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The University of Texas at Arlington
Department of Kinesiology

Testing the Test: An Evaluation of Computerized Neurocognitive Assessments

Objectives

- Evidence Based Practice
- Psychometrics
  - Reliability
  - Validity
- Clinical Application
Financial Disclosures

- Advisory Committees
  - Pearson Scientific Advisory Committee
    - www.pearson.com
  - Natus Scientific Advisory Committee
    - www.natus.com
  - Bertec Scientific Advisory Committee
    - www.bertec.com

Concussion Epidemiology

- Overall Incidence
  - 1.6 to 3.8 million concussions occur annually (Langlois et al, 2006)
  - 254,000 concussions (5 ≤ 19 years of age) (Gilchrist et al, 2011)
    - 68% between 10 – 19 y/o
      - 56% go unreported (McIntosh, 2000)
      - 15% of concussed athletes will incur a second injury during the same season (Guskiewicz, 2000)
  - Motor Vehicle Accidents, Falls, Assault, Domestic Abuse, Sport (19%) (Meehan et al, 2010) (Langlois et al 2006)

Figure 2.1 Injury Diagnosis by Type of Exposure, High School Sports-Related Injury Surveillance Study, US, 2011–12 School Year

- 309,846 concussions

- Comstock et al, 2012
### Table 1.4 Injury Diagnoses by Year, High School Sports-Related Injury Surveillance Study, USA, 2005-06 to 2011-12 School Years

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain</td>
<td>12.5%</td>
<td>8.3%</td>
<td>6.3%</td>
<td>4.7%</td>
<td>4.3%</td>
<td>4.2%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Contusion</td>
<td>12.2%</td>
<td>13.7%</td>
<td>12.4%</td>
<td>11.5%</td>
<td>14.1%</td>
<td>9.4%</td>
<td>10.8%</td>
</tr>
<tr>
<td>Fracture</td>
<td>0.9%</td>
<td>0.9%</td>
<td>2.2%</td>
<td>3.9%</td>
<td>9.8%</td>
<td>12.2%</td>
<td>7.7%</td>
</tr>
<tr>
<td>Concussion</td>
<td>0.1%</td>
<td>0.4%</td>
<td>0.7%</td>
<td>1.6%</td>
<td>14.0%</td>
<td>25.0%</td>
<td>22.5%</td>
</tr>
<tr>
<td>Other</td>
<td>19.8%</td>
<td>20.8%</td>
<td>18.8%</td>
<td>22.2%</td>
<td>17.5%</td>
<td>17.5%</td>
<td>17.1%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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</tr>
</tbody>
</table>
Brain Injury Lab at UT Arlington

Concussion Webinar Series

• Investigate Current Clinical Measures

• More fully Comprehend Concussion
  – Pediatric
  – Adult

• Develop Innovative Clinical Measures

Evidence Based Practice (EBP)

Concussion Webinar Series

• Definition
  – “Integration of the best research evidence with clinical expertise and patient values to make clinical decisions”
    • Buck et al, 1996

• Evidence-Based Practice (EBP)
  • Improves care
  • Promotes Clinical Thinking
  • Professional Development/Implementation
  • Not a Blueprint
    (Stevens et al, 2004)
Background

Concussion Management

- “A medical assessment including a comprehensive history and detailed neurologic examination, including a thorough assessment of mental status, cognitive functioning, and gait and balance” – McCrory et al, 2009, Harmon et al, 2013

Clinical Tests

- Physical/Neurological Examination
- Neurocognitive Testing: ImPACT, Concussion Vital Signs, ANAM, CogState/AxonSport
  - Balance Assessment: Sensory Organization Test, VSR Sport, BESS
- Self-reported symptoms

Psychometric Properties

Objectivity
- “The degree to which multiple scorers agree on the values of collected scores”

Reliability
- “The degree which a measure is consistent and unchanged over a short period of time”
  - Stability Reliability: “Consistency of test scores across several days”

Validity
- “The degree to which interpretations of test scores or measures derived from a measuring instrument lead to correct conclusions” (Baumgartner et al, 2006)

Neurocognitive Testing

Paper & Pencil
- Examples
  - Hopkins Verbal Learning Test
  - Symbol Digit Modalities Test
  - Trail Making Test

Computerized Neurocognitive Testing
- Examples
  - Concussion Vital Signs
  - ImPACT
  - Headminder CRI
  - CogState / Axon Sports
Background

• Computerized Neurocognitive Testing
  – Advantages
    • Alternate forms
    • Standardized delivery
    • Potential for mass testing
    • Centralized
      – Data storage, analysis, reporting (Collie et al, 2001)
  – Disadvantages
    • Access
    • Cost
    • Limited psychometric properties reported in the literature (Randolph, 2005)

Current Clinical Practice

Meehan et al, 2012
Finger Tapping Test

In a moment you will be taking the Finger Tapping Test.

The objective of this test is to tap as quickly as possible.

First you will need to tap the space bar with your right index finger as quickly as possible for 50 seconds.

You will now practice the Finger Tapping Test.

There are a total of three executions.

Press the [Enter] key to continue.

PRACTICE. Do not remanide the grid.

ANSWER GRID:

2 3 4 5 6 7 8 9

TEST GRID:

Take in the numbers from the ANSWER GRID and try to reproduce them in the TEST GRID.
### Concussion Vital Signs

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Neurocognitive domain measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory</td>
<td>Verbal Learning, Memory for Words, Word Recognition, Immediate and Delayed Recall</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>Visual Learning, Memory for Geometric Shapes, Geometric Shapes Recognition, Immediate and Delayed Recall</td>
</tr>
<tr>
<td>Finger Tapping</td>
<td>Motor Speed &amp; Control</td>
</tr>
<tr>
<td>Symbol Digit Coding</td>
<td>Information Processing, Complex Attention, Visual-Perceptual Speed, Information Processing Speed</td>
</tr>
<tr>
<td>Stroop Test</td>
<td>Executive Function, Simple and Complex Reaction Time, Speed-Accuracy Trade-off, Information Processing Speed, Inhibition/Disinhibition</td>
</tr>
<tr>
<td>Shifting Attention</td>
<td>Executive Function, Reaction Time, Information Processing Speed, Speed-Accuracy Trade-Off</td>
</tr>
<tr>
<td>Continuous Performance</td>
<td>Sustained Attention, Choice Reaction Time, Impulsivity</td>
</tr>
</tbody>
</table>

Gualtieri et al, 2006

### Clinical Domains

<table>
<thead>
<tr>
<th>Clinical Domains</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurocognitive Index</td>
<td>Average of Composite Memory, Psychomotor Speed, Cognitive Flexibility, RT, Complex RT</td>
</tr>
<tr>
<td>Verbal Memory</td>
<td>VBM Correct Hits + VBM Correct Passes (Immediate and Delayed)</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>VIM Correct Hits + VIM Correct Passes (Immediate and Delayed)</td>
</tr>
<tr>
<td>Psychomotor Speed</td>
<td>Average RFT + Average LFT + Average FTT + SDC Correct</td>
</tr>
<tr>
<td>Executive Functioning</td>
<td>Shifting Attention Test (Correct) – Shifting Attention Test (Incorrect)</td>
</tr>
<tr>
<td>Cognitive Flexibility</td>
<td>Shifting Attention Test (Correct) – SAT Errors – Stroop Commission Errors</td>
</tr>
<tr>
<td>CPT Correct Responses</td>
<td>Continuous Performance Test ( + Correct)</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Average time on Stroop ( + Correct)</td>
</tr>
<tr>
<td>Simple RT</td>
<td>Average time on Stroop (−)</td>
</tr>
<tr>
<td>Choice RT Correct</td>
<td>Average time for Continuous Performance Test (Correct)</td>
</tr>
<tr>
<td>Shifting Attention Correct RT</td>
<td>Average RT for Shifting Attention Test</td>
</tr>
</tbody>
</table>

Gualtieri et al, 2006
### Baseline → Post-Injury (1)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Baseline</th>
<th>Post-Injury (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Memory</td>
<td>Verbal recognition memory</td>
<td></td>
</tr>
<tr>
<td>Design Memory</td>
<td>Spatial recognition memory</td>
<td></td>
</tr>
<tr>
<td>X's and O's</td>
<td>Visual working memory/cog. speed</td>
<td></td>
</tr>
<tr>
<td>Symbol Match</td>
<td>Memory and visual motor speed</td>
<td></td>
</tr>
<tr>
<td>Color Match</td>
<td>Impulse inhibition and visual motor speed</td>
<td></td>
</tr>
<tr>
<td>Three Letter Memory</td>
<td>Verbal working memory and cognitive speed</td>
<td></td>
</tr>
<tr>
<td>Symptom Scale</td>
<td>Self-Reported Symptoms</td>
<td></td>
</tr>
</tbody>
</table>

Schatz et al., 2006

### Baseline → Post-Injury (2)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Baseline</th>
<th>Post-Injury (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Memory</td>
<td>Verbal recognition memory</td>
<td></td>
</tr>
<tr>
<td>Design Memory</td>
<td>Spatial recognition memory</td>
<td></td>
</tr>
<tr>
<td>X's and O's</td>
<td>Visual working memory/cog. speed</td>
<td></td>
</tr>
<tr>
<td>Symbol Match</td>
<td>Memory and visual motor speed</td>
<td></td>
</tr>
<tr>
<td>Color Match</td>
<td>Impulse inhibition and visual motor speed</td>
<td></td>
</tr>
<tr>
<td>Three Letter Memory</td>
<td>Verbal working memory and cognitive speed</td>
<td></td>
</tr>
<tr>
<td>Symptom Scale</td>
<td>Self-Reported Symptoms</td>
<td></td>
</tr>
</tbody>
</table>

Schatz et al., 2006
### ImPACT Composite scores Contributing Scores

<table>
<thead>
<tr>
<th>Verbal Memory</th>
<th>Word Memory, Symbol Match memory, Three Letters Memory Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Memory</td>
<td>Design Memory, X’s and O’s correct</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>X’s and O’s, Symbol Match, Color Match</td>
</tr>
<tr>
<td>Visual Motor Processing Speed</td>
<td>X’s and O’s, Symbol Match, Three Letters</td>
</tr>
<tr>
<td>Impulse Control</td>
<td>X’s and O’s and Color Match</td>
</tr>
</tbody>
</table>

### Reliability of Neurocognitive Tests

<table>
<thead>
<tr>
<th>Program</th>
<th>Time Interval</th>
<th>R</th>
<th>ICC Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANAM</td>
<td>1 week / 166.5 days</td>
<td>.48 - .88</td>
<td>.38 - .87</td>
</tr>
<tr>
<td>CogState</td>
<td>50 days</td>
<td>--</td>
<td>.23 - .76</td>
</tr>
<tr>
<td>Headminder CRI</td>
<td>2 weeks / 50 days</td>
<td>--</td>
<td>.15 - .82</td>
</tr>
<tr>
<td>ImPACT</td>
<td>50 days / 2 years</td>
<td>.30 - .60</td>
<td>.15 - .82</td>
</tr>
<tr>
<td>CNS Vital Signs</td>
<td>282 days</td>
<td>.31 - .87</td>
<td>--</td>
</tr>
</tbody>
</table>

### Example

![Example Graph](image-url)
• Discrepancies
  – Multiple Tests (Broglio et al, 2007)
  – Time Intervals
    • 50 days vs. 1 or 2 years (Schatz et al, 2009) (Elbin et al, 2011)
  – Error
    • Random
      – Extraneous variables
    • Systematic errors
      – Athletes vs. Non-athletes
      – Participant age
      – Software

• Purpose:
  – Clinically relevant time points
  – One Computerized Neurocognitive Test

• Data Collection
  – 2009 – 2010
  – Healthy college aged participants
    • 18 – 24 years old
  – Testing Protocol
    • 3 time Points
      – Day 1, Day 45 and Day 50

• Test-Retest Reliability
  – Intraclass Correlations (1)
    • Values range from 0 to 1
      – Estimate reliability over time
        • Day 1 and Day 45
        • Day 1 and Day 50
        • Day 45 and Day 50
      – Acceptable Reliability
        • $>$.75 (Portney et al, 1993)
Participants

- English not primary language
- Self-reported learning disability
- Self-reported ADD/ADHD
- Any psychiatric condition
- Concussion x < 6 m of study
- Prior exposure to ImPACT

- 58 Participants
- 12 Participants
- 1 Participant
- 45 Participants

Invalid baseline assessment based automated criteria

Results

ImPACT Composite Scores
Mean (SD) (n = 45)

<table>
<thead>
<tr>
<th></th>
<th>Verbal Memory</th>
<th>Visual Memory</th>
<th>Visual Motor Speed</th>
<th>Reaction Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>.90 (.09)</td>
<td>.79 (.12)</td>
<td>42.00 (6.08)</td>
<td>.56 (.09)</td>
</tr>
<tr>
<td>Day 45</td>
<td>.92 (.08)</td>
<td>.82 (.10)</td>
<td>41.57 (5.87)</td>
<td>.55 (.07)</td>
</tr>
<tr>
<td>Day 50</td>
<td>.92 (.08)</td>
<td>.81 (.12)</td>
<td>43.44 (6.75) †</td>
<td>.54 (.07)</td>
</tr>
</tbody>
</table>

† = significantly different from time point 1
‡ = significantly different from time point 2

Results

ImPACT Intraclass Correlation Values
n = 45

<table>
<thead>
<tr>
<th>Days Mean ± SD</th>
<th>Memory Composite</th>
<th>Memory Composite</th>
<th>Visual Motor Speed</th>
<th>Composite Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Verbal</td>
<td>Visual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1 to Day 45</td>
<td>.47 ± 2.7</td>
<td>-45</td>
<td>-.54</td>
<td>.76</td>
</tr>
<tr>
<td>Day 1 to Day 50</td>
<td>.54 ± 3.8</td>
<td>-37</td>
<td>-.52</td>
<td>.74</td>
</tr>
<tr>
<td>Day 45 to Day 50</td>
<td>.69 ± 1.1</td>
<td>.40</td>
<td>-.55</td>
<td>.66</td>
</tr>
</tbody>
</table>
ImPACT Misclassifications
(n = 45)

<table>
<thead>
<tr>
<th>Day 45</th>
<th>Memory Composite Verbal</th>
<th>Memory Composite Visual</th>
<th>Visual Motor Speed</th>
<th>Reaction Time</th>
<th>Impulse Control</th>
<th>Self-Reported Symptoms</th>
<th>Any variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 4</td>
<td>8.9%</td>
<td>2.2%</td>
<td>15.6%</td>
<td>n = 3</td>
<td>n = 0</td>
<td>n = 1</td>
<td>n = 10</td>
</tr>
<tr>
<td>Day 50</td>
<td>n = 5</td>
<td>8.0%</td>
<td>6.7%</td>
<td>n = 4</td>
<td>n = 0</td>
<td>n = 1</td>
<td>n = 13</td>
</tr>
<tr>
<td>n = 4</td>
<td>8.9%</td>
<td>6.7%</td>
<td>8.6%</td>
<td>0%</td>
<td>2.2%</td>
<td>28.9%</td>
<td></td>
</tr>
</tbody>
</table>

*Misclassification*: A significant difference (as determined by ImPACT) in performance in comparison to time point 1.

ICC Value:

- Verbal Memory

- Visual Memory
Psychometric Considerations

• **Improve reliability**
  • Account for various sources of error
    -- Random
    -- Systematic
    -- Form used
    -- Equivalence of forms
    -- Hardware
  • Determine reliability
    -- Age groups
    -- Time frames.

Validity

• **Sensitivity**
  -- “the test can differentiate between clinical patients, athletes who are concussed, and normal controls” (Randolph et al, 2005)

• **Specificity**
  -- “the number of false positives, those who are classified as impaired when actually normal” (Randolph et al, 2005)

Sensitivity and Specificity

• **Schatz et al, 2006**
  -- Participants
    • High School Athletes (72 Concussed / 66 Control)
  -- Methods
    • Baseline Data Collected
    • Post-Concussion Assessment within 72 hr after injury
  -- Results
    • Sensitivity (81.9%) 
    • Specificity (89.4%)
Sensitivity and Specificity

Purpose:
- Determine the sensitivity and specificity ImPACT
- How much better than chance

Methods
- Data Collection
  - 2004 – 2008
  - Division I Collegiate Athletes
  - Sports
    - Football
    - Men’s & Women’s Basketball
    - Men’s Baseball & Women’s Softball
    - Cheerleading
    - Women’s Soccer
    - Women’s Gymnastics

UGA/UT Arlington Concussion Paradigm

Concussion diagnosed by a MD or ATC

Baseline Testing

Concussion

Day 1

Full Test Battery

Day 2 → n

Self-Reported Symptom Scale

Asymptomatic

Full Test Battery

Concussion Testing Results

WNL

NOT WNL

Send to medical staff for evaluation, exertional testing, and RTP Decision
Results (Participants)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Concussed Athletes</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>19.73 ± 1.4 y</td>
<td>19.03 ± 1.7 y</td>
</tr>
<tr>
<td>Years of Education</td>
<td>13.24 ± 1.2 y</td>
<td>12.76 ± 1.2 y</td>
</tr>
<tr>
<td>Males</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Females</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>33</td>
</tr>
</tbody>
</table>

Subjects also matched on:
- Handedness, learning disabilities, history of special education
- Control group also reported no history of concussion

Results (Participants)

<table>
<thead>
<tr>
<th>Sport</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Football</td>
<td>24</td>
<td>72.7</td>
</tr>
<tr>
<td>Cheerleading</td>
<td>4</td>
<td>12.1</td>
</tr>
<tr>
<td>Soccer</td>
<td>2</td>
<td>6.1</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Mens’ Basketball</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Equestrian</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

*Control group matched concussed sample by sport & position

Results

- Data Analysis
  - Multivariate Analysis of Variance (MANOVA)
    - Overall Group Membership (68.2%)
    - Sensitivity (57.6%)
    - Specificity (78.8%)
  - I score
    - 36.4% (Z = 2.95, P < .05)
### Sensitivity and Specificity

<table>
<thead>
<tr>
<th>Program</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ImPACT</td>
<td>57.6% – 93%</td>
<td>78.8% – 89.4%</td>
<td>Schatz et al, 2006; Broglio et al, 2007; Van Kampen, 2006; Resch et al, 2009</td>
</tr>
<tr>
<td>ANAM</td>
<td>9.3%</td>
<td>95.2%</td>
<td>Mihalik et al, 2012</td>
</tr>
<tr>
<td>Concussion Vital Signs</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>CogState/AxonSport</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>HeadMinder</td>
<td>78.6%</td>
<td>--</td>
<td>Broglio et al, 2007</td>
</tr>
</tbody>
</table>

### Sensitivity of a Battery of Tests to Manage Sport-Related Concussion

- **Computerized Neurocognitive Testing**
  - --% 81%
- **Self-Reported Symptoms**
  - 32% 62%
- **Full Test Battery**
  - 38% 63%
### Sensitivity & Specificity

<table>
<thead>
<tr>
<th>Tests Analyzed</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANAM</td>
<td>9.3%</td>
<td>95.2%</td>
</tr>
<tr>
<td>SOT</td>
<td>20%</td>
<td>92.3%</td>
</tr>
<tr>
<td>Self Reported Symptoms</td>
<td>23.4%</td>
<td>86.8%</td>
</tr>
<tr>
<td>Complete Test Battery</td>
<td>50%</td>
<td>96.7%</td>
</tr>
</tbody>
</table>

*Multifaceted & Interdisciplinary Approach To Sport-Related Concussion Management*

### Table 2.11 Methods for Injury Evaluation and Assessment, High School Sports-Related Injury Surveillance Study, US, 2011-12 School Year

<table>
<thead>
<tr>
<th>Injuries Evaluated by*</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certified athletic trainer</td>
<td>1,305,457</td>
<td>92.8%</td>
</tr>
<tr>
<td>General physician</td>
<td>452,862</td>
<td>32.5%</td>
</tr>
<tr>
<td>Orthopedic physician</td>
<td>648,721</td>
<td>32.2%</td>
</tr>
<tr>
<td>Neurologist/neurophysiologist</td>
<td>37,073</td>
<td>2.7%</td>
</tr>
<tr>
<td>Chiropractor</td>
<td>12,833</td>
<td>0.9%</td>
</tr>
<tr>
<td>Physician’s assistant</td>
<td>12,345</td>
<td>0.9%</td>
</tr>
<tr>
<td>Dental surgeon</td>
<td>2,075</td>
<td>0.1%</td>
</tr>
<tr>
<td>Nurse practitioner</td>
<td>1,011</td>
<td>0.1%</td>
</tr>
<tr>
<td>Other</td>
<td>43,322</td>
<td>3.1%</td>
</tr>
<tr>
<td>Total</td>
<td>1,362,262</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Comstock et al., 2012*
Multifaceted & Interdisciplinary Approach

- Computerized Neurocognitive Testing
  - Reliability
  - Sensitivity
  - Specificity
  - Misclassification Rate (19% to 38%) (Broglio et al, 2007) (Resch et al, In Press)

  - Neuropsychologists
    - http://www.sportneuropsychologistsociety.com/
      - Insurance
      - Fee per athlete ($25/athlete)
      - Flat Rate
      - Based on # of athletes (500 athletes = $500)

Incorporating Neurocognitive Testing

- Testing Environment
  - Number of Athletes
    - As few as possible
    - † ImPACT Cognitive Domains
    - † Invalidity Rate (Moser et al, 2011)

- Software
  - Operating System
  - Computers
  - NC program only program operating
  - Display/Mouse/Keyboard
  - Internet Connection/Bandwidth (Cernich et al, 2007)

Conclusions

- Clinicians must make informed decisions when deciding which clinical measures are to be used in a concussion management protocol

- Currently, a gold standard does not exist for the management of sport-related concussion

- A battery of tests consisting of neuropsychological and balance assessment and self-reported symptoms possesses the greatest sensitivity and specificity when managing concussed athletes
Thank you!

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