noninjured controls underwent assessment of symptoms, cognitive functioning, and postural stability immediately, 3 hours, and 1, 2, 3, 5, 7, and 90 days after injury.

Main Outcome Measures Scores on the Graded Symptom Checklist (GSC), Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), and...
### NCAA, Project Sideline & CDC Concussion Studies

<table>
<thead>
<tr>
<th></th>
<th>NCAA</th>
<th>Project SL</th>
<th>CDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teams</td>
<td>25</td>
<td>20</td>
<td>124</td>
</tr>
<tr>
<td>Player Seasons</td>
<td>4,251</td>
<td>3,279</td>
<td>9,094</td>
</tr>
<tr>
<td>Concussions</td>
<td>196</td>
<td>87</td>
<td>375</td>
</tr>
<tr>
<td>AAN Grade 1-2</td>
<td>93.2%</td>
<td>82.1%</td>
<td>80.7%</td>
</tr>
<tr>
<td>AAN Grade 3</td>
<td>6.8%</td>
<td>17.9%</td>
<td>9.3%</td>
</tr>
<tr>
<td>LOC</td>
<td>6.8%</td>
<td>17.9%</td>
<td>9.3%</td>
</tr>
<tr>
<td>PTA</td>
<td>19.1%</td>
<td>37.3%</td>
<td>21.9%</td>
</tr>
<tr>
<td>RGA</td>
<td>7.4%</td>
<td>29.9%</td>
<td>17.3%</td>
</tr>
<tr>
<td>No LOC/PTA</td>
<td>77.8%</td>
<td>49.1%</td>
<td>64.5%</td>
</tr>
<tr>
<td>% Complete Protocol</td>
<td>84%</td>
<td>98%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Totals: 16,624 Player Seasons, 658 Concussions Studied (3.9% IR)
**Methods**

- **Main Outcome Measures**: Graded Symptom Checklist (GSC), Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), Neuropsychological Test Battery, (fMRI)

- **Injury Follow-up**: Injured player & matched control

- **Data Analyses**: Longitudinal regression - GEE (*GROUP*), standard regression based (SRB) indices of change (*INDIVIDUAL*)

**Sports Concussion Research Protocol**

<table>
<thead>
<tr>
<th>Pre-season Baseline</th>
<th>Time of Injury</th>
<th>Post-Game/Post-Practice</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 5</th>
<th>Day 6/7</th>
<th>Day 45/90</th>
</tr>
</thead>
<tbody>
<tr>
<td>History</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
<td>GSC</td>
</tr>
<tr>
<td>GSC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
<td>SAC</td>
</tr>
<tr>
<td>SAC</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
<td>BESS</td>
</tr>
<tr>
<td>BESS</td>
<td>NP Test</td>
<td>fMRI</td>
<td>NP Test</td>
<td>NP Test</td>
<td>NP Test</td>
<td>NP Test</td>
<td>NP Test</td>
<td>NP Test</td>
</tr>
</tbody>
</table>

Neuropsychological testing on days 1, 8, & 45 for HS, days 2, 7, and 90 for college; fMRI in high school only.
91% of subjects report full symptom recovery within 7 days

Higher score indicates more severe symptoms; error bars represent 95% CI

McCrea et al., JAMA 2003
### Standardized Assessment of Concussion - SAC

**Orientation:**
- Day, Month, Date, Year, Time

**Immediate Memory:**
- Repeated List Learning Paradigm

**Exertional Maneuvers:**
- Provocative conditions

**Neurologic Exam:**
- Strength, Sensation, Coordination
- Record LOC, PTA

**Concentration:**
- Digits Backward
- Months Backward

**Delayed Recall:**
- Word List Recall

---

**Total Score (30)**
- Orientation /5
- Im. Memory /15
- Concentration /5
- Delayed Recall /5
Lower score indicates more severe cognitive impairment; error bars = 95% CI
McCrea et al., JAMA 2003
SAC Sensitivity/Specificity

Reliable Change Index:
Change Score of ≥ -1:
95% Sensitivity
76% Specificity
Combined S/S Factor: 1.71

Barr & McCrea, JINS 2001
<table>
<thead>
<tr>
<th>Neuropsychological Test Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hopkins Verbal Learning Test</strong></td>
</tr>
<tr>
<td><strong>Trail Making Test</strong></td>
</tr>
<tr>
<td><strong>Letter Number Span</strong></td>
</tr>
<tr>
<td><strong>Stroop C-W Test</strong></td>
</tr>
<tr>
<td><strong>Controlled Oral Word Assoc. Test</strong></td>
</tr>
<tr>
<td><strong>Symbol Digit Modalities Test</strong></td>
</tr>
<tr>
<td><strong>HVLT Delayed Recall</strong></td>
</tr>
<tr>
<td><strong>HVLT Recognition</strong></td>
</tr>
</tbody>
</table>
No Perfect Test

• Any tool is only as good as its user…

• …only after demonstrating that the tool is valid and reliable for its intended use
Neuropsychological Data Analysis

- **Simple Group Comparisons/RMANOVA**: injured vs. control group performance; confounded by BL performance, practice effects, RTTM, other serial testing factors, mult comp’s

- **Generalized Estimating Equations (GEE)**: longitudinal regression estimating mean group differences between concussion and controls adjusted for baseline score, age, education, history

- **Standard regression based (SRB)**: empirical method to detect meaningful change at individual case level with correction for BL, practice effects & regression to the mean; (Obtained-Predicted/SE prediction) larger than criterion (translated 90% CI)

Clinical Decision-Making Influenced by method applied to measure recovery
### SIMPLE GROUP COMPARISONS*

<table>
<thead>
<tr>
<th>Test</th>
<th>Day 1-2</th>
<th>Day 6-7</th>
<th>Day 45-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVLT Immediate Memory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVLT Delayed Recall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVLT Recognition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMS-3 Letter-Number Sequencing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trails A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trails B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDMT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDMT Recall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Word</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Color</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Color-Word</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COWAT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Without controlling for BL, multiple comparisons

- **CC < NC (p > .05)**
- **CC < NC (p < .10)**
<table>
<thead>
<tr>
<th>G.E.E MODELING*</th>
<th>Day 1-2</th>
<th>Day 6-7</th>
<th>Day 45-90</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVLT Immediate Memory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVLT Delayed Recall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVLT Recognition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMS-3 Letter-Number Sequencing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trails A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trails B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDMT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDMT Recall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Word</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Color</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroop Color-Word</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COWAT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

: CC < NC (p > .05)  : CC < NC (p < .10)  * Controlling for covariates (BL, education, history)
Translating to Clinical Decision-Making

Emphasis on measuring *individual* recovery
Classifying Individual Impairment

- **SRB Model**: Linear regression on control BL scores to generate formula to predict scores at T2...

- **Regression coefficient**, intercept of regression line used with BL score to predict score for each subject at T2 and subsequent time points

- **Meaningful change**: (Obtained-Predicted/SE prediction) > criterion (translated 90% CI)

- **Empirical method** to detect “true” impairment/recovery; correction for practice effects, RTTM
**Incremental Value of Neuropsychological Testing**

- **Sensitivity:** refers to probability of individual player abnormal on any measure (Specificity > 84%)

- **Brief Battery:** GSC, BESS, SAC

- **Neuropsychological Testing:** minimal increase (5%) in sensitivity over brief battery on Day 2, but more than doubles sensitivity on Day 7 (14% to 30%)

- **Neurocognitive Impairment:** Delayed memory, processing speed, verbal fluency
BASIC GUIDELINE:

No player with any symptoms, reported or observed, should be returned to play.

Relying Solely on Symptom Self Report:

How do you know when a player is recovered?
After an apparent second concussion this season, Drew Bledsoe refused to describe his symptoms as concussion related. “I’m saying it’s a hit to the head that knocked me out a little bit,” Bledsoe said, when asked about the second hit. “I feel a little fuzzy, but I’m going to go and play,” Bledsoe said. “This is football, man, you play.”

Associated Press, November 29, 2003
Incremental Value of Neuropsychological Testing

How sensitive is neuropsychological testing in detecting real abnormalities in the asymptomatic player who says “I’m fine” and would otherwise be returned to play?
### Safeguard Against Risk

<table>
<thead>
<tr>
<th></th>
<th>Day 2</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sx-Impaired (n=68)</td>
<td>Controls Impaired (n=56)</td>
</tr>
<tr>
<td>BESS</td>
<td>37%</td>
<td>9%</td>
</tr>
<tr>
<td>SAC</td>
<td>16%</td>
<td>7%</td>
</tr>
<tr>
<td>NP Battery</td>
<td>15% (true +)</td>
<td>8% (false +)</td>
</tr>
</tbody>
</table>

Impaired relative to own pre-injury baseline performance on each measure
Role of Neuropsychological Testing

“A combination of brief screening tools appropriate for use on the sideline & more extensive measures (e.g., neuropsychological testing…) to more precisely evaluate recovery later after injury is recommended.”
Evolution of Neuropsychological Testing

- **2004**: “Neuropsychological testing should not be done while the athlete is symptomatic because it adds nothing to return-to-play decisions and may contaminate the testing process by allowing practice effects to confound results”

- “recommended that neuropsychological testing remain one of the cornerstones of concussion evaluation in complex concussion...is not currently regarded as important in the evaluation of simple concussion...should not be the sole basis for management decisions, either for continued time out or return to play decisions”

(CISG, Prague Agreement Statement)
One Size Doesn’t Fit All

Implementation of Neuropsychological Testing Models for the High School, Collegiate, and Professional Sport Settings

Christopher Randolph

Loyola University Medical Center, Maywood, IL, and Chicago Neurological Institute, Chicago, IL

Address correspondence to Christopher Randolph, PhD, Chicago Neurological Institute, 233 East Erie Street, Suite 704, Chicago, IL 60611. Address e-mail to crandolph@lumc.edu.

Objectives: To review models for the use of neuropsychological testing in the management of sport-related concussi-

sion. In this paper, I describe a systematic model for the imple-

mentation of neuropsychological assessment of athletes at var-

ious levels of competition.

Background: As we come to understand the natural history of sport-related concussion brain injury, it is increasingly evident that significant neurologic risks are associated with this type of injury. These risks include (1) acute intracranial pathology, (2) catastrophic brain swelling from second-impact syndrome, and (3) the potential risk for markedly prolonged recovery or per-

manent cognitive dysfunction associated with multiple concus-

sions.

Description: Neuropsychological testing has proved to be a use-

ful tool in the medical management of sport-related concus-

sion. In this paper, I discuss a systematic model for the imple-

mentation of neuropsychological assessment of athletes at vari-

ous levels of competition.

Clinical Advantages: The systematic model was designed to incorporate state-of-the-art methods for the diag-

osis and tracking of neurocognitive deficits associated with concussion into recently formulated guidelines for the medical management of sport-related concussion. Current applications of the model are discussed, as well as ongoing studies designed to elaborate the empirical underpinnings of the model and refine clinical decision making in this area.

Key Words: concussion, sports, brain injury

Mild traumatic brain injury (concurrency) suffered by athletes engaged in organized sports has become the focus of increased attention by medical personnel engaged in the care of athletes, sport administrative bodies, the news media, and the players themselves. The growing number of legal and medical reports and news articles devoted to this topic of sport-related concussion is a testament to the sig-

nificance and complexity of this problem.

Concussion is typically the result of trauma to the head in contact sports, but it can occur in noncontact sports as well, usually as a result of falls. Concussion can also occur without a direct blow to the head if sufficient rotational forces are applied to the brain (e.g., a whiplash injury).1 Kelly et al.2 defined concussion as "a traumatic alteration in mental status that may or may not involve loss of consciousness." This trauma-induced alteration in mental status can range in severity from a brief feeling of being dazed after the injury to an immediate loss of consciousness.

Traumatic brain injury has been recognized as a serious haz-

ard for athletes since at least the turn of the century. President Theodore Roosevelt’s concern over the 19 athletes who were killed or paralyzed by football injuries in 1904 led to the for-

mation of the National Collegiate Athletic Association as a governing body to establish rules for safer competition.3 Al-

though rules have been changed to improve player safety and protective equipment continues to evolve, concussive brain in-

jury remains common in football. Approximately 63,000 in-

cidents per year are estimated to occur in high school football alone in the United States.4

Football is not the only organized sport that carries a sig-

nificant risk of concussion. Ice hockey has been reported to have even higher rates of concussion, and soccer has only slightly less risk.5 Even sports such as field hockey, wrestling, and lacrosse carry a substantial risk of concussion, and each sport is associated with specific injuries.6,7 Obviously, there is an inherent risk of physical injury (including concussion) associated with any sport, and changes in rules and improvements in equipment can only reduce these risks to a point. This is where the medical management of concussion becomes essential. A sophisticated medical man-

agement system for sport-related concussion is important for 3 main reasons:

1. Diagnosis and appropriate management of acute concus-

sion. The appropriate management of the athlete at the time of the injury includes evaluating the severity of the concus-

sion and identifying any potential neurotraumatic emergencies (eg, epidural, subdural, or intracerebral hem-

orrha). The initial evaluation and subsequent monitoring are of pri-

mary importance in cases of more severe injury, and the critical importance of appropriate medical intervention in such cases is obvious.8

2. Prevention of second-impact syndrome. This potentially fatal syndrome is thought to result from the effects of a second concussion that occurs while the player is still


Methodologic Issues in Neuropsychological Testing

William B. Barr

New York University Comprehensive Epilepsy Center, Department of Neurology, Mount Sinai—New York University Medical Center and Health System, New York, NY

William B. Barr, PhD, provided conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

Address correspondence to William B. Barr, PhD, NYU Comprehensive Epilepsy Center, 560 First Avenue, Rivergate Fourth Floor, New York, NY 10016. Address e-mail to william.barr@med.nyu.edu.

Objective: To familiarize athletic trainers with methodologic issues regarding the development and implementation of neu-

ropsychological testing in clinical settings for monitoring sport-re-

lated brain concussion.

Knowledge base: Knowledge base and MEDLINE and PsychLit searches from 1980-2000 using the terms sports, athletics, concussion, and brain.

Data Synthesis: Neuropsychological testing is a proven method for assessing symptoms of concussion that results from a variety of different causes. These tests have been shown to be effective in evaluating symptoms of subjective cognitive dysfunction in a number of patient groups. Additionally, these tests in an athletic population have shown some procedural modifications, including the use of a collection of pre-

season baseline data, and evaluation of subtest postconcussive

changes in test scores over time. New methods are now being used for improved evaluation of the reliability and validity of neuropsychological tests in athletes. Proper scientific analysis of the psychometric properties of neuropsychological tests and the clinical value of their use in the sport setting will require years of detailed study on large numbers of athletes with and without symptoms of concussion.

Conclusions/Recommendations: Athletic trainers and re-

lated personnel need to be aware of the training and method-

ologic issues associated with neuropsychological testing. Knowledge of the scientific properties of these tests, their ad-

vantages, and current limitations will ultimately enhance the athletic trainer’s ability to use information from neuropsycholog-

ical testing in an effective manner.

Key Words: concussion, head injury, assessment, psychomet-

rics

Symptoms of sport-related cerebral concussion are, by na-

ture, subjective and typically transient. People who evalu-

ate head injuries in the athlete need objective measures to determine the pattern and severity of symptoms. The field of sports medicine has turned to neuropsychology, the scientific study of brain-behavior relationships, to provide methods that can be used on the sideline and in the athlete training room for assessment of postconcussive changes in orientation, con-

centration, and memory. In this article, I will review many of the methodologic issues involved in using neuropsychological tests and the advantages they offer for assessment of athletes with symptoms of sport-related cerebral concussion.

WHAT IS CLINICAL NEUROPSYCHOLOGY?

Clinical neuropsychology is a relatively new professional field that has evolved over the years from advancements in both clinical and experimental psychology to a distinct special-

ty. Individuals who practice clinical neuropsychology are doctoral-level professionals who specialize in the evaluation of diseases that affect the brain. Clinical neuropsychologists complete graduate training in psychology plus additional training in the internship and postdoctoral levels in the assessment and treatment of brain disorders. The practice of neuropsychology requires state licensure as a psychologist. Many prac-

titioners also receive board certification in the field. Most neu-

ropsychologists work in medical and mental health facilities, whereas others work in private practice or rehabilitation set-

tings.

Assessment of concussion is by no means new to the field of neuropsychology. Many years of experience have gone into developing tests for evaluating impairments in attention, mem-

ory, and higher-order executive functions that may be exhib-

ited by those with concussion secondary to various causes, including motor vehicle crashes, work injuries, or violent crimes.

Neuropsychologists are very much aware that no single test is effective in diagnosing the presence or absence of concus-

sion. The tests that are used are not effective when used in isolation, and they are not designed for that purpose. Neu-

ropsychological tests are administered most appropriately as groups, otherwise termed test batteries.9 The purpose of using a test battery is to look for consistencies in symptoms as ex-

hibited in variations among a number of different test scores. In a typical clinical setting, assessment of a patient with a concussion often requires a long test battery that may take from 4 to 8 hours to administer. Neuropsychologists are trained to consider the patient’s medical and emotional status, in addition to measuring the pattern and severity of cognitive impairments. They also consider what degree an individual’s age, educational background, or a multitude of other factors may influence test performance. Interpretation of these tests
Is Neuropsychological Testing Useful in the Management of Sport-Related Concussion?

<table>
<thead>
<tr>
<th>Methodological Issues</th>
<th>Clinical Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Practicality</td>
<td>• Sensitive Injury Detection</td>
</tr>
<tr>
<td>• Data-supported</td>
<td>• Tracking Recovery</td>
</tr>
<tr>
<td>• Reliability and Validity</td>
<td>• Clinically Meaningful Data</td>
</tr>
<tr>
<td>• Serial Testing Factors</td>
<td>• Sensitivity and Specificity</td>
</tr>
<tr>
<td>• Conventional vs. Computerized</td>
<td>• Incremental Clinical Utility</td>
</tr>
</tbody>
</table>

Randolph, McCrea, Barr JAT 2005, in press
Passing Grade Criteria

- **Established Test-Retest Reliability (Stability):** How sturdy are results for normals at T1,T2?
- **Establish Validity:** Are we measuring concussion effects or other (non-specific) constructs?
- **Establish Sensitivity:** What’s the lowest threshold of injury for appropriate use?
- **Establish RCI & method for classifying individual impairment:** Given normal reliability, what’s abnormal?
- **Determine Clinical Utility:** Detection of impairment in the absence of symptoms
**Neuropsychological Testing**

*Methods in Sports Concussion*

No Baseline Testing:
- Test players only after a suspected concussion

Baseline Testing Protocols:
- Conduct baseline testing on a group of players to be comparison group
- Conduct baseline testing on players identified at risk for concussion
- Conduct baseline testing on all players
Why Do Baseline Testing?

- Significant inter-player variability
- Comparison of player to his/her own “normal” performance
- Advanced methods for measuring change from baseline as indicator of injury severity and recovery
- Control for extraneous variables (ADD, LD, etc)
- Control for effects of earlier concussion
- Assess cumulative effects of repeat concussion
- Benefits clearly outweigh the time/effort
When to do Neuropsych Testing?

- Fixed Research Protocols: Day 1, 3, 7, etc.
- Symptom driven: flexible, not until player completely symptom-free
- Minimize burden on athlete, staff
- Empirical decision-making
- Avoid psychometric complications
Serial Testing Practice Effects

- Interpretation of Change
- RCI’s
- Confidence Intervals
- Repeated F/U

Test Scores

Concussion

Recovery

Practice Effects

Time, Repeat Testing
Neuropsychological Testing

When To Refer?

- Any Grade 3 Concussion (w/ amnesia or LOC)
- When confusion persists
- When amnesia persists
- When concussive symptoms persist
  - headache, nausea, apathy, etc.
- When “something’s not right”

_ even when routine exam appears normal_
“Computer tells when safe to return to play”
Barriers to Practice Standard

Population: 873  ATC: 0  Physician: 0  Neuropsychologists: 0
Assessment: Take Home Tips

- Have a plan and stick with it
- Objectivity beats subjectivity every time
- Phone a friend
- Protect the future with a good history
- All pieces of the puzzle count equally
Michael McCrea, PhD, ABPP

Director, ProHealth Care Neuroscience Center
721 American Avenue, Suite 501
Waukesha, WI 53188
(262) 928-2156
FAX: (262) 544-1213
michael.mccrea@phci.org
Potential Barriers/Hurdles

- Evidence-based Use: tests, batteries, timing
- Time constraints - history and reputation
- Financial considerations - low perceived risks?
- Lack of understanding - IQ testing, make team, etc.
- Apprehension about test results – will it hold players out longer?
- Expectation of playing injured
Heads-up: NFL has eye on concussions

Green Bay quarterback Brett Favre, who suffered a concussion during the game with the New York Giants Sunday, had to pass a series of tests before he was cleared to play.

By LORI NICKEL
lnickel@journalsentinel.com

Green Bay — It’s one thing to get out there on game day with a bruised thigh and a loose shoulder that needs to be popped back in now and then.

But even Brett Favre’s alter ego, Lethal Weapon cop Martin Riggs (played by Mel Gibson), doesn’t have to dodge explosions or win high speed chases after a concussion.

Favre, however, is expected to play Monday night against Tennessee, keeping alive his NFL record streak of 193 consecutive starts at quarterback.

But just because he’s The Men’s Journal’s No. 1 Tough Guy doesn’t make this injury any less serious. Actually, it draws more of a concern than a broken bone or a knee sprain.

“We’ll watch him very closely, there’s no question about that,” said Packers coach Mike Sherman. “Yeah, we will keep a good eye on him.”

So will the National Football League.

The NFL is conducting eight different studies on concussions to better diagnose, treat and ultimately prevent the concussions, and for good reason.

Everyone wants to see Favre on the field for as long as possible. Concussions are a somewhat mysterious injury that have ended the careers of NFL players such as Al Toon, Troy Aikman and Steve Young and NHL...
OK, YOU CALL IT... HEADS OR TAILS?

COULD YOU REPEAT THE QUESTION?
Symptom Impairment (GSC)

Postural Stability Impairment (BESS)
Future Directions

Beyond signs & symptoms - When is the brain recovered?

Window of cerebral vulnerability?
Implication: Symptom Free Waiting Period
Summary: Acute Effects & Recovery

- **Measurable Effects**: acute symptoms, cognitive dysfunction, balance deficits – without LOC/PTA/RGA/focal neuro changes;

- **Signs & symptoms**: different than historically thought

- **Gradual Recovery**: 5-7 days in 80-90% of cases, but variable across athletes in pattern and duration; parallels animal models of recovery

- **Not all look alike**: value of multidim. assessment, no one test is perfect

- **Tool Kit**: brief screening tools sensitive/specific; incremental value of Neuropsych testing further out from injury; quantify immediate effects of injury and establish objective anchor point to measure recovery

- **Critical First Week**: recovery and risks of recurrent injury

- **HS and College Athletes**: show similar recovery patterns

- **“I’m Fine”**: >25% of asymptomatic players not fully recovered


Hecht et al (2004): SAC has poor inter-rater reliability, practice effects, and poor sensitivity
Pottinger, Cullum, Stallings (1999): SAC sensitive measure of impairment and recovery

Barr & McCrea (2001): SAC valid, sensitive (94%) and specific (76%)


Valovich et al (2003): No significant practice effects on SAC

Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion

WILLIAM B. BARR¹ AND MICHAEL MCCREA²,³

¹Departments of Neurology and Psychiatry, New York University Medical Center, New York, NY
²Neuropsychology Service, Waukesha Memorial Hospital, Waukesha, WI
³Department of Neurology, Medical College of Wisconsin, Milwaukee, WI

(RECEIVED April 4, 2000; REVISED August 25, 2000; ACCEPTED August 29, 2000)

Abstract

Neuropsychology, with its emphasis on standardized and empirically based methods, has made a number of scientific contributions to address growing concerns about concussions resulting from sports injuries. This study employs a test–retest paradigm to determine the immediate effects of concussion in high-school and college athletes. The Standardized Assessment of Concussion (SAC) was administered to 1,313 male athletes prior to the beginning of the competitive season. Reliable change indices and multiple regression models were computed on retest scores obtained from 68 noninjured athletes who were readministered the SAC at either 60 or 120 days following baseline testing. Receiver operating characteristic (ROC) curve analyses were used to test these models with data obtained on 50 athletes tested immediately following concussion. The results indicate that a decline of 1 point on the SAC at retesting classified injured and noninjured participants with a level of 94% sensitivity and 76% specificity. The RCI and multiple regression models provided comparable levels of group classification, but provided cut-offs that are conservative for use with this population. The results support and extend previous research findings indicating that the SAC is a valid instrument for detecting the immediate effects of mild traumatic brain injury. (JINS, 2001, 7, 693–702.)
Higher score indicates more severe postural instability; error bars = 95% CI
McCrea et al., JAMA 2003
Balance Error Scoring System (BESS)

### Types of Errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of testing position > 5 seconds

The BESS is calculated by adding one error point for each error during the six 20-second tests.

<table>
<thead>
<tr>
<th>SCORE CARD: (# errors)</th>
<th>FIRM Surface</th>
<th>FOAM Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Leg Stance (narrow stance – feet together)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Leg Stance (non-dominant foot)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tandem Stance (non-dominant foot in back)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Scores:</td>
<td></td>
<td>Total Score:</td>
</tr>
</tbody>
</table>

Source: Guskiewicz, 1999
Neuropsychological Test Batteries

- Feasible for sports sideline
- Minimal training required
- Objective injury assessment
- Injury severity scaling
- Beyond traditional means
- Multiple cognitive domains
- Sensitive to recovery
- Alternate forms for f/u
- Valid, sensitive, specific
Clinical Sensitivity/Specificity

- **Brief Battery**: GSC, BESS, SAC
  - 15 minutes administration time

- **Sensitivity**: probability of injured player correctly classified as “impaired” on any measure

- **Specificity**: refers to probability of control correctly classified as “normal”

- Screening acute injury

- Incremental value of neuropsychological testing
Injury Assessment Tools

% of ATC's

- Clinical Exam: 75
- PCSS: 44
- SAC: 20
- Player: 18
- NP Test: 17
- Bess: 9
# Graded Symptom Checklist

<table>
<thead>
<tr>
<th>Symptom</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HEADACHE</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2. NAUSEA (SICK TO STOMACH)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3. VOMITING (THROWING UP)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4. TEETH HURTING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5. BALANCE PROBLEMS/DIZZINESS</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>6. FATIGUE</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7. SKIN RASH/ITCHING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8. TROUBLE SLEEPING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>9. SLEEPING MORE THAN USUAL</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>10. DROWSINESS (FEELING TIRED)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>11. SENSITIVITY TO LIGHT</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>12. BLURRED VISION</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>13. SENSITIVITY TO NOISE</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>14. JOINT STIFFNESS (E,G,FINGERS)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>15. SADNESS</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>16. NERVOUSNESS</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>17. IRRITABILITY</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>18. BURNING FEELING IN FEET</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>19. NUMBNESS/TINGLING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>20. FEELING SLOWED DOWN</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>21. FEELING LIKE “IN A FOG”</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>22. DIFFICULTY CONCENTRATING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>23. DIFFICULTY REMEMBERING</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>24. NECK PAIN</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>25. OTHER</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

## Column Total Score

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Total # of Items Endorsed

## Overall Total Score

Assuming you were at 100% before your concussion, give a rating for what percentage you are at now in terms of your overall condition: (enter a number between 0 and 100)_______%
### Neurocognitive Assessment

#### Rapid Sideline Assessment
- Feasible for sports sideline
- Minimal training required
- Beyond traditional means
- Objective injury assessment
- Injury severity scaling
- Sensitive to acute recovery
- Alternate forms for f/u
- Reliable, valid, sensitive, specific

#### Extended Follow-up
- Brief, Repeatable, Portable
- Established Norms
- Concussion Literature
- Multiple cognitive domains
- Alternate forms - serial testing
- Sensitive to recovery
- Reliable, valid, sens/spec
- Special Considerations (e.g., language)
Measuring Brain-Behavior Relations

- Objective, quantitative measurement of neurocognitive functioning is considered the defining skill that sets the neuropsychologist apart from other clinicians and researchers in the neurosciences.

- Reliability and validity are the cornerstones of all measurement, including neuropsychological testing.
Reliability

- Consistency or stability of measurement when obtained for an individual after repeated observations or under different testing conditions

- No tests are error-free

- A test’s value lies in its capability to measure a certain ability (true score) and minimize effects of extraneous factors (test error)
Confidence Intervals = Confident Clinical Decision-Making

Baseline Score

90% Confidence Interval (+ or - X)

Reliably Defined Deficit
Validity

- How well a test measures what it’s supposed to be measuring
  - Accurate, representative content
  - Comparison to other measures
  - Accuracy for clinical decision-making
- How well does the test distinguish between those with and without brain dysfunction
Sensitivity and Specificity

• **Sensitivity**: proportion of individuals afflicted by condition (injured) whose scores exceed the criterion for the condition (impaired)

  Concussed Player Impaired on Testing

• **Specificity**: number of individuals without the condition (uninjured) classified accurately as not meeting the criterion (unimpaired)

  Non-injured Player Not Impaired on Testing
Clinically Meaningful Change

- Reliable measurement of unreliable functions
- Reliable Change Index (RCI)
- Examining changes in test scores over time

Change Score of > -1:
95% Sensitivity
76% Specificity
Neuropsychological Testing

Why Do It?

Protect players
- Assess injury severity
- Help determine readiness to return to play
- Assess cumulative effects of recurrent injury
- Prevent catastrophic injury (Second Impact Syndrome)

Standard of care
- Collaboration b/w sports med, neuro & neuropsych
- Most sensitive means of diagnosis
- Best index of player’s functional status & recovery

Protect institutions, teams, coaches, parents
### Neuropsychological Testing

**Baseline vs. Post-injury**

19-year-old College Football Player

<table>
<thead>
<tr>
<th>Test</th>
<th>Baseline</th>
<th>Injury</th>
<th>Interpret</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trails B</td>
<td>70”</td>
<td>119”</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>HVLT</td>
<td>30</td>
<td>25</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>Stroop Color</td>
<td>45</td>
<td>33</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>Letter # Span</td>
<td>12</td>
<td>9</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>SDMT</td>
<td>51</td>
<td>39</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>COWA</td>
<td>36</td>
<td>18</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>HVLT Recall</td>
<td>10/12</td>
<td>7/12</td>
<td>&lt; NORMAL</td>
</tr>
<tr>
<td>HVLT Recog.</td>
<td>24/24</td>
<td>23/24</td>
<td>NORMAL</td>
</tr>
</tbody>
</table>

Injury Testing 2 days after concussion
# Neuropsychological Testing

## Follow-up

### 19-year-old College Football Player

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Injury</th>
<th>Follow-Up</th>
<th>Interpret</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trails B</td>
<td>70”</td>
<td>119”</td>
<td>75”</td>
<td>NORMAL</td>
</tr>
<tr>
<td>HVLT</td>
<td>30</td>
<td>25</td>
<td>31</td>
<td>NORMAL</td>
</tr>
<tr>
<td>Stroop Color</td>
<td>45</td>
<td>33</td>
<td>50</td>
<td>NORMAL</td>
</tr>
<tr>
<td>Letter # Span</td>
<td>12</td>
<td>9</td>
<td>12</td>
<td>NORMAL</td>
</tr>
<tr>
<td>SDMT</td>
<td>51</td>
<td>39</td>
<td>51</td>
<td>NORMAL</td>
</tr>
<tr>
<td>COWA</td>
<td>36</td>
<td>18</td>
<td>39</td>
<td>NORMAL</td>
</tr>
<tr>
<td>HVLT Recall</td>
<td>10/12</td>
<td>7/12</td>
<td>10/12</td>
<td>NORMAL</td>
</tr>
<tr>
<td>HVLT Recog.</td>
<td>24/24</td>
<td>23/24</td>
<td>24/24</td>
<td>NORMAL</td>
</tr>
</tbody>
</table>

Injury testing 2 days after concussion; Follow-up at 14 days
Neuropsychological Testing of Athletes: Key Ingredients

- Brief, Repeatable, Practical, Portable
- Established Norms - age, education, gender
- Sensitive to Effects of Concussion
- Neuropsychological Concussion Literature
- Alternate, equivalent forms
- Free of Noise - ADD, LD, drugs, depression
- Special Considerations (e.g., language - hockey)

RELIABLE and VALID!
Neuropsychological Testing

**Domain Driven Approach**

- concentration/attention
- short term memory
- learning & working memory
- verbal fluency
- complex scanning
- visual tracking
- mental processing speed
- fine motor speed and coordination
<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hopkins Verbal Learning Test</strong></td>
<td>4 trials of immediate recall for a 12-word list of semantically-related words. Total recall over 4 trials.</td>
</tr>
<tr>
<td><strong>Trail Making Part B</strong></td>
<td>An attentional task requiring rapid visual processing and working memory.</td>
</tr>
<tr>
<td><strong>Letter Number Span</strong></td>
<td>A working memory task, increasing levels of difficulty.</td>
</tr>
<tr>
<td><strong>Stroop C-W Test</strong></td>
<td>An attentional test that requires speeded processing and response inhibition.</td>
</tr>
<tr>
<td><strong>Controlled Oral Word Assoc. Test</strong></td>
<td>A verbal fluency test that requires the subject to rapidly retrieve words that begin with a certain letter.</td>
</tr>
<tr>
<td><strong>Symbol Digit Modalities Test</strong></td>
<td>A coding test, requiring rapid processing speed.</td>
</tr>
<tr>
<td><strong>HVLT Delayed Recall</strong></td>
<td>Delayed Recall of the 12-word list learned.</td>
</tr>
<tr>
<td><strong>HVLT Recognition</strong></td>
<td>Delayed Recognition of the 12-word list. Yes-No response to 24 words (12/12).</td>
</tr>
</tbody>
</table>
Neuropsychological Testing: 
*What We Know*

- Sensitive tool for assessing concussion
  - *BUT it is only one piece of the puzzle*
- Must assess all aspects of the injury
- Baseline testing yields the best results
- Useful in tracking recovery, return to play
- All players and concussions not created equal
- Immediate (acute) assessment data may not be necessary?
Neuropsychological Testing: What We Don’t Know?

- Most effective test battery
- Benefit of computerized over conventional
- Best model for interpreting recovery
- Psychometric issues of serial testing
- Exact standards for return to play
- Effects of neurodevelopmental factors, etc.
Neuropsychological Testing: Future Directions

- Evidence-based RTP direction from neuropsych testing
- Unique contribution of neuropsych testing over brief measures
- Predicting outcome
- Reliability, validity of computerized testing
- Correlate with Advanced Imaging
- Application beyond sports
There is no perfect marker for concussion or recovery
Part V: Longterm Effects of Sports Concussion

"Not tonight, hon, I have a concussion."
Sensitive, Accurate Injury Detection

Improved Injury Management

Prevention of Re-injury, Cumulative Impairment, Second Impact Syndrome

...Empirically-Based Approach
The Role of Neuropsychological Testing in Sports

Michael McCrea, Ph.D., ABPP
Neuropsychological Testing & Sports Concussion

- Methodological Issues
  - Test selection
  - Population characteristics
  - Normative/Clinical Data
  - Reliability/Validity
  - Sensitivity/Specificity
  - Reliable change
  - Defining “recovery”
  - Consultant’s role
  - Recognizing limitations

- Clinical Application
  - Why do baseline testing
  - How to do BL testing
  - Who does testing?
  - Sideline/acute eval
  - F/U assessment (timing)
  - Defining injury ‘grade’
  - Determining recovery
  - RPT decision-making
  - Cumulative injury
  - DQ determination
• Dozens of studies, most in past 8 years
• Strong leadership presence by Neuropsychologists
• Estimates of symptom, cognitive recovery range from hours to weeks to months (to > 1 year)
• Findings difficult to interpret based on methods:
  - Varied definitions of concussion
  - Small sample sizes; lack of control group
  - Baseline vs. no baseline studies
  - No acute assessment of signs, symptoms, cognition
  - Limited objective follow-up assessment, varied intervals
  - Not all domains of recovery evaluated (sx, cognitive, balance)
  - Recovery endpoint beyond study design
• What’s the incremental value of neuropsych testing?
A Survey of Practice Patterns in Concussion Assessment and Management

Michael S. Ferrara*; Michael McCrea†; Connie L. Peterson*; Kevin M. Guskiewicz‡

*NovaCare Athletic Training Research and Education Laboratory, University of Georgia, Athens, GA; †Waukesha Memorial Hospital, Waukesha, WI, and Medical College of Wisconsin, Milwaukee, WI; ‡Sports Medicine Research Laboratory, University of North Carolina at Chapel Hill, Chapel Hill, NC

Michael S. Ferrara, PhD, ATC, Michael McCrea, PhD, Connie L. Peterson, MS, ATC, and Kevin M. Guskiewicz, PhD, ATC, contributed to conception and design, acquisition and analysis and interpretation of the data, and drafting, critical revision, and final approval of the article.

Address correspondence to Michael S. Ferrara, PhD, ATC, Department of Exercise Science, University of Georgia, 300 River Road, Athens, GA 30602-6554. Address e-mail to mlferrara@coe.uga.edu.

Objectives: To identify methods used by athletic trainers to assess concussions and the use of that information to assist in return-to-play decisions and to determine athletic trainers' familiarity with new standardized methods of concussion assessment.

Design and Setting: A 21-item questionnaire was distributed to attendees of a minicourse at the 1999 National Athletic Trainers’ Association Annual Meeting and Clinical Symposia entitled “Use of Standardized Assessment of Concussion (SAC) in the Immediate Sideline Evaluation of Injured Athletes.”

Subjects: A total of 338 valid surveys were returned by the attendees of the minicourse.

Measurements: We used frequency analysis and descriptive statistics.

Results: Clinical examination (33%) and a symptom checklist (15.3%) were the most common evaluative tools used to assess concussions. The Colorado Guidelines (28%) were used more than other concussion management guidelines. Athletic trainers (34%) and team physicians (40%) were primarily responsible for making decisions regarding return to play. A large number of respondents (83.5%) believed that the use of a standardized method of concussion assessment provided more information than routine clinical and physical examination alone.

Conclusions: Athletic trainers are using a variety of clinical tools to evaluate concussions in athletes. Clinical evaluation and collaboration with physicians still appear to be the primary methods used for return-to-play decisions. However, athletic trainers are beginning to use standardized methods of concussion to evaluate these injuries and to assist them in assessing the severity of injury and deciding when it is safe to return to play.

Key Words: mild brain injury, grading scales, head injury, evaluation
Measuring Concussion Effects & Recovery

Symptoms
Cognition
Postural Stability
Cerebral Function