Sensitivity and Specificity of the ImPACT in Determining Presence of Concussion: A Systematic Review

A Capstone Seminar Paper for PTY 768
Presented to the Faculty of the Physical Therapy Department
The Sage Colleges
School of Health Sciences

In Partial Fulfillment
of the Requirements for the Degree of
Doctor of Physical Therapy

Bridgett Arresta, SPT
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May 2013

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ABSTRACT
**Introduction:** Concussions are traumatic brain injuries typically caused by violent collisions, occurring with or without loss of consciousness and potential physical, mental, or emotional effects. Rising athletic participation is correlated with increased concussion incidence, raising the question of what screening tool is best for diagnosis and helping make return-to-play decisions. **Purpose:** The purpose of this systematic review was to identify the sensitivity and specificity of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) which includes the Post-Concussion Symptom Scale (PCSS). **Method:** MEDLINE, Ovid, ERIC, Google Scholar, Cochrane, PubMed, CINAHL, PEDro and Science Direct were searched. Reference lists and databases were searched specifically for the ImPACT and computerized post-concussion assessment tool. Studies were examined for bias based on published recommendations. Articles were examined using the tool adapted from Jerosch-Herold & Terwee. **Results:** Six studies on the ImPACT were included, which were of moderate methodological quality. Each article either discussed the ImPACT exclusively or in comparison with other concussion screens/tests. When compared to other available tools, the ImPACT tested highest in regards to sensitivity and specificity. **Discussion:** Research was limited by the lack of available studies. The articles included limitations of author/researcher bias and methodological imperfections. Regardless, articles proved to be of enough quality to draw conclusions based on their results. **Conclusions:** The ImPACT test which includes the PCSS has been deemed sensitive and specific to high school and college athletes. The ImPACT is a conclusive test as compared to the gold standard of sideline screening.

*Key words: ImPACT, PCSS, concussion*

**INTRODUCTION**
As athletics become increasingly popular and age of introduction to and participation in organized sports decreases, sports-related injuries are on the rise; namely concussions. A concussion is a traumatic brain injury typically caused by a blow to the head or when the head or upper body is violently shaken, with or without loss of consciousness. Concussions alter brain function and may be seen with immediate effects on concentration, memory, judgment, balance, and coordination.\(^1\) Annually, 1.7 million traumatic brain injuries are reported. Of these, 75\%, or roughly 1,275,000, are concussions or other forms of mild traumatic brain injuries.\(^2\)

The Center for Disease Control (CDC) classifies concussion symptoms into four categories: Thinking/Remembering, Physical, Emotional/Mood, and Sleep. Table 1, adapted from the CDC website, gives a more extensive list of concussion symptoms divided into the four categories listed above.\(^3\) Concussions require appropriate care and attention which varies with each individual. The length of symptoms from a concussion can range from days to weeks, up to months and years. Recovery may also be slower among older adults, young children, and teens. As stated, the rise of high school and college sports increases exposure of teens and young adults to high risk situations. Additionally, those who have experienced a concussion are at a greater risk of further injury and may find that the recovery period is prolonged with each subsequent incident.\(^3\)

Vast amounts of screening tools and outcome measures have been developed to establish the presence of a concussion, its severity, and appropriate time for return to sport, work, etc. Because concussions are time sensitive with respect to emerging and diminishing symptoms and relatively quick decisions being made for return to play or work, time of administration and scoring are significant. Furthermore, with respect to increased incidence
and need to re-test patients as part of the clinical decision making process, cost can be a factor—especially when used by a school for athletic teams. Several aspects of the test also are considered in choosing an evaluation tool including time for administration, practicality, and the potential need of a certification to accurately score tests. For the sake of the players, staff, school, and sport, tests are chosen for their accuracy in combination with the factors listed above.

The ImPACT is a computerized concussion assessment tool increasingly used by schools and national athletic teams due to positive ongoing research and ease of use. The ImPACT Test Battery software contains 6 neuropsychological tests to address cognitive functioning including attention, memory, processing, and reaction time. The ImPACT also contains a 22-item Post-Concussion Symptom Scale (PCSS) that evaluates symptoms including headache, nausea, dizziness, and trouble sleeping. Each item on the PCSS is rated by the athlete on a Likert scale from 0 (asymptomatic) to 6 (symptomatic) in patient-friendly terminology (i.e. sensitivity to light as opposed to photophobia). The items are sent through the computer system and a raw and percentile score is generated. The ImPACT website states that there is a webinar available to become familiar with the software. The website states “all examinations must be monitored by an athletic trainer, doctor, or other qualified medical professional that is familiar with the software”. Developers suggest taking the webinar three times to become proficient, however there is no certification. Even though it is a computerized program, the creators state the testing is to be performed under specific environmental conditions. They suggest testing to be done in groups of 10-15 athletes with close proctoring, empty spaces between each athlete, and never taking the test at home.
Testing is performed before the start of an athletic season so as to determine a baseline score for each athlete. Administration time is about 20 minutes including the sample testing for each category. It is recommended to take the test within 24-72 hours after injury to get the most accurate results and a follow up test is recommended after 1-2 weeks. The test has been deemed appropriate for anyone over the age of 11 years old, however any parent of a child under 11 years can help with the completion of the test for their child. Consent forms are available from the ImPACT website (http://www.impacttest.com/), though recommendations for specific populations are not identified (i.e. specific sports, activities, etc.). Norms have been generated for age, sex and school grade (i.e. normally A, B or C students) that print out on the results section of each test to easily see variations or oddities. The norms help those interpret results without having a baseline score; it is recommended to have baseline testing done pre-season. To prevent floor-effects, an “invalidity index” was designed to alert examiners of an intentionally low score or if test error occurred.

The ImPACT has been a chosen concussion outcome measure for athletes and military personnel and all institutions that utilize this test can be found on the ImPACT website www.impacttest.com. The gold standard for diagnosing a concussion continues to be an on-field evaluation by medical personnel or a doctor; the creators of ImPACT state the test assists in diagnosis and should not be used alone. It is important to note that diagnosis by medical personnel is not standardized and does not quantify the severity of each individual case, rather simply the presence or absence of concussion. The ImPACT and PCSS give coaches and team officials quantifiable results through raw scores to indicate severity of injury and whether or not a player has returned to their baseline score for return-to-play decisions. However, the ImPACT website states that regulations vary by institution or
state for determining when an individual may return to play after a concussion. Coaches and staff should consult and consider those guidelines before making any decision. Again, a demonstration is available on the ImPACT website to allow those proctoring the test to become proficient prior to administering it. Additionally, an application for smart phones and tablets has been developed for an easy way to track symptoms to assist with post-injury evaluation.

Systematic evaluation of any outcome measure is critical in determining its ability to assist a clinician in appropriate plans of care through the use of evidence-based practice. Outcome measures must be proven both reliable (consistent over time and when used by different raters) and valid (appropriate and accurate in measuring what they are intended to). Moreover, they must be both sensitive (correctly identifies concussion in those with concussion, or true positives), specific (correctly confirms lack of concussion in those who are not concussed, or true negatives), and responsive to change (able to detect even minor changes in the condition of interest). Sensitivity and specificity are critical to ensure players are not exposed to conditions that are inappropriate for their level of injury. Sensitivity and specificity eliminate any mistake of having an athlete sit out who does not have a concussion, or playing an athlete who actually does have a concussion. Avoiding placing a player at further risk ensures they have time to heal, and decreases likelihood of the adverse effects associated with multiple concussions which can range from mild cognitive impairments to post-concussion syndrome. Therefore, choosing an outcome measure that has been tested and proven to be valid, reliable, sensitive, specific, and responsive to change drastically improves a clinician’s ability to make appropriate decisions about a patient’s condition, plan of care, and return to activity.
The purpose of this systematic review is to determine the sensitivity and specificity psychometric properties of the ImPACT, which is used to diagnose concussions, and determine whether it is an effective tool in high school and college athletes. Two systematic reviews on the psychometric properties of the ImPACT were reviewed as well; however the sensitivity and specificity results from only one article were included.

METHODS

Two researchers performed the data collection. The following computerized bibliographic databases were searched via EBSCO Host to identify papers: MEDLINE, Ovid, ERIC, Google Scholar, Cochrane, PubMed, CINAHL, PEDro and Science Direct. A list of search terms used is listed in Table 2. Variations of the search terms were combined with “AND” and “OR” to specify the topic. The terms were searched in all parts of the articles. The ImPACT test includes the PCSS and therefore both were identified within each of the articles. The references of the identified articles were searched to find any further articles pertaining to the topic. The searches were performed between July 2012 and December 2012, checking periodically for new studies, though none were published in these databases. The ImPACT website has a research section, which was also explored to identify articles and research that may not have showed up in the database searches.

Inclusion and exclusion criteria were set for the articles as listed below:

Inclusion criteria:

1. Demonstrate content/face validity
2. Use of the ImPACT as the outcome measure
3. Include a majority of subjects as football athletes
4. Athletes were high school and college level
Exclusion criteria:

1. Articles that were not peer reviewed
2. Did not include athletes
3. Did not explore the psychometric properties of the instrument

Initially 3,021 articles were returned from the databases. Of those, 495 studies were identified as incorporating the ImPACT as a functional test or outcome measure. Articles that included only the PCSS were not included due to the specifications made for the inclusion with the ImPACT. Through reviews of their abstracts, multiple articles were excluded based on the criteria listed above. After full text screens, 6 articles met the identification criteria. These studies underwent data extraction and critical appraisal processes. The articles were appraised and in consensus by both authors using an appraisal tool developed by Jerosch-Herold and Terwee. Refer to Table 3 for psychometric properties of each article as well as demographic information for study populations.

RESULTS

After a critical appraisal of the 6 articles, a visual of strengths and weaknesses was constructed. Refer to Table 3 which was adapted from Jerosch-Herold and Terwee to explore methodology, validity, reliability, appropriate statistic use, etc. The ImPACT was either the chief outcome measure analyzed or was a critical part of the concussion battery utilized.
All of the included studies explored pre- and post-concussion screening in high school and college athletes. All of the articles provided detailed demographics including the sport participated in by each of the participants, which ranged from non-contact to high contact. Results were based on concussions from high contact sports such as football, soccer, and lacrosse, as concussions were not experienced by non-contact athletes and thus, no data was available. Due to the predominance of male participation in contact sports associated with concussions (i.e. football), the articles utilized had a significantly higher percentage of male participants than female. Because the studies were aimed at high school and college sports, age ranges were similar. Please refer to the critically appraised topics, which outline the clinical bottom line, methods, results, and strengths and limitations of each article, in the Appendix for a thorough overview of the included papers.

Overall, the reviewed studies found sensitivity between 65.22% - 85% and specificity between 80.36% - 89.4%. The sensitivity and specificity were broken down into: symptom cluster 46.94% sensitivity, 77.20% specificity and migraine cluster 44.9% sensitivity, 78.95% specificity. Lau et al 2012\(^9\) was a continuation of the 2011\(^{10}\) research with the same athletes however the sensitivity was set at 75%-85% and the specificity was individually found to be: 22.8%-10.5% for verbal memory, 3.5%-1.8% for visual memory, 8.6% - 5.2% for processing speed, 15.5% - 5.2% for reaction time, 17.2% - 5.2% for migraine cluster, 18% - 6.9% for cognitive cluster, 15% - 1.7% for sleep cluster, and 25.9% - 19% for neuropsychiatric cluster. Refer to Table 4 for more in-depth item analysis of sensitivity and specificity as well as study demographics and sampling data.
DISCUSSION

After reviewing the articles it is clear that research supports the use of the ImPACT as a sensitive and specific test. It is responsive to change such that it indicates the presence or absence of a concussion and assists medical professionals in determining diagnosis and when return to sports may be appropriate. Like any medical screen, it is recommended to be conducted and interpreted by professionals. The use of a computerized tool increases feasibility, ease, and cost effectiveness. Articles have compared the ImPACT with other traditional concussion screens as well as newer technology and have supported its sensitivity and specificity to far supersede any paper and pencil test or any other battery.

There is some discrepancy within the articles debating the usefulness of certain individual clusters of the ImPACT and PCSS. Each section of the outcome measure should be considered important as a whole and therefore relevant. The cause for debate stems from the low specificity of the individual clusters when tested alone. However, the usefulness for using just one symptom to assist in diagnosis would not be substantial in any circumstance. The systematic review that had previously been done by Alia 2009\textsuperscript{11} explains the other aspects of the ImPACT as a well-constructed outcome measure. Reliability, validity and other construct variables had been deemed significant with the ImPACT. When reviewing this systematic review, the sensitivity and specificity was only included from the article by Shatz 2006\textsuperscript{12}. Since then, two very relevant studies on sensitivity and specificity of the ImPACT were published. These two studies (Lau 2011, 2012) were included in this review. A systematic review by McLeod in 2012\textsuperscript{13} was completed, though it only included the information from the 2009 systematic review. The systematic review by McLeod\textsuperscript{13} stated that the ImPACT along with all other concussion screening tools in the study were not developed
with an appropriate systematic process. However, an “appropriate systematic process” was
not explained and thus our review did not agree with these results. McLeod 2012\textsuperscript{13} also
explains that Alia 2009\textsuperscript{11} only used the abstracts to articles unavailable in full text; which
was the reason for the lack of sensitivity and specificity.

Although the body of evidence surrounding the ImPACT is growing, there are flags
about the studies performed thus far. Many do not indicate some of the most basic
information relative to sampling, methodology, IRB approval, informed consent and
monitoring of the test. Only in one study by Broglio et al 2007\textsuperscript{14} wrote that they received IRB
approval and informed consent. None of the studies addressed the necessary guidelines of
using minors or identified who was overseeing/administering the test.

Many of the articles shared the same limitations that threatened the methodological
strength of the research. In Broglio et al 2007\textsuperscript{14}, limitations included no discussion of
recruitment, no ages given, lack of a control group and no discussion of attrition. More
concerning is that twelve athletes had missing baseline data on postural control which skews
sensitivity and specificity of sensory testing and combined batteries, median time between
baseline and follow-up was 129 days which is extremely long, there was no discussion of
athletes with numerous concussions or return to play time after concussion, and the research
did not account for learning disabilities, concussion history, or age.

Iverson et al 2003\textsuperscript{15} did not cite from where or how participants were recruited, did
not provide the same baseline demographics of both groups, no inclusion or exclusion criteria
was provided, nor did they blind or randomize groups. IRB approval, consent, and funding
were not discussed. Researchers did not identify whether initial group had any history of
concussions, omitted data regarding baseline results for one group, and did not discuss
explore between groups differences to determine statistically significant differences. Further
limitations included the lack of who administered the ImPACT, how “concussed” individuals
were diagnosed, lack of grading concussion severity and its relation to outcome assessments,
heterogeneous ages and education levels, and owner participation in the research.
Interestingly, these researchers made adjustments to the processing speed composite score
reliable change indices, as they noted practice effects were present in healthy individuals.

Schatz et al 2006\(^\text{12}\) shared some limitations, including no mention of IRB approval or
funding. This study was limited to 5 states with an unknown number of schools participating.
The follow-up post-concussion assessment within 72 hours may be long enough for
symptoms to diminish, and there was no blinding. The researchers did not explore cutoff
scores for return to play, nor did they report on number or severity of either in-season or pre-
study concussions. Additionally, the study was conducted by creators and owners of the
ImPACT Test Battery which presents a conflict of interest.

VanKampen et al 2006\(^\text{16}\) was a well-developed study which included IRB approval,
preseason baseline testing with a follow up within the two days of injury. Athletes with a
history of seizures, neurologic disorders, attention deficit or psychiatric disorders were
omitted. There was an analysis to appropriately monitor the outcomes for the athletes with a
history of concussions which they found this group to have better performance on the
ImPACT than those that had no previous history. The test was supervised by
neuropsychologists, athletic trainers or physicians. This study explained the importance of
the PCSS within the ImPACT since it is based on the patient’s personal symptoms. The fear
that athletes may underscore their symptoms in hopes to return to play in less time has been
proved insignificant when paired with the ImPACT. Therefore the ImPACT was found to be
highly sensitive and could assist in diagnosis when compared to the gold standard of onsite diagnosis by a healthcare professional.

Lau et al 2011\(^\text{10}\) and 2012\(^\text{9}\) was a convenience retrospective study that found the individual symptoms clusters and the PCSS would increase the overall sensitivity and specificity of the ImPACT. Unlike other studies, these two included athletes with previous history of concussions as well as headaches, migraines, attention deficit and hyperactive disorders and learning disabilities. The 2011\(^\text{10}\) study determined scores for each symptom cluster for athletes that had a short (<14 days) and protracted recovery (≥14 days). This information allows healthcare professionals to make individualized recovery plans for the athlete. For example, if an athlete has a low reaction time score within a certain time frame, they can suggest a recovery time for that athlete and suggest their rehabilitation to focus on reaction time. The 2012\(^\text{9}\) study looked into the relevance of the individual symptom clusters in assisting in diagnosing and recovery time for those with a protracted recovery. For this study, they looked at the outcomes for athletes with a protracted recovery (≥14 days) since that was 80% of their sample. They used a receiver-operating characteristic curve (ROC Curve) with three cutoff scores for sensitivity and determined the specificity for the migraine, cognitive, visual memory and processing speed to be statistically significant. They found that reaction time and verbal memory was not found to be statistically significant however they stated they need further studies with more subjects to truly identify this.

It is important to note regardless of the extensive list of limitations listed above, each article was chosen and deemed to be of high enough quality through the use of critical appraisals. Though there are limitations, there are also significant strengths. Referral to the
appendices and critically appraised topics will provide strengths and further justification for article inclusion.

The ImPACT has been used on populations including athletics and military, and the majority of research has been done in these areas. For this systematic review, articles were chosen that looked specifically at high school and college athletics, focusing on sports that are highly correlated with head trauma and concussions such as football. Two of the studies did account for subjects with pre-existing conditions that would have skewed a normal ImPACT and PCSS and thus allowing for clinically relevant conclusions. While the demographic data tends to be more homogenous in that subjects tend to be male and more than likely football players, homogeneity is not a negative aspect. Most of the studies had someone monitoring the subjects completing the outcome measure to rule out any testing threats, though none identified if the administrator had taken the recommended three courses to be proficient in monitoring the test. Indeed, we are interested in seeing the utility of a tool that measures concussion symptoms. It is only logical that the population of greatest interest is male contact sports due largely to societal trends.

The overall quality of evidence supporting sensitivity and specificity of the ImPACT is relatively high within these articles. Therefore we can make the recommendation for the use of the ImPACT for the generalized population of high school and college athletes based on the review of its sensitivity and specificity. As a whole, the test shows high quality, in other words, further research is very unlikely to change our confidence in the estimate of effect. The ImPACT shows consistency as a whole proving the positive and negative predictive values along with the sensitivity and specificity. These articles have supported the ability of diagnosing even a mild concussion via computer, thus preventing premature return
to play. Predicting the athletes whom required long recovery times were found to be sensitive and specific to allow added medical/educational intervention.

Lau 2011\textsuperscript{10} stated that some cluster categories should be ignored due to their poor association with diagnosing concussions as substantiated with poor specificity. However, rejection of these categories would detract from the quality. These categories may be assessed inappropriately through the ImPACT and may need a revision to increase their effectiveness. Regardless, the other studies had proved that the ImPACT as a whole is sensitive and specific therefore it is not appropriate at this time to ignore individual clusters with low specificity.

Five of the articles involved two of the owners and cofounders, Collins and Lovell of ImPACT Applications; which is the company that distributes the ImPACT program\textsuperscript{9,10,12,15,16}. This contributes significantly to bias. While statistics are sound and may be logically chosen, readers must be careful to examine studies to ensure data hasn’t been manipulated or statistics weren’t chosen to portray a test in any special light.

Studies will need to be more specific in explaining who is administering the test and the location including the room/participant set up. Study recruitment details, informed consent and IRB approval need to be included in each study to ensure validity of the work. Further information is needed regarding individual clusters in the test to determine if categories can be altered to become more sensitive and specific. Future studies should include qualitative measures to see if students/athletes fully comprehend and understand the test. Also, the usefulness of the webinar should be studied, and it should be determined if a certification needs to be mandated for administrators. More studies completed by different coaches/administrators and their experience in rating the test would also be beneficial.
The articles used in this review are the most up to date literature available. The ImPACT and PCSS are not currently being updated and there is no identification of research in progress.

CONCLUSION:

While there are many concussion screening tools available, the ImPACT has been spreading throughout athletic programs within recent years. It is a costly investment that needs to be determined, above all, sensitive and specific to its population. The systematic review conducted finds the sensitivity and specificity of the ImPACT as a whole to be a conclusive test as compared to the current gold standard of sideline screening by a specialized trainer. The threat of athletes getting back on the field too quickly is important in preventing prolonged symptoms or post-concussion syndrome. We found the use of ImPACT to be extremely useful in assisting doctors and other medical professionals with the diagnosis of a concussion as well as the continued diagnosis and return to play decisions.
REFERENCES


## TABLES

Table 1. Adapted table from CDC identified Symptoms of a Concussion

<table>
<thead>
<tr>
<th>Thinking/Remembering</th>
<th>Physical</th>
<th>Emotional/Mood</th>
<th>Sleep</th>
</tr>
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<tr>
<td>Difficulty thinking clearly</td>
<td>Headache</td>
<td>Irritability</td>
<td>Sleeping more than usual</td>
</tr>
<tr>
<td>Feeling slowed down</td>
<td>Fuzzy or blurry vision</td>
<td>Sadness</td>
<td>Sleeping less than usual</td>
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<tr>
<td>Difficulty concentrating</td>
<td>Nausea or vomiting</td>
<td>Heightened emotions</td>
<td>Trouble falling asleep</td>
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<td>Difficulty remembering new information</td>
<td>Dizziness</td>
<td>Nervousness</td>
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<td>Sensitivity to light or sound</td>
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<td></td>
<td>Balance problems</td>
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<td></td>
<td>Fatigue</td>
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Table 2. List of Search Terms Used for all Databases

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<td>Immediate Post-Concussion Assessment and Cognitive Testing</td>
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<td>Statistical significance tested?</td>
<td>-</td>
</tr>
<tr>
<td>Clinically relevant conclusions?</td>
<td>+</td>
</tr>
</tbody>
</table>

+/White indicates strong methodology, clearly stated or good to excellent psychometric properties demonstrated; -/light gray indicates slightly weaker methodology/some limitations; N/A/dark gray indicates unclear or not addressed in the article.
<table>
<thead>
<tr>
<th>Paper</th>
<th>OMs</th>
<th>Psychometric Properties</th>
<th>Sample Diagnosis (number)</th>
<th>Age Range Male/Female</th>
<th>Sports Sampled</th>
<th>Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broglio et al 2007</td>
<td>ImPACT, NeuroCom SOT, Hopkins Verbal Learning Test, the Trail Making Test, the Symbol Digit Modalities Test, the Digit Span, and the Controlled Oral Word Association Test, HeadMinder CRI</td>
<td>Reliability, Validity, Responsiveness, Sensitivity 79.2%</td>
<td>Of an unknown population size, 75 athletes were reported in the study</td>
<td>Ages not explicitly given. Division I college athletes. 62/13</td>
<td>Football, Women’s soccer, Men’s basketball, cheerleading, equestrian, softball</td>
<td>Stratified Sampling</td>
</tr>
<tr>
<td>Schatz et al 2006</td>
<td>ImPACT</td>
<td>Reliability, Validity, Responsiveness, Sensitivity 81.9%, Specificity 89.4%</td>
<td>Of approximately 1500 athletes, 138 were reported in the study</td>
<td>High school athletes mostly 14-19. 86/52</td>
<td>Football, Soccer, Ice Hockey, Field Hockey, Basketball, Basketball, Softball, Volleyball, Gymnastics, Track, Tennis</td>
<td>Convenience</td>
</tr>
<tr>
<td>Iverson et al 2003</td>
<td>ImPACT</td>
<td>Reliability, Validity, Responsiveness, Sensitivity: large effect (listed as effect size with 80% CI)</td>
<td>97 participants</td>
<td>High school and college athletes mostly 14-19. 66/31</td>
<td>Football, Hockey, Soccer, Basketball, Wrestling</td>
<td>Not cited</td>
</tr>
<tr>
<td>VanKampen et al 2006</td>
<td>ImPACT (includes PCSS)</td>
<td>Sensitivity 83%</td>
<td>122 concussed subjects/70 control subjects</td>
<td>High school and college athletes between 12-27 years old. 82% male.</td>
<td>Football, Soccer, Basketball, other/ control included soccer,</td>
<td>Not cited</td>
</tr>
<tr>
<td>Lau et al 2011</td>
<td>ImPACT (includes PCSS)</td>
<td>Sensitivity 65.22% and specificity 80.36%. Symptom cluster scores 46.94% sensitivity, 77.20% specificity. Migraine cluster 44.9% sensitivity, 78.95% specificity</td>
<td>177 participants</td>
<td>High school, mean age 16. 100% male</td>
<td>Football</td>
<td>Conveniences</td>
</tr>
<tr>
<td>Lau et al 2012</td>
<td>ImPACT (includes PCSS)</td>
<td>Sensitivity set at 75%, 80% and 85% :specificity : 22.8%, 15.8%, 10.5% verbal memory; 3.5%, 1.8%, 1.8% visual memory; 8.6%, 5.2%, 5.2% processing speed; 15.5%, 13.8%, 5.2% reaction time; 17.2%, 6.9%, 5.2% migraine cluster; 18%, 15%, 6.9% cognitive cluster; 15%, 8.6%, 1.7% sleep cluster; 25.9%, 22.5%, 19% neuropsychiatric cluster.</td>
<td>177 participants</td>
<td>High school, mean age 16. 100% male</td>
<td>Football</td>
<td>Conveniences</td>
</tr>
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APPENDICES

Critically Appraised Topic (CAT)
Clinical Question: To determine cutoff scores in neurocognitive and Post-Concussion Symptom Scale (PCSS) symptom cluster scores when classifying protracted recovery in concussed athletes.

Clinical Bottom Line: This study showed the cutoff scores for each neurocognitive and symptom cluster for the ImPACT, hoping to correctly identify mild concussions. The specificity was set at 75%, 80% and 85% to determine each cluster’s sensitivity. Their hopes were to specify what category the child needs extra help or support in to overcome to concussion. Adverse events that occurred during the research was a high rate of attrition occurred. The internal validity was moderate in this study due to meeting only a few of the points on the validity screen; see limitations below.

1. Study Design: Cohort study
2. Sample: 108 concussed male high school football athletes were a part of this study. Inclusion criteria: (1) Athlete who had suffered a concussion during preseason and regular season football (2) Athletic Trainer and/or physicians present on the sidelines diagnosed the concussion (3) Completion of ImPACT and PCSS assessment during follow up until full recovery Exclusion criteria: (1) athletes who were injured in postseason playoff.
3. Methods: This was a 5 year study where each high-school football athlete in the Pennsylvania area completed the ImPACT (which includes the PCSS) within a median of 2 days after injury.
4. Outcome Measures: The ImPACT software evaluates different aspects of attention, memory, processing speed and reaction time. The PCSS assessment identifies the subjective symptoms of the patient: migraine, cognitive, neuropsychiatric and sleep. It takes about 20 minutes to complete on a computer.
5. Results: When the Sensitivity was at 75%, 80% and 85% the specificity was: 22.8%, 15.8%, 10.5% for verbal memory, 3.5%, 1.8%, 1.8% for visual memory, 8.6%, 5.2%, 5.2% for processing speed, 15.5%, 13.8%, 5.2% for reaction time, 17.2%, 6.9%, 5.2% for migraine cluster, 18%, 15%, 6.9% for cognitive cluster, 15%, 8.6%, 1.7% for sleep cluster, and 25.9%, 22.5%, 19% for neuropsychiatric cluster. The positive predictive value was within 40.1%-47.5% for all clusters. The clusters/symptoms that were statistically significant were migraine, cognitive, visual memory and processing speed.

Appraisal and Application
Strengths: 1. No significant differences within groups 2. Previous history of concussions, headaches, migraines, ADHD and learning disability was evaluated through a series of t tests 3. Fairly accurate description of participants involved 4. Good follow up times 5. Similarity between patients regarding age and onset 6. No ceiling or floor effects were noticed 7. The ImPACT was said to be reliable and valid from previous studies 8. Statistical conclusion validity was met 9. Definition of concussion was stated 10. Decent sample size
Limitations: 1. Individual effects are not noted 2. Unknown number of schools participating therefore unknown, Inter/intra -rater reliability however it was said that clinical and referral management were consistent between schools 3. Observational study, no experimental control factors 4. Athletes didn’t have a specific number of assessments 5. Never stated the time and place of the tests 6. No blinding was done 7. Not sure if patients were treated the same 8. Convenience sample 9. Natural attrition 10. Not all the students had baseline scores 11. Baseline data was not stable 12. Cannot generalize past male, football, high schoolers (poor external validity) 13. Conflict of interest study- the source of funding came from owners of the ImPACT 14. Not stated if the test was supervised 15. Did not explain tests in-depth


Appraiser: Bridgett Arresta, SPT Date: 10/20/12
Critically Appraised Topic (CAT)
Clinical Question: To quantify the prognostic ability of computerized neurocognitive testing in combination with symptoms during the subacute recovery phase from sports-related concussion.

Clinical Bottom Line: This study showed that the ImPACT alone (64.10%) or in conjunction with the PCSS (73.17%) administered 2-3 days after a concussion could accurately predict whether or not the athlete will require a protracted recovery (>14 days). Adverse events that occurred during the research was a high rate of attrition occurred. The internal validity was moderate in this study due to meeting only a few of the points on the validity screen; see limitations below.

1. Study Design: Cohort study (prognosis)

2. Sample: 108 concussed male high school football athletes were a part of this study. Inclusion criteria: (1) Athlete who had suffered a concussion during preseason and regular season football (2) Athletic Trainer and/or physicians present on the sidelines diagnosed the concussion (3) Completion of ImPACT and PCSS assessment during follow up until full recovery Exclusion criteria: (1) athletes who were injured in postseason playoff.

3. Methods: This was a 5 year study. Conducting the first evaluation within 72 hours, then approximately 1, 2, and 3 weeks after the concussion.

4. Outcome Measures: The ImPACT software evaluates different aspects of attention, memory, processing speed and reaction time. The PCSS assessment identifies the subjective symptoms of the patient: migraine, cognitive, neuropsychiatric and sleep.

5. Results: 108 of the athletes were cleared for return to play. 58 of them were classified as short recovery (≤14 days) and 50 were classified as protracted recovery (>14 days). The ImPACT was able to correctly classify 65.38% of athletes into long or short recovery. It had 53.20% sensitivity and 75.44% specificity in predicting prolonged recovery. The positive predictive value and negative predictive value were 64.10% and 66.15% respectively. The PCSS was able to correctly identify 63.21% of athletes into long or short recovery. It had 46.94% sensitivity and 77.20% specificity to predict prolonged recovery. The positive predictive value and negative predictive value were 63.90% and 62.86% respectively. Combining the ImPACT and the PCSS together was found to correctly classify 73.53% of athletes into long or short recovery. Sensitivity was 65.22% and specificity was 80.36% in predicting long recovery. Positive predictive value and negative predictive value were 73.17% and 73.8% respectively. Symptom cluster only scores had 46.94% sensitivity, 77.20% specificity, 63.9% PPV and 62.86% NPV. Migraine only cluster had 44.9% sensitivity, 78.95% specificity, 64.71% PPV and 62.5% NPV. Significant different variables were: migraine cluster, reaction time, visual memory and verbal memory.

Appraisal and Application
Strengths: 1. No significant differences between short recovery or protracted recovery groups 2. Previous history of concussions, headaches, migraines, ADHD and learning disability was evaluated through a series of t tests 3. Fairly accurate description of participants involved 4.
Good follow up times 5. Similarity between patients regarding age and onset 6. No ceiling or floor effects were noticed 7. The ImPACT was said to be reliable and valid from previous studies 8. Statistical conclusion validity was met 9. Definition of concussion was stated 10. Decent sample size

Limitations: 1. Individual effects are not noted 2. Unknown number of schools participating therefore unknown, Inter/intra-rater reliability however it was said that clinical and referral management were consistent between schools 3. A remark was made about some of the athletes wanted to return to football therefore eager to retake these tests 4. Observational study, no experimental control factors 5. Athletes didn’t have a specific number of assessments 6. Never stated the time and place of the tests 7. No blinding was done 8. Not sure if patients were treated the same 9. Convenience sample 10. Natural attrition-69 athletes were either lost to follow up or did not return to football (graduation etc) 11. Not all the students had baseline scores 12. Baseline data was not stable 13. Cannot generalize past male, football, high schoolers (poor external validity) 14. Conflict of interest study- the source of funding came from owners of the ImPACT 15. Not stated if the test was supervised 16. Did not explain tests in-depth


Appraiser: Bridgett Arresta, SPT  
Date: 10/20/12
Critically Appraised Topic (CAT)

Clinical Question: Use of computer-based neurocognitive testing results in an increased capacity to detect postconcussive abnormalities, compared with PCS alone, in a large group of athletes with diagnosed concussions.

Clinical Bottom Line: This study showed that the subjective PCS had a sensitivity of 64% then it was compared with the combination of the neurocognitive testing of the ImPACT which proved to have a sensitivity of 83%. No adverse events occurred. The internal validity was good in this study due to meeting most of the points on the validity screen; see limitations below.

1. Study Design: Case control study

2. Sample: 122 concussed athletes and 70 non-concussed athletes with preseason baseline testing completed with ImPACT. The male and female athletes were from high schools (concussed: n=97; non-concussed: n=50) and colleges (concussed: n=25; non-concussed n=20) in PA, MI, IL, OR, ME & CA. The majority of the concussed sample was football players, the majority of the un-concussed sample was swimmers. Inclusion criteria: (1) Athletic Trainer and/or physicians present on the sidelines diagnosed the concussion (2) Completion of ImPACT and PCS assessment during follow up until full recovery. Exclusion criteria: (1) Athletes with a history of ADHD or psychiatric disorder for which they were receiving medication. (2) History of seizures or any other known neurologic disorder.

3. Methods: This was a 3 years study. 1 follow-up evaluation with the ImPACT completed within 2 days of the concussion and within 1 week for the control group.

4. Outcome Measures: The ImPACT software evaluates different aspects of attention, memory, processing speed and reaction time. The ImPACT contains a 22-item PCS that evaluates postconcussive symptoms (such as headache, nausea, dizziness, and trouble sleeping) which is rated by the athlete on a Likert scale from 0 (asymptomatic) to 6 symptomatic).

5. Results: Sensitivity of ImPACT and PCS combined was 83%, sensitivity for PCS alone was 64%. Positive predictive value for PCS was 93%, negative predictive value was 59%. ImPACT positive predictive value was 83%, negative predictive value was 70%. ImPACT & PCS positive predictive value was 81% and negative predictive value was 83%. The control group did not have abnormal results in both the ImPACT and PCS.

Appraisal and Application
Strengths: 1. No loss of data 2. Fairly accurate description of participants involved 3. Good follow up times 4. Decent sample size 5. No ceiling or floor effects were noticed 6. The ImPACT was said to be reliable and valid from previous studies 7. Statistical conclusion validity was met 8. Analysis was conducted on all athletes to take into account the possible impact of prior concussion(s) 9. No statistical significant differences noted in ImPACT test performance or in symptom reporting at either baseline or postconcussion with the exception of differences between the 2 groups at baseline with regard to verbal memory composite
score. 10. Test retest fluctuations were addressed 11. All injuries diagnosed by physician or AT that were present 12. Reliable Change Index (RCI) was addressed to account for measurement error surrounding test-retest difference scores and adjusts for practice effects 13. Good statements about how the ImPACT and PCS is set up 14. The tests were supervised by a team of clinical neuropsychologists, AT’s and/or physicians who were trained and supervised in the administration of the tests 15. Definition of concussion was stated 16. Stated they compared with gold standard (on-field diagnosis) for the diagnostic yield 17. Significant change was based on each athlete’s baseline, not compared to the control 18. No loss of data

Limitations: 1. Individual effects are not noted 2. Unknown number of schools participating therefore unknown Inter/intra-rater reliability of diagnosing concussions 3. Different genders/sports 4. Observational study, no experimental control factors 5. Athletes didn’t have a specific number of assessments 6. Never stated the time and place of the tests 7. No blinding was done 8. Not sure if patients were treated the same 9. It was stated that a rigorous statistical method was used for determining significant change after concussion, instead of a clinical approach 10. Because of RCI scores, milder concussions might not have been classified appropriately in the study 11. Control group mostly consisted of non contact sport athletes 12. Conflict of interest study- the source of funding came from owners of the ImPACT 13. Not the best matched demographic data 14. Not all information was made into charts


Appraiser: Bridgett Arresta, SPT Date: 10/20/12
Critically Appraised Topic (CAT)
Clinical Question: Previous studies have explored the stability of test scores and reliable change intervals for test-retest scores for the ImPACT Version 1.0. The aim of this study was to examine these and other psychometric properties of the ImPACT Version 2.0.

Clinical Bottom Line: The computerized ImPACT Version 2.0 is sensitive to the acute effects of concussion. The majority of athletes showed substantial changes (medium to large effect sizes) in functioning in the first few days following injury. Version 2.0’s sensitivity is consistent with research for Version 1.0.

1. Study Design: Exploratory

2. Sample: 97 participants. Group 1: n=56 (males=29, females=27); average age 17.6 years (+/- 1.7); education level: high school=64%, college=36%. In this group, subjects completed the ImPACT Version 2.0 twice for test-retest exploration, with an average time between tests of 5.8 days (ranged from 3-11 days). Group 2: n=41; males=90% (36.9); median age= 16 (+/-2.4); education level: high school=71%, college=29%. Group 2 was comprised of athletes who sustained a sports-related concussion, and was largely comprised of football players (88%). Athletes in this group were given sufficient information to classify the severity of their concussions using the American Academy of Neurology Concussion Grading System. Breakdown of severity: Grade I=54%, Grade II=22%, Grade II=7%, missing data prevented confident classification of 17% (7 athletes). No inclusion or exclusion criterion stated.

3. Methods: Group 1 completed the ImPACT twice for test-retest exploration. Approximately 29% re-tested within 3 days, 43% within 4 days, 82% within 7 days, and 95% within 11 days. Days between testing ranged from 1 to 13 days. Group 2 completed the ImPACT at the beginning of the season and were tested again within 72 hours of sustaining their injury (mean=1.3, median=1, SD=0.7). As previously stated, 88% of participants in group 2 were football players. Other sports included hockey, soccer, basketball, and wrestling. Groups were examined with a Pearson Correlation and dependent t-tests and within subjects was examined. The reliable change methodology was used to estimate measurement error surrounding test-retest difference scores. Effect sizes were calculated for both groups.

4. Outcome Measures: The ImPACT Test Battery software Version 2.0. It contains 6 neuropsychological tests to address cognitive functioning including attention, memory, processing, and reaction time. The ImPACT also contains a 22-item Post-Concussion Symptom Scale that evaluates symptoms including headache, nausea, dizziness, and trouble sleeping. Each item is rated by the athlete on a Likert scale from 0 (asymptomatic) to 6 (symptomatic) in patient-friendly terminology (i.e. sensitivity to light in place of photophobia).

5. Results: In Group 1, analyses of both scores showed strong correlation coefficients. Paired samples t-tests showed no within group differences except for a significant difference in the Processing Speed Composite (about 68% were faster than at baseline). Overall, subjects’ scores followed a normal distribution after both rounds of testing. In Group 2, effect sizes were calculated for pre- and post-concussion testing within the group. Large effect sizes were
calculated for Verbal Memory, Reaction Time, and subjective symptom reporting. Medium to large effect size was calculated for Visual Memory, while significantly slower Processing Speed was correlated with a medium effect size. For both groups an 80% confident interval was used.

Appraisal and Application
Strengths: 1. No attrition 2. All participants received the measure 3. Comparisons made to ImPACT Version 1.0 4. Effect sizes calculated for both group 5. Statistics used were simple and reader-friendly 6. Authors provided good discussion of how ImPACT was scored and how composite scores were comprised 7. All concussion grades included 8. Provided calculations for calculating Standard Error of the Mean and Standard difference to create confidence intervals 9. Used a confidence level of 80% to more closely simulate clinical situations and account for error 10. ImPACT uses randomization of stimuli to reduce practice effects 11. Discussed outliers and regression to the mean.

Limitations: 1. Did not identify whether initial group had any history of concussions 2. No inclusion or exclusion criteria stated 3. Did not cite from where or how participants were recruited 4. Did not provide the same baseline demographics of both groups 5. Allowed Group 1 participants to re-test the following day. 6. Did not state whether baseline ImPACT for Group 2 was before pre-season or before any contact. 7. Small sample size 8. Unable to classify severity of all concussions 9. Did not relate concussion severity to outcome assessments 10. Did not cite who was administering tests 11. Did not discuss how concussions were determined 12. Did not discuss differences between groups to determine statistically significant differences 13. No statistical values presented for sensitivity and specificity 14. Medium to large effect sizes for Group 2 demonstrated sensitivity of ImPACT to acute concussion symptoms 15. Made adjustments to Processing Speed composite score reliable change indices because practice effects were present 16. No blinding or randomization 17. Homogeneous subjects 18. Ages and education levels were heterogeneous 19. Significant differences in healthy group for improved processing times with testing 20. Owner participation in research study.


Appraiser: Danielle Lamb, SPT Date: 10/23/12
Critically Appraised Topic (CAT)

Clinical Question: There have been numerous advancements in the tools available to screen for concussions. Assessments range from paper-and-pencil to computerized and examine concussion-related symptoms, a postural control evaluation, and neurocognitive function. The purpose of this study was to compare the sensitivity of different concussion-assessment batteries given within 24 hours of an injury diagnosis for college athletes.

Clinical Bottom Line: Although this study had limitations (see below), it is the first of its kind to combine several assessment tools and batteries to determine sensitivity of different batteries’ ability to recognize a concussion. The study recognizes that computerized assessments offer increased ease, convenience, less time, improved accuracy, mass administration, no need to consult a licensed neuropsychologist and increased sensitivity than its predecessors. Sensitivity of the ImPACT (79.2%) and HeadMinder CRI (78.6%) was highest and increased when coupled with postural control and symptom assessments (ImPACT= 91.7%, HeadMinder CRI= 89.3%). Additionally paper-and-pencil tests proved to identify 95.7% impairment in at least one measure after a concussion, but results were skewed based on type of tests and time between baseline and post-injury assessments.

1. Study Design: Longitudinal

2. Sample: Of an unknown population size, 75 athletes sustained a physician-diagnosed concussion between 1998 and 2005. Inclusion criteria: 1) university athletes who were determined to be at high-risk for concussion; 2) competed at a Division I varsity level. The study included 62 males (83%) and 13 females (17%). Football accounted for 59 concussions, women’s soccer followed with 8, men’s basketball and cheerleading had 3 each, and equestrian and softball each had one concussion.

3. Methods: From 1998 to 2005 all high-risk athletes completed a baseline concussion-assessment battery that included a measure of self-reported symptoms, a postural control evaluation, and a neurocognitive assessment. The assessments administered varied depending on the year. If an athlete was injured, a follow-up battery was performed within 24 hours of injury diagnosis. Concussion symptoms were measured by nine self-reported items graded on a Likert Scale. Postural control assessment was completed using the NeuroCom SOT. Three neurocognitive assessment methods were used throughout the study. From fall 1998-spring 2001, a trained clinician administered a paper-and-pencil neurocognitive assessment battery which included the Hopkins Verbal Learning Test, the Trail Making Test, the Symbol Digit Modalities Test, the Digit Span, and the Controlled Oral Word Association Test. In the fall of 2001 the pencil-and paper battery was replaced with the HeadMinder CRI, and beginning in the fall of 2004 the HeadMinder CRI was replaced with the ImPACT software. ImPACT software versions were updated as the study progressed, with version 2.1a used in 2004-2005 and version 4.5.729 used in 2005. All baselines were supervised by a test administrator in controlled areas free from noise and distraction. Pencil-and-paper tests were given in a 1:1 ratio of administrator to athlete, computerized testing was done in small groups with athletes positioned away from each other to allow maximal concentration.

4. Outcome Measures: A number of Outcome Assessments were used including self-reports, SOT machines, paper-and-pencil, and computerized assessments (see above).
5. Results: Regardless of outcome measure, authors determined a significant change between baseline and post-injury scores to be 1 standard deviation from the athlete’s baseline score. Of the self-reported concussion symptoms, 68.0% showed a clinically significant increase in duration or severity of symptoms while 32% did not show a significant change. For the NeuroCom SOT 61.9% were identified as having impaired postural control on at least one SOT variable, while 38.1% showed no impairment. The pencil-and-paper battery as a whole revealed impairments in 43.5% of athletes, while failing to identify 56.5% of athletes who were impaired. For the ImPACT, 62.5% of athletes showed at least one cognitive variable impaired after injury with an additional 16.7% showing a significant increase over baseline assessments leading to a sensitivity of 79.2%. No significant change was noted in 20.8% of concussed athletes with the ImPACT. The HeadMinder identified 78.6% of athletes with a concussion, with an additional 21.5% showing no change on the test. For athletes who were tested using an entire battery of pencil-and-paper tests, postural control assessment, and self-reported symptoms, 95.7% of concussed athletes showed significant impairment. When the HeadMinder was combined with symptom and postural assessments, sensitivity was 89.3%. When the ImPACT was combined with symptom and postural assessments, sensitivity was 91.7%.

Appraisal and Application
Strengths: 1. All baseline scores taken prospectively so any athlete who sustained a concussion already had baseline data 2. IRB approval 3. Informed consent 4. Sufficient description of all assessments used in the batteries with supporting research for use of each 5. Progressed outcome assessments as technology evolved to keep current and protect athletes 6. When appropriate, licensed professionals administered tests (such as the SOT) 7. Baseline testing was in a controlled environment and was appropriate for the assessment used 8. Provided severities of concussions 9. Determined sensitivity of each battery 10. Determined combined sensitivity of batteries 11. Concussions determined by a physician 12. Used 1 SD to determine significance 13. Identified current gold standards for assessments.

Limitations: 1. Small sample size 2. Demographics not given 3. No discussion of recruitment 4. Twelve athletes had missing baseline data on postural control, skews sensitivity and specificity of SOT and combined batteries 5. No discussion of attrition 6. Median time between baseline and follow-up was 129 days 7. Extended time could be years between assessments 8. Did not use research to determine appropriate significance for change in scores specific to each test 9. No blinding 10. No discussion of athletes with numerous concussions or return to play time after concussion 11. No gold standard for comparison 12. Did not account for learning disabilities, concussion history, or age 13. Statistical values for combined specificity, PPV and NPV not provided 14. Use of multiple tests 15. Severity of concussions was different depending on year which could make one test seem more or less sensitive than another 16. Lack of control group.

Citation: Broglio SP, Macciocchi SN, Ferrara MS. Sensitivity of the concussion assessment battery. Neurosurgery. 2007 Jun;60(6):1050-7; discussion 1057-8.

Appraiser: Danielle Lamb, SPT Date: 10/27/12
Critically Appraised Topic (CAT)

Clinical Question: There have been numerous advancements in the tools available to screen for concussions. Assessments range from paper-and-pencil to computerized and examine concussion-related symptoms, a postural control evaluation, and neurocognitive function. The purpose of this study was to compare the sensitivity of different concussion-assessment batteries given within 24 hours of an injury diagnosis for college athletes.

Clinical Bottom Line: This study reported the ImPACT had a combined sensitivity and symptom score to be 81.9% with a specificity of 89.4%, indicating the ImPACT computerized test battery to be a sensitive and specific instrument to assess the presence of a concussion. No adverse events occurred. The internal validity was threatened—see limitations below.

1. Study Design: Observational

2. Sample: 138 participants (previously concussed: n=72; no history of previous concussion: n=660). Inclusion criteria for concussion group: 1) concussed high school athletes who were tested within 72 hours of sustaining a concussion; 2) from within the states of Pennsylvania, Michigan, Illinois, Oregon, or Maine as part of an ongoing clinical program. Inclusion criteria for non-concussion group: 1) high school athletes with no history of concussion; 2) completed baseline measurements; 3) from within the states of Pennsylvania, Michigan, Illinois, Oregon, or Maine as part of an ongoing clinical program. The majority of the concussion group were football players (72.7%), male (79.2%), and significantly (p=0.002) younger (16.5[2.3] years). The majority of the non-concussion group were non-contact sports (78.8%), female (56.1%) and older (17.3[1.7] years). Exclusion criteria was 1) achieving a score of 20 or higher on the Impulse control, as it raised questions regarding those individuals’ test taking approaches.

3. Methods: All athletes underwent baseline or pre-injury testing and were administered the ImPACT before their 2000-02 athletic seasons before pre-season or contact drills. Test administrators were trained to define a concussion based on the American Academy of Neurology nomenclature as a “traumatically induced alteration in mental status that may or may not be accompanied by a loss of consciousness.” Certified athletic trainers or team physicians who were on the sideline at the time of injury were responsible for making the initial diagnosis of concussion, and the referred athletes for a post-injury ImPACT evaluation which was completed within 72 hours of injury.

4. Outcome Measures: The ImPACT Test Battery software. It contains 6 neuropsychological tests to address cognitive functioning including attention, memory, processing, and reaction time. The ImPACT also contains a 22-item Post-Concussion Symptom Scale that evaluates symptoms including headache, nausea, dizziness, and trouble sleeping. Each item is rated by the athlete on a Likert scale from 0 (asymptomatic) to 6 (symptomatic) in patient-friendly terminology (i.e. sensitivity to light in place of photophobia).

5. Results: Sensitivity of the combined ImPACT and PCS was 81.9%. Specificity reported at 89.4%. Positive Predictive Value was 89.4% and Negative Predictive Value was 81.9%.
The Positive Likelihood Ratio was reported as 7.73:1 while the Negative Likelihood Ratio was reported as 0.20:1.

Appraisal and Application
Strengths: 1. No attrition 2. Cutoff score for participation based on questionable test-taking strategies 3. ImPACT taken in off-season for baseline measurement 4. All participants received the measure 5. Psychometric properties of the outcome measure were explored prior to the study 6. All appropriate demographic information provided 7. Appropriate statistical analyses of between and within group differences 7. Statistical analyses of individual differences from baseline to post-concussion values 8. Concussions determined by athletic trainer or team physician 9. Thorough discussion about choice of ImPACT and how the Battery is comprised as well as what it looks for 10. Trained test administrators with an operative definition of what a concussion is based on the American Academy of Neurology 11. Although between-group demographics varied (not including sport), the only significant difference was age, which was less than a year different. 12. Athletic trainers or team physicians were given an operational definition of a concussion. 13. Addressed lack of change in baseline scores even after multiple tests.

Limitations: 1. Small sample size 2. Study limited to 5 states 3. Unknown number of schools participating 4. Follow-up post-concussion assessment within 72 hours may be long enough for symptoms to diminish 5. Did not explore cutoff scores for return to play 6. Observational study design with no experimental factors. 7. Did not report on number or severity of either in-season or pre-study concussions 8. No blinding 9. No gold standard for comparison 10. Concussion group consisted primarily of males 11. Variables may have skewed statistical results 12. Statistical values for combined specificity, PPV and NPV not provided 13. Study was conducted by creators and owners of the ImPACT Test Battery which presents a conflict of interest 14. No discussion of IRB approval or funding.


Appraiser: Danielle Lamb, SPT
Date: 10/24/12