ImPACT©

The Best Approach to Concussion Management

ImPACT Version 2.0

Clinical USER'S MANUAL

Introduction to ImPACT...

ImPACT: A review of the past and a look into the future

The past several years have witnessed an explosion in the use of computer-based neuropsychological testing in the field of sports medicine. In fact, neuropsychological testing has recently been defined as the "cornerstone" of concussion management by the International Olympic Committee, FIFA, and a number of other prominent organizations. Thanks to your interest and support, ImPACT has been at the forefront of this revolution. While ImPACT was initially developed and field tested for the sport of football, ImPACT has now become the standard in other sports such as soccer, ice hockey, rugby, basketball and lacrosse. Most recently, ImPACT has been implemented by all major automobile racing leagues, including CART, the Indianapolis Racing League, and Formula 1.

Through years of careful research and a good deal of constructive feedback from our clients, ImPACT has continued to evolve as a software package. As we look forward to the next five years, we will continue to improve the clinical utility of ImPACT for sports-medicine practitioners.

One particularly exciting development has been the use of ImPACT internationally. During 2002, we established programs in Australia, Sweden, South Africa, New Zealand, and Canada to name just a few. We are currently working on a number of other projects that will make the software available to non-English speaking populations. For instance, ImPACT has recently been translated into French, and its translation into Spanish will also be completed this summer. Plans are also underway to develop Russian, German, and Czech versions during the next six months.

In addition to the continued development of ImPACT as a concussion management tool, we are also working to develop ImPACT for use in other settings outside of sports medicine. For instance, ImPACT Trauma is now under development, and the introductory research edition of this test battery will undergo field testing in January 2004 at the University of Pittsburgh and several other major trauma centers nationally. Through a grant with the Centers for Disease Control and Prevention, we are also developing a version of ImPACT for use with younger children (6-11 years old).

As we continue to look toward the future, we will continue to rely on your ideas, comments, and criticisms in making the best possible concussion management software.

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Director, UPMC Sports Concussion Program

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ImPACT: Rationale and Description

RATIONALE:

The ImPACT clinical software program is designed to provide sensitive information in the form of cognitive data and symptom reporting in athletes suspected of sustaining a concussion. This information can be used to help determine recovery from injury and safe return to participation. Our approach to managing concussion has been found to be reliable, valid and extremely sensitive in determining when an athlete has recovered sufficiently from a concussion. One of the key factors in determining an athlete's recovery is to compare his/her post-concussive performance and symptoms to baseline (pre-concussion) levels. This is the best method of controlling for individual differences. In order to do this, the athlete must have taken ImPACT prior to sustaining a concussion. However, in the event that baseline testing is not possible, ImPACT has a normative database of thousands of non-injured athletes, and such data can be used effectively for adequate comparison and safe decisions for return to play. Thus, ImPACT may now be used effectively in a clinical setting when baseline data is not available for comparison.

BASELINE ADMINISTRATION

If baseline data is collected, ImPACT should be administered prior to athletic competition. Typically, this can be done at the beginning of preseason training or even a few months prior to season training. It is important to have athletes complete ImPACT before they start any type of contact that might result in a concussion (e.g., hitting drills, scrimmages, etc.). If possible logistically, we recommend that athletes in the sports of football, soccer, lacrosse, basketball, wrestling, field hockey, and hockey receive a baseline evaluation.

POST-CONCUSSION TESTING:

ImPACT should be re-administered if an athlete is suspected of having suffered a concussion, even if it is considered to be mild, without loss of consciousness. ImPACT post-concussion follow-up evaluations can be conducted within 24-72 hours of injury (to help determine severity of injury) and subsequently as needed (e.g. days 5 and 10 post-injury) to help manage the injury and determine return to sport participation. With regards to the testing within 24 hours of the concussion, the athlete must be alert and oriented before taking ImPACT. Please note that while these testing intervals are optimal, the athlete's situation (e.g., other injuries requiring more immediate attention) may make it difficult to follow any specific testing protocol.

TEST ENVIRONMENT:

ImPACT is designed to run using Windows NT or 95 or higher. It will operate using both desk top PCs and laptops with a color monitor/screen. However, if using a laptop, it must be plugged into an electrical outlet. <u>Do not</u> run the laptop off of the battery as this may cause a general failure of the software with some (particularly older) laptops. Also, an external mouse should **always** be utilized to help avoid variability in the some aspects of the data profile. ImPACT can be administered individually or as a group in a computer lab. Although a standard mechanical mouse performs well, an optical mouse may be less subject to failure. The environment should be relatively free of noise and distractions. We have also found that athletes should be separated by at least one seat when doing group administration so as not to distract each other. Administration is relatively self-explanatory but we strongly recommend that all testing sessions be proctored to discourage horseplay. Baseline testing takes approximately 22 minutes. Post-concussion testing takes approximately 18 minutes. Please note that testing an athlete on the same machine, network system, or a system with access to the baseline data will reduce the amount of time it takes to administer a post-concussion session. At the time of post-concussion testing, the computer will search for the baseline data and extract the demographic data, thus bypassing the re-entry of this information. In order to do this appropriately, the specific 9-digit ID # (e.g., Social Security #) and date of birth both need to be entered. Thus, these ID numbers should be inventoried at baseline and readily available when an athlete has sustained a concussion.

REPORT GENERATION:

The procedures for producing a report is as follows: After administration is completed open Tools from the menu bar. Next open Report. In the unsent tab make sure the name of the athlete appears. Click next and then click on the printer image. The report will produce the baseline and the post-concussion data. If you would like graphs printed, you must click on the print graph box, in the Report Generation section.

IMPACT: Program and Test Description

ImPACT, is a user-friendly, Windows-based computer program that can be administered by a properly trained athletic trainer or physician. Reaction time is accurately and reliably measured to one-hundredth of a second across individual test modules (7 modules total) and allows for an assessment of cognitive speed. The test battery consists of a near infinite number of alternate forms by randomly varying the stimulus array for each administration. This feature was built in to the program to minimize the "practice effects" that have limited the usefulness of more traditional neuropsychological tests. ImPACT takes approximately 20 minutes to complete. The program measures multiple aspects of cognitive functioning, including:

- *Attention span*
- *Working memory*
- *Reaction time*
- *Verbal and Visual Memory*
- *Response variability*
- *Non-verbal Problem Solving*

I. Demographic and Background Information

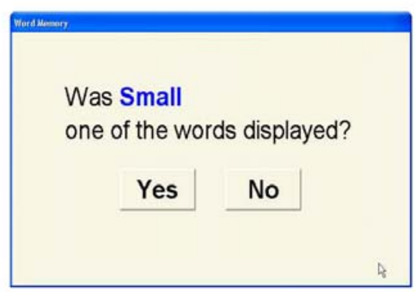
This section of ImPACT requires the subject or proctor to input basic demographic and descriptive information through a series of easy to follow instructional screens. The subject inputs this information via the keyboard and utilizes an external mouse to navigate/select responses on the screen. Many of the questions in this section can be answered through the use of windows "pull down" screens. This section asks the subject to answer questions regarding height, weight, sport, position, concussion history, history of learning disabilities and other important descriptive information. The subject is asked to input a 9 digit ID number, which may be the social security number or other assigned number. This, along with athletes birthdate provides unique identification of each subject within the user's database.

II. Symptoms

This section of ImPACT requires the subject to rate the severity of 22 concussive symptoms (e.g. headache, dizziness, sensitivity to light, etc), via a 7-point Likert scale. Individual scores are provided as well as a graphic representation of the symptom total score. The ImPACT sympom scale is administered at both baseline and post-injury testing sessions so that preexisting and post-injury symptoms may be documented and compared.

III. Neuropsychological Testing: Description of Individual Test Modules

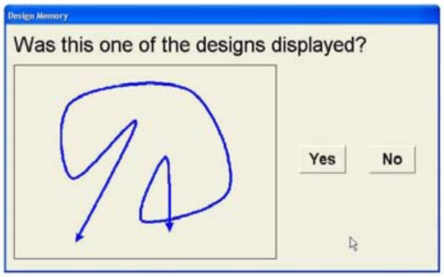
Module 1 (Word Discrimination)



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

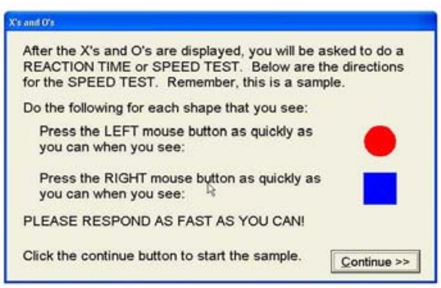
***Delay Condition**: Following the administration of all other test modules (approximately 20 minutes), the subject is again tested for recall via the same method described above. The same scores that are described above are provided for the delay condition.*

Module 2 (Design Memory)



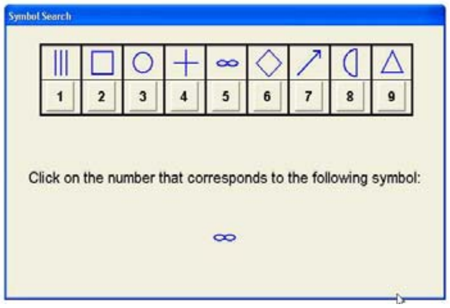
- Evaluates attentional processes and visual recognition memory.
- Includes both immediate and delayed recall conditions.
- An example is included to increase test reliability.
- Utilizes a design discrimination paradigm.
- Twelve target designs are presented for 750 milliseconds (twice to facilitate learning).
- The subject is then tested for recall of the 24-designs.
  - ✓ comprised of 12 target designs and 12 non-target designs.
  - ✓ EX: target designs that have been rotated in space.
  - ✓ The subject responds by mouse-clicking the "yes" or "no" buttons.
  - ✓ Individual scores are provided both for correct "yes" and "no" responses.
  - ✓ In addition, a total percent correct score is provided.
- There are five different forms of this module.

Module 3 (X's and O's)



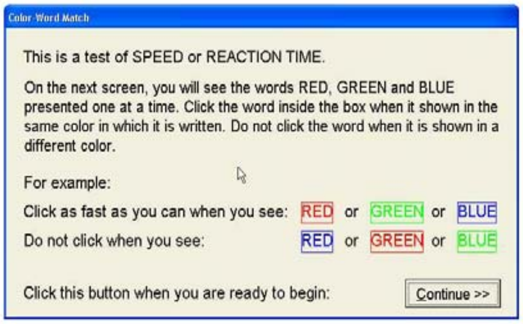
- Measures visual working memory, visual processing speed, and visual memory.
- Incorporates a distractor task following the initial presentation of stimuli.
- An example allows for practice.
- The distractor is a choice reaction time test: the subject is asked to click the left mouse button if a blue square is presented and the right mouse button if a red circle is presented.
- Once the subject has completed this task, the memory task is presented.
  - ✓ Memory task: a random assortment of X's and O's is displayed for 1.5 sec.
  - ✓ For each trial: three of the X's or O's are illuminated in YELLOW (the subject has to remember the location of the illuminated objects).
  - ✓ Immediately after the presentation of the 3 X's or O's, the distractor task re-appears on the screen.
  - ✓ Following the distractor task, the memory screen (X's and O's) re-appears and the subject is asked to click on the previously illuminated X's and O's.
  - ✓ Scores are provided for correct identification of the X's and O's (memory), reaction time for the distractor task, and number of errors on the distractor task.
- For each administration of ImPACT, the subject completes 4 trials.

Module 4 (Symbol Matching)



- Evaluates visual processing speed, learning and memory.
- Initially, the subject is presented with a screen that displays 9 common symbols (triangle, square, arrow, etc).
- Directly under each symbol is a number button from 1 to 9.
- Below this grid, a symbol is presented.
  - ✓ The subject is required to click the matching number as quickly as possible and to remember the symbol/number pairings.
  - ✓ Correct performance is reinforced through the illumination of a correctly clicked number in GREEN. Incorrect performance illuminates the number button in RED.
  - ✓ Following the completion of 27 trials, the symbols disappear from the top grid.
  - ✓ The symbols again appear below the grid and the subject is asked to recall the correct symbol/number pairing by clicking the appropriate number button.
  - ✓ An example allows the athlete to practice the test prior to administration.
- This module provides an average reaction time score and a score for the memory condition.

Module 5 (Color Matching)



- Represents a reaction time task and measures impulse control/response inhibition.
- First, the subject is required to respond by clicking a red, blue or green button as they are presented on the screen. This procedure is completed to assure that subsequent trials will not be affected by color blindness.
- Next, a word is displayed on the screen in the same colored ink as the word (e.g. printed in "RED" ink), or in a different colored ink (printed in "GREEN" or "BLUE").
  - ✓ The subject is instructed to click in the box as quickly as possible only if the word is presented in the matching ink.
- In addition to providing a reaction time score, this task also provides an error score.

Module 6 (Three letters)

- Measures working memory and visual-motor response speed.
- First, the subject is allowed to practice a distractor task that consists of 25 numbered buttons (5 x 5 grid).

  - ✓ The subject is instructed to click as quickly as possible on the numbered buttons in backward order starting with "25." (has an initial practice task).
  - ✓ Then he or she is asked to remember three consonant letters displayed on the screen.
  - ✓ Immediately following display of the 3 letters, the numbered grid re-appears and the subject is instructed to click the numbered buttons in backward order, again.
  - ✓ After a period of 18 seconds, the numbered grid disappears and the subject is asked to recall the three letters by using the keyboard.
  - ✓ Both the number placement on the grid and letters displayed are randomized for each trial.

- Yields a memory score (total number of correctly identified letters) and a score for the average number of correctly clicked numbers per trial from the distractor test.
- Five trials of this task are presented for each administration of the test.

IV. Injury Description

Following the initial evaluation of the athlete following a concussion, the professional who is conducting the evaluation is asked to describe the characteristics of the injury and treatment undertaken, if any. The mouse is used to identify appropriate descriptors of the injury (e.g. duration of loss of consciousness, retrograde amnesia, on-field symptoms) as well as a description of evaluation and treatment, if any (e.g. CT, MRI, emergency room visit, etc.). This section also tracks other potentially important information such as whether or not a dental protection device (mouth guard) was utilized.

V. Composite (Summary) Scores

In addition to the individual scores for each module described above, ImPACT 2.1 also yields summary composite scores for ***Verbal Memory***, ***Visual Memory***, ***Reaction Time***, ***Processing Speed and Impulse Control***. ImPACT 1.0 yields the following composite scores: ***Memory, Reaction Time, Processing Speed, and Impulse Control***.

Following is a summary of the composition of the ImPACT 2.0 and 2.1 composite scores.

- **Verbal Memory Composite** (Higher score is better performance)
- **Visual Memory Composite** (Higher score is better performance)
- **Visual Motor Speed Composite** (Higher score is better performance)
- **Reaction Time Composite** (Lower score is better performance)
- **Impulse Control Composite Score** (Lower score is better performance)

The composite scores were constructed to provide summary information regarding different broad cognitive domains. Thus far, our studies have indicated that all composite scores accurately discriminate concussed from non concussed control subjects.

ImPACT 2.1 has been designed to integrate data from previous versions into the new report format. This allows 1.0 users to keep baseline testing data that was acquired using earlier versions of the software. ImPACT 2.0 and 2.1 software can therefore be installed in the same folder as ImPACT 1.0 and automatically "read" the previous data. In other words, when more recent version of ImPACT is installed on a computer that contains ImPACT 1.0 data, the newer program transfers the ImPACT 1.0 data into the new composite score format.

Numeric Display of Composite Scores (Page 3 of Clinical Report)

ImPACT © Clinical Report
ImPACT Applications

Exam Type:	Baseline	Post-concussion	Post-concussion	Post-concussion
Date Tested:	09/04/02	01/28/03	02/03/03	02/05/03
Last Concussion:		01/27/03	01/27/03	01/27/03
Composite Scores				
Memory composite (Verbal)	96 %	66 %	84 %	90 %
Memory composite (Visual)*	78 %	65 %	61 %	84 %
Visual motor speed composite	32.85	16.05	15.25	32.55
Reaction time composite	0.50	0.63	0.53	0.53
Impulse control composite	7	120	15	9

- Verbal Memory Composite (Higher score is better performance)

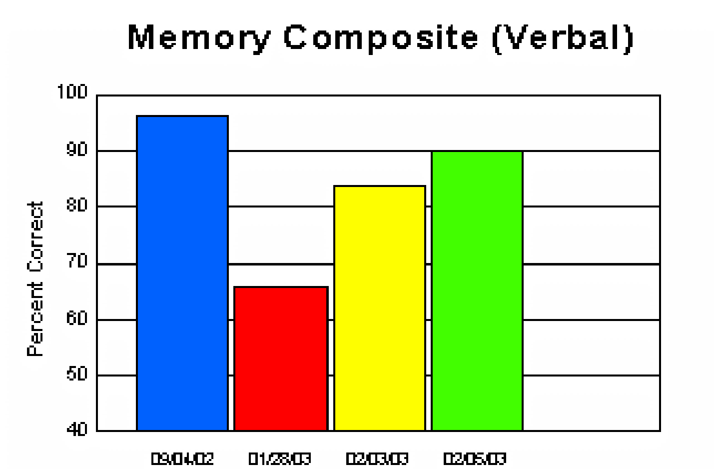
Is comprised of the average of the following scores:

1) Total percent correct score from Module 1 (Word Discrimination).

2) Total correct hidden symbols from Module 4 (Symbol Matching).

3) Percent of total letters correct from Module 6 (3 Letters).

Graphic Display of Verbal Memory Composite



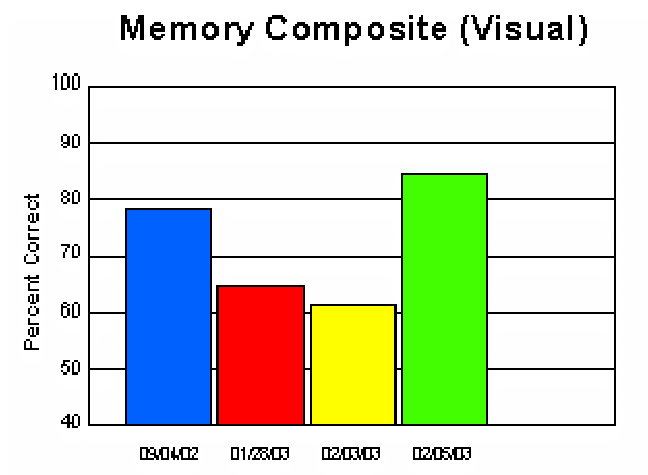
- Visual Memory Composite (Higher score is better performance)

This score is comprised of the average of:

1) Total percent correct score from module 2 (Design Memory).

2) Total correct-memory score from module 3 (X's & O's).

Graphic Display of Visual Memory Composite



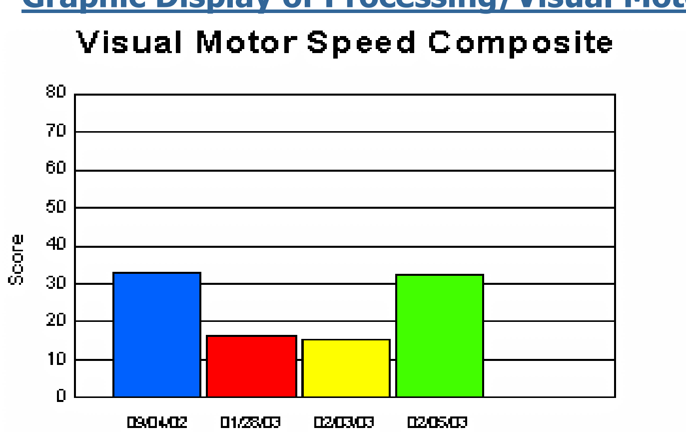
- Processing/Visual Motor Speed Composite (Higher score is better performance)

Is comprised of the average of following scores:

1) Total number correct /4 during interference of module 3 (X's & O's).

2) Average counted correctly x3 from countdown phase of module 6 (3 Letters).

Graphic Display of Processing/Visual Motor Speed Composite



- Reaction Time Composite (Lower score is better performance)

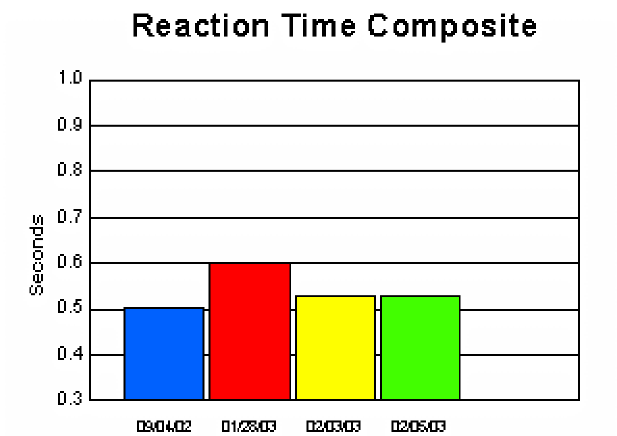
Is comprised of the average of the following scores:

1) Average Correct RT of interference stage of module 3 (X's & O's).

2) Average Correct RT /3 of module 4 (Symbol Match).

3) Average Correct RT of module 5 (Color Match).

Graphic Display of Reaction Time Composite



- Impulse Control Composite (Lower score is better performance)

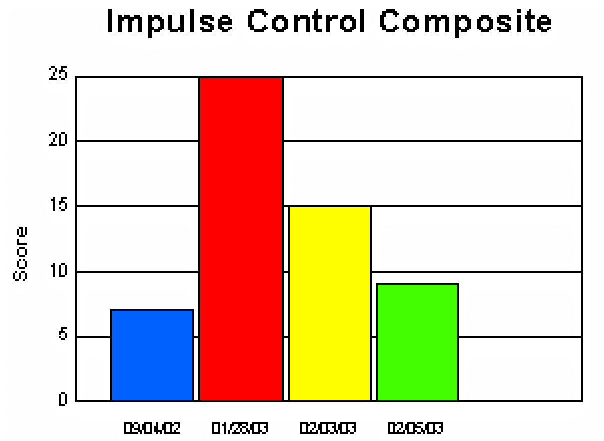
This score indicates the sum of errors committed during certain aspects of the test. This summary score is not intended to be a clinical scale. Rather, the impulse control score indicates how many errors were committed during the test and the general testing approach taken by the patient. High scores (above 20) may suggest carelessness in completing ImPACT. Very high scores (above 20), may suggest confusion between left and right, as measured by the Total Correct-Interference score from the X's and O's module.

The Impulse Control score is obtained by adding:

1) Total errors on the interference phase of module 3 (X's & O's).

2) Total commissions from module 5 (Color Match).

Graphic Display of Impulse Control Composite

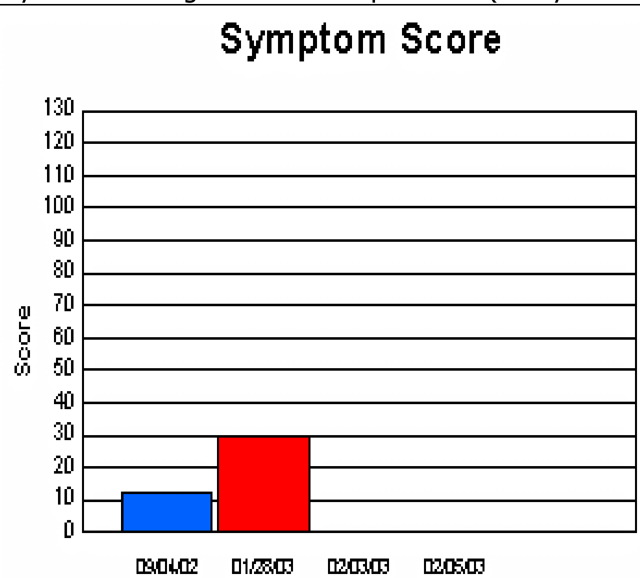


- Total Symptom Composite

On page 4 of the clinical report, a table is displayed indicating each individual symptom and its numeric value as endorsed by the athlete/patient. In addition, a total symptom score is tabulated across all 22 symptoms. A higher score indicates an increase in symptom reporting. This summary score, as well as all other composite scores are also represented graphically on page 5 of the ImPACTclinical report.

Represented symptoms in the ImPACT Concussion Symptom Scale	
✓ Headache	✓ Nausea
✓ Vomiting	✓ Balance Problems
✓ Dizziness	✓ Fatigue
✓ Trouble falling asleep	✓ Sleeping more than usual
✓ Sleeping less than usual	✓ Drowsiness
✓ Sensitivity to light	✓ Sensitivity to noise
✓ Irritability	✓ Sadness
✓ Nervousness	✓ Feeling more emotional
✓ Numbness or tingling	✓ Feeling slowed down
✓ Feeling mentally foggy	✓ Difficulty concentrating
✓ Difficulty remembering	✓ Visual problems (blurry or double vision)

Graphic Display of Total Symptom Composite



Reliability & Validity of ImPACT

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Overview

The purpose of this section is to provide extensive information regarding the psychometric properties of ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing), a computerized neuropsychological test battery designed to assess recovery from sports-related concussion. Test-retest reliability was examined in 49 healthy amateur athletes who completed the battery at least twice, with an average retest interval of 14 days (Range = 7-21). Standard errors of measurement and the standard error of difference were calculated to generate confidence intervals for change, based on reliable change methodology. The internal structure of ImPACT was examined through a series of exploratory factor analyses in large samples of healthy high school students, university students, and concussed amateur athletes (sample sizes ranged from 120 to 800). There were minor variations in the factor structure, based on sample characteristics, but two- or three-factor solutions consistently emerged. Validity was investigated with 120 amateur athletes who completed preseason testing and who were evaluated within three days of sustaining a concussion. Concurrent criterion validity was examined by determining whether the composite scores were sensitive to the acute effects of concussion. Divergent validity was studied through an intercorrelation matrix of the composite scores at preseason and at post injury. Convergent validity was explored by correlating the composite scores with specific items from the post concussion scale, for the post-injury assessment. This series of psychometric analyses demonstrated that ImPACT has well-defined stability and internal structure. The concurrent, divergent, and convergent validity analyses support clinical inferences regarding outcome from concussion in amateur athletes.

Reliability of the Performance Measures

Neuropsychological test scores can be influenced by numerous factors, such as practice effects, regression to the mean, and more random or unpredictable forms of measurement error. Therefore, proper interpretation of the test requires an understanding of the probable range of measurement error that surrounds test-retest difference scores. This allows more precise determinations of deterioration, improvement, and recovery in the initial days following concussion.

The purpose of this study was to examine test-retest reliability and reliable change on the ImPACT composite scores[1]. Participants were 49 amateur athletes who completed the computerized test battery on at least three occasions. The second evaluation was conducted an average of 14 days (Range = 7-21 days) post-baseline. The third evaluation was conducted an average of 4.5 days after the second evaluation (Range = 2-7 days). Their average age was 17.8 years (SD = 2.6, Range = 14 – 23). The male-female gender ratio was 78:22. Fifty-four percent were high school athletes and 46% played college-level sport. The breakdown of athletes by sport was as follows: swimming = 42.9%, football = 32.7%, soccer = 22.4%, and wrestling = 2%.

The standard error of the difference (S_{diff}) can be used to create a confidence interval (i.e., a prediction interval in the statistical literature) for test-retest difference score. Essentially, this confidence interval represents the probable range of measurement error for the distribution of difference scores. The formula for calculating the S_{diff} is printed below.

- $SEM_1 = SD\sqrt{1-r_{12}}$ Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.
- $SEM_2 = SD\sqrt{1-r_{12}}$ Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.
- $S_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$) Square root of the sum of the <u>squared</u> SEMs for each testing occasion.

The confidence interval for the test-retest difference score is obtained by multiplying the S_{diff} by a value from the <u>z</u>-distribution. Multiplying by a value of 1.64, for example, results in a change score in either direction that would be unlikely to occur by chance ($p < .05$ in each tail). Multiplying by a value of 1.28 forms a .80 confidence interval ($p < .10$ in each tail).

[3] This section was derived from a conference handout and article that is currently in preparation.
[4] Iverson, G.L., Lovell, M.R., Collins, M.W., & Norwig, J. (2002). Tracking recovery from concussion using ImPACT: Applying reliable change methodology. Archives of Clinical Neuropsychology, 17, 770.

Results

Parametric and nonparametric test-retest correlation coefficients for multiple time intervals are presented in Table 2. There is considerable variability in the magnitude of the coefficients across the various time intervals. The time 1 to time 2 interval was selected for further analyses. Pairwise t-tests were conducted to determine if there were within-subject changes in level of performance (i.e., practice effects). The descriptive statistics and t-test results are presented in Table 3. There were no significant differences in these analyses, indicating no practice effects on the neuropsychological composite scores.

Table 2. Parametric and Nonparametric Test-Retest Correlation Coefficients.

Composite	Time 1 – Time 2	Time 2 – Time 3	Time 1 – Time 3
Reaction time	.63 (.58)	.62 (.66)	.71 (.74)
Processing speed	.76 (.79)	.86 (.82)	.80 (.81)
Memory	.54 (.36)	.48 (.33)	.40 (.36)

Pearson coefficients are listed first and Spearman coefficients are listed in parentheses.

Table 3. Descriptive Statistics, SEMs, Sdiffs, and Reliable Change Confidence Intervals.

	Time 1		**Time 2**					**Confidence intervals**		
Composite	M	**(SD)**	M	**(SD)**	**p**	**SEM_1**	**SEM_2**	**S_{diff}**	**.80**	**.90**
Reaction time	.57	(.10)	.56	(.09)	.30	.061	.055	.080	.10	.13
Processing speed	35.49	(8.18)	36.86	(9.08)	.12	4.01	4.45	5.99	7.67	9.82
Memory	88.50	(7.34)	89.01	(8.86)	.66	4.99	6.02	7.82	10.01	12.82

SEM = Standard error of measurement and S_{diff} = Standard error of difference

Standard errors of measurement for time 1 and time 2 were calculated using the formula presented in the analyses section. Pearson correlation coefficients were used. The SEMs from time 1 and 2 were used to calculate the standard error of difference for each score. At each step in the calculation of the SEMs and the S_{diffs}, decimals were rounded to two places. The SEMs, S_{diffs}, and .80 and .90 confidence intervals for the test-retest difference scores are presented in Table 3. The reliable change difference scores associated with the two confidence intervals were then applied to the original data. If the distributions of difference scores were perfectly normal, then you would expect to see 10% in each tail for the .80 confidence interval and 5% in each tail for the .90 confidence interval. As seen in Table 4, the percentages of subjects that would be classified as reliably improved or declined was reasonably close to what would be predicted from the theoretical normal distribution.

Table 4. Percentages of the Sample that would be Classified as Reliably Improved or Declined Based on the .80 and .90 Confidence Intervals.

	.80 Confidence interval		.90 Confidence interval	
	Declined	Improved	Declined	Improved
Reaction time	10.2%	8.2%	4.1%	2%
Processing speed	8.2%	8.2%	4.1%	2%
Memory	10.2%	8.2%	2%	6.1%

In the present study, it was unnecessary to make adjustments to the ImPACT composite score reliable change indices because practice effects were not present. ImPACT was designed to reduce practice effects through randomization of stimuli presentation. This was an essential design feature because the battery is intended to be used repeatedly, over short intervals.

This preliminary study was limited by the relatively small sample size. The effect of the heterogeneity of the sample (i.e., high school and college athletes who participated in swimming, football, or soccer) on the test-retest coefficients is unknown. Future research with larger, more homogeneous samples might further refine the interpretation of change on this battery.

With regard to the use of neuropsychological assessment procedures in sports medicine, it is important to stress that the reliable change difference scores are meant to supplement, not replace, clinical judgment. The determination of decline and then subsequent improvement in functioning following concussion is a complex clinical process that involves multiple sources of data. This reliable change methodology simply allows clinicians to estimate the probable range of measurement error surrounding test-retest difference scores. Obviously, it is possible for athletes to experience real decline or improvement even if their scores do not exceed the .80 confidence interval for measurement error. The practitioner simply should have less confidence in clinical inferences based on changes that fall within the probable range of measurement error, and seek more ancillary evidence to support his or her opinion.

Preliminary, Exploratory Factor Analyses of ImPACT (Version 1)

Exploratory factor analyses across multiple samples have yielded roughly similar results. The same method has been applied to multiple groups. Principal Components Analysis with eigenvalues set at 1.0 was used as the extraction method. This was followed by an orthogonal, Varimax rotation.

Sample	N	# of Factors	Variance Explained	Factor Names
Males	1,391	2	42.1%	- Memory - Speed / Reaction Time
Females	355	3	54.0%	- Verbal Memory - Concentration - Speed / Reaction Time
High School Males	588	3	49.1%	- Memory - Speed / Reaction Time
High School Females	119	4	63.8%	- Memory - Speed / Reaction Time
College Males	803	2	44.6%	- Memory - Speed / Reaction Time
College Females	236	3	54.7%	- Verbal Memory - Concentration - Speed / Reaction Time
Concussed Amateur Athletes (Less than 3 days post)	172	2	53.1%	- Memory - Speed / Reaction Time

Factor analyses results are influenced by group composition. Most analyses yielded 2 or 3 factor solutions. These results suggest that there might be a reliable gender difference in the factor structure.
Additional research using more sophisticated analyses is needed.

Validity

The purpose of this study was to examine the validity of ImPACT for measuring the effects of sports-related concussion. Participants were 120 amateur athletes <u>who completed preseason testing and who were evaluated within three days of sustaining a concussion</u> (Mean = 1.4 days post injury). Their average age was 16.9 years (SD = 2.3), and 80% were male. The majority were in high school (77.5%), with the remaining in college. The breakdown of athletes by sport was as follows: football (63.3%), soccer (14.2%), basketball (8.3%), hockey (7.5%), and other (6.7%). The breakdown of athletes by American Academy of Neurology Concussion Grades was as follows: Grade 1 = 70%, Grade 2 = 11.7%, Grade 3 = 10.8%, and insufficient data to classify = 7.5%. This was the first concussion for 57% of the athletes, and 29% reported a history of one or more concussions. Data on previous concussion history was missing for 14%.

Concurrent criterion validity was examined by determining whether the composite scores were sensitive to the acute effects of concussion. The athletes reported significantly more symptoms ($p < .000001$, $d = 1.0$, large effect), and they performed worse on Memory ($p < .000001$, $d = .66$, medium-large effect) and Reaction Time ($p < .014$, $d = .27$, small effect). The athletes did not perform significantly worse on Processing Speed ($p < .07$, $d = .19$, small effect) after their concussions, as compared to preseason testing. These group effects are illustrated in Figures 1-3.

Figure 1
Total - Self-reported symptoms

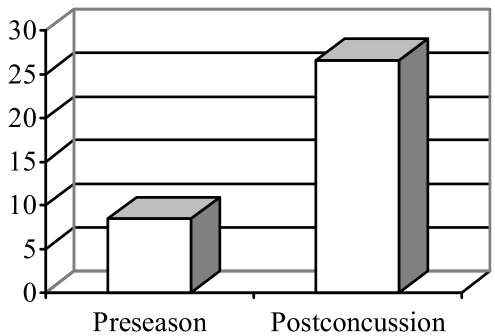


Figure 2.
Memory Index

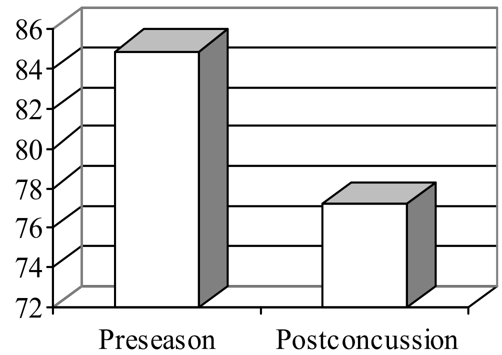
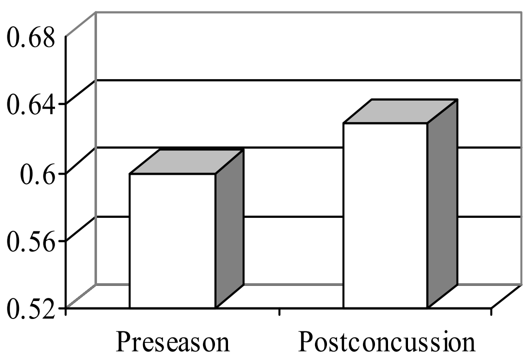


Figure 3. Reaction Time



Divergent validity was examined through an intercorrelation matrix of the composite scores at preseason and at post injury. At preseason, the only statistically significant correlation occurred between the Reaction Time and Processing Speed composites (r = -.35). At post injury, there was a significant correlation between symptoms and Memory (r = -.38), Memory and Reaction Time (r = -.27), Memory and Processing Speed (r = .35), and Reaction Time and Processing Speed (r = -.32). These small correlations indicate that the composite scores do not have much shared variance, and thus appear to be measuring different constructs or abilities.

Convergent validity was examined by correlating the composite scores with specific items from the postconcussion scale, for the post-injury assessment. A subset of physical, cognitive, and emotional symptoms were selected for these analyses. There were medium to high correlations (r's from .53 to .83) between the total symptom score and selected individual items (i.e., vomiting, balance problems, poor concentration, poor memory, light sensitivity, noise sensitivity, and feeling more emotional). The Memory composite score was significantly correlated with the poor memory (r = -.40) and poor concentration (r = -.40) items, slightly less correlated with the balance problems (r = -.27) and light sensitivity (r = -.32) items, and uncorrelated with the remaining physical and emotional items. The Reaction Time composite was not significantly correlated with any of these symptoms. There was a very small correlation between the Processing Speed composite and vomiting (-.19). It is clear that ImPACT is sensitive to the acute effects of concussion in young athletes. This was most apparent on the Postconcussion Symptom Scale (self-reported symptoms) and the Memory composite. The memory composite is comprised of tests believed to measure aspects of concentration and memory.

Reliability of the ImPACT Post-Concussion Symptom Scale

According to classical test theory, obtained scores (or measures) are only estimates of "true" scores because they contain measurement error. Measurement error is closely related to test reliability. Reliability refers to the consistency or stability of test scores. Reliability can be viewed as the ability of an instrument to reflect an individual score that is minimally influenced by error. Reliability should not be considered a dichotomous concept; rather it falls on a continuum. One cannot say an instrument is reliable or unreliable, but more accurately should say it possesses a high or low degree of reliability for a specific purpose, with a specific population (Franzen, 1989, 2000)[1].

The Post Concussion Symptom Scale is a 22-item scale designed to measure the severity of symptoms in the acute phase of recovery from concussion (Lovell & Collins, 1998). An earlier version of this scale has been used with large samples of professional and collegiate football players (Lovell, 1996; Collins et al., 1999). The version of the scale administered for this research project is reprinted in this document.

The Post Concussion Symptom Scale is essentially a "state" measure of perceived symptoms associated with concussion. That is, the athlete is asked to report his or her "current" experience of the symptoms. This allows tracking of symptoms over very short intervals, such as consecutive days or every few days.

Sample

A sample of 2,304 high school and university students was used for this project. The vast majority of subjects were healthy at the time of their evaluations (i.e., 894 high school students and 1,295 university students). In addition, a sample of 115 high school and university athletes in the acute recovery period from concussion were examined (i.e., within 3 days).

Preliminary analyses showed that women tend to report more symptoms than men. Moreover, young people with a self-reported history of learning or speech problems, or special education placement, reported more symptoms than those without this history. Therefore, psychometric analyses were stratified by level (high school / university), gender, and learning / special education status.

The "regular education" samples were comprised of 588 high school boys, 119 high school girls, 803 university men, and 236 university women. The special education samples were comprised of 156 high school boys, 31 high school girls, 196 university men, and 60 university women.

It is important to note that inclusion in the so-called "special education" groups does not mean that the person (a) had a formally diagnosed learning disability, or (b) attended special education classes or programs. All subjects who self-reported any past speech therapy, learning problems (e.g., reading or math), ADHD, or special education placement were included in these groups.The concussed athletes were all evaluated within 3 days of injury. The sample was comprised of 83 young men and 32 young women.

[1] *Franzen, M.D. (1989). Reliability and validity in neuropsychological assessment. New York: Plenum Press.*
Franzen, M.D. (2000). Reliability and validity in neuropsychological assessment. (2nd Edition) New York: Kluwer Academic/Plenum Press.

Post-Concussion Symptom Scale

Directions: After reading each symptom, please circle the number that best describes the way you have been feeling **today**.

Symptom	Minor		Moderate		Severe	
Headache	1	2	3	4	5	6
Nausea	1	2	3	4	5	6
Vomiting	1	2	3	4	5	6
Balance Problems	1	2	3	4	5	6
Dizziness	1	2	3	4	5	6
Fatigue	1	2	3	4	5	6
Trouble Falling Asleep	1	2	3	4	5	6
Sleeping More Than Usual	1	2	3	4	5	6
Sleeping Less Than Usual	1	2	3	4	5	6
Drowsiness	1	2	3	4	5	6
Sensitivity to Light	1	2	3	4	5	6
Sensitivity to Noise	1	2	3	4	5	6
Irritability	1	2	3	4	5	6
Sadness	1	2	3	4	5	6
Nervousness	1	2	3	4	5	6
Feeling More Emotional	1	2	3	4	5	6
Numbness or Tingling	1	2	3	4	5	6
Feeling Slowed Down	1	2	3	4	5	6
Feeling Mentally "Foggy"	1	2	3	4	5	6
Difficulty Concentrating	1	2	3	4	5	6
Difficulty Remembering	1	2	3	4	5	6
Visual Problems	1	2	3	4	5	6

Subjects checked a box if they were "not experiencing the symptom."

Descriptive Statistics & Psychometric Analyses for Post-Concussion Symptom Scale

Descriptive statistics and psychometric analyses are provided in Table 1. The mean, median, standard deviation, interquartile range, and range of total scores, for each group, are presented. As seen from the measures of central tendency (mean and median) and the ranges, the distributions of total symptom scores are clearly skewed. The distribution of scores for the clinical sample is not severely skewed.

Table 1. Descriptive and psychometric analyses.

Group	N	Mean	Median	SD	IQR	Range	Alpha	SEM	Confidence Interval .80	.90
High School – Regular Education										
Boys	588	4.8	2	7.9	0-6	0-54	.89	2.62	3.35	4.30
Girls	119	7.7	3	13.7	0-9	0-78	.94	3.36	4.30	5.50
High School – Special Education										
Boys	156	8.8	3	13.0	0-11	0-64	.92	3.68	4.71	6.03
Girls	31	5.3	3	6.3	1-8	0-26	.75	3.15	4.03	5.17
College – Regular Education										
Young Men	803	4.5	2	7.5	0-6	0-56	.88	2.60	3.33	4.26
Young Women	236	8.0	5	10.3	0-10	0-55	.88	3.57	4.57	5.85
College – Special Education										
Young Men	196	9.9	5	13.5	0-13	0-63	.91	4.05	5.18	6.64
Young Women	60	9.8	7	11.4	2-14	0-55	.91	3.42	4.38	5.61
Athletes with Concussions										
Young Men	83	26.8	22	20.2	10-39	0-81	.92	5.71	7.31	9.37
Young Women	32	35.8	29.5	25.2	18-57	2-95	.94	6.17	7.90	10.12
Total Sample	115	29.3	25	22.0	11-43	0-95	.93	5.82	7.45	9.55

Post-Concussion Sympotm Scale: Reliability

The internal consistency reliability of the scale was estimated using Cronbach's alpha (Cronbach, 1951). As seen in Table 1, internal consistency reliability ranged from .88 - .94 in the large samples of high school and college regular education students. The small sample of high school girls in special education (n = 31) had a lower reliability estimate (α = 0.75), but the other three larger samples of special education students had high reliability estimates (.91 - .92). The internal consistency reliability for the clinical sample of 115 concussed athletes also was high (α = 0.93).The standard error of measurement (SEM) is considered an estimate of measurement error in a person's observed test score. Typically, SEMs are calculated in standard deviation units using the formula below. SEMs are calculated in three steps. First, the reliability coefficient is subtracted from one. Second, the square root of this value is obtained. Third, this square root is multiplied by the sample standard deviation. SEMs for the different groups also are presented in Table 1. These SEMs were used to create confidence intervals. A confidence interval represents a range or band of scores, surrounding an observed score, in which the individual's "true" score is believed to fall. The 80% (.80) confidence interval is obtained by multiplying the SEM by a z-score of 1.28 and the 90% (.90) confidence interval is obtained by multiplying the SEM by a z-score of 1.64. For college men, the 80% confidence interval for the total score is approximately +/- 4 points (i.e., 3.3) and the 90% confidence interval is approximately +/- 5 points (i.e., 4.26).

Interpreting Change on ImPACT (Version 2.0) Following Sport Concussion

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Abstract

The purpose of this study was to examine the psychometric characteristics of Version 2.0 of ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing). The focus was on the stability of the test scores and the calculation of reliable change confidence intervals for the test-retest difference scores. A sample of 46 non-concussed adolescents and young adults completed the test battery on two occasions. Test-retest coefficients, reliable change difference scores, and confidence intervals for measurement error are provided. These reliable change parameters were applied to a second sample of 41 concussed amateur athletes who were tested preseason and within 72 hours of injury. Applying these confidence intervals allows more precise determinations of deterioration, improvement, and recovery in the initial days following concussion.

Interpreting Change on ImPACT Following Sport Concussion

Estimating change is the foundation of clinical neuropsychology. Every neuropsychological evaluation includes a careful determination of change. Typically, we try to estimate decline in functioning that can be attributed to a brain injury, condition, or disease. Other evaluations are undertaken to assess interval change. Neuropsychological assessment can be very useful for tracking recovery from a traumatic brain injury or a stroke, or for monitoring progression of a dementing disease such as Alzheimer's. For practical, clinical, and economic reasons, follow-up evaluations typically are conducted after 6 – 24 months.

Sports neuropsychology is relatively unique in that cognitive assessments often occur over very brief retest intervals to facilitate decisions regarding returning an athlete to practice and competition. This creates special challenges relating to estimating change. For example, the phenomenon under study, the effects of concussion on cognitive functioning, is rapidly changing. The accuracy with which we can assess this phenomenon is related to the sensitivity of the measures, and, of course, their reliability.

The purpose of this study was to provide detailed information regarding the interpretation of change on Version 2.0 of ImPACT. Test scores can be influenced by numerous factors, such as practice effects, regression to the mean, and more random or unpredictable forms of measurement error. Therefore, proper interpretation of the test requires an understanding of the probable range of measurement error that surrounds test-retest difference scores. This allows more precise determinations of deterioration, improvement, and recovery in the initial days following concussion. First, test-retest reliability, practice effects, and reliable change parameters were estimated in a sample of healthy young people who completed the battery over a brief retest interval (i.e., approximately 5 days). Second, the derived reliable change parameters were applied to a sample of amateur athletes who underwent preseason testing and were re-evaluated within 72 hours of sustaining a concussion.

Method

Participants & Procedures

Two distinct samples were used for this study. The first sample was comprised of 46 adolescents and young adults who completed Version 2.0 of ImPACT twice for the purpose of a test-retest study. There were equal numbers of males and females (i.e., 23 each). Their average age was 17.9 years (SD = 1.7, Range = 15 – 22). Approximately 59% were in high school and 41% were in university. The average retest interval was 5.3 days (median = 5, SD = 2.8, Range = 1-13). Approximately 33% were retested within 3 days, 50% within 4 days, 89% within 7 days, and 96% within 10 days.

The second sample was comprised of 41 amateur athletes who sustained a sports-related concussion. All athletes completed ImPACT at the beginning of the season. All were retested within 72 hours of their concussions (mean = 1.3 days, median = 1 day, SD = .7 days). This sample was 90% male. Their average age was 16.8 years (median = 16, SD = 2.4, range = 13-22). Approximately 71% were in high school and 29% were in university. The vast majority of athletes were football players (88%), with small numbers of athletes in other sports such as hockey, soccer, basketball, and wrestling. Most athletes had sufficient information to classify the severity of their concussions using the American Academy of Neurology Concussion Grading System (Quality Standards Subcommittee, 1997). Approximately 54% had Grade I Concussions, 22% had Grade II Concussions, and 7% had Grade III Concussions. Missing data prevented the confident classification of 17% (i.e., 7 athletes).

Measure

Version 2.0 of ImPACT is a computer administered neuropsychological test battery that consists of six individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed. The battery also contains a post-concussion symptom scale. Five composite scores were used for this study. The Verbal and Visual memory composites are omnibus, relatively domain-specific measures of working memory, immediate memory, and delayed memory.

Design & Analysis

The first set of analyses are based on the healthy young people tested twice. This is a within subjects design. Relative position across the two distributions were examined with a Pearson correlation. Level of performance within subjects were examined with dependent t-tests. Reliable change estimates were derived from a modification of the method proposed by Jacobson and Truax (1991). This methodology has been used extensively in clinical psychology (Hageman & Arrindell, 1993; Hsu, 1989; Jacobson & Revenstorf, 1988; Jacobson, Roberts, Berns, & McGlinchey, 1999; Ogles, Lambert, & Masters, 1996; Speer, 1992; Speer & Greenbaum, 1995), clinical neuropsychology (Chelune, Naugle, Luders, Sedlak, & Awad, 1993; Heaton et al., 2001; Iverson, 1998, 1999, 2001; Temkin, Heaton, Grant, & Dikmen, 2000), and sports neuropsychology (Barr & McRea, 2001; Hinton-Bayre, Geffen, Geffen, McFarland, & Friis, 1999; Iverson, Lovell et al., 2002). The reliable change methodology allows the clinician to estimate measurement error surrounding test-retest difference scores. Specifically, the standard error of difference (S_{diff}) is used to create a confidence interval for the baseline-retest difference score. The steps for calculating the S_{diff} are provided below.

- $SEM_1 = SD\sqrt{1-r_{12}}$ Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.
- $SEM_2 = SD\sqrt{1-r_{12}}$ Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.
- $S_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$ Square root of the sum of the squared SEMs for each testing occasion.

The reader should note that the formula used in this study for calculating the Sdiff uses the SEM for baseline and retest, whereas many past studies have used an "estimated" Sdiff by simply multiplying the baseline SEM by two (i.e., $\sqrt{SEM_1^2}$). The estimated Sdiff should only be used when retest data are not available (Hageman & Arrindell, 1993; Iverson 1998, 2001). Several refinements and modifications to the reliable change methodology have been debated in the literature (Hageman & Arrindell, 1993, 1999a, 1999b; Hsu, 1989, 1999; Speer, 1992; Speer & Greenbaum, 1995). The issues are far from resolved. We chose to use the reliable change method that corrects for practice (Chelune et al., 1993; Iverson & Green, 2001), when practice effects are present.

Results

Descriptive statistics for the healthy young people tested twice are presented in Table 1. The Pearson test-retest correlation coefficients for the composite scores were as follows: Verbal Memory = .56, Visual Memory = .59, Reaction Time = .78, Processing Speed = .84, and Post-Concussion Symptom Scale = .63. The standard errors of measurement (SEMs), standard errors of difference (Sdiffs), and reliable change confidence intervals also are presented in Table 1. The probable ranges of measurement error for the ImPACT composites are as follows: Verbal Memory Composite = 7.24 points, Visual Memory Composite = 10.82 points, Reaction Time Composite = .05 seconds, Procession Speed Composite = 3.96 points, and Post-Concussion Scale 7.49 points. The 80% confidence intervals for estimating change are as follows: Verbal Memory ≥ 10 points, Visual Memory ≥ 14 points, Reaction Time > .06 seconds, Processing Speed ≥ 5 points, and Post-concussion Total Scores ≥ 10 points.

Table 1. Descriptive Statistics, SEMs, S_{diffs}, and Reliable Change Confidence Intervals

	Time 1		Time 2						Confidence intervals	
Composite	M	(SD)	M	(SD)	p	SEM_1	SEM_2	S_{diff}	.80	.90
Verbal Memory	89.35	(7.95)	88.76	(7.48)	.59	5.27	4.96	7.24	9.27	11.87
Visual Memory	78.50	(12.24)	78.13	(11.66)	.82	7.84	7.47	10.82	13.86	17.75
Reaction time	.555	(.086)	.541	(.065)	.07	.04	.03	.05	.06	.08
Processing speed	40.03	(7.37)	41.95	(6.62)	.002	2.95	2.65	3.96	5.07	6.50
Post-Concussion Scale	5.26	(6.99)	5.37	(10.14)	.93	4.25	6.17	7.49	9.59	12.29

SEM = Standard error of measurement and S_{diff} = Standard error of difference

Level of performance was compared using paired samples t-tests. There were no within group differences for Verbal Memory [$t(45) = .55$, $p < .59$], Visual Memory [$t(45) = .23$, $p < .82$], Reaction Time [$t(45) = 1.84$, $p < .08$], or total symptoms [$t(45) = -.09$, $p < .93$]. There was a significant difference between baseline and retest on the Processing Speed Composite [$t(45) = -3.22$, $p < .003$, $d = .27$, small effect size]. On average, there was a two point practice effect for the Processing Speed Composite. Approximately 70% of the sample was faster at retest than at baseline.

The reliable change difference scores associated with the two confidence intervals were applied to the original data. If the distributions of difference scores were perfectly normal, then you would expect to see 10% in each tail for the .80 confidence interval and 5% in each tail for the .90 confidence interval. As seen in Table 2, the percentages of subjects that would be classified as reliably improved or declined was reasonably close to what would be predicted from the theoretical normal distribution.

Table 2. Percentages of the Sample that would be Classified as Reliably Improved or Declined Based on the .80 and .90 Confidence Intervals.

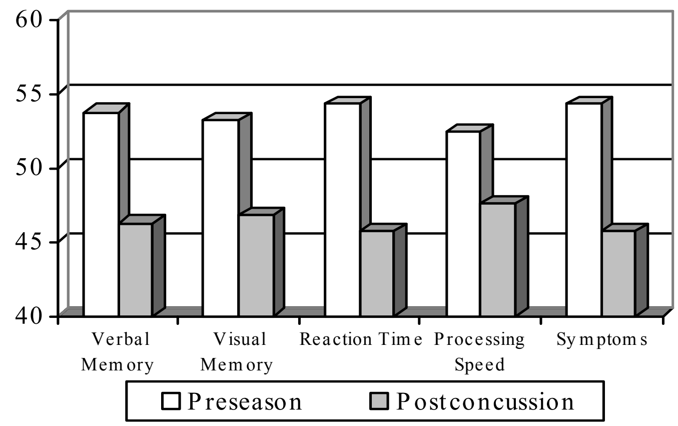
	.80 Confidence interval		.90 Confidence interval	
	Declined	Improved	Declined	Improved
Verbal Memory	10.9%	13%	2.2%	2.2%
Visual Memory	10.9%	10.9%	2.2%	4.3%
Reaction time	2.2%	10.9%	2.2%	8.7%
Processing Speed*	8.7%	10.9%	4.3%	6.5%
Post-Concussion Scale	10.9%	8.7%	8.7%	4.3%

*The confidence intervals for the Processing Speed composite were adjusted for a 2-point practice effect.

The number of scores that reliably declined for each subject was computed. A decline was defined as reliably lower verbal or visual memory, slower processing speed or reaction time, or greater symptoms at retest versus baseline (80% confidence interval). The percentages of subjects showing declines across the five composite scores are as follows: no declines = 63.0%, one decline = 30.4%, two declines = 4.3%, and 3 declines = 2.2%.

The sensitivity of the composite scores to the acute effects of concussion was estimated in the sample of 41 amateur athletes who were tested preseason and within 72 hours of injury. The athletes demonstrated a significant decline in Verbal Memory (baseline M = 84.9, SD = 7.2; postconcussion M = 76.8, SD = 12.6; $p < .0002$, d = .82, large effect size) and Visual Memory (baseline M = 75.7, SD = 12.3; postconcussion M = 66.4, SD = 14.7; $p < .0002$, d = .69, medium-large effect size). They also demonstrated significantly slower Processing Speed (baseline M = 36.9, SD = 6.8; postconcussion M = 33.1, SD = 8.8; $p < .006$, d = .49, medium effect size), and Reaction Time (baseline M = .56, SD = .08; postconcussion M = .65, SD = .11; $p < .00005$, d = .95, large effect size). The athletes also demonstrated a large increase in symptom reporting (baseline M = 8.2, SD = 10.7; postconcussion M = 24.3, SD = 21.7; $p < .00001$, d = .99, large effect size). These findings are illustrated in Figure 1.

Figure 1.
Comparison of preseason and post-injury scores on the five composites transformed into uniform T-scores.



Note: These T-scores are not normative T-scores. They are standardized scores. The distributions of baseline and postconcussion scores for each composite were standardized with a mean of 50 and a standard deviation of 10. The direction of the symptom score and the reaction time score was reversed, so that lower T-scores represent worse scores. Thus, all five composites can be compared graphically on a common metric.

The 80% confidence interval for estimating reliable change was applied to each of the concussed athlete's composite scores. The confidence interval for Processing Speed was adjusted by two points for the presumed practice effect. The breakdown of reliable change for each composite score was as follows: Verbal Memory, 39% declined, 7.3% improved; Visual Memory, 41.5% declined, 2.4% improved; Reaction Time, 51.2% declined, 7.3% improved; Processing Speed, 41.5% declined, 4.9% improved; Post-Concussion Scale, 53.7% reported more symptoms, 2.4% reported fewer symptoms.

The number of scores that reliably declined for each subject was computed. A decline was defined in the same manner as it was for the healthy test-retest sample. The percentages of athletes showing declines across the five composite score are as follows: no declines = 24%, one decline = 12.2%, two declines = 19.5%, three declines = 12.2%, four declines = 19.5%, and five declines = 12.2%. Athletes with concussions are much more likely to have two or more declines across the five composites than the healthy subjects [63.4% versus 6.5%; $\chi^2(1, 87) = 31.6$, $p < .00001$; Odds Ratio = 24.8, 95% CI = 6.6 – 94.1].

Discussion

This study illustrates important aspects of the psychometric properties of Version 2.0 of ImPACT. When evaluating changes in neurocognitive performance following concussion, it is critically important to understand the probable range of measurement error surrounding test-retest difference scores to more accurately document deterioration from preseason testing and recovery during the initial days post-injury.

In the present study, we made adjustments to the ImPACT Processing Speed composite score reliable change indices because practice effects were present. It was not necessary to adjust the other composite scores because practice effects were not identified. ImPACT was designed to reduce practice effects through randomization of stimuli presentation. This was an essential design feature because the battery is intended to be used repeatedly, over short intervals. A quick reference guide for estimating change on the composite scores is presented in Table 3.

Table 3. Quick Reference Reliable Change Estimates: 80% confidence Interval.

Composite	Declined	Improved
Verbal Memory	10 points	10 points
Visual Memory	14 points	14 points
Reaction Time	.07 seconds	.07 seconds
Processing Speed	3 points	7 points
Post-Concussion Scale	10 points	10 points

In the second part of this study, preseason and postconcussion scores were examined for 41 concussed athletes. As a group, these athletes demonstrated a large change in verbal memory, reaction time, and self-reported symptoms. They experienced a medium-to-large change in visual memory and processing speed.

When the reliable change methodology was applied to the concussed athletes, 39% - 54% showed statistically reliable declines across the five individual composite scores. Athletes with concussions were 25 times more likely to have 2 or more declines across the five composites than non-concussed subjects tested twice. Clearly, the computerized screening battery is sensitive to the acute effects of concussion, and a large percentage of athletes show substantial changes in functioning in the first few days post injury. This sensitivity to the acute effects of concussion is consistent with research with version 1.0 of ImPACT (Collins et al., 2001; Iverson et al., 2002a; Lovell et al., 2003; Lovell et al., 2003).

This was a preliminary study designed to investigate reliable change on Version 2.0 of ImPACT. It is limited by the relatively small sample size. The effect of the heterogeneity of the sample (i.e., high school and college students) on the test-retest coefficients is unknown. Future research with larger, more homogeneous samples might further refine the interpretation of change on this battery.

Another limitation in this study is the retest interval. This interval was very short. Thus, it is relevant for post-concussion testing over at least one, short interval. However, it is possible that the reliable change estimates would change over a longer interval, such as from preseason to post-concussion. This limits the external validity of these results because the brief retest interval in healthy subjects was used to estimate reliable change in healthy then concussed athletes tested at a longer interval. It is also possible that the practice effect seen on the Processing Speed composite might diminish or disappear over a longer retest interval.

Estimating reliable change on cognitive tests and psychological inventories is a difficult process with several unresolved methodological issues. It is beyond the scope of this paper to provide a detailed discussion of these issues. Instead, three practical methodological issues will be presented. First, there is the statistical issue of regression to the mean and the practical issue of an unusually good or unusually poor performance. As a general rule, extreme scores are likely to be less extreme at retest. The reliable change methodology essentially averages this phenomenon into the measurement error estimate. The end result is that the reliable change estimate is optimized for the entire sample but is not as accurate for subsamples, such as the top 20%, middle 60%, and bottom 20% of scores. In other words, one of the most important predictors of a retest score is the level of the baseline score (Sawrie, Chelune, Naugle,, & Luders, 1996; Temkin et al., 2000). Optimally, reliable change estimates would be based on large samples of more homogeneous baseline scores.

Second, it is most common to present 90% or 95% confidence intervals for reliable change. This is a sensitivity and specificity issue. Do we really want to be 95% sure that the change observed is not due to possible measurement error, leaving only 2.5% in each tail? Under many clinical circumstances we want to adopt a more liberal statistical criterion so that we are more likely to identify real change when it occurs. That is why the 80% confidence interval was emphasized in this study and in previous work (Iverson, 1999, 2001; Iverson & Green, 2001).

Third, the issue of practice effects is important (Chelune et al., 1993), yet complicated. Is it appropriate to correct all scores for an "average" practice effect? What if 55% of subjects score higher at retest and 15% score substantially higher? Correcting for the average practice effect might not be optimal for a large percentage of these subjects. Iverson and Green (2001) recommended correcting for the average practice effect if 75% or more of the sample had a higher score, of any magnitude, at retest. This approach, of course, has limitations too, and more research, especially with regression modeling of large representative samples over relevant retest intervals, is needed.

With regard to the use of neuropsychological assessment procedures in sports medicine, it is important to stress that the reliable change difference scores are meant to supplement, not replace, clinical judgment. The determination of decline and then subsequent improvement in functioning following concussion is a complex clinical process that involves multiple sources of data. This reliable change methodology simply allows clinicians to estimate the probable range of measurement error surrounding test-retest difference scores. Obviously, it is possible for athletes to experience real decline or improvement even if their scores do not exceed the .80 confidence interval for measurement error. The practitioner simply should have less confidence in clinical inferences based on changes that fall within the probable range of measurement error, and seek more ancillary evidence to support his or her opinion.

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

Normative Data

Versions 2.0 and 2.1 Only - 2003

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1. Introduction

Purpose

The purpose of this section is to provide normative data for ImPACT Version 2.0 (Immediate Post-Concussion Assessment and Cognitive Testing). ImPACT is a computerized neuropsychological test battery developed specifically for the evaluation of sports concussion.

Description of Test

ImPACT is a computer administered neuropsychological test battery that consists of 6 individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed (see Table 1). Some of these test modules have two distinct subtests that measure different cognitive functions (e.g., working memory and processing speed).

Table 1. ImPACT Neuropsychological Test Modules.

Test Module	Ability Areas
Word Memory	Immediate and delayed memory for words
Design Memory	Immediate and delayed memory for designs
X's and O's	Attention, concentration, working memory, reaction time
Symbol Match	Visual processing speed, learning and memory
Color Match	Focused attention, response inhibition, reaction time
Three Letters	Attention, concentration, working memory, visual-motor speed

Results from above tests are computed into composite scores.

Computation of COMPOSITE SCORES

Verbal Memory Composite Score

Average of these scores:

- Word Memory total percent correct (immediate + delay) / 2
- Symbol Match (hidden symbols)/9*100
- Three letters Total letters correct

Visual Memory Composite Score

Average of these scores:

- X's and 0's Total correct (memory)/12*100
- Design memory-total percent correct (immediate + delay) / 2

Reaction Time Composite Score

Average of these scores:

- X's and 0's average correct RT
- Symbol Match average correct RT/3
- Color Match average correct RT

Processing Speed Composite Score

Average of the following scores:

- X's and 0's-total correct (interference) total/4
- Three letters-average counted correctly*3

Impulse Control Composite Score (experimental; not normed yet)

Sum of the following scores:

- X's and 0's-total incorrect –interference
- Color match total commissions

Conceptualizing normative scores

The profession of clinical neuropsychology has a long history of over-pathologizing test scores. The most obvious and pervasive example is the use of the term "impaired." It is extremely common for researchers to state that a specific group of patients has impaired cognitive abilities because, as a group, they had statistically lower scores than a group of control subjects. This often occurs when the effect sizes for these differences are small or modest. Moreover, it is frequently the case that the mean scores for the patient group on various neuropsychological tests, although lower than the control group, still fall in the average or low average classification range; thus, they represent a presumed lowering, decline, diminishment, or decrement in performance, but not impairment.

Although it can be argued that the term impairment simply refers to a negative change in function, for most people the term carries much more serious connotations. This is a particularly important issue when working with people who have sustained mild injuries or disease processes that could have affected their brains. Neuropsychologists must guard against iatrogenesis (i.e., health care providers making the problem worse). It is quite possible that by over-pathologizing test scores, the health care provider can inadvertently make the patient worse. Focusing, dwelling, and worrying about symptoms and "brain damage" can magnify them and protract the recovery period. Having stated this, it is important to accurately detect change that has occurred, and to determine whether this is a statistically and clinically meaningful change.

A basic conceptualization of initial level of performance is provided below. Standardized tests yield scores that fall within certain classification ranges. The following classification ranges and their corresponding percentile rank ranges are commonly used, although not universally accepted: Mildly Impaired < 2nd percentile; Borderline 3rd – 9th percentile; Low Average 10th – 24th percentile; Average 25th – 75th percentile; High Average 76th – 90th percentile; Superior 91st – 98th; Very Superior > 99th percentile. Thus, if an individual obtained a score at the 42nd percentile, this would mean that his performance would be greater than or equal to 42% of his same-aged peers in the general population, and that his score would fall in the Average classification range.

Different normative scores and their corresponding descriptors (i.e., their classification ranges) are illustrated in Table 2. It is important to note that there is not precise agreement in our profession as to where exactly the cutoffs should fall between certain classification ranges (e.g., some may call a percentile rank of 9 low average instead of borderline, because it corresponds to an IQ of 80). There is also disagreement as to the three "impaired" classification ranges. The system below is similar to the more traditional IQ classifications corresponding to mild, moderate, and severe mental retardation.

Table 2. Normative scores and classification ranges in neuropsychology				
Descriptor / Classification Range	Scaled Scores M=10, SD=3	IQs/Index Scores M=100, SD=15	T-Score M=50, SD=10	Percentile Rank
Severely Impaired	<1	<55	<20	<.13
Moderately Impaired	1	55-59	20-23	.13 - .35
Mildly Impaired	2 – 4	60 – 69	24 – 29	.38 – 1.9
Borderline	5 – 6	70 – 79	30 – 36	2 - 9
Low Average	7	80 – 89	37 – 43	10 - 24
Average	8 – 12	90 - 109	44 – 56	25 - 75
High Average	13	110 - 119	57 - 63	76 - 90
Superior	14 - 15	120 - 129	64 - 69	91 - 97
Very Superior	16 - 19	130+	70+	98+

2. Normative Data for High School Students

Purpose

Initial analyses were based a sample of 545 adolescents between the ages of 13 and 18, inclusive. A portion of these subjects reported some history of education-related problems, such as reading, math, or spelling difficulty; special education placement; or attention-deficit disorder. Athletes with any self-reported history of this nature were compared to those without a self-report history. The groups differed on the Verbal Memory Composite ($p < .006$; $d = .32$), Visual Memory Composite ($p < .006$; $d = .31$), Processing Speed Composite ($p < .002$; $d = .37$), and Reaction Time Composite ($p < .045$; $d = .24$). Therefore, subjects with a self-reported history of one or more of these problems were dropped from the normative sample.

The remaining subjects were 341 boys and 83 girls. The girls performed better on the Verbal Memory Composite ($p < .01$, $d = .32$), and there was a trend toward better performance on the Processing Speed Composite ($p < .055$, $d = .24$). Therefore, the normative data needed to be presented by gender.

The sample of 424 subjects was analyzed for age effects. The breakdown of subjects by age was as follows: 13 = 23, 14 = 122, 15 = 87, 16 = 87, 17 = 61, and 18 = 44. There was a significant main effect for age on the Processing Speed Composite ($p < .00001$) and the Reaction Time Composite ($p < .03$). Tukey planned comparisons revealed significantly higher Processing Speed scores for 16, 17, and 18 year olds compared to 13 and 14 year olds. There were no other differences. Tukey planned comparisons revealed no pairwise differences on the Reaction Time Composite.

The sample was sorted into two groups, those between the ages of 13 and 15 and those between the ages of 16 and 18. The 15 year olds were included with the 13-14 year olds because they did not differ from younger or older subjects. The sample was then sorted by gender, and age-group comparisons were run. For the boys, the older subjects (aged 16-18) performed better on the Processing Speed Composite ($p < .00001$, $d = .58$), Reaction Time Composite ($p < .0009$, $d = .37$), and the Impulse Control Composite ($p < .004$, $d = .32$). There were no differences attributable to age among the girls, although the sample sizes, and thus power, were much smaller.

The normative tables are based on 183 boys between the ages of 13 and 15, 158 boys between the ages of 16 and 18, and 83 girls between the ages of 14 and 18. Normative data are based on the natural distributions of scores within these two samples.

The distributions of scores within these groups were examined and exact percentile ranks corresponding to the natural distribution of scores were assigned. Thus, these could be considered uniform percentile ranks. The distributions were not force-normalized, nor were raw scores converted to standard scores.

Norms for Boys Ages 13 – 15 (N = 183)

Table 3. Approximate Classification Ranges for Index Scores: Boys Ages 13 – 15

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 63	≤ 49	≤ 16.2	≥ .76
Borderline	64 – 73	50 – 60	16.3 – 24.2	.75 - .67
Low Average	74 – 79	61 – 68	24.3 – 30.1	.66 - .61
Average	80 – 92	69 – 86	30.2 – 37.8	.60 - .53
High Average	93 – 96	87 – 93	37.9 – 44.2	.52 - .49
Superior	97 – 99	94 – 97	44.3 – 50.2	.48 - .45
Very Superior	100	98 – 100	≥ 50.3	≤ .44

Sometimes it is useful to know if an athlete performs particularly poorly on a specific subtest. Cutoff scores for the 10th percentile and the 2nd percentiles for 11 scores derived from the 6 subtests are provided in Table 4. This table allows you to identify unusually and abnormally low subtest scores.

Table 4. Cutoff Scores for Specific Subtests: Boys Ages 13 – 15

Subtests Score	Unusually Low (≤ 10th Percentile)	Impaired (≤ 2nd Percentile)
Word Memory – Learning Percent Correct	≤ 92%	≤ 86%
Word Memory – Delayed Memory Percent Correct	≤ 79%	≤ 67%
Design Memory – Learning Percent Correct	≤ 67%	≤ 50%
Design Memory – Delayed Memory Percent Correct	≤ 58%	≤ 44%
X's and O's – Total Correct (Memory)	≤ 5	≤ 3
X's and O's – Avg. Correct RT (Interference)	≥ .48	≥ .68
Symbol Match – Total Correct (Symbols)	≤ 26	≤ 25
Symbol Match – Avg. Correct RT (Symbols)	≥ 1.70	≥ 2.05
Color Match – Avg. Correct RT	≥ .98	≥ 1.15
Three Letters – Percent of Total Letters Correct	≤ 76%	≤ 67%
Three Letters – Avg. Counted Correctly	≤ 7.7	≤ 2.6

Normative Table 5: Boys Ages 13 – 15 (N = 183)

Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite	Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite
1	62.88	42.68	14.63	0.810	51	88.00	78.00	34.09	0.570
2	64.00	49.40	16.33	0.753	52	88.00	78.00	34.16	0.570
3	67.52	52.52	17.92	0.730	53	88.00	79.00	34.25	0.565
4	69.00	53.36	21.48	0.706	54	88.00	79.00	34.33	0.560
5	70.00	55.20	22.35	0.698	55	88.00	79.00	34.53	0.560
6	71.00	57.00	22.51	0.690	56	88.04	79.04	34.58	0.560
7	71.88	57.88	22.81	0.681	57	89.00	80.00	34.70	0.560
8	72.72	59.00	23.85	0.673	58	89.00	80.00	35.09	0.560
9	73.00	60.00	24.23	0.670	59	89.00	80.00	35.32	0.560
10	73.00	60.40	25.36	0.660	60	89.00	81.00	35.53	0.560
11	74.00	61.00	26.04	0.658	61	89.24	81.00	35.57	0.558
12	74.08	61.16	26.69	0.649	62	90.00	81.00	35.66	0.550
13	75.00	63.00	26.82	0.640	63	90.00	81.00	35.83	0.550
14	76.00	64.00	27.19	0.640	64	90.00	82.00	35.87	0.550
15	76.00	65.00	27.39	0.634	65	90.00	82.00	35.93	0.550
16	76.44	65.00	27.56	0.630	66	91.00	82.44	36.03	0.540
17	77.00	65.28	27.79	0.630	67	91.00	83.00	36.56	0.540
18	77.12	66.00	28.06	0.620	68	91.00	83.00	36.70	0.540
19	78.96	66.00	28.30	0.620	69	91.96	83.00	36.93	0.540
20	79.00	66.80	29.20	0.620	70	92.00	84.00	37.07	0.540
21	79.00	67.00	29.59	0.610	71	92.00	84.00	37.27	0.534
22	79.00	67.00	29.69	0.610	72	92.00	85.00	37.49	0.530
23	79.00	67.00	29.93	0.610	73	92.00	85.32	37.53	0.530
24	80.00	68.00	30.02	0.608	74	92.00	86.00	37.56	0.530
25	80.00	69.00	30.23	0.600	**75**	93.00	86.00	37.78	0.530
26	80.00	69.00	30.28	0.600	76	93.00	88.00	37.98	0.520
27	80.00	69.00	30.34	0.600	77	93.00	88.00	38.12	0.520
28	80.00	69.00	30.43	0.600	78	93.00	88.00	38.81	0.520
29	81.00	69.00	30.57	0.600	79	93.00	88.00	39.13	0.520
30	81.00	69.00	30.63	0.600	80	93.20	88.20	39.42	0.518
31	81.00	70.00	30.70	0.590	81	94.00	89.00	39.60	0.510
32	81.88	70.88	30.79	0.590	82	94.00	89.00	40.27	0.510
33	82.00	71.00	31.48	0.590	83	94.00	90.00	40.39	0.510
34	82.00	71.56	31.80	0.590	84	95.00	90.56	40.58	0.504
35	82.00	72.00	31.93	0.590	85	96.00	91.00	40.69	0.500
36	83.00	72.24	32.13	0.590	86	96.00	91.24	40.99	0.500
37	83.00	73.00	32.33	0.590	87	96.00	92.00	41.88	0.500
38	83.00	73.00	32.53	0.590	88	96.00	92.00	42.53	0.500
39	84.00	73.00	32.57	0.582	89	96.00	92.00	43.49	0.492
40	84.00	73.00	32.63	0.580	90	96.00	92.60	44.21	0.490
41	85.00	73.00	32.74	0.580	**91**	96.44	94.00	44.52	0.480
42	85.00	74.00	33.01	0.580	92	97.28	94.00	44.81	0.480
43	85.00	74.00	33.27	0.580	93	98.12	94.12	45.21	0.479
44	85.00	74.00	33.43	0.580	94	99.00	95.96	45.42	0.470
45	85.00	74.80	33.47	0.570	95	99.00	96.00	46.42	0.470
46	86.00	75.64	33.57	0.570	96	99.00	96.64	46.98	0.464
47	86.48	76.00	33.64	0.570	**97**	99.00	97.00	50.19	0.445
48	87.00	77.00	33.70	0.570	98	100.00	98.00	51.93	0.437
49	87.00	77.16	33.73	0.570	99	100.00	98.16	52.55	0.355
50	87.00	78.00	33.95	0.570					

Table 6. Approximate Classification Ranges for Index Scores: Boys Ages 16 – 18

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 51	≤ 26.4	≥ .74
Borderline	69 – 74	52 – 59	26.5 – 29.6	.73 - .64
Low Average	75 – 79	60 – 70	29.7 – 33.6	.63 - .59
Average	80 – 92	71 – 88	33.7 – 42.5	.58 - .50
High Average	93 – 98	89 – 93	42.6 – 47.7	.49 - .47
Superior	99	94 – 96	47.8 – 51.1	.46 - .43
Very Superior	100	97 – 100	≥ 51.2	≤ .42

Cutoff scores for the 10^{th} percentile and the 2^{nd} percentiles for 11 scores derived from the 6 subtests are provided in Table 7. This table allows you to identify unusually and abnormally low subtest scores.

Table 7. Cutoff Scores for Specific Subtests: Boys Ages 16 – 18

Subtests Score	Unusually Low (≤ 10^{th} Percentile)	Impaired (≤ 2^{nd} Percentile)
Word Memory – Learning Percent Correct	≤ 92%	≤ 83%
Word Memory – Delayed Memory Percent Correct	≤ 79%	≤ 63%
Design Memory – Learning Percent Correct	≤ 71%	≤ 55%
Design Memory – Delayed Memory Percent Correct	≤ 67%	≤ 54%
X's and O's – Total Correct (Memory)	≤ 5	≤ 3
X's and O's – Avg. Correct RT (Interference)	≥ .46	≥ .59
Symbol Match – Total Correct (Symbols)	---	≤ 25
Symbol Match – Avg. Correct RT (Symbols)	≥ 1.67	≥ 2.06
Color Match – Avg. Correct RT	≥ .94	≥ 1.12
Three Letters – Percent of Total Letters Correct	≤ 80%	≤ 67%
Three Letters – Avg. Counted Correctly	≤ 9.6	≤ 7.3

Symbol match total correct is a highly skewed distribution. A 10^{th} percentile cutoff is not available.

Normative Table 8: High School Boys Ages 16 – 18 (N = 158)

Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite	Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite
1	65.36	47.36	19.18	0.764	51	86.00	79.00	37.91	0.530
2	68.18	51.36	26.47	0.738	52	86.00	79.68	38.10	0.530
3	69.00	53.00	26.71	0.730	53	86.00	80.00	38.31	0.530
4	71.00	56.00	27.24	0.696	54	86.86	80.86	38.51	0.530
5	71.00	56.95	27.60	0.690	55	87.00	81.00	38.73	0.526
6	72.54	58.00	27.84	0.674	56	88.00	81.00	38.88	0.520
7	74.00	58.13	28.06	0.650	57	88.00	81.63	38.91	0.520
8	74.00	59.00	28.52	0.643	58	88.00	82.00	39.01	0.520
9	75.00	60.00	29.57	0.640	59	88.81	82.00	39.18	0.520
10	75.00	60.00	29.65	0.640	60	89.00	82.00	39.28	0.520
11	75.49	63.00	30.01	0.630	61	89.99	82.99	39.35	0.520
12	76.00	65.08	30.25	0.630	62	90.00	83.00	39.42	0.510
13	76.00	66.00	30.61	0.630	63	90.00	83.00	39.51	0.510
14	76.00	66.00	31.57	0.627	64	90.76	83.00	39.62	0.510
15	76.00	66.00	31.80	0.620	65	91.00	84.00	40.13	0.510
16	77.00	66.00	31.84	0.620	66	91.00	84.00	40.24	0.510
17	77.03	67.03	32.06	0.610	67	91.00	84.00	40.45	0.505
18	78.00	68.00	32.41	0.610	68	91.00	84.12	40.75	0.500
19	78.00	68.00	32.51	0.610	69	91.00	85.00	40.85	0.500
20	78.80	68.00	32.63	0.610	70	91.00	85.30	41.04	0.500
21	79.00	69.00	32.85	0.606	71	91.00	87.78	41.42	0.500
22	79.00	69.00	32.93	0.600	72	92.00	88.00	41.84	0.500
23	79.00	69.57	33.23	0.594	73	92.00	88.00	42.11	0.499
24	79.00	70.00	33.41	0.590	74	92.00	88.00	42.31	0.490
25	79.75	70.00	33.69	0.583	**75**	92.25	89.00	42.58	0.490
26	80.00	70.34	33.85	0.580	76	93.00	89.00	42.60	0.490
27	80.00	71.00	33.99	0.580	77	93.00	89.00	42.72	0.490
28	81.00	71.52	34.32	0.575	78	94.00	89.00	43.20	0.490
29	81.00	72.11	34.51	0.570	79	94.00	89.61	43.23	0.490
30	81.70	73.00	34.59	0.570	80	94.00	90.00	43.56	0.490
31	82.00	73.00	34.87	0.570	81	94.79	90.00	43.68	0.490
32	82.00	73.00	35.21	0.570	82	95.38	91.00	44.40	0.486
33	82.00	74.00	35.41	0.560	83	96.00	91.97	44.65	0.480
34	82.06	74.06	35.48	0.560	84	96.00	92.00	45.12	0.480
35	83.00	75.00	35.51	0.560	85	96.00	92.00	45.61	0.480
36	83.00	76.00	35.84	0.560	86	96.00	92.00	46.10	0.480
37	83.00	76.00	36.03	0.560	87	97.00	93.00	46.72	0.470
38	84.00	76.00	36.06	0.556	88	97.00	93.00	46.95	0.470
39	84.00	77.00	36.10	0.550	89	97.51	93.00	47.23	0.470
40	84.00	77.00	36.28	0.550	90	98.10	93.00	47.46	0.469
41	84.00	77.19	36.48	0.550	**91**	99.00	93.69	47.79	0.460
42	84.00	78.00	36.54	0.550	92	99.00	94.28	48.23	0.460
43	84.37	78.00	36.65	0.550	93	99.00	95.00	48.88	0.460
44	85.00	78.00	36.87	0.550	94	99.00	95.46	49.31	0.455
45	85.00	78.00	37.10	0.550	95	100.00	96.00	50.21	0.450
46	85.00	78.14	37.24	0.540	96	100.00	96.00	50.60	0.444
47	85.00	79.00	37.34	0.540	**97**	100.00	97.00	50.75	0.435
48	85.00	79.00	37.44	0.540	98	100.00	97.00	51.21	0.420
49	85.91	79.00	37.55	0.540	99	100.00	97.41	51.59	0.359
50	86.00	79.00	37.78	0.530					

Norms for High School Girls Ages 14 – 18 (N = 83)

Table 9. Approximate Classification Ranges for Index Scores: Girls Ages 14 – 18

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 49	≤ 18.9	≥ .75
Borderline	69 – 77	50 – 59	19.0 – 28.9	.74 - .67
Low Average	78 – 83	60 – 69	29.0 – 32.7	.66 - .61
Average	84 – 93	70 – 88	32.8 – 42.3	.60 - .51
High Average	94 – 98	89 – 92	42.4 – 47.0	.50 - .49
Superior	99 – 100	93 – 98	47.1 – 51.1	.48 - .45
Very Superior	--	99 – 100	≥ 51.2	≤ .44

Cutoff scores for the 10^{th} percentile and the 2^{nd} percentiles for 11 scores derived from the 6 subtests are provided in Table 10. This table allows you to identify unusually and abnormally low subtest scores.

Table 10. Cutoff Scores for Specific Subtests: High School Girls Ages 14 – 18

Subtests Score	Unusually Low (≤ 10^{th} Percentile)	Impaired (≤ 2^{nd} Percentile)
Word Memory – Learning Percent Correct	≤ 91%	≤ 87%
Word Memory – Delayed Memory Percent Correct	≤ 82%	≤ 78%
Design Memory – Learning Percent Correct	≤ 66%	≤ 54%
Design Memory – Delayed Memory Percent Correct	≤ 57%	≤ 50%
X's and O's – Total Correct (Memory)	≤ 5	≤ 3
X's and O's – Avg. Correct RT (Interference)	≥ .49	≥ .59
Symbol Match – Total Correct (Symbols)	≤ 25	≤ 23
Symbol Match – Avg. Correct RT (Symbols)	≥ 1.69	≥ 1.96
Color Match – Avg. Correct RT	≥ .96	≥ 1.18
Three Letters – Percent of Total Letters Correct	≤ 80%	≤ 67%
Three Letters – Avg. Counted Correctly	≤ 9.1	0

Normative Table 11: Girls Ages 14 – 18 (N = 83)

Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite	Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite
1	58.00	43.00	14.13	0.790	51	90.00	79.00	38.79	0.540
2	61.40	49.80	15.91	0.770	52	90.00	79.00	39.02	0.540
3	68.72	53.52	19.05	0.739	53	90.00	79.00	39.17	0.540
4	74.72	54.00	21.49	0.713	54	90.36	79.00	39.32	0.540
5	76.00	54.40	22.74	0.698	55	91.00	79.20	39.53	0.540
6	76.04	56.12	25.53	0.690	56	91.04	80.00	39.55	0.540
7	76.88	58.64	26.67	0.690	57	91.88	80.00	39.62	0.540
8	77.00	59.00	27.85	0.683	58	92.00	80.00	39.72	0.540
9	77.56	59.00	28.83	0.669	59	92.00	80.56	39.81	0.534
10	78.40	59.80	29.28	0.656	60	92.00	81.00	40.09	0.530
11	79.24	61.00	29.28	0.650	61	92.00	81.24	40.48	0.530
12	80.00	61.00	29.32	0.648	62	92.00	82.08	40.58	0.529
13	80.00	61.00	29.48	0.632	63	92.00	82.92	40.58	0.521
14	80.76	62.52	29.88	0.630	64	92.00	83.76	40.71	0.520
15	81.60	63.00	30.09	0.630	65	92.00	84.00	40.75	0.520
16	82.00	63.44	30.27	0.626	66	92.00	84.44	40.77	0.520
17	82.00	64.00	30.44	0.620	67	92.28	85.00	40.81	0.520
18	82.00	64.24	30.52	0.620	68	93.00	85.00	40.88	0.520
19	82.00	65.92	30.84	0.620	69	93.00	85.00	41.07	0.520
20	82.00	66.80	30.93	0.612	70	93.00	85.80	41.32	0.512
21	82.64	67.64	31.91	0.610	71	93.00	86.00	41.64	0.510
22	83.00	68.00	32.50	0.610	72	93.00	86.96	42.01	0.510
23	83.00	68.32	32.56	0.607	73	93.00	88.00	42.26	0.507
24	83.16	69.16	32.69	0.600	74	93.16	88.00	42.29	0.500
25	84.00	70.00	33.28	0.600	**75**	94.00	88.00	42.33	0.500
26	84.00	70.00	33.41	0.600	76	94.00	88.84	42.37	0.500
27	84.00	70.68	33.51	0.593	77	94.00	89.00	42.67	0.500
28	84.52	71.00	33.77	0.590	78	95.04	89.00	43.01	0.495
29	85.00	71.00	34.00	0.590	79	96.00	89.00	43.47	0.490
30	85.00	71.20	34.03	0.588	80	96.00	89.20	44.00	0.490
31	85.00	72.04	34.04	0.580	81	96.00	90.00	44.20	0.490
32	85.00	72.88	34.36	0.580	82	96.00	90.00	44.29	0.490
33	85.72	73.00	34.67	0.573	83	96.00	90.00	44.48	0.490
34	86.56	73.00	34.78	0.570	84	96.56	90.56	45.24	0.490
35	87.40	73.40	34.89	0.566	85	97.00	91.00	46.06	0.490
36	88.00	74.00	35.16	0.560	86	97.24	91.00	46.53	0.490
37	88.00	74.00	35.50	0.560	87	98.00	91.08	46.71	0.489
38	88.00	74.00	35.53	0.560	88	98.00	91.92	46.77	0.481
39	88.00	74.76	35.76	0.560	89	98.76	92.00	46.80	0.480
40	88.00	75.00	35.87	0.560	90	99.00	92.60	47.00	0.480
41	88.00	75.00	36.24	0.556	**91**	99.00	93.00	47.31	0.480
42	88.00	75.28	36.69	0.550	92	99.28	93.56	47.91	0.480
43	88.00	76.00	36.78	0.550	93	100.00	95.00	48.88	0.479
44	88.00	76.00	37.13	0.550	94	100.00	95.00	49.23	0.470
45	88.00	76.80	37.17	0.550	95	100.00	95.00	50.61	0.462
46	88.64	77.00	37.37	0.544	96	100.00	96.28	50.95	0.460
47	89.48	77.00	37.72	0.540	**97**	100.00	97.96	51.12	0.446
48	90.00	77.00	38.18	0.540	98	100.00	99.32	51.89	0.385
49	90.00	77.32	38.62	0.540	99	100.00	100.00	53.15	0.290
50	90.00	79.00	38.73	0.540					

3. Normative Data for University Students

Within this college sample, there were no differences on the four composites that were attributable to year. There was a gender effect for the Verbal Memory Composite, but not for Visual Memory, Reaction Time, or Processing Speed. The final normative tables are based on 410 university men, and 97 university women. Normative data are based on the natural distributions of scores within these two samples.

The distributions of scores within these groups were examined and exact percentile ranks corresponding to the natural distribution of scores were assigned. Thus, these could be considered uniform percentile ranks. The distributions were not force-normalized, nor were raw scores converted to standard scores.

Table 12. Approximate Classification Ranges for Index Scores – University Men (N = 410).

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 71	≤ 51	≤ 23.8	≥ .75
Borderline	72 – 77	52 – 60	23.9 – 28.3	.74 - .67
Low Average	78 – 82	61 – 68	28.4 – 32.4	.66 - .61
Average	83 – 94	69 – 94	32.5 – 42.0	.60 - .52
High Average	95 – 97	95 – 97	42.1 – 46.0	.51 - .48
Superior	98 – 99	98 – 99	46.1 – 50.0	.47 - .45
Very Superior	100	100	≥ 50.1	≤ .44

Sometimes it is useful to know if an athlete performs particularly poorly on a specific subtest. Cutoff scores for the 10th percentile and the 2nd percentiles for 11 scores derived from the 6 subtests are provided in Table 13. This table allows you to identify unusually and abnormally low subtest scores

Table 13. Cutoff Scores for Specific Subtests

Subtests Score	Unusually Low (≤ 10^{th} Percentile)	Impaired (≤ 2^{nd} Percentile)
Word Memory – Learning Percent Correct	≤ 88%	≤ 83%
Word Memory – Delayed Memory Percent Correct	≤ 75%	≤ 63%
Design Memory – Learning Percent Correct	≤ 61%	≤ 50%
Design Memory – Delayed Memory Percent Correct	≤ 57%	≤ 45%
X's and O's – Total Correct (Memory)	≤ 5	≤ 3
X's and O's – Avg. Correct RT (Interference)	≥ .48	≥ .59
Symbol Match – Total Correct (Symbols)	---	≤ 25
Symbol Match – Avg. Correct RT (Symbols)	≥ 1.78	≥ 2.19
Color Match – Avg. Correct RT	≥ .95	≥ 1.12
Three Letters – Percent of Total Letters Correct	≤ 80%	≤ 67%
Three Letters – Avg. Counted Correctly	≤ 9.2	≤ 6.6

Symbol match total correct is a highly skewed distribution. A 10^{th} percentile cutoff is not available.

Normative Table 14: Men, University, N = 410

Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite	Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite
1	68.00	45.99	19.41	0.813	51	88.96	77.78	37.28	0.552
2	71.49	51.39	23.90	0.748	52	89.03	77.78	37.46	0.550
3	72.01	51.39	24.46	0.703	53	89.24	77.78	37.75	0.547
4	73.00	53.39	25.61	0.690	54	89.58	79.17	37.87	0.546
5	74.07	55.56	26.01	0.685	55	89.58	79.17	38.08	0.544
6	75.05	55.56	26.60	0.678	56	90.00	79.17	38.34	0.543
7	75.85	58.33	27.62	0.672	57	90.00	80.56	38.56	0.542
8	76.70	59.72	28.13	0.665	58	90.28	80.56	38.71	0.540
9	76.88	59.72	28.33	0.661	59	90.31	80.56	38.86	0.539
10	77.31	61.11	28.62	0.657	60	90.63	81.94	38.99	0.537
11	77.88	61.11	29.11	0.650	61	90.69	81.94	39.03	0.536
12	78.19	61.56	29.38	0.641	62	91.17	81.94	39.13	0.536
13	78.82	62.50	29.54	0.640	63	91.32	81.94	39.30	0.534
14	79.00	63.25	29.65	0.635	64	91.67	81.94	39.55	0.532
15	79.17	65.28	30.02	0.630	65	92.07	82.15	39.73	0.530
16	79.86	65.28	30.26	0.629	66	92.36	83.33	40.01	0.528
17	80.63	65.28	30.71	0.625	67	92.73	83.33	40.16	0.527
18	81.24	66.64	30.92	0.618	68	92.78	84.00	40.26	0.526
19	81.41	66.67	31.40	0.615	69	93.40	84.72	40.43	0.524
20	81.79	66.67	31.66	0.610	70	93.40	84.72	40.55	0.520
21	82.08	68.06	31.88	0.608	71	93.40	84.72	40.65	0.518
22	82.36	68.06	32.03	0.606	72	93.40	84.72	40.75	0.517
23	82.99	68.06	32.18	0.605	73	93.48	84.72	41.08	0.516
24	83.03	69.44	32.37	0.602	74	94.11	86.11	41.59	0.515
25	83.18	69.44	32.55	0.600	**75**	94.44	86.11	41.96	0.515
26	83.33	69.44	32.68	0.599	76	94.47	86.11	42.09	0.513
27	83.47	70.83	32.77	0.596	77	94.55	86.11	42.46	0.511
28	83.68	70.83	33.20	0.595	78	94.79	86.92	42.68	0.509
29	83.92	70.83	33.44	0.594	79	94.94	87.50	42.78	0.507
30	84.05	70.83	33.76	0.592	80	95.14	87.50	43.00	0.505
31	84.44	71.40	33.86	0.588	81	95.14	87.50	43.22	0.503
32	84.51	72.22	34.05	0.587	82	95.56	88.89	43.55	0.502
33	84.72	72.22	34.34	0.586	83	96.18	88.89	43.82	0.500
34	85.07	72.22	34.44	0.583	84	96.18	88.89	44.17	0.497
35	85.48	72.22	34.53	0.578	85	96.42	88.89	44.32	0.494
36	85.76	73.61	34.70	0.574	86	96.88	90.28	44.74	0.491
37	86.11	73.61	34.90	0.574	87	97.22	90.28	45.03	0.489
38	86.25	73.61	34.98	0.572	88	97.22	90.28	45.15	0.487
39	86.46	75.00	35.33	0.570	89	97.22	90.28	45.42	0.485
40	86.60	75.00	35.51	0.569	90	97.28	91.67	45.94	0.483
41	86.81	75.00	35.73	0.565	**91**	97.92	91.67	46.55	0.480
42	86.88	75.00	35.83	0.564	92	97.92	91.67	47.49	0.472
43	87.12	75.00	35.98	0.562	93	98.33	91.99	47.86	0.468
44	87.35	76.39	36.12	0.561	94	98.96	93.06	48.39	0.464
45	87.50	76.39	36.23	0.560	95	98.96	93.06	48.77	0.460
46	87.85	76.39	36.45	0.560	96	98.96	94.44	49.30	0.458
47	87.85	76.39	36.56	0.558	**97**	99.66	94.44	50.03	0.450
48	88.29	76.78	36.76	0.557	98	100.00	95.83	51.25	0.429
49	88.54	77.78	37.03	0.555	99	100.00	98.46	52.00	0.343
50	88.82	77.78	37.23	0.553					

Table 15. Approximate Classification Ranges for Index Scores – University Women (N=97)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 70	≤ 48	≤ 23.3	≥ .70
Borderline	71 – 82	49 – 59	23.4 – 29.7	.69 - .64
Low Average	83 – 86	60 – 69	29.8 – 34.3	.63 - .60
Average	87 – 97	70 – 88	34.4 – 42.1	.59 - .52
High Average	98 – 100	89 – 93	42.2 – 46.3	.51 - .50
Superior	---	94 – 96	46.4 – 49.2	.49 - .48
Very Superior	---	97 – 100	≥ 49.3	≤ .47

Cutoff scores for the 10^{th} percentile and the 2^{nd} percentiles for 11 scores derived from the 6 subtests are provided in Table 16. This table allows you to identify unusually and abnormally low subtest scores.

Table 16. Cutoff Scores for Specific Subtests

Subtests Score	Unusually Low (≤ 10^{th} Percentile)	Impaired (≤ 2^{nd} Percentile)
Word Memory – Learning Percent Correct	≤ 94%	≤ 87%
Word Memory – Delayed Memory Percent Correct	≤ 82%	≤ 74%
Design Memory – Learning Percent Correct	≤ 62%	≤ 50%
Design Memory – Delayed Memory Percent Correct	≤ 57%	≤ 46%
X's and O's – Total Correct (Memory)	≤ 4	≤ 2
X's and O's – Avg. Correct RT (Interference)	≥ .44	≥ .49
Symbol Match – Total Correct (Symbols)	---	≤ 25
Symbol Match – Avg. Correct RT (Symbols)	≥ 1.66	≥ 1.94
Color Match – Avg. Correct RT	≥ .93	≥ 1.02
Three Letters – Percent of Total Letters Correct	≤ 86%	≤ 73%
Three Letters – Avg. Counted Correctly	≤ 9.5	≤ 7.2

Symbol match total correct is a highly skewed distribution. A 10^{th} percentile cutoff is not available.

Normative Table 17: Females, University, N = 97

Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite	Percentile Rank	Verbal Memory Composite	Visual Memory Composite	Processing Speed Composite	Reaction Time Composite
1	55.14	43.06	22.55	0.774	51	91.81	79.17	38.70	0.539
2	60.81	48.39	23.39	0.693	52	92.01	79.17	38.70	0.537
3	70.70	49.92	25.66	0.674	53	92.01	79.17	38.92	0.537
4	71.58	53.83	26.97	0.661	54	92.34	80.47	38.93	0.537
5	75.47	54.17	28.43	0.660	55	92.36	80.56	38.99	0.535
6	79.69	54.17	29.08	0.652	56	92.99	80.56	39.05	0.534
7	81.52	57.75	29.39	0.637	57	93.36	80.56	39.07	0.532
8	82.20	59.50	29.57	0.632	58	93.82	81.75	39.35	0.532
9	82.58	59.72	29.74	0.631	59	94.06	83.11	39.53	0.531
10	82.75	59.72	29.80	0.630	60	94.38	83.33	39.67	0.531
11	82.94	59.72	30.07	0.626	61	94.44	83.33	39.98	0.531
12	83.78	60.78	30.23	0.623	62	94.50	83.33	40.25	0.529
13	84.03	62.14	30.32	0.623	63	94.57	84.39	40.57	0.528
14	84.08	62.50	30.84	0.618	64	95.05	84.72	40.69	0.527
15	84.19	62.50	31.11	0.613	65	95.51	84.72	40.75	0.525
16	84.38	63.44	31.59	0.611	66	96.01	84.72	40.81	0.523
17	84.63	63.89	31.82	0.609	67	96.18	85.67	40.89	0.521
18	84.72	63.89	32.56	0.608	68	96.18	86.11	40.94	0.519
19	84.94	64.75	33.22	0.607	69	96.63	86.11	40.97	0.519
20	85.07	66.11	33.47	0.606	70	96.88	86.11	41.11	0.519
21	85.11	67.47	33.54	0.601	71	97.08	86.11	41.23	0.518
22	85.29	68.06	33.80	0.597	72	97.26	86.92	41.47	0.515
23	85.60	68.81	34.11	0.595	73	97.29	87.50	41.78	0.513
24	85.76	69.44	34.28	0.594	74	97.63	88.25	41.90	0.512
25	86.81	70.14	34.40	0.592	**75**	97.92	88.89	42.06	0.510
26	87.85	71.50	34.53	0.589	76	97.92	88.89	42.26	0.508
27	87.85	72.22	34.88	0.586	77	98.12	88.89	42.39	0.508
28	87.88	72.22	35.25	0.585	78	98.33	89.53	42.46	0.507
29	88.03	72.22	35.36	0.583	79	98.61	90.28	42.62	0.505
30	88.33	72.22	35.44	0.580	80	98.96	90.28	42.80	0.504
31	88.54	72.75	35.54	0.576	81	98.96	90.83	43.43	0.503
32	88.54	73.61	35.63	0.575	82	98.96	91.67	44.42	0.503
33	88.57	73.61	35.76	0.571	83	98.96	91.67	44.55	0.502
34	88.70	74.06	35.90	0.569	84	98.96	92.14	45.03	0.500
35	88.91	75.00	36.06	0.568	85	99.29	93.06	45.82	0.499
36	88.98	75.00	36.09	0.565	86	100.00	93.06	45.97	0.499
37	89.10	75.36	36.15	0.565	87	100.00	93.06	46.09	0.498
38	89.34	76.39	36.40	0.562	88	100.00	93.06	46.13	0.496
39	89.48	76.39	36.98	0.560	89	100.00	93.06	46.17	0.492
40	89.67	76.39	37.13	0.557	90	100.00	93.06	46.29	0.489
41	90.11	76.39	37.27	0.557	**91**	100.00	93.06	46.72	0.489
42	90.64	76.39	37.39	0.556	92	100.00	93.31	47.89	0.488
43	90.69	76.58	37.48	0.552	93	100.00	94.44	47.99	0.487
44	90.75	77.78	37.66	0.551	94	100.00	94.44	48.24	0.484
45	91.19	77.78	37.76	0.551	95	100.00	94.61	48.42	0.483
46	91.35	77.78	37.82	0.547	96	100.00	95.83	48.97	0.479
47	91.67	77.78	38.09	0.544	**97**	100.00	95.83	49.24	0.476
48	91.67	77.78	38.36	0.544	98	100.00	96.00	50.64	0.457
49	91.67	77.81	38.65	0.541	99	100.00	98.67	51.69	0.451
50	91.67	77.81	38.65	0.541					

4. Normative Data for the Postconcussion Scale[1]

The Postconcussion Symptom Scale is a 22-item scale designed to measure the severity of symptoms in the acute phase of recovery from concussion (Lovell, 1996; Lovell & Collins, 1998). An earlier version of this scale has been used with large samples of collegiate football players (Collins et al., 1999). The version of the scale used for this project is reprinted on page 17.

The Postconcussion Symptom Scale is essentially a "state" measure of perceived symptoms associated with concussion. That is, the athlete is asked to report his or her "current" experience of the symptoms. This allows tracking of symptoms over very short intervals, such as consecutive days or every few days.

Sample

A sample of 2,304 high school and university students was used for this project. The vast majority of subjects were healthy at the time of their evaluations (i.e., 894 high school students and 1,295 university students). In addition, a sample of 115 high school and university athletes in the acute recovery period from concussion were examined (i.e., within 3 days).

Preliminary analyses showed that women tend to report more symptoms than men. Moreover, young people with a self-reported history of learning or speech problems, or special education placement, reported more symptoms than those without this history.

Therefore, normative and psychometric analyses were stratified by level (high school / university), gender, and learning / special education status.

The "regular education" samples were comprised of 588 high school boys, 119 high school girls, 803 university men, and 236 university women. The special education samples were comprised of 156 high school boys, 31 high school girls, 196 university men, and 60 university women.

It is important to note that inclusion in the so-called "special education" groups does not mean that the person (a) had a formally diagnosed learning disability, or (b) attended special education classes or programs. All subjects who self-reported any past speech therapy, learning problems (e.g., reading or math), ADHD, or special education placement were included in these groups.

The concussed athletes were all evaluated within 3 days of injury. The sample was comprised of 83 young men and 32 young women.

Acknowledgements
Grant L. Iverson, Ph.D., University of British Columbia & Riverview Hospital; Mark R. Lovell, Ph.D., University of Pittsburgh Medical Center; Kenneth Podell, Ph.D., Henry Ford Hospital; Michael W. Collins, Ph.D., University of Pittsburgh Medical Center

Original Post-Concussion Symptom Scale

Directions: After reading each symptom, please circle the number that best describes the way you have been feeling **today**. A rating of **0** means you have **not** experienced this symptom today. A rating of **6** means you have experienced **severe** problems with this symptom today.

Symptom	None	Mild		Moderate		Severe	
Headache	0	1	2	3	4	5	6
Confusion/Disorientation	0	1	2	3	4	5	6
Difficulty Remembering Incident	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Balance Problems	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Trouble Falling Asleep	0	1	2	3	4	5	6
Sleeping More Than Usual	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Sensitivity to Light/Noise	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervousness	0	1	2	3	4	5	6
Numbness or Tingling	0	1	2	3	4	5	6
Feeling Slowed Down	0	1	2	3	4	5	6
Feeling Like "In a Fog"	0	1	2	3	4	5	6
Difficulty Concentrating	0	1	2	3	4	5	6
Difficulty with Memory	0	1	2	3	4	5	6

Current Version of the Scale – Used for this Project (Instructions remain the same)

Symptom	Minor		Moderate		Severe	
Headache	1	2	3	4	5	6
Nausea	1	2	3	4	5	6
Vomiting	1	2	3	4	5	6
Balance Problems	1	2	3	4	5	6
Dizziness	1	2	3	4	5	6
Fatigue	1	2	3	4	5	6
Trouble Falling Asleep	1	2	3	4	5	6
Sleeping More Than Usual	1	2	3	4	5	6
Sleeping Less Than Usual	1	2	3	4	5	6
Drowsiness	1	2	3	4	5	6
Sensitivity to Light	1	2	3	4	5	6
Sensitivity to Noise	1	2	3	4	5	6
Irritability	1	2	3	4	5	6
Sadness	1	2	3	4	5	6
Nervousness	1	2	3	4	5	6
Feeling More Emotional	1	2	3	4	5	6
Numbness or Tingling	1	2	3	4	5	6
Feeling Slowed Down	1	2	3	4	5	6
Feeling Mentally "Foggy"	1	2	3	4	5	6
Difficulty Concentrating	1	2	3	4	5	6
Difficulty Remembering	1	2	3	4	5	6
Visual Problems	1	2	3	4	5	6

Instead of zero, subjects check a box indicating they are not experiencing the symptom. This form is administered via computer.

Descriptive statistics and psychometric analyses

Descriptive statistics and psychometric analyses are provided in Table 18. The mean, median, standard deviation, interquartile range, and range of total scores, for each group, are presented. As seen from the measures of central tendency (mean and median) and the ranges, the distributions of total symptom scores are clearly skewed. This is illustrated graphically, for two samples, in Figures 1 and 2. The distribution of scores for the clinical concussed sample is not severely skewed (Figure 3).

Table 18. Descriptive and psychometric analyses.

Group	N	Mean	Median	SD	IQR	Range	Alpha	SEM	Confidence Interval .80	.90
High School – Regular Education										
Boys	588	4.8	2	7.9	0-6	0-54	.89	2.62	3.35	4.30
Girls	119	7.7	3	13.7	0-9	0-78	.94	3.36	4.30	5.50
High School – Special Education										
Boys	156	8.8	3	13.0	0-11	0-64	.92	3.68	4.71	6.03
Girls	31	5.3	3	6.3	1-8	0-26	.75	3.15	4.03	5.17
College – Regular Education										
Young Men	803	4.5	2	7.5	0-6	0-56	.88	2.60	3.33	4.26
Young Women	236	8.0	5	10.3	0-10	0-55	.88	3.57	4.57	5.85
College – Special Education										
Young Men	196	9.9	5	13.5	0-13	0-63	.91	4.05	5.18	6.64
Young Women	60	9.8	7	11.4	2-14	0-55	.91	3.42	4.38	5.61
Athletes with Concussions										
Young Men	83	26.8	22	20.2	10-39	0-81	.92	5.71	7.31	9.37
Young Women	32	35.8	29.5	25.2	18-57	2-95	.94	6.17	7.90	10.12
Total Sample	115	29.3	25	22.0	11-43	0-95	.93	5.82	7.45	9.55

Descriptive statistics: Sample size, Mean, Median, Standard Deviation, Interquartile Range, Range. Reliability: Cronbach's Unstandardized Alpha (this represents the lower bound of reliability), Standard Error of Measurement, .80 and .90 Confidence Intervals.

Scale Reliability

According to classical test theory, obtained scores (or measures) are only estimates of "true" scores because they contain measurement error. Measurement error is closely related to test reliability. Reliability refers to the consistency or stability of test scores. Reliability can be viewed as the ability of an instrument to reflect an individual score that is minimally influenced by error. Reliability should not be considered a dichotomous concept; rather it falls on a continuum. One cannot say an instrument is reliable or unreliable, but more accurately should say it possesses a high or low degree of reliability for a specific purpose, with a specific population (Franzen, 1989, 2000)[2].

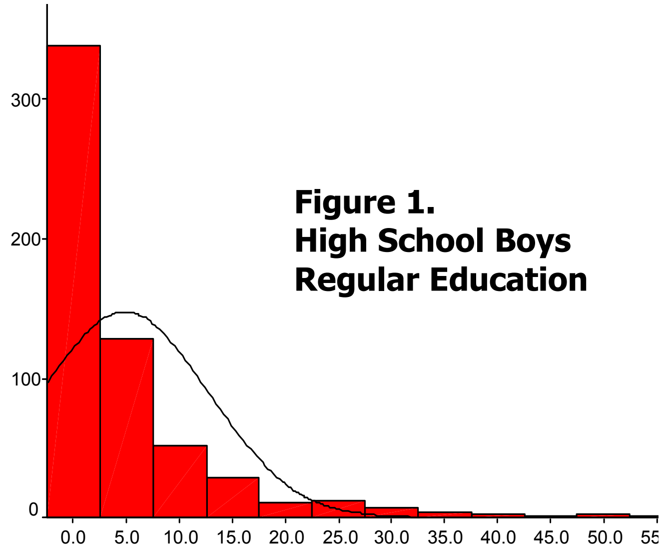

Figure 1. High School Boys Regular Education

The internal consistency reliability of the scale was estimated using Cronbach's alpha (Cronbach, 1951). Alpha is believed to represent the lower bound for the true reliability of the scale (SPSS 9.0 Base Manual, p. 362). Alpha is influenced by the number of items on the scale, the average inter-item covariance, and the average item variance.

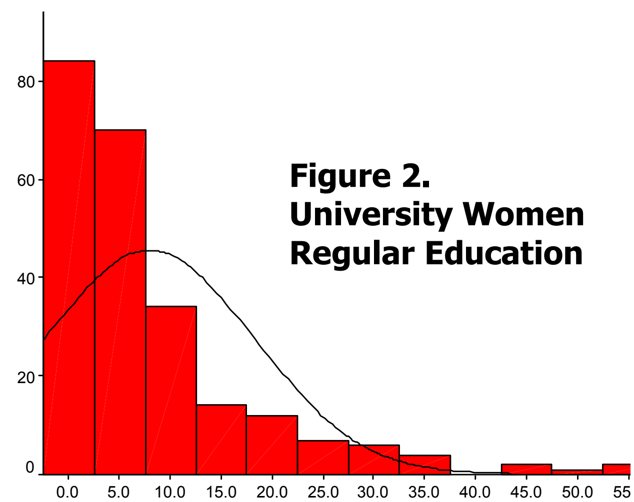

Figure 2. University Women Regular Education

As seen in Table 18, internal consistency reliability ranged from .88 - .94 in the large samples of high school and college regular education students. The small sample of high school girls in special education (n = 31) had a lower reliability estimate ($\alpha = 0.75$), but the other three larger samples of special education students had high reliability estimates (.91 - .92). The internal consistency reliability for the clinical sample of 115 concussed athletes also was high ($\alpha = 0.93$). The standard error of measurement (SEM) is considered an estimate of measurement error in a person's observed test score. Typically, SEMs are calculated in standard deviation units using the formula below. SEMs are calculated in three steps. First, the reliability coefficient is subtracted from one. Second, the square root of this value is obtained. Third, this square root is multiplied by the sample standard deviation. SEMs for the different groups also are presented in Table 18. These SEMs were used to create confidence intervals. A confidence interval represents a range or band of scores, surrounding an observed score, in which the individual's "true" score is believed to fall. The 80% (.80) confidence interval is obtained by multiplying the SEM by a z-score of 1.28 and the 90% (.90) confidence interval is obtained by multiplying the SEM by a z-score of 1.64.

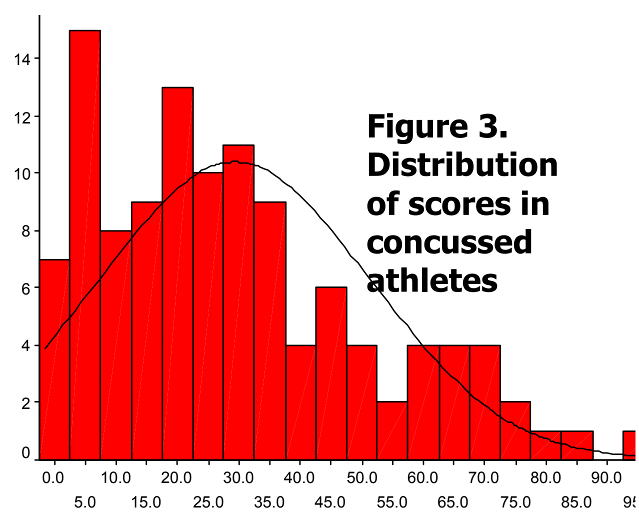

Figure 3. Distribution of scores in concussed athletes

For college men, the 80% confidence interval for the total score is approximately +/- 4 points (i.e., 3.3) and the 90% confidence interval is approximately +/- 5 points (i.e., 4.26).

Test-retest reliability was examined in 82 concussed high school and college athletes. They completed the scale within 2 days of their concussion and again within 4 days. The test-retest reliability in this sample was .80. Notably, their mean score at time 1 was 24.6 and their mean score at time 2 was 12.0.

[1]Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika, 16:3, 297-234.
Franzen, M.D. (1989). Reliability and validity in neuropsychological assessment. New York: Plenum Press.
Franzen, M.D. (2000). Reliability and validity in neuropsychological assessment. (2nd Edition) New York: Kluwer Academic/Plenum Press.

Normative Scores & Classification Ranges

As seen in Figures 1 – 3, the distributions of total scores are skewed. With this degree of skew, forced-normalization of the distributions will (a) distort the true nature of the construct being measured; that is, healthy young people's total symptoms are not normally distributed in the population, and (b) result in increased interpretation error.

Therefore, the natural distribution of scores was examined and classification ranges were created that reflect proportions of normative subjects. Classification descriptors were created that reflect raw score ranges and percentile rank ranges in the natural distribution of scores. For example, in Table 19, 40.5% of high school boys obtained a total score of zero on the scale. Thus, a score of zero would be considered "Low – Normal". In contrast, only 10% scored 14 or higher, so scores between 14 and 21 are considered "High" and scores of 22 or greater are considered "Very High."

The classification ranges for high school and university students in regular education are presented in Tables 19 – 22. The ranges for those with a history of special education are presented in Tables 23 – 26. The sample of high school girls with a history of special education is very small; this table is provided for general information (Table 24). We recommend using Table 3 for all high school girls.

Table 19. Classifications, raw scores, and percentile ranks based on a sample of 588 regular education high school boys.

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	40.5
Normal	1 – 6	49 – 76
Unusual	7 – 13	79 – 90
High	14 – 21	91 – 95
Very High	22+	> 95

Table 20. Classifications, raw scores, and percentile ranks based on a sample of 119 regular education high school girls.

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	29.4
Normal	1 – 8	40 – 75
Unusual	9 – 17	76 – 90
High	18 – 39	91 – 95
Very High	40+	> 95

Table 21. Classifications, raw scores, and percentile ranks based on a sample of 803 regular education university men.

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	43.3
Normal	1 – 5	50 – 75
Unusual	6 – 12	78 – 90
High	13 – 20	91 – 95
Very High	21+	> 95

Table 22. Classifications, raw scores, and percentile ranks based on a sample of 236 regular education university women.

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	26.7
Normal	1 – 10	32 – 75
Unusual	11 – 21	79 – 90
High	22 – 31	91 – 95
Very High	32+	> 95

Table 23. Classifications, raw scores, and percentile ranks based on a sample of 156 high school boys with a history of "special education3".

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	31
Normal	1 – 10	39 – 74
Unusual	11 – 26	76 – 90
High	27 – 38	92 – 95
Very High	239+	> 95

Table 24. Classifications, raw scores, and percentile ranks based on a sample of 31 high school girls with a history of "special education".

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	19
Normal	1 – 6	32 – 74
Unusual	8 – 14	81 – 90
High	15 – 19	93 – 97

[1] It is important to note that inclusion in the so-called "special education" groups does not mean that the person (a) had a formally diagnosed learning disability, or (b) attended special education classes or programs. All subjects who self-reported any past speech therapy, learning problems (e.g., reading or math), ADHD, or special education placement were included in these groups.

Table 25. Classifications, raw scores, and percentile ranks based on a sample of 196 university men with a history of "special education".		
Classification	**Raw Scores**	**Percentile Ranks for Players**
Low – Normal	0	28
Normal	1 – 12	34 – 74
Unusual	13 – 28	77 – 90
High	29 – 41	91 – 95
Very High	42+	> 95

Table 26. Classifications, raw scores, and percentile ranks based on a sample of 60 university women with a history of "special education".		
Classification	**Raw Scores**	**Percentile Ranks for Players**
Low – Normal	0	17
Normal	1 – 13	22 – 73
Unusual	14 – 21	78 – 90
High	22 – 31	91 – 95
Very High	32+	> 95

Interpreting Change on the Postconcussion Scale

A common method for interpreting change on a self-report inventory is to apply the reliable change methodology. This method relies heavily on the standard error of the difference score. The standard error of the difference (S_{diff}) can be used to create a confidence interval (i.e., a prediction interval in the statistical literature) for test-retest difference score. Essentially, this confidence interval represents the probable range of measurement error for the distribution of difference scores.

The reliable change methodology allows the clinician to reduce the adverse impact of measurement error on test interpretation. To represent clinically significant improvement, the change score must be statistically reliable. However, the converse is not true; a statistically reliable change does not necessarily guarantee a clinically meaningful change. For example, if an athlete demonstrated a major increase in symptoms measured 24 hours post injury, and then obtained a score that showed statistically reliable improvement a few days later, yet the symptom endorsement was still extremely high, this change might not be interpreted as clinically meaningful improvement. In other words, there was real change for the better, but the athlete was still far from recovered.

Using the earlier example of the concussed athletes, the test retest reliability was .80. The standard deviation for time 1 was 24.6 and the standard deviation for time 2 was 12.0. The SEM for time 1 was 11.0 and for time 2 is 5.4. Thus, the S_{diff} = 12.2, and the .80 confidence interval = 15.7.

The problem with applying the reliable change methodology to concussed athletes is that their experience of postconcussion symptoms is rapidly changing over a short time period. Thus, the phenomenon under study is not reasonably stable. In the example of the 82 concussed athletes, only 2.4% got worse over time by 10 or more points, whereas 45% got better by 10 or more points. Ten points represents the 90% confidence interval surrounding the time 1 test score in concussed athletes (see Table 18, last column).

Thus, because concussions typically result in a radical change in symptom reporting from baseline, followed by rapid improvement, the reliable change methodology has serious limitations in its practical application.

Clinical Interpretation of the Postconcussion Symptom Scale

Baseline Testing: If baseline testing is conducted, and an athlete endorses a high number of symptoms, he or she should be questioned to identify factors relating to this symptom reporting. For example, an athlete might report a large number of symptoms due to depression or situational life stress. Retesting will likely be necessary following resolution of these factors, if transient, to get a better estimate of baseline functioning.

Postconcussion Testing: Immediately following concussion, athletes often report a large number of symptoms on a postconcussion symptom inventory. There typically is rapid resolution of these symptoms over the next several days, and sometimes weeks. Knowing normal and abnormal symptom score ranges for athletes is helpful for interpreting the clinical significance of the symptom reporting patterns, irrespective of the reliability of the measures.

Step 1: Look up the classification range in Tables 19 – 26.

Step 2: Consider that the athlete’s “true score” falls in the range of +/- 8 points surrounding the obtained score (last row of Table 18).

Step 3: Retest the athlete in a few days. If his/her score drops by 10 or more points, this is probably real improvement. If his/her score gets worse by 2 or more points, this should be taken seriously because athletes rarely get worse over time. In fact, of the 82 players tested twice, only 5% got worse by 5 or more points over the retest interval.

Step 4: Keep in mind that improvement doesn’t mean recovery. Tables 19 – 26 can be used to determine when an athlete’s score falls in the broadly normal range. In our view, athletes who continue to report symptoms outside the broadly normal range, under most circumstances, should continue to rest.

Appendix A.

Normative Tables - Quick Reference

Table A.1. Approximate Classification Ranges for Index Scores: Boys Ages 13 – 15 (N = 183)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 63	≤ 49	≤ 16.2	≥ .76
Borderline	64 – 73	50 – 60	16.3 – 24.2	.75 - .67
Low Average	74 – 79	61 – 68	24.3 – 30.1	.66 - .61
Average	80 – 92	69 – 86	30.2 – 37.8	.60 - .53
High Average	93 – 96	87 – 93	37.9 – 44.2	.52 - .49
Superior	97 – 99	94 – 97	44.3 – 50.2	.48 - .45
Very Superior	100	98 – 100	≥ 50.3	≤ .44

Table A.2. Approximate Classification Ranges for Index Scores: Boys Ages 16 – 18 (N = 158)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 51	≤ 26.4	≥ .74
Borderline	69 – 74	52 – 59	26.5 – 29.6	.73 - .64
Low Average	75 – 79	60 – 70	29.7 – 33.6	.63 - .59
Average	80 – 92	71 – 88	33.7 – 42.5	.58 - .50
High Average	93 – 98	89 – 93	42.6 – 47.7	.49 - .47
Superior	99	94 – 96	47.8 – 51.1	.46 - .43
Very Superior	100	97 – 100	≥ 51.2	≤ .42

Table A.3. Approximate Classification Ranges for Index Scores: Girls Ages 13 – 18 (N = 83)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 49	≤ 18.9	≥ .75
Borderline	69 – 77	50 – 59	19.0 – 28.9	.74 - .67
Low Average	78 – 83	60 – 69	29.0 – 32.7	.66 - .61
Average	84 – 93	70 – 88	32.8 – 42.3	.60 - .51
High Average	94 – 98	89 – 92	42.4 – 47.0	.50 - .49
'Superior	99 – 100	93 – 98	47.1 – 51.1	.48 - .45
Very Superior	--	99 – 100	≥ 51.2	≤ .44

Table A.4. Approximate Classification Ranges for Index Scores – University Men (N = 410)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 71	≤ 51	≤ 23.8	≥ .75
Borderline	72 – 77	52 – 60	23.9 – 28.3	.74 - .67
Low Average	78 – 82	61 – 68	28.4 – 32.4	.66 - .61
Average	83 – 94	69 – 94	32.5 – 42.0	.60 - .52
High Average	95 – 97	95 – 97	42.1 – 46.0	.51 - .48
Superior	98 – 99	98 – 99	46.1 – 50.0	.47 - .45
Very Superior	100	100	≥ 50.1	≤ .44

Table A.5. Approximate Classification Ranges for Index Scores – University Women (N=97)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 70	≤ 48	≤ 23.3	≥ .70
Borderline	71 – 82	49 – 59	23.4 – 29.7	.69 - .64
Low Average	83 – 86	60 – 69	29.8 – 34.3	.63 - .60
Average	87 – 97	70 – 88	34.4 – 42.1	.59 - .52
High Average	98 – 100	89 – 93	42.2 – 46.3	.51 - .50
Superior	---	94 – 96	46.4 – 49.2	.49 - .48
Very Superior	---	97 – 100	≥ 49.3	≤ .47

Appendix B.
Postconcussion Scale - Quick Reference Tables

Step 1: Look up the classification range.

Step 2: Consider that the athlete's "true score" falls in the range of +/- 8 points surrounding the obtained score (last row of Table 18).

Step 3: Retest the athlete in a few days. If his/her score drops by 10 or more points, this is probably real improvement. If his/her score gets worse by 2 or more points, this should be taken seriously because athletes rarely get worse over time. In fact, of the 82 players tested twice, only 5% got worse by 5 or more points over the retest interval.

Step 4: Keep in mind that improvement doesn't mean recovery. The tables can be used to determine when an athlete's score falls in the broadly normal range. In our view, athletes who continue to report symptoms outside the broadly normal range, under most circumstances, should continue to rest.

Table B.1. 588 regular education high school boys.

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	40.5
Normal	1 – 6	49 – 76
Unusual	7 – 13	79 – 90
High	14 – 21	91 – 95
Very High	22+	> 95

Table B.2. 119 regular education high school girls

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	29.4
Normal	1 – 8	40 – 75
Unusual	9 – 17	76 – 90
High	18 – 39	91 – 95
Very High	40+	> 95

Table B.3. 803 regular education university men

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	43.3
Normal	1 – 5	50 – 75
Unusual	6 – 12	78 – 90
High	13 – 20	91 – 95
Very High	21+	> 95

Table B.4. 236 regular education university women

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	26.7
Normal	1 – 10	32 – 75
Unusual	11 – 21	79 – 90
High	22 – 31	91 – 95
Very High	32+	> 95

Table B.5. 156 high school boys with a history of "special education4"

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	31
Normal	1 – 10	39 – 74
Unusual	11 – 26	76 – 90
High	27 – 38	92 – 95
Very High	239+	> 95

Table B.6. 31 high school girls with a history of "special education"

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	19
Normal	1 – 6	32 – 74
Unusual	8 – 14	81 – 90
High	15 – 19	93 – 97

Table B.7. 196 university men with a history of "special education"

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	28
Normal	1 – 12	34 – 74
Unusual	13 – 28	77 – 90
High	29 – 41	91 – 95
Very High	42+	> 95

Table B.8. 60 university women with a history of "special education"

Classification	Raw Scores	Percentile Ranks for Players
Low – Normal	0	17
Normal	1 – 13	22 – 73
Unusual	14 – 21	78 – 90
High	22 – 31	91 – 95
Very High	32+	> 95

[1] It is important to note that inclusion in the so-called "special education" groups does not mean that the person (a) had a formally diagnosed learning disability, or (b) attended special education classes or programs. All subjects who self-reported any past speech therapy, learning problems (e.g., reading or math), ADHD, or special education placement were included in these group.

ImPACT Version 2.0 Normative Data - Quick Reference Tables

Table 1. Approximate Classification Ranges for Index Scores: Boys Ages 13 – 15 (N = 183)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 63	≤ 49	≤ 16.2	≥ .76
Borderline	64 – 73	50 – 60	16.3 – 24.2	.75 - .67
Low Average	74 – 79	61 – 68	24.3 – 30.1	.66 - .61
Average	80 – 92	69 – 86	30.2 – 37.8	.60 - .53
High Average	93 – 96	87 – 93	37.9 – 44.2	.52 - .49
Superior	97 – 99	94 – 97	44.3 – 50.2	.48 - .45
Very Superior	100	98 – 100	≥ 50.3	≤ .44

Table 2. Approximate Classification Ranges for Index Scores: Boys Ages 16 – 18 (N = 158)				
	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 51	≤ 26.4	≥ .74
Borderline	69 – 74	52 – 59	26.5 – 29.6	.73 - .64
Low Average	75 – 79	60 – 70	29.7 – 33.6	.63 - .59
Average	80 – 92	71 – 88	33.7 – 42.5	.58 - .50
High Average	93 – 98	89 – 93	42.6 – 47.7	.49 - .47
Superior	99	94 – 96	47.8 – 51.1	.46 - .43
Very Superior	100	97 – 100	≥ 51.2	≤ .42

Table 3. Approximate Classification Ranges for Index Scores: Girls Ages 13 – 18 (N = 83)				
	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 68	≤ 49	≤ 18.9	≥ .75
Borderline	69 – 77	50 – 59	19.0 – 28.9	.74 - .67
Low Average	78 – 83	60 – 69	29.0 – 32.7	.66 - .61
Average	84 – 93	70 – 88	32.8 – 42.3	.60 - .51
High Average	94 – 98	89 – 92	42.4 – 47.0	.50 - .49
Superior	99 – 100	93 – 98	47.1 – 51.1	.48 - .45
Very Superior	--	99 – 100	≥ 51.2	≤ .44

Table 2. Approximate Classification Ranges for Index Scores – University Men (N = 410)

	Verbal Memory	Visual Memory	Processing Speed	Reaction Time
Impaired	≤ 71	≤ 51	≤ 23.8	≥ .75
Borderline	72 – 77	52 – 60	23.9 – 28.3	.74 - .67
Low Average	78 – 82	61 – 68	28.4 – 32.4	.66 - .61
Average	83 – 94	69 – 94	32.5 – 42.0	.60 - .52
High Average	95 – 97	95 – 97	42.1 – 46.0	.51 - .48
Superior	98 – 99	98 – 99	46.1 – 50.0	.47 - .45
Very Superior	100	100	≥ 50.1	≤ .44

UPMC Center for Sports Medicine Sports Concussion Program
Peer-Reviewed Scientific References

We have just reviewed a brief summary of reliability, validity, and normative data regarding the neurocognitive and symptom scales contained within the ImPACT Concussion Management Software. Dr. Mark Lovell and `Dr. Micky Collins at the UPMC (University of Pittsburgh Medical Center) Sports Concussion Program have published extensive literature examining relevant clinical issues pertaining to sports concussion and the utility of ImPACT. What follows is a recent (1999 to present) listing of peer-reviewed references in various medical journals. Many of these peer-reviewed publications contain additional psychometric data regarding the clinical use of ImPACT. Please contact Dr. Collins (412-432-3668) or Dr. Lovell (412-432-3670) if you desire copies of these manuscripts or having questions pertaining to these references.

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Clinical Evaluation - CASE STUDY

Injury Description and Patient Background:

Sam (not his actual name) is a 14-year-old, right-handed, student-athlete who was referred for evaluation of cerebral concussion. The patient was injured while playing lacrosse. In terms of injury mechanism, Sam stated that he was "body-checked" in the chest, causing a rather discernable whip-lash motion, and was subsequently hit from behind by a second opponent. Acute markers of injury include no witnessed loss of consciousness, though Sam reports a notable forty-five minute retrograde amnesia and approximately two-three hour anterograde amnesia. Sam stated that he remembers sitting in the locker room prior to the game and being attended to in the trauma center after the game. He has no recollection of interim events. Sam was apparently transported via ambulance to the Trauma Center where initial symptoms included confusion (e.g. repeating himself), a rather significant generalized headache, nausea, lassitude, bilateral numbness and tingling, and photosensitivity. Sam received a Cervical X-ray and CT scan of the head, both of which were unremarkable. He was released from the hospital that evening.

Sam was referred to the clinic four days after his injury. He was also seen in clinic for two follow-up evaluations.

At the time of the first evaluation, Sam continued to report a left-temporal headache that he graded a 5 on a 10-point severity scale. He also reported experiencing "mild" levels of fatigue, mental slowing, irritability. Given his symptoms, Sam had not returned to school nor had he engaged in overt physical activity.

In terms of prior medical history, Sam did report two prior diagnosed concussions. Specifically, eight months earlier, he struck the sub-occipital portion of his cranium on a desk. Acute markers of injury did not include overt confusion, amnesia, or LOC. Initial symptoms included feeling slowed down and an occipital headache, though he reports that all symptoms remitted within three to four days. He was held out of football participation for approximately two weeks and, upon his return, stated he was entirely symptom-free. Seven months before that injury, Sam received a knee to the left side of his helmet during a football game. There was no loss of consciousness, though there was a retrograde amnesia for approximately 1 hour as well as an approximate 2-hour post-traumatic amnesia. Acute symptoms of injury included a generalized headache, fatigue, and bilateral numbness and tingling. He was taken to the hospital by ambulance where a CT scan was normal. Sam was held out of contact sport activity for two months and when he returned to sport activity, which at that point was basketball, he did notice the onset and exacerbation of generalized headache with physical exertion. He reports that his headache finally remitted after approximately one month.

Sam's other medical history is essentially unremarkable. Family medical history is negative for Alzheimer's disease, seizure disorder, Parkinson's disease, psychiatric disorders, or any other neurological disorders. Sam's mother did report a long-standing history of migraine headache, for which she has been maintained on Topamax. In terms of educational history, Sam is currently a 9th grade student with a GPA of 3.70. He has no prior history of learning disability or attention-deficit disorder.

ImPACT Test Results; 4 Days Post-Concussion:

Sam was evaluated on ImPACT 4 days Post-Concussion (Word Group 2). There was no baseline data available. Given Sam's academic history (no LD, GPA = 3.7), premorbid estimates of functioning would likely place Sam at least in the Average range, and more likely High Average range.

Conversely, however, a perusal of ImPACT's composite scores four days post-concussion (Page 3 of the clinical report) indicate discernable deficits across all neurocognitive areas. Specifically, based upon ImPACT 2.0 Normative Data (13-15 year old boys), Sam's performance fell in the Borderline range (6^{th} percentile) for both Verbal Memory (Score = 71) and Reaction Time (Score = .73; 3^{rd} percentile). The patient's Visual Motor Speed score (26.08) fell in the Low Average range (11^{th} percentile), whereas Visual Memory (Score = 78%) fell within the Average range. In terms of individual subtest scores, Sam displayed a pattern typical of concussed athletes, whereas his learning of the information (immediate trials) were relatively intact, though his delayed recall of the information was attenuated. Also, not only was Sam's Reaction Time attenuated, he also made a total of 42 errors on the test (Impulse Control score = 42). These scores indicate a relatively slow and inaccurate response style. Interestingly, Sam's most troublesome performance occurred on the Three Letters test (Module 6). His Total Letters Correct score (Total = 6), falls in the Severely Impaired range. Lastly, in terms of self-report of symptoms, Sam's score on the Symptom Scale (Page 4) indicates only mild to moderate levels of symptomatology (Total Score = 17). His most discernable symptoms included headache and feeling mentally "foggy."

Impressions:

Based upon Sam's acute markers of injury (discernable retrograde / anterograde amnesia), in addition to data derived from ImPACT, it was felt that Sam had experienced at least a moderate cerebral concussion. Data from ImPACT was most consistent with a subcortical injury (deficits with Reaction Time, Processing Speed), but was also suggestive of possible frontal involvement (significant deficits with working memory and the Three Letters test). Thus, data from ImPACT reflected impairments that would be caused by whiplash injury. Lastly, based upon Sam's mostly mild symptom reporting, it was felt that he might be minimizing symptomatology for hopes of a quicker return to lacrosse participation. This feeling was also corroborated by Sam's mother.

Given the overall test findings, there were several recommendations regarding Sam's management. First, given Sam's overt cognitive deficits, it was felt that he should be taken out of school for 2 days and that he return for ½ day sessions subsequently. Moreover, it was recommended that he not engage in any overt physical activity until cleared to do so by the clinic. Recent research has indicated that decreased cerebral blood flow (secondary to either mental/physical activity) in the acute stages of concussive injury may help to facilitate recovery from concussive injury. Thus, we felt that Sam should be rather sedentary for at least 3-4 days and that his symptoms be monitored closely. An obvious recommendation was that Sam also be removed from lacrosse participation or any other activity that could pose a risk for concussive injury. It was also recommended that Sam be removed from gym class. These specific recommendations were communicated to Sam's parents, his primary care physician, and athletic trainer. It was recommended that Sam return for evaluation at the clinic in eight days for follow-up evaluation. It was felt that the second data point would be important to help determine his speed of recovery and overall prognostic considerations.

Interview and ImPACT Data: 12 Days Post-Concussion:

Sam returned to clinic 12 days after his concussive injury. At that time, Sam reported little improvement in his presentation. He continued to report a constant left-temporal/generalized headache that he rated as an 8 on a 10-point severity scale. Moreover, the patient continued to report lingering difficulties with dizziness upon standing, feeling fatigued, mild levels of nausea, overt levels of irritability, hypersomnia, and continued cognitive difficulties. Regarding the latter, the patient reported forgetting incidents at school, forgetting conversations, and feeling "foggy" with his thinking and presentation. The patient also reported some difficulties in falling asleep at night. Otherwise, the patient denied any levels of numbness/tingling, hyperacusis, photosensitivity, or vomiting. Notably, per our recommendations, Sam returned to school for one-half day. At this time, his teachers became concerned given his overt levels of nausea and lethargic presentation. As a result, Sam was again taken out of school, rested over the weekend, and returned to school four days later. Sam was again evaluated on ImPACT (Word Group 3). As noted in the attached report, Sam's performance had actually declined in terms of both Verbal and Visual Memory. Specifically, his performance remained in the Borderline range for Verbal Memory (Score = 69; 4th percentile) and fell to the Low Average range for Visual Memory (Score = 63; 13th percentile). Minimal improvement occurred in terms of Visual-Motor Speed (Score = 29.58; Low Average range; 21st percentile) and Reaction Time (Score = .66; Low Average Range; 10th percentile). In terms of individual ImPACT test scores, Sam was noted to have difficulty with both learning and retrieval aspects for both Word and Design Memory subtests. Importantly, however, improvement was evidenced in terms of working memory on the Three Letters subtest (Total Letters Correct = 11). Sam's Symptom Score actually increased and was indicative of moderate levels of concussive symptomatology (ImPACT Symptom Scale score = 27). Interestingly, Sam now endorsed moderate difficulties with hypersomnia and difficulties falling asleep, two areas that were not endorsed during the first evaluation.

Impressions;

Overall data indicated that Sam was experiencing at least moderate lingering effects from his cerebral concussion. Little improvement had occurred relative to our first evaluation. It was felt that such findings were not unusual for someone with rather discernable acute markers of injury (amnesia) and may also have been affected by his unsuccessful return to school (increased cognitive demands and cerebral blood flow). Given his lack of overall improvement, a potential rule-out hypothesis was whether Sam's deficits may be indicative of an "acute on chronic" presentation. This hypothesis was based on his prior history of concussion and rather significant concussive injury eight months earlier. On a positive note, Sam did report a rather quick and uncomplicated recovery from his concussion eight months ago which would argue against this hypothesis. Given Sam's lingering sequelae, an MRI was ordered immediately, which was normal.

Given the overall data, it was again recommended that Sam not return to lacrosse participation, gym class, or other group sport activity that could pose a risk for concussive injury. It was also recommended that he not be involved in physical activity that worsened his symptomatology. A letter was provided to his guidance counselor indicating his cognitive impairments and a request for academic accommodations during the recovery period (untimed examinations, tutoring, other support). We allowed Sam to return to school for ½ day sessions until 18 days post-concussion, at which point we recommended a full return to school. Results of ImPACT testing were directly communicated to Sam, his parents, the PCP, and the high school athletic trainer. We recommended that Sam return for evaluation in two weeks.

Interview and ImPACT Data; 26 Days Post-Concussion:

Sam was seen back in clinic 26 days post-concussion. At this time, Sam reported a significant amelioration of his concussion-related symptoms. Specifically, the patient denied experiencing any level of headache for the past eight days. Moreover, the patient denied any levels of dizziness, hyperacusis, and feeling foggy. He did, however, continue to report some mild levels of fatigue, hypersomnia, and irritability. Sam had returned to full-time school 18 days post-concussion and reported very mild difficulties with worsening symptomatology at the end of the school day (fatigue). The patient had also begun light physical exertion (playing golf, shooting baskets by himself) with no reported exacerbation of symptoms. Sam was again evaluated on ImPACT (Word Group 4). As noted in the attached report, Sam exhibited demonstrable improvement across all measured domains. Specifically, scores across the domains of Verbal Memory (Score = 87; 49th percentile), Visual-Motor Speed (Score = 33.15; 43rd percentile), and Reaction Time (Score = .54; 66th percentile) fell within the Average Range. Visual Memory (Score = 91; 85th percentile) had actually improved to the High Average range, which was felt to be entirely normal. A perusal of individual test data indicated improvement with learning and retrieval of verbal/visual information. Similarly, improvement had occurred with working memory (Three Letters), though his performance fell in the Low Average range for both Total Sequences Correct and Total Letters Correct (normal scores are 5 and 14-15, respectively). Sam's report of symptoms was commensurate with the neurocognitive improvement, as he endorsed only mild levels of difficulty (ImPACT Symptom Score = 4).

Impressions and Current Presentation:

Overall test results indicated a considerable degree of recovery since the prior evaluation. Based upon these improvements, it was likely that Sam's presentation was more consistent with acute effects of his cerebral concussion, rather than cumulative effects of prior concussive injury. Based upon these data, it was felt that his prognosis was excellent. Within this context, however, test findings on June 3rd were consistent with mild, lingering sequelae of concussive injury. Though we did not have baseline data, it was likely that the patient's performance in terms of Visual-Motor speed was likely a lingering deficit. Moreover, Sam's performance on the Three Letters test, though improved, was still consistent with mild deficit. Interestingly, these two lingering deficits were also consistent with the biomechanics of his injury. In general, processing speed is typically a more subcortical process (i.e. back, deeper structures of the brain), whereas working memory (Three Letters test) is traditionally considered a frontal-lobe skill. Thus, the consistency of lingering deficits with the cognitive data highlights that full recovery had yet to occur. Moreover, from a symptom standpoint, Sam continued to experience subtle levels of fatigue and irritability. Irritability, in particular, is typically a frontal lobe symptom that reinforces the aforementioned interpretation of the data.

In summary, it was felt that Sam has experienced a very good, though incomplete recovery from concussive injury. Based upon these findings, it was recommended that Sam begin to increase his physical activity, though should remain out of lacrosse participation. It was felt that he could be as physically active as desired insofar as this activity did not pose a risk for another concussion or increased symptomatology (e.g. headache, dizziness, worsened fatigue, etc). Also, it was felt that his academic performance would essentially return to normal limits and that there were no limitations in this regard. Lastly, it was recommended that Sam return for ImPACT evaluation in two weeks.

Current Status

Sam is scheduled to return to the clinic in next month. It is expected that he will display entirely intact ImPACT test performance, which will subsequently serve as a "baseline" if he is to sustain another concussive injury. If, as expected, Sam is symptom-free and demonstrates intact functioning on ImPACT, he will be cleared for full sport activity and return to lacrosse participation.

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CLINICAL EVALUATION
CASE STUDY for the User's Manual

Subject Name

Organization:	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Subject ID#:	XXXXXXX

Date of birth:	XXXXXX	Age:	**14**
Gender:	**Male**	Height:	**68** inches
Handedness:	**Right**	Weight:	**125** lbs

Native country / region:	**United States of America**	Second language:	**(None)**
Native language:	**English**	Years speaking:	**0**

Years of education completed excluding kindergarten:	**7**	Received speech therapy:	**No**
Diagnosed learning	**No**	Problems with ADD/Hyperactivity:	**No**
Attended special education classes:	**Yes**	Repeated one or more years of school:	**No**

Current sport:	**Lacrosse**	Primary position/event/class:	
Current level of participation:	**Junior High**	Years experience at this level:	**2**

Number of times diagnosed with a concussion (excluding current injury):	**2**
Concussions that resulted in loss of consciousness:	**0**
Concussions that resulted in confusion:	**1**
Concussions that resulted in difficulty remembering events that occurred immediately after injury:	**1**
Concussions that resulted in difficulty remembering events that occurred immediately before injury:	**1**
Total games missed as a result of all concussions combined:	**2**
Concussion history:	

Treatment for headaches by physician:	**No**		
Treatment for migraine headaches by physician:	**No**	Treatment for psychiatric condition (depression, anxiety):	**No**
Treatment for epilepsy / seizures:	**No**	History of meningitis:	**No**
History of brain surgery:	**No**	Treatment for substance/alcohol abuse:	**No**

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CLINICAL EVALUATION CASE STUDY for the User's Manual

Exam Type:	Post-	Post-	Post-
Date Tested:	4 Days	12 Days	26 Days
Last Concussion:	Post Injury	Post Injury	Post Injury
Exam Language:	English	English	English
Test Version:	2.2.729	2.2.729	2.2.729
Word Memory	*WG = 2*	*WG = 3*	*WG = 4*
Hits (immediate)	12	6	12
Correct distractors (immediate)	12	11	12
Learning percent correct	100%	71%	100%
Hits (delay)	9	5	11
Correct distractors (delay)	12	10	11
Delayed memory percent	88%	63%	92%
Total percent correct	94%	67%	96%
Design Memory			
Hits (immediate)	5	6	11
Correct distractors (immediate)	12	6	12
Learning percent correct	71%	50%	96%
Hits (delay)	5	5	9
Correct distractors (delay)	9	7	11
Delayed memory percent	58%	50%	83%
Total percent correct	65%	50%	90%
X's and O's			
Total correct (memory)	11	9	11
Total correct (interference)	91	107	126
Avg. correct RT (interference)	0.38	0.53	0.43
Total incorrect (interference)	42	14	3
Avg. incorrect RT (interference)	0.35	0.28	0.41
Symbol Match			
Total correct (symbols)	27	27	27
Avg. correct RT (symbols)	1.93	1.70	1.36
Total correct (symbols hidden)	7	6	7
Avg. correct RT (symbols	1.50	1.40	1.41
Color Match			
Total correct	8	8	9
Avg. correct RT	1.17	0.89	0.75
Total commissions	0	3	0
Avg. commissions RT	0.00	1.16	0.00
Three Letters			
Total sequence correct	2	3	3
Total letters correct	6	11	13
Percent of total letters correct	40%	73%	87%
Avg. time to first click	2.95	2.81	1.95
Avg. counted	11.6	10.8	12.2
Avg. counted correctly	9.8	10.8	11.6

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CLINICAL EVALUATION CASE STUDY for the User's Manual

Exam Type: Date Tested: Last Concussion:	**Post-** 4 Days Post Injury	**Post-** 12 Days Post Injury	**Post-** 26 Days Post Injury
Composite Scores			
Memory composite (verbal)	71%	69%	87%
Memory composite (visual)*	78%	63%	91%
Visual motor speed composite	26.08	29.58	33.15
Reaction time composite	0.73	0.66	0.54
Impulse control composite	42	17	3

** New clinical/research composite score for ImPACT version 2.0. All other composite scores are identical to ImPACT version 1.1.*

Concussion Details

Loss of consciousness	1-20 seconds
Retrograde amnesia	> 15 minutes
Anterograde amnesia	31-180 minutes
Confusion / disorientation	> 30 minutes
Returned to play	
Taken to hospital	Yes
CT/MRI scan of head	Negative
Mouthguard type	Boil and Bite
Mouthguard condition	Good
Symptoms	headache, nausea, personality change, numbness or tingling, fatigue
Description of injury and additional information	Unknown mechanism of injury...struck in the chest initially and in the lower back. Whiplash potential, unsure of other mechanisms.

The information provided by this report should be viewed as only one source of information regarding the athlete's level of functioning. Diagnostic or return to play decisions should not be based solely on the data generated by ImPACT but should be based on an evaluation by medical personnel in accordance with usual and standard medical practice. If an athlete is suspected of suffering a mild traumatic brain injury or concussion, this individual should be evaluated by medical personnel and should be followed carefully for the emergence of symptoms.

Consultation is recommended to help facilitate proper interpretation of the outlined test scores. For consultation please feel free to contact Dr. Mark Lovell or Dr. Micky Collins at the University of Pittsburgh Center for Sports Medicine. To reinforce proper interpretation of the test data, there will be no charge for the initial post-injury consultation.

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CLINICAL EVALUATION
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Exam Type:	Post-concussion	Post-concussion	Post-concussion
Date Tested:	4 Days Post Injury	12 Days Post Injury	26 Days Post Injury
Last Concussion:			

Symptoms			
Headache	4	4	0
Nausea	0	1	0
Vomiting	0	0	0
Balance Problems	0	2	0
Dizziness	2	1	0
Fatigue	0	1	1
Trouble falling asleep	0	3	0
Sleeping more than usual	0	2	2
Sleeping less than usual	0	0	0
Drowsiness	0	1	0
Sensitivity to light	0	0	0
Sensitivity to noise	2	0	0
Irritability	0	1	0
Sadness	0	1	0
Nervousness	0	1	0
Feeling more emotional	0	1	1
Numbness or tingling	0	0	0
Feeling slowed down	2	1	0
Feeling mentally foggy	3	1	0
Difficulty concentrating	2	2	0
Difficulty remembering	1	2	0
Visual problems	1	2	0
Total Symptom Score	**17**	**27**	**4**

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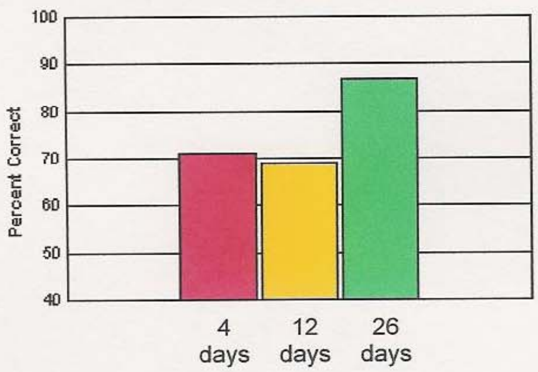
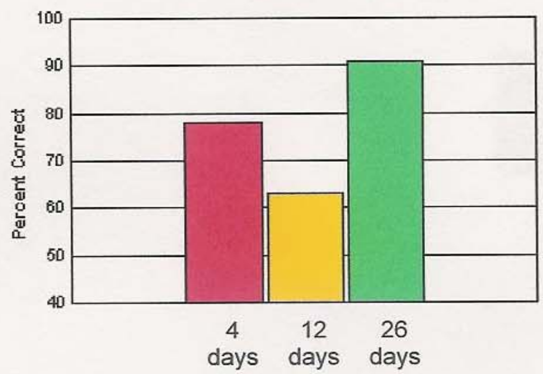
CLINICAL EVALUATION
CASE STUDY for the User's Manual

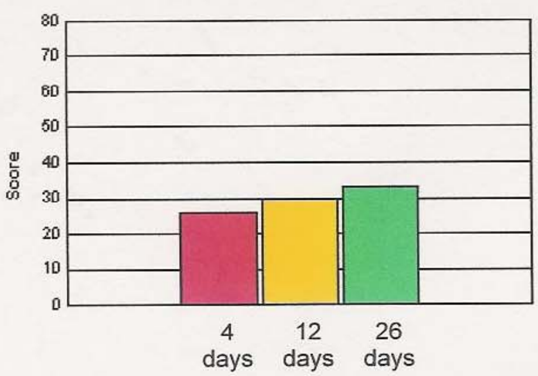
Memory Composite



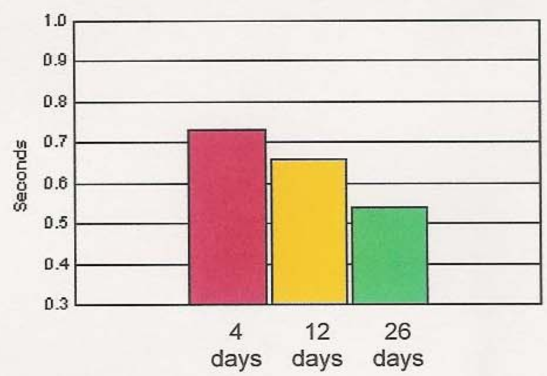
Memory Composite



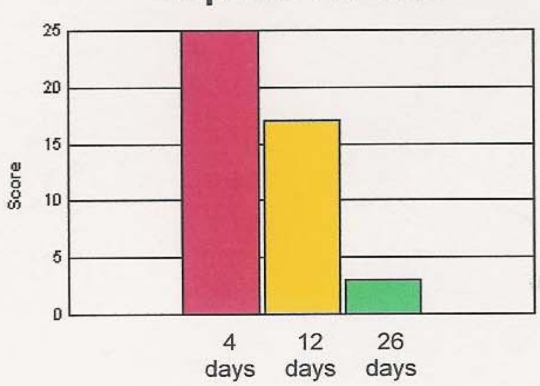
Visual Motor Speed



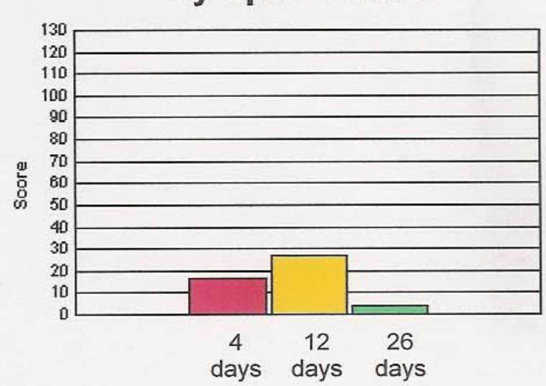
Reaction Time Composite



Impulse Control



Symptom Score



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This manual has been structured to present reliability, validity, and normative data regarding the ImPACT test battery. Given our multiple ongoing research projects, this manual will be updated regularly as new studies are completed. (please check our website for updates) The ImPACT team remains committed to a program of vigorous clinical research to assure that the ImPACT program represents the "state of the art" in concussion management.

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