ImPACT®

Administration Manual

ATTENTION:

PLAYER DEVELOPMENT CLUB TEST ADMINISTRATORS

Tests may only be conducted by non-technical club staff, including administrators, trainers, or medical professionals. The test is not to be conducted at home. No coaches are to administer the ImPACT test. The test administrator must first complete ImPACT training, available at no cost online, at https://concussioncaretraining.com/courses/free-courses/impact-onboarding-bundle/

Notwithstanding anything to the contrary herein, results should only be interpreted by a licensed neuropsychologist.

Acknowledgments

This manual has been formatted to accomplish several goals. First and foremost, this guide is structured to provide necessary background information regarding the role of neurocognitive assessment in the evaluation of the athlete. The information presented below assumes a basic level of knowledge regarding the medical treatment of sports injuries. A basic strategy is provided for the initial diagnosis of concussion on the athletic field as well as signs or symptoms that may signify a more severe injury.

In addition to presenting background information regarding concussion, this manual also presents general information that is presented to help the user get the most out of the software. As emphasized throughout the manual, ImPACT is a sophisticated tool that has been developed through years of careful university-based research. ImPACT is not structured to provide diagnostic information and the diagnosis of concussion should always be made by a health care professional who has the requisite training and is licensed to manage concussion in his/her State, Province or country.

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Intended Use

ImPACT is a medical device intended for use as a computer-based neurocognitive test battery to aid in the assessment and management of concussion.
ImPACT is a neurocognitive test battery that provides healthcare professionals with objective measure of neurocognitive functioning as an assessment aid and in the management of concussion in individuals ages 12-59.

Warnings and Cautions

ImPACT is not intended to provide a diagnosis or decision about the Test Taker. ImPACT results should be interpreted only by qualified healthcare professionals.

ImPACT does not identify the presence or absence of a clinical diagnosis.
ImPACT cannot be used as a stand-alone diagnostic for concussion.
The device is not intended to be used as a stand-alone assessment for making determinations regarding return to athletic play.

Caution should be exercised when using this test to assess individuals that have been diagnosed with or are currently experiencing other confounding conditions including but not limited to the following: insomnia, post-traumatic stress disorder (PTSD), depression, attention deficit hyperactivity disorder (ADHD), memory impairment, dementia, delirium, prescription and non-prescription medication, some nutritional supplements, as well as other neurological and psychiatric disorders in which impaired cognitive function may be present and a variety of other psychological states (e.g. fatigue and stress).

The safety and effectiveness of ImPACT for individuals under the age of 12 years and over the age of 59 years has not been established.
The reliability and validity of the ImPACT results in individuals with color blindness has not been established.
The reliability and validity of the ImPACT results in individuals with a reading level below the sixth grade has not been established.
Baseline testing performed in an unsupervised manner may include a higher possibility for distraction than baseline testing performed in a supervised manner, which requires clinical judgment when interpreting these results.

ImPACT is intended to be used by medical professionals qualified to interpret the results of a concussion assessment examination and aid in the management of concussion.

Caution: US Federal Law restricts this device to use by, or on the order of a licensed healthcare professional.

Contact the ImPACT Applications Support Team for product or training support, to submit a complaint or report if the use of the device contributed to a serious injury, or to obtain a free printed copy of this manual.

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MD
Medical Device
UDI: 00864127000301

Chapter 1 - ImPACT Neurocognitive Test Battery

Overview

Interest in evaluating individuals to determine their neurocognitive status has evolved significantly throughout the years. With this interest, comes an increasing demand for a computerized neurocognitive battery that is practical, cost effective, and efficient for healthcare professionals to use with large numbers of athletes and individuals. ImPACT is designed to meet these demands while maintaining high standards for reliability, validity, sensitivity, and specificity. This manual is designed to describe, educate, and fully support the use of ImPACT in clinical and research settings.

What Is a Concussion?

A concussion is a disturbance in brain function that occurs following either a blow to the head or as a result of the violent shaking of the head. Existing research suggests that concussion produces metabolic rather than anatomic injury to the brain. In other words, following concussion there is a temporary disruption of energy utilization in the brain that does not appear to produce permanent injury in the majority of cases. However, research also suggests that repeated injury, particularly during the recovery period, may result in more severe and, in some rare cases, life-threatening injury. It is important to emphasize that the underlying pathophysiology of concussion is still being investigated and the definition of the injury continues to develop.

Because concussion is currently thought to be primarily a metabolic rather than structural injury, traditional neurodiagnostic techniques (e.g., CT scan, MRI) are often normal following concussive insult. These techniques can be invaluable in ruling out more serious difficulties (e.g., cerebral bleed, skull fracture) that also may occur with head trauma.

When Is a Head Injury More Than a Concussion?

Most individuals recover relatively quickly from head injury (within two to three weeks). However, healthcare professionals need to be aware of the warning signs of severe injury. Any penetrating injury to the skull signifies a more severe head injury and should be treated as such. Any loss of consciousness requires a prompt and complete medical evaluation. Although headache is common following concussion, a severe headache that increases in intensity should be treated as a medical emergency. A pronounced decline in mental status in the minutes to hours following injury also is a cause for emergency care. Finally, sensory or motor loss in the limbs may indicate spinal injury or a subdural or epidural hematoma and should be evaluated immediately. As noted throughout this manual, decisions regarding whether or not a concussion has or has not occurred and the management of that injury always should be made by a qualified healthcare professional and should not be based on neurocognitive test results alone.

What Symptoms Are Often Associated with a Concussion?

Identifying a concussion can be difficult under the best of circumstances. There may be no direct trauma to the head and the athlete is often not rendered unconscious. The individual may be unaware that he or she has been injured immediately after the injury and may not show any obvious signs of concussion such as imbalance, gross confusion, or obvious amnesia. To complicate this situation, athletes at all levels of competition may intentionally minimize or hide symptoms in an attempt to prevent being removed from the game, thereby creating the potential for additional injury. Finally, individuals may have different symptoms following injury depending on the biomechanical forces involved and the individual's injury history. Signs (observed by others) and symptoms (reported by the athlete) differ from person to person and therefore an individualized approach to evaluation is necessary.

Some signs and symptoms that are frequently associated with a concussion include:

- Headache or a sensation of pressure in the head
- Nausea with or without vomiting
- Confusion or disorientation to time, place
- Retrograde amnesia (loss of memory for events preceding injury)
- Posttraumatic amnesia (difficulty with formation of new memory)
- Feeling mentally slowed down
- Feeling mentally “foggy” or “groggy”
- Dizziness
- Disruption of balance
- Sensitivity to light (photosensitivity)
- Sensitivity to noise (phonosenstivity)
- Visual blurriness, fuzziness, or difficulty tracking
- Short-term memory difficulties
- Concentration problems
- Motor clumsiness (stumbling, slowed movement)

What Is Neurocognitive Assessment and Why Use It?

Neurocognitive assessment is a performance-based method to assess the many aspects of cognitive functioning. Included in this assessment are measurements of reaction time, processing speed and memory. A neurocognitive assessment is used to examine normal cognitive function and differentiate the cognitive consequences of traumatic brain injury, brain disease, and mental illness. Neurocognitive assessment may be used to aid clinicians and researchers in formulating diagnostic impressions, assessment of treatment response, and prediction of functional potential and functional recovery. Recent advances in neurocognitive assessment include computerized presentation of many of the tasks traditionally presented in paper and pencil format.

Computer-based neurocognitive testing has become the principle component of concussion evaluation. International expert meetings on the topic of concussion in sports explicitly endorsed neuropsychological testing as the “cornerstone” of concussion management. Seventy percent of pediatricians who currently manage concussions report using neurocognitive testing as part of their evaluation. Given the large number of reported concussions and the notion that there is significant underreporting of concussions that actually occur, there is an increasing need for high-quality, empirically validated tools to aid healthcare professionals in their identification and treatment of head injury.

Rationale for the Development of ImPACT

Because a concussion is primarily a pathophysiological event rather than a structural event, and because traditional imaging tests are of little value in identifying the injury, there is a need to identify the neurocognitive changes associated with a concussion. ImPACT is designed to provide relevant information regarding cognitive and clinical symptoms in individuals suspected of having sustained a mild Traumatic Brain Injury (TBI), in other words, a concussion. This information, combined with other relevant clinical data and objective test information, can be used to help identify a concussion and describe recovery from an injury. This approach to clinical management of a concussed individual is a reliable and valid method for determining when an athlete is sufficiently recovered from a concussion to return to athletic competition, or if an individual is capable of returning to daily activity.

The most common and effective way to use the ImPACT concussion model is to establish baseline performance in an athlete or individual prior to participation in a sport. This baseline test can be administered by a trained proctor who is following established standard administration procedures. (See Chapter 2 for a complete description.) After a suspected concussion, an individual should be reevaluated by a train healthcare professional. The individual’s performance on the post-injury evaluation is compared with his/her performance on the baseline evaluation. Any discrepancies in the results, along with other medical, behavioral, and psychological information should be used by the healthcare provider to make a determination about the individual’s concussion status and to serve as a guide for future treatment strategy.

Chapter 2 - Administration and Scoring of ImPACT

What is ImPACT?

ImPACT is a computerized neurocognitive test battery that is used to assess Sequencing/Attention, Word Memory, Visual Memory and Reaction Time. When used to obtain baseline neurocognitive functioning, it can be Individually self-administered or administered to a group that is supervised by a trained proctor. However, when used for a post-injury evaluation, ImPACT should only be administered and interpreted by a trained healthcare professional.

Ages

ImPACT is designed to be administered to test takers ages 12 years 0 months to 59 years 11 months of age.

Qualifications for Administration and Interpretation

The results of ImPACT has been specifically developed for professional use. Post-injury testing should always be completed by properly trained and licensed healthcare providers with specific knowledge and experience in interpreting neurocognitive test results. For more information on the qualifications necessary for administering and interpreting ImPACT or access to online training tools, please visit www.impacttest.com.

Administration Time

In general, test administration can be completed within 20 minutes. A variety of factors can contribute to differences in administration time such as the age of the individual being tested, their speed in responding, their attention and focus on the task or other psychological or behavioral factors.

Technical Requirements

ImPACT is designed to be administered on any laptop or desktop computer that has a color monitor and a pointing device such as mouse or trackpad. The test is delivered as a web application thus it requires a modern web browser and a reliable Internet connection.

The full set of current computer requirements are available in the Quick Reference Guide, which can be accessed inside the ImPACT Applications' Customer Center, under the 'Resources' tab on the left.

Test Environment

There are specific requirements with regard to the test environment that should be followed to ensure it is free from distractions and interruptions. Administration is guided by the software and assumes sixth grade reading level. Test takers' performance can be affected by distraction or engaging in other activities while attempting to take the test. Therefore, we recommend the following:

1. The physical environment should be quiet and free of noise.
2. All cell phones, music players, and other electronic devices should be turned off.
3. The test taker should not be engaging in another activity or conversing with others.
4. Seating arrangements should allow the test taker to sit comfortably with at least 1 seat between test takers when being administered in a group setting.
5. Ideally, the test should be administered in an area that prevents from issues with glare on the screen. Testing outdoors in direct sunlight is not recommended due potential issues with glare.

Note: It is recommended that test takers are well-rested and do not complete testing immediately after vigorous exercise as this may affect test results.

General Guidelines for Test Administration

Test directions for ImPACT are embedded within the test battery rendering administration of the test quite straightforward. Nevertheless, to help with the understanding of the administration process, the following section provides general guidelines as well as specific instructions for administering the test battery. It is important that examiners become familiar with the instructions in this section in order to maintain standard procedure and yield valid interpretation.

Providers are offered free and fee-based online and live training content at www.impacttest.com to enhance their knowledge and skills interpreting ImPACT.

Order of Administration

Each administration of ImPACT is fixed and follows a set sequence. The order of administration is as follows:

1. Demographics > 2. Symptom Scale > 3. Word Memory > 4. Design Memory > 5. X's and O's > 6. Symbol Match > 7. Color Match > 8. Three Letters > 9. Word Memory Delayed Recall > 10. Design Memory Delayed Recall.

Instructions for Starting a New Test or Reviewing Test Records from the Customer Center

ImPACT Customer Center Login Screen

Enter the Username (Email) and Password that was provided to you by ImPACT Applications, Inc. Your Username and Password should be kept secure at all times and should NOT be shared with test takers as this would allow them to have access to other test takers' records.

Navigating Selection Menu in Customer Center

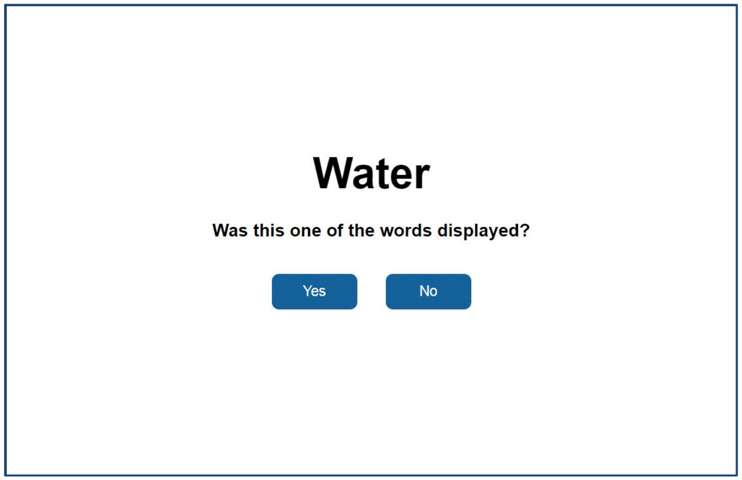
Start New Test: Selecting "Start New Test" proceeds to the next screen for test-type selection.
First time test takers: Select the organization with which to associate this test by choosing it from the organization drop-down.
Previously tested individuals: Type the first few characters of their last name. Matches will be displayed in a drop-down list. Select the appropriate individual from the list.

Select the type of test: For pre-injury evaluations, select the "Baseline" test option. Following injury or when a concussion is suspected, select one of the "Post-injury" test options.

Basic Test Instructions: Ensure all technical requirements are fulfilled and the environment is quiet and free of distractions (see Technical Requirements and Test Environment sections of the manual for more information).
Once you select the test type, a new browser window will open, and it will begin the administration of the test battery.

Neurocognitive Test Modules Descriptions, Administration Instructions, and Scoring

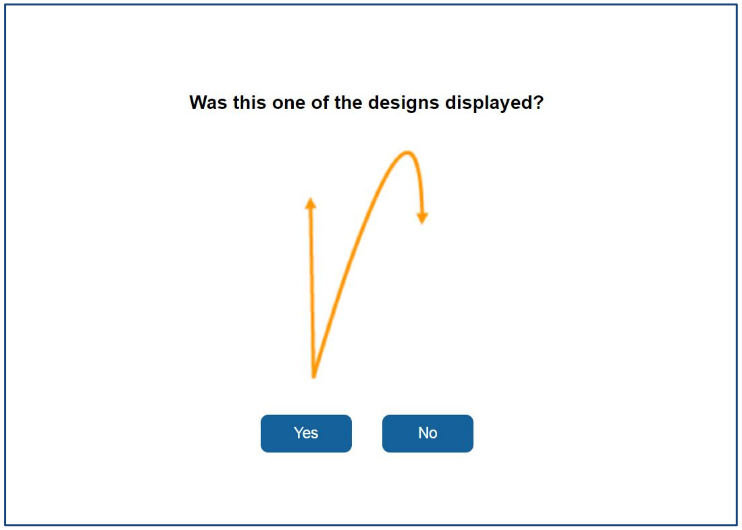
Word Memory – Module 1



- Evaluates attentional processes and verbal recognition memory
- Utilizes a word discrimination paradigm
  - Presents 12 target words twice for 750 milliseconds to facilitate learning the list.
  - Tests recall via the presentation of the 24-word list.
  - The words are chosen from the same semantic category as the target word.
  - There are five different forms of the word list to minimize practice effects from one administration to the next.
  - Twelve target words were selected for inclusion in each of the five word lists.
  - Twelve related but not identical words make up each of the administrations. -Non-target words are included to create a challenge situation.
  - For example, if the target word is SMALL, the non-target word might be BIG.
  - To respond to each question, the test-taker clicks the “yes” or “no” buttons.
- Individual scores are provided for both correct “yes” and “no” responses. In addition, a total percent correct score is provided.

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

Design Memory – Module 2

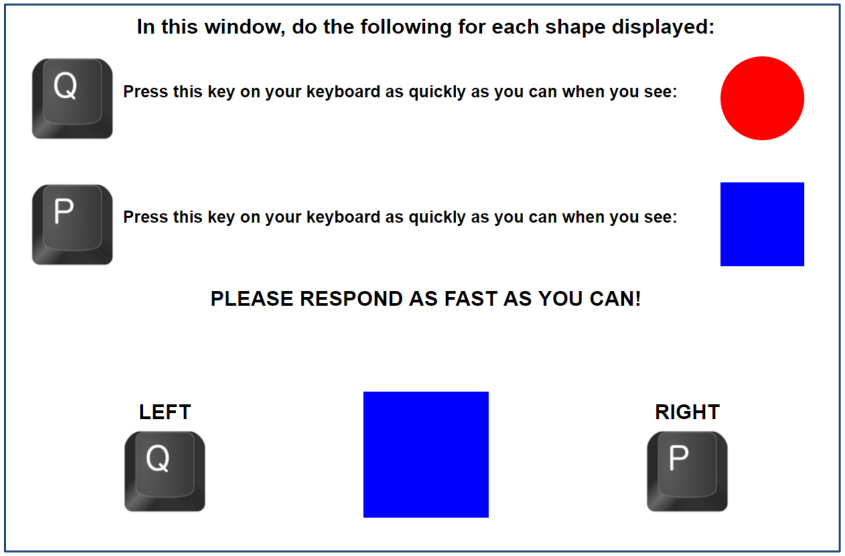


- Evaluates attentional processes and visual recognition memory
- Utilizes a design discrimination paradigm
  - Tests recall of the 24-designs
  - Comprised of 12 target designs and 12 non-target designs (target designs that have been rotated in space).
  - Presents 12 target designs twice for 750 milliseconds to facilitate learning the list.
  - The subject responds by mouse-clicking the “yes” or “no” buttons.
  - Individual scores are provided for both correct “yes” and “no” responses.
  - In addition, a total percent correct score is provided.
- Test stimuli were selected to be relatively difficult to encode verbally.
- Designs were “assigned” to one of the five administrations randomly.

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.

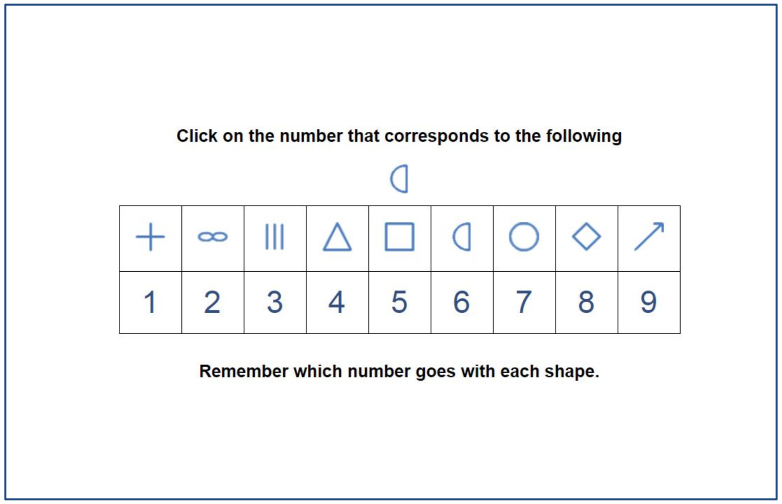
X's and O's – Module 3

- Measures visual working memory and visual processing/visual motor speed
- Includes a distracter task to interfere with memory rehearsal
- The distracter is a choice reaction time test and performance on this measure is incorporated into other aspects of ImPACT (e.g., visual motor processing speed and reaction time).
- The test taker practices the distracter task prior to presentation of the memory task.
- During this task, the subject is asked to perform a specific action if a blue square is presented or if a red circle is presented.
- Once the test taker 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 seconds
    - 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 distracter task re-appears on the screen.
    - Following the distracter task, the memory screen (X's and O's) re-appears and the test taker 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 distracter task, and the number of errors on the distracter task.
- For each administration of ImPACT, the test taker completes 4 trials.

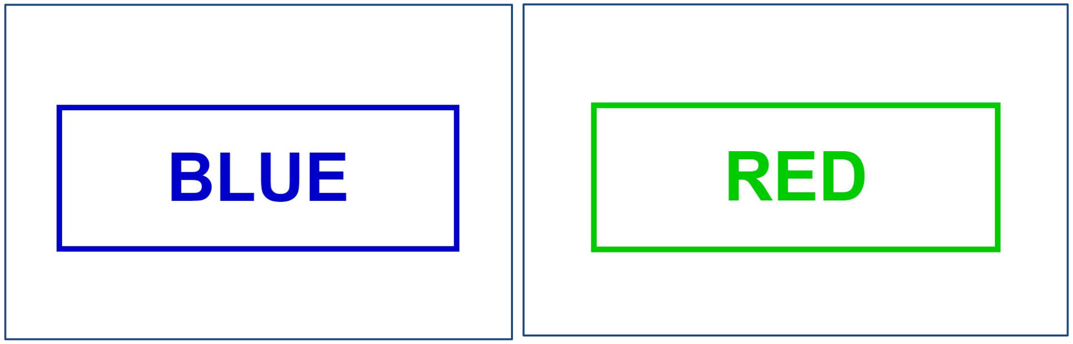


Symbol Match–Module 4

- Evaluates visual processing speed, learning, and memory
    - Presents a screen that displays 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 test taker is required to click the matching number as quickly as possible and to remember the symbol/number of 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 reappear below the grid and the test taker is asked to recall the correct symbol/number pairing by clicking the appropriate number button.
- This module provides an average reaction time score and a score for the memory condition.



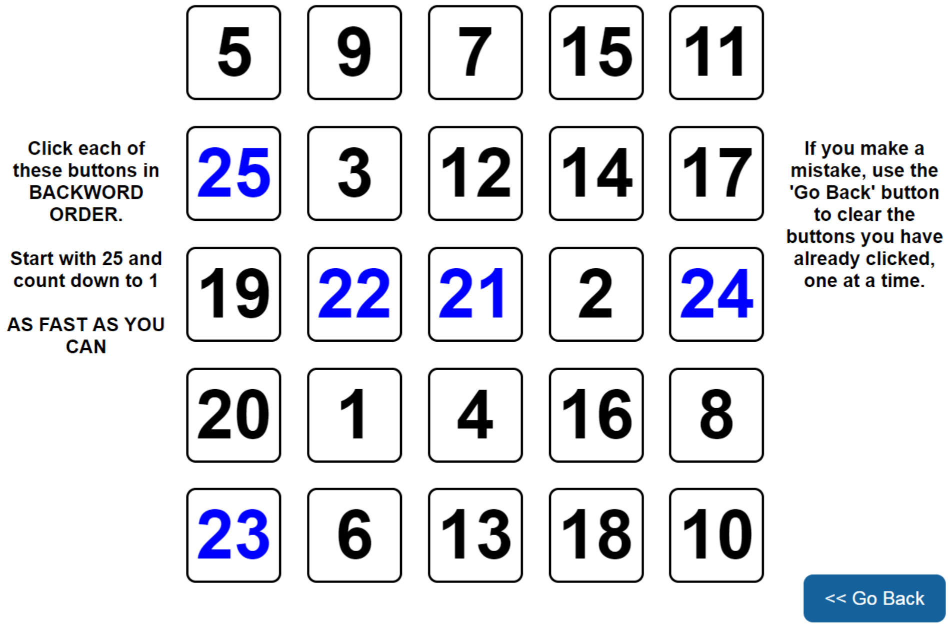
Color Match–Module 5



- Represents a choice 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 would not be affected by color blindness.
  - Next, a word is displayed on the screen in the same color ink as the word (e.g. **RED**), or in a different color ink (**GREEN** or **BLUE**)
  - The subject is instructed to click in the box as quickly as possible <u>only</u> if the word is presented in the matching ink.
- In addition to providing a reaction time score, this task also provides an error score.

Three Letters – Module 6

- Measures working memory and visual-motor response speed
- First, the test taker is allowed to practice a distracter task that consists of 25 numbered buttons on a 5x5grid.
  - The test taker is instructed to click as quickly as possible on the numbered buttons in backward order starting with 25.
  - The position of the numbers on the grid are randomized after each trial to minimize practice effects.
  - The test taker is then presented with three consonants displayed on the screen.
  - Immediately following display of the three letters, the numbered grid re-appears and the test taker is again instructed to click the numbered buttons in backward order.
  - After18 seconds, the numbered grid disappears and the test taker is asked to recall the three letters by typing them on the keyboard.
  - This task 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 distracter test.
- Five trials of this task are presented for each administration of the test.



ImPACT Post Concussion Symptom Inventory

The symptom section is designed to obtain information that is helpful in identifying whether the test taker is experiencing symptoms characteristic of a concussion. The administrator may read the questions to the test taker but the administrator should never provide the test taker with answers to the questions.

Click "OK" to start the section. As you move through each screen of the section, select "Continue" to move to the next screen or "Back" to go to a previous screen to make changes. All questions must be answered before continuing to the next screen.

The symptoms are:

- Headache
- Trouble Falling Asleep
- Nausea
- Sleeping More than Usual
- Vomiting
- Sleeping Less than Usual
- Balance Problems
- Drowsiness
- Dizziness
- Sensitivity to Light
- Sensitivity to Noise
- Irritability
- Feeling Mentally Foggy
- Sadness
- Difficulty Concentrating
- Nervousness
- Difficulty Remembering
- Feeling More Emotional
- Visual Problems
- Numbness or Tingling
- Feeling Slowed Down
- Fatigue

Scoring

All tests are automatically scored within the software. In addition to scores that are provided for each module, composite scores, a symptom score, measures of efficiency, validity, and a Reliable Change Index (RCI) score are all calculated. Each of these are discussed below.

Module Scores

Each module has a set of scores that are unique to that module. Scores were designed to reflect speed of performance or accuracy, which are the two primary components measured by the ImPACT Modules. Each of the modules and the associated scores are presented below.

Word Memory	
Hits (immediate)	Number of correctly identified words (out of 12)
Correct distracters (immediate)	The number of correctly identified distracter items (out of 12)
Learning percent correct	((Hits + correct distracters)/24) X 100.
Hits (delay)	Number of correctly identified words (out of 12)
Correct distracters (delay)	Number of correctly identified distracter items (out of 12)
Delayed memory percent correct	Delay hits + correct distracter delay items (out of 12)
Total percent correct	Average percent correct (learning percent correct + delayed percent correct/2)

Design Memory	
Hits (immediate)	Number of correctly identified designs (out of 12)
Correct distracters (immediate)	Number of correctly identified incorrect distracter items (out of 12)
Learning percent correct	((Hits + correct distracters)/24) X 100
Hits (delay)	Number of correctly identified designs (out of 12)
Correct distracters (delay)	Number of correctly identified distracter designs (out of 12)
Delayed memory percent correct	Delay hits + correct distracter items (out of 12)
Total percent correct	Average percent correct ((learning percent correct + delayed percent correct)/2)

X's and O's	
Total correct (memory)	Measures the number of correctly identified items (total possible correct =12)
Total correct (interference)	This score provides a measure of the number of errors made on the interference test
Average correct RT (interference)	Measures the average reaction time for correct responses on the interference (distracter) test
Total incorrect (interference)	Measures the number of errors on the distracter test
Total incorrect RT (interference)	Provides an index of the reaction time for incorrect responses on the interference test

Symbol match	
Total correct (visible)	Provides the number of correct matches out of 27 when the symbol number pairings are visible
Total correct RT (visible)	The average reaction time for the 27 matches
Total correct (hidden)	This represents the number of items correctly recalled when symbol number pairings are hidden
Total correct RT (hidden)	The average reaction time for recall of the memory items

Color Match	
Total correct	Number of correct matches
Average correct RT	Average reaction time for correct matches
Total commissions	Number of incorrect for color/word matches
Average commissions RT	Average reaction time for commissions

Three Letters	
Total sequence correct.	Total number of letter sequences correct (out of 5)
Total letters correct	Total letters correct (out of 15)
Percent of total letters correct	Percent letters correctly identified
Average time to first click	Time to initiation of first click of mouse
Average counted	The average number of numbers clicked, regardless of errors
Average counted correctly	The average number of numbers clicked that are in correct sequence

The Composite Indices and Scores

ImPACT composite indices represent summary scores that provide basic information regarding the individual's performance in core cognitive domains. Scores are expressed as percentiles compared to individuals of their own age group and sex. These percentiles are calculated on a group of 16,566 subjects for ages 12 years 0 months through 59 years 11 months. (See Standardization Chapter for a complete description of this sample.)

In addition to the presentation of both raw and percentile-based scores, the program also provides RCI scores that provide information about the magnitude of change from baseline testing performance to post-injury. If a particular score is significantly different from the baseline scores, the scores are printed in red. A full description of the RCI score is provided later in this manual.

Verbal Memory Composite

Evaluates attentional processes, learning, and memory within the verbal domain
This composite score represents the average performance on:

- Word Memory (Module 1) Total Percent Correct
- Symbol Match (Module 4) Total Correct Hidden/9*100
- Three Letters (Module 6) Percent Total Letters Correct

EXAMPLE

Word Memory Total Percent Correct =	98%
Symbol Match (Total Correct Hidden)/9*100 = 6/9*100 =	66.7%
Three Letters Percent Total Letters Correct =	80%
Total Divided by 3=	244.7/3 = 82

Verbal Memory Composite Score= 82

WORD MEMORY

Hits (Immediate)	12	11
Correct Distractors (immed.)	12	7
Learning percent correct	100%	75%
Hits (delay)	11	8
Correct distractors (delay)	12	6
Delayed memory pct. correct	96%	58%
Total percent correct	**98%**	66.5%

SYMBOL MATCH

Total correct (visible)	27	27
Avg. correct RT (visible)	1.52	1.85
Total correct (hidden)	**6**	4
Avg. correct RT (hidden)	1.94	2.79

THREE LETTERS

Total sequence correct	3	1
Total letters correct	12	9
Pct. of total letters correct	**80%**	60%
Avg. time to first click	2.26	3.15
Avg. counted	12.8	9.6
Avg. counted correctly	12.8	9.6

Visual Memory Composite

Evaluates visual attention and scanning, learning, and memory
This score in its current form is comprised of the average of:

- Design Memory (module 2) Total Percent Correct
- X's and O's (module 3) (Total Correct Memory)/12*100

EXAMPLE

Design Memory Total Percent Correct =	90 %
X's and O's (Total Correct Memory)/12= 8/12*100	66.7%
Total Divided by 2 = 156.7/2 =	78

Visual Memory Composite Score= 78

DESIGN MEMORY

Hits (Immediate)	12	10
Correct distractors (immediate)	10	5
Learning percent correct	92%	63%
Hits (delay)	12	4
Correct distractors (delay)	9	7
Delayed memory pct. correct	88%	46%
Total percent correct	**90%**	54.5%

X'S AND O'S

Total correct (memory)	**8**	5
Total correct (interference)	109	67
Avg. correct RT (interference)	0.55	1.17
Total correct (interference)	3	3
Avg. incorrect RT (interference)	0.43	1.04

Visual Motor Speed Composite

Evaluates visual processing, learning and memory, and visual-motor response speed.
This score is comprised of the average of following scores:

- Total Number Correct/4 during Interference of X's and O's (module 3).
- Average Counted Correctly*3 from Countdown Phase of Three Letters (module 6).

EXAMPLE

Total Number Correct/4 during Interference of X's and O's=	109/4 = 27.25
Average Counted Correctly x 3 from Countdown Phase of Three Letters =	12.8 x 3 = 38.40
Total Divided by 2 =	65.65/2 = 32.83

Visual Motor Speed Composite Score= 32.83

X'S AND O'S

Total correct (memory)	8	5
Total correct (interference)	**109**	67
Avg. correct RT (interference)	0.55	1.17
Total correct (interference)	3	3
Avg. incorrect RT (interference)	0.43	1.04

THREE LETTERS

Total sequence correct	3	1
Total letters correct	12	9
Pct. of total letters correct	80%	60%
Avg. time to first click	2.26	3.15
Avg. counted	12.8	9.6
Avg. counted correctly	**12.8**	9.6

Reaction Time Composite

Evaluates average response speed.
This score is comprised of the average of the following scores:

- Average Correct RT of Interference Stage of X's and O's (module 3).
- Symbol Match (module 4) Average Correct RT Visible/3.
- Color Match (module 5) Average Correct RT.

EXAMPLE

Average Correct RT of Interference Stage of X's and O's =	0.55
Symbol Match Average Correct RT Visible/3 =	1.52/3 = 0.51
Color Match Average Correct RT =	0.76
Total Divided by 3 =	1.82/3= 0.61

Reaction Time Composite Score= 0.61

X'S AND O'S

Total correct (memory)	8	5
Total correct (interference)	109	67
Avg. correct RT (interference)	**0.55**	1.17
Total correct (interference)	3	3
Avg. incorrect RT (interference)	0.43	1.04

SYMBOL MATCH

Total correct (visible)	27	27
Avg. correct RT (visible)	**1.52**	1.85
Total correct (hidden)	6	4
Avg. correct RT (hidden)	1.94	2.79

COLOR MATCH

Total correct	9	9
Avg. correct RT	**0.76**	1.58
Total commissions	0	1
Avg. commissions RT	0	1.31

Impulse Control Composite

While not one of the core composites for ImPACT scoring, this composite provides a measure of errors on testing and is useful in determining test validity. This score indicates the sum of errors committed during different phases of the test, and while clinical decisions should not be based on this composite, its inclusion may help in the interpretation of other composites. Scores above 30 should be viewed as invalid.
This score is obtained by adding:

- Total Incorrect on the Interference Phase of X's and O's (module 3).
- Color Match Total Commissions (module 5).

EXAMPLE

Total Incorrect on the Interference Phase of X's and O's =	3
Color Match Total Commissions =	0
Total=	3

Impulse Control Composite Score= 3

X'S AND O'S

Total correct (memory)	8	5
Total correct (interference)	109	67
Avg. correct RT (interference)	0.55	1.17
Total correct (interference)	**3**	3
Avg. incorrect RT (interference)	0.43	1.04

COLOR MATCH

Total correct	9	9
Avg. correct RT	0.76	1.58
Total commissions	**0**	1
Avg. commissions RT	0	1.31

Total Symptom Composite Scores

This score presents summary information regarding the athlete's self-reported symptom data. A higher score reflects a higher symptom total.

Reliable Change Index Score

Test score change over repeated administrations is to be expected. The issue for healthcare professionals is to determine when this change is significant and clinically meaningful. ImPACT provides Reliable Change Index Scores (RCI's) for each Module and Composite. 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. It is also important to emphasize that an RCI score does not provide a diagnosis.

Cognitive Efficiency Index (CEI)

ImPACT was designed specifically to simultaneously measure both speed and accuracy of responding. Therefore, an athlete may attempt to increase accuracy by taking a slower and more deliberate approach to the test. On the other hand, some athletes will attempt to increase their speed without regard for accuracy. As noted above, the CEI was developed to provide an index of the "tradeoff" between speed and accuracy on the Symbol Match subtest. Extremely low scores (0 to .20) may in some cases suggest a very poor performance on this subtest.

The CEI is derived from the Symbol Match (module 4) test; speed is measured by the number of items correctly clicked and accuracy is the number of items correctly identified on the memory component of the test (at the end of the module). The CEI score is calculated by the following process: First, the proportion correct on the memory component of the test (total correct hidden) is calculated where 9 reflects a perfect score. In other words, if the athlete obtained a memory score of 8, the score would be 8 divided by 9 equals .89. This score is then multiplied by 1 minus the average correct (visible) reaction time score divided by 3. If an athlete obtains a score of .89 on the memory component and 1.50 on the reaction time, his or her CEI index would be .50 times .89 or .45. On the other hand, if the athlete obtained the same memory score (.89) but a higher (slower) reaction time score of 1.65), the CEI would be .45 times .89 or .40.

It is important to emphasize that the CEI is intended to be used to help understand the athlete's performance on Symbol Match and should not be used as an overall concussion severity scale.

What are the Most Common Causes of Test Invalidity during Baseline?

- Failure to properly read directions due to a reading disability or carelessness.
- Attention deficit disorder and/or hyperactivity (ADD or ADHD).
- Excessive fatigue (e.g. completion of testing after vigorous exercise).
- "Horseplay". This often occurs when athletes are not properly supervised or are placed too close together in a room.
- Left-right confusion. This most often is evidenced by scores about 20 on the Impulse Control composite and is usually the result of the reversal of left and right on the X's and O's distracter task
- "Sandbagging" or poor performance to attempt to set a low baseline standard.
- Other neurological and psychological disorders in which impaired cognitive function is commonly present

ImPACT Invalidity Indicators

ImPACT provides a validity index designed to aid in identifying invalid baseline examinations. This index is based on the following algorithm:

- X's and O's Total Incorrect + Color Match Total Commissions > 30 **OR**
- Impulse Control Composite > 30 **OR**
- Word Memory Learning Pct Correct < 69% **OR**
- Design Memory Learning Pct Correct < 50% **OR**
- Three Letters Total Letters Correct < 8

If any of these criteria are reached for a given baseline test, the ImPACT report will automatically print a sentence that identifies the test results as being of questionable validity. If this is the case, the test administrator is encouraged to repeat the baseline exam, only after discussing the test results with the athlete and identifying the reasons for the invalid test (e.g. difficulty understanding one or more of the modules, not taking the test seriously, etc.).

Sandbagging a baseline

The ability of the ImPACT validity index to identify unrealistically poor scores has recently been researched. Erdal (2012) conducted a study with 75 undergraduate collegiate athletes who had previously completed ImPACT as part of the pre-participation process for their sport. Study participants were then instructed to attempt to "fake bad" on a second administration of the test without reaching the threshold on the validity indicator. Of the 75 athletes, only 8 were able to successfully fake the test (89 percent detection rate).

In a second study, Schatz et al. (2013) compared three groups of college students who were either instructed to perform their best, fake the test without guidance or were coached on how to successfully fake the test. All groups were given ImPACT as well as the Medical Symptom Validity Test and the Balance Error Scoring Test (BEST). ImPACT successfully identified 95 percent of the naïve and 100 percent of the coached malingers. The authors concluded that "sandbagging" on baseline neurocognitive testing can be detected.

Chapter 3 - Development and Standardization

Content Development

ImPACT is a computer-based neurocognitive testing platform created to measure aspects of attentional processes, immediate and delayed memory, visuo-spatial processes, impulse inhibition, and visual motor speed in individuals ages 12 years 0 months to 59 years 11 months. As noted throughout this manual, ImPACT is designed to serve as a neurocognitive battery that complements other types of assessment (e.g., balance, visuo-spatial) and clinical information (behavioral, psychological, etc.) gathered as part of the comprehensive evaluation of an individual suspected of having a concussion. The content for the various modules was selected with these specific goals in mind:

- The tasks have been shown in past research to be sensitive to the effects of a concussion.
- The tasks had to be challenging and assess the major areas of neurocognition.
- The tasks needed to provide an efficient means of assessing neurocognitive status.
- The tasks must produce reliable results for individuals across age and time periods so that change metrics are interpretable.
- The tasks had to be compatible with a laptop or desktop computer.
- The test must allow individual and group administration.

Alpha testing and development of the test modules

Early item development was conducted from 1994-1996 based on the need to assess the relevant neurocognitive domains that are often affected by concussion. The assessment was based on the author's prior experience in administering and interpreting traditional "paper and pencil" tests in professional and amateur athletes. Items were initially selected based on measuring the key domains of memory and processing speed. Within these broad domains, specific subtests were created that measured word memory; X's and O's (spatial memory); symbol match (memory for symbols and reaction time); three letter memory (verbal memory and motor speed) and color match (reaction time). See Chapter 2 for a complete description of the subtests. After this data was consolidated and evaluated, several items were eliminated from further consideration, some items were modified based on field tester recommendations, and others were retained in their original form. For example, the alpha version of ImPACT included a sequential memory task that was dropped because it did not provide unique information.

Alpha testing was completed in one Midwestern University and four high schools in the Midwest. From 1996-2000, this initial version of the test was utilized as a research tool in ten universities and eight high schools in the Midwest and in select high schools in Maine and Oregon. Subsequent research did not reveal any geographic difference between groups (Lovell et al., 2003).
Items were reviewed again using the aforementioned criteria and once selected, the remaining items were piloted in the Detroit metropolitan area. A final review of the items was conducted with data on the ease of administration, the individual's ability to understand and complete the task, the performance differences between individuals who were concussed versus those who were not (sensitivity and specificity). This final version was published as the Desktop version of ImPACT.
The Desktop version was in use for approximately 5 years until an online version of the test was developed and validated. This process is described below. The desktop version of the test has been discontinued and is no longer commercially available.

Description of the Standardization Sample

The standardization sample was collected from a variety of different sources including high schools under the auspices of the Western Pennsylvania Interscholastic Athletic League (WPIAL), colleges across the U.S. who had previous experience using an earlier version of ImPACT and professional sports teams across the U.S. Older adults (beyond the college and professional ranks) consisted of coaches, school administrators and teachers from participating schools. Data collection commenced in 2006 and was completed in 2007. All data were collected by Athletic Trainers who had previously undergone training in the use of ImPACT and were familiar with the identification of concussion, utilizing an internationally recognized protocol (Aubry et al., Lovell et al.). The stratification of the sample was implemented to assure inclusion of adequate cell sizes across gender and age and to include large numbers of athletes from contact and collision sports such as football, Ice Hockey and soccer. Although not keyed specifically to the US Census, the sample was inclusive of minorities at a rate that reflected the composition of the school systems involved. It is important to note that published data have not indicated significant differences between minority and Caucasian athletes on the ImPACT test (Kontos et al., 2010), nor in a large multi-racial South African sample (Shuttleworth et al. 2009). Age bands were constructed based on level of competition (e.g. High School, College and adult populations).

All subjects prior to inclusion had to complete a pre-participation physical examinations as required by their institutions (this is mandatory at all levels of competition). All of the subjects in the normative group were symptom free and were deemed to be free of any medical or psychological conditions that would affect their performance and were cleared for athletic participation by their institution. Specifically, subjects did not have a history of epilepsy, a history of meningitis or other neurological disease. Although the majority of the sample did not report a history of learning disability or attention deficit disorder, a small percentage of the sample (less than 1 percent) did report being diagnosed with a learning disability. Although there was no significant difference between athletes with LD and without LD on the 2 memory scale composites and the impulse control composite, there were clinically small but statistically significant differences between the groups on the Visual Motor ($t=5.36$, $P< .001$) and Reaction Time composites ($t=-11.53$, $p<.001$). With regard to attention deficit disorder (ADD), approximately 4 percent of the sample reported a history of ADD. Similar to the LD group, the athletes with ADD performed slightly more poorly on the Visual Motor and Reaction Time composites ($t=4.83$ $p<.001$ and $t=-7.74$ $p<.001$). These results of internal analysis have been replicated by others.

The sample consisted of 73% males and 27% females. Further, while 2363 reported 1 prior concussion, 771 reported 2 prior concussions and 490, 3 or more prior concussions, none of the subjects in the normative group were concussed or restricted from play due to concussion symptoms.

ImPACT data collection

Normative data were collected by research partners acknowledged earlier in this manual. All testing was completed by professionals who were specifically trained to administer the tests. These professionals consisted of neuropsychologists, psychologists, neuropsychology/psychology graduate students, certified athletic trainers, athletic training graduate students, and nurses. All testing was completed in a supervised setting and data were later uploaded onto a secure HIPAA compliant server. Data were de-identified and placed in a database for analysis.

The standardization sample consisted of 16,566 individuals who underwent baseline ImPACT testing. The older subjects represented teachers, coaches, school administrators, and adult athletes. Athletes who participated in the normative sample played in the following sports: tackle football (males only), soccer (males and females), lacrosse (males and females), wrestling (males only), baseball (males only), softball (females only), swimming/diving (males and females), cheerleading (females only), crew/rowing (males and females), volleyball (males and females), track and field (males and females), field hockey (females only) and cross country (males and females).

The specific age and gender breakdown is presented in Table 1.

Table 1. Age and Gender Breakdown for ImPACT Normative Sample

Age Group	Males	Females
12	243	134
13 to 15	4461	1891
16 to 18	4629	1663
19 to 29	1931	551
30 to 39	461	129
40 to 49	182	89
50 to 59	138	64
Total	12045	4521

Although there were more male athletes in the sample (72%) than female athletes (28%), this difference reflects the large number of males who participate in football. Despite the difference in sample size for females versus males, the size of the female sample is adequate for the purposes of providing normative data.

Derived Scores

The standardization sample described above was used to generate all of the scores that are reported on the Clinical Report and are described in Chapter 2 of this manual. In addition to the individual subtest scores, Composite scores were developed by combining specific subtest scores that were selected a priori. Composite scores were derived logically rather than through factor analysis and were designed to provide summary level information to the healthcare professional using the test. The composite scores provide a summary raw score that represents unweighted average raw scores for the component subtests. Percentile rank scores were developed separately for the specific age and gender groups. Percentile ranks were created by using a standard computer software conversion table; any resulting irregularities were identified and smoothed manually.

Reliable Change Scores

The Reliable Change Index (RCI) method for interpreting change on neurocognitive tests is a well-accepted method for determining change. 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 a test-retest difference score. Essentially, this confidence interval represents the probable range of measurement error for the distribution of difference scores.

RCI scores were calculated to provide an index of change from baseline to post-injury. RCI scores were calculated by an independent professional statistician based on methodology described in detail by Iverson et al. (2003) and Jacobson & Truax, 1991) to assess whether a change among repeated assessments was reliable and meaningful. The RCI provides an estimate of the probability that a given difference in a test taker's obtained score would not be obtained as a result of measurement error (Iverson, Sawyer, McCracken, Kozora, 2001). This allows clinicians to reduce any effects of measurement error, usually in the form of practice effects (Iverson, Brooks, Collins, Lovell, 2006) or inattentiveness or fatigue.

Given two baseline assessment scores (Time 1 and Time 2), calculation of RCIs involves the use of the standard error of difference (S_{diff}), which is used to create a confidence interval around the two baseline assessment scores. The formula for S_{diff} is provided below.

1. $SEM_1 = SD\sqrt{1-r_{12}}$ Standard deviation from time 1 multiplied by the square root of 1 minus the test-retest coefficient.
2. $SEM_2 = SD\sqrt{1-r_{12}}$ Standard deviation from time 2 multiplied by the square root of 1 minus the test-retest coefficient.
3. $S_{diff} = \sqrt{SEM_1^2 + SEM_2^2}$) Square root of the sum of the squared SEMs for each testing occasion.
4. Reliable Change Confidence Intervals: The S_{diff} is multiplied by the following z-scores: ±1.04 (70% CI), ±1.28 (80% CI), ±1.64 (90% CI) and ±1.96 (95% CI)

The values used for the RCI calculation were obtained from the study by Iverson, Lovell and Collins (2005). A description of this study follows.

Participants

The first sample was comprised of 56 adolescents and young adults who completed the ImPACT test twice for the purpose of a test-retest study. There were 29 males and 27 females. Their average age was 17.6 years (SD=1.7, range=15–22). Approximately 64% were in high school and 36% were in university. The average retest interval was 5.8 days (median=7, SD=3.0, range=1–13). Approximately 29% were retested within 3 days, 43% within 4 days, 82% within 7 days, and 95% within 11 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, median=1, SD=0.7 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. 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).

Design

The first set of analyses were based on the healthy young people tested twice. Relative position across the two distributions was examined with a Pearson correlation. Level of performance within subjects was examined with dependent t-tests. Reliable change estimates were derived from a modification of the method proposed by Jacobson and Truax (1991).

Results

The descriptive statistics, standard errors of measurement (SEMs), standard errors of difference (Sdiff), and reliable change confidence intervals are presented in the Table below.

Table 2. Adopted from *Table 1 from Iverson 2003*

Composite	*M (SD)*		*p*	SEM_1	SEM_2	S_{diff}	Confidence intervals	
	Time 1	Time 2					**0.80**	**0.90**
Verbal Memory	88.68 (9.50)	88.84 (8.09)	0.86	5.20	4.43	6.83	8.75	11.21
Visual Memory	78.70 (13.39)	77.48 (12.67)	0.40	7.69	7.28	10.59	13.55	17.37
Reaction Time	0.543 (0.087)	0.536 (0.063)	0.34	0.03	0.03	00.5	0.06	0.08
Processing Speed	40.54 (7.64)	42.24 (7.06)	0.002	2.64	2.64	3.89	4.98	6.38
Post-concussion Scale	5.23 (6.75)	5.79 (10.07)	0.59	5.96	5.96	7.17	9.18	11.76

Note. SEM: standard error of measurement; S_{diff}: Standard error of difference

The Pearson test-retest correlation coefficients for the composite scores were as follows:

- Verbal Memory = .70,
- Visual Memory = .67,
- Reaction Time = .79,
- Processing Speed = .86,
- Post-concussion Scale = .65.

These coefficients are used in the calculation of the RCI, which are referred to as r12 test-retest coefficients.

The Mean and SD by composite with the calculated S_{diff} is presented in the Table 2.

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 one would expect to see 10% in each tail for the 0.80 confidence interval and 5% in each tail for the 0.90 confidence interval. As seen in Table 3, 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 3. Adopted from *Table 2 from Iverson 2003*

Composite	0.80 confidence interval		0.90 confidence interval	
	Declined (%)	Improved (%)	Declined (%)	Improved (%)
Verbal Memory	10.7	16.1	5.4	8.9
Visual Memory	10.7	8.9	5.4	3.6
Reaction Time	8.9	14.3	5.4	7.1
Processing Speed	7.1	8.9	3.6	5.4
Post-concussion Scale	12.5	7.1	10.7	3.6

Note. 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 = 39.3%, two declines = 1.8%, 3 declines = 0%, and 4 declines = 1.8%.

It should be noted that adjustments of 2 points were made to the ImPACT Processing Speed composite score to account for practice effects. 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.

The reliable change methodology allows the clinician to reduce the adverse effect of measurement error on test interpretation. Clinically significant improvement can only be identified using this approach if the change score is statistically reliable. However, a statistically reliable change does not guarantee a clinically meaningful change. For that reason, we recommend that change scores found to be significant should be areas the clinician focus attention on for further investigation. We do not suggest that statistically significant changes are synonymous with clinically significant events.

Chapter 4 - Statistical Properties of ImPACT

This chapter includes technical and psychometric information on ImPACT, including details on the reliability of the modules, and the various forms of validity evidence that have been established. All data presented here are for the current online version of ImPACT. In addition, there is substantial reliability and validity data presented on the ImPACT website at www.impacttest.com.

Reliability Data for ImPACT

Several recently published studies have explored the reliability of the online version of ImPACT. In general, ImPACT has been found to be highly reliable across time.

Test-retest reliability

Multiple studies have evaluated the reliability of ImPACT across two time intervals. In a study of collegiate athletes by Schatz (2010) the reliability of the ImPACT test battery over time was investigated. The author studied 95 athletes completing baseline cognitive testing at two time periods, approximately 2 years apart. No participant sustained a concussion between assessments. All athletes completed the ImPACT test battery; dependent measures were the composite scores and total symptom scale score. Intraclass correlation coefficient estimates for visual memory (.65), processing speed (.74), and reaction time (.68) composite scores reflected stability over the 2-year period, with the greatest variability occurring in verbal memory (.46) and symptom scale (.43) scores. Using RCIs and regression-based methods, only a small percentage of participants' scores showed reliable or "significant" change on the composite scores (0%-6%), or symptom scale scores (5%-10%). These results suggest that college athletes' cognitive performance at baseline remains considerably stable over a 2-year period.

In a follow up study, Schatz and Ferris (2013) evaluated the reliability of the ImPACT test battery over a shorter time span. Two ImPACT tests were administered with 4 weeks between assessments. Participants had not previously completed ImPACT and had no history of concussion. Pearson's correlation coefficients (r) and intra-class correlation coefficients (ICCs) were as follows: Verbal Memory = .66/.79 (r/ICC), Visual Memory = .43/.60, Visual Motor Speed = .78/.88, Reaction Time = .63/.77, and Total Symptoms = .75/.81. Dependent sample t-tests revealed significant improvement on only Visual Motor Speed Composite Scores. Reliable Change Indices showed a significant number of participants fell outside 80% and 95% confidence intervals for only Visual Motor Speed scores (but no other indices), whereas all scores were within 80% and 95% confidence intervals using regression-based measures. Results suggest that repeated exposure to the ImPACT test may result in significant improvements in the physical mechanics of how college students interact with the test (e.g., performance on Visual Motor Speed), but repeated exposure across 1 month does not result in practice effects in memory performance or reaction time.

Most recently, (Nakayama et al.) in a 2014 study of 85 college age students, concluded that ImPACT is a reliable neurocognitive test battery at 45 and 50 days after the baseline assessment. These findings support those of other reliability studies that have reported acceptable intraclass correlation coefficients (ICCs) across 30-day to 1-year testing intervals, and they support the utility of the ImPACT's use in a multidisciplinary approach to concussion management.
Other research has produced similar findings. A summary of the findings, is presented in table 4.

Table 4. Summary of the obtained test-retest reliability coefficients

Variable	Interval Between Assessments						
	30 days Schatz (2013) n=25	30 days Cole (2013) n=44	0-45 days Nakayama (2014) n=85	0-50 days Nakayama (2014) n=85	45-50 Nakayama (2014) n=85	1 year Elbin (2011) n=369	2 years Schatz (2010) n=95
Verbal Memory							
ICC	0.79	0.6	0.76	0.65	0.69	0.62	0.46
r	0.66	0.61	-	-	-	0.45	0.3
Visual Memory							
ICC	0.6	0.5	0.72	0.6	0.69	0.7	0.65
r	0.43	0.49	-	-	-	0.55	0.49
Visual Motor Speed							
ICC	0.88	0.83	0.87	0.85	0.88	0.82	0.74
r	0.78	0.86	-	-	-	0.74	0.6
Reaction Time							
ICC	0.77	0.53	0.67	0.71	0.81	0.71	0.68
r	0.63	0.53	-	-	-	0.62	0.52

Validity, and sensitivity and specificity of ImPACT

Several studies have been completed that evaluate the validity of ImPACT. Studies include sensitivity, specificity and aspects of validity.

Sensitivity and specificity

In 2006, Schatz and Pardini studied 138 high school athletes (72 concussed and 66 non-concussed) selected from a larger sample of 1,500 individuals. Non-concussed athletes self-reported no history of diagnosed concussion on their health questionnaire. All athletes from both groups self-reported no significant medical problems on their health questionnaire and all subjects from both groups successfully completed a baseline evaluation prior to participation.

A MANOVA on all ImPACT subscales and Composites found significant differences found on Verbal Memory, Visual Memory, Reaction Time, Processing Speed and Symptom scale with concussed athletes performing significantly worse on all variables than their matched controls. When considering classification accuracy, 82.4 % of concussed group were correctly identified as were 89.4% of non-concussed group.

A 2007 study (Broglio et al., 2007) found lower levels of sensitivity and specificity, but also discovered values that were superior to comparable tests, concluding that a battery of tests was ideal. ImPACT and HeadMinder Concussion Resolution Index* (Erlanger, D., Feldman, D., & Kutner, K. (1999).) were the most sensitive to concussion (79.2 and 78.6%, respectively). These tests were followed by self-reported symptoms (68.0%), the postural control evaluation (61.9%), and a brief pencil-and-paper assessment of neurocognitive function (43.5%). When the complete battery was assessed, sensitivity exceeded 90%. These findings supported previous recommendations that sports-related concussion should be approached through a multifaceted assessment with components focusing on distinct aspects of the athlete's function.

In a 2012 study, Schatz and Sandel examined the sensitivity of ImPACT in matched samples of symptomatic concussed high school athletes and matched controls who were not concussed. They reviewed the cases of 81 athletes observed to sustain a concussion and who had completed the ImPACT test within 3 days of injury. Data were compared with an independent sample of 81 athletes who completed preseason baseline cognitive assessments using ImPACT and who were matched (with concussed athletes) on the basis of sex, age, sport, concussion history, absence of attention deficit hyperactivity disorder (ADHD) and learning disability.

The authors determined that data from ImPACT yielded 91.4% sensitivity and 69.1% specificity. For asymptomatic athletes suspected of hiding their concussion, data from ImPACT yielded 94.6% sensitivity and 97.3% specificity."
A summary of the studies described above are and additional supporting research is presented in table 5.

Table 5 – Summary of study results supporting sensitivity and specificity of ImPACT

Study	Sample	Analysis Performed	Summary of Results
Schatz, Pardini (2006)	N= 138	**ANOVA** for between group differences on age/education **MANOVA** on ImPACT subscales and composites Stepwise Discriminant Function Analysis Chi square on gender, handedness, diagnosed Hx of LD or Special Ed.	**ANOVA**: No significant findings **MANOVA**: Significant effects of concussion group on Verbal Memory [F(1,136) = 32.4; p = .001], Visual Memory [F(1, 136) = 34.9; p = .001], reaction time [F(1, 136) = 43.6; p = .001], Processing Speed [F(1, 136) = 61.1; p = .001], and symptom scale scores [F(1, 136) = 39.6; p = .001], **Stepwise DFA**: concussed performing worse than controls 82.4 % of concussed group were correctly identified as were 89.4% of non-concussed group **Chi Square**: Males found to be more likely in concussion group.
Thoma, Cook (2015)	N = 87	**MANOVA** on days since most recent concussion and total number of concussions ANOVA on Visual Memory	**MANOVA:** Number of days was significant on Visual Memory Composite and Reaction Time Composite. The overall main effect of Days was significant (F(5,69)=3.11, p=0.01; partial ε^2=0.198) and there were significant univariate effects for Days on Visual Memory Composite score (VMC; F(1,73)=10.89, p=0.004; partial

		Composite	ε^2=0.133) and Reaction Time Composite score (RTC; F(1,73)=6.12, p=0.02; partial ε^2=0.079). **ANOVA**: Significant main effect for Group for Visual Memory Composite. VMC (F(1,72)=7.59, p=0.007; partial ε^2=0.095), and higher scores associated with longer time since concussion. Significant main effect for group for the Reaction time composite (F(1,74)=7.74, p=0.007; partial ε^2=0.095), and Days (F(1,74)=4.43, p=0.04; partial ε^2=0.058)
Schatz & Sandel (2012)	N=81	Symptomatic and Asymptomatic MANOVA on ImPACT subscales Stepwise Discriminant Function Analysis **Chi square** on between group differences for sex and concussion Hx	**- Symptomatic MANOVA**: Significant differences were found on all ImPACT scales and composites between concussed and controls. Cognitive performance (F[20,302] = 558.6; P = .001; partial η^2 = .97). Symptoms (F[1,162]=141.5; P = .001; Partial η^2 = .47). **Asymptomatic**- MANOVA: Significant differences were found on all ImPACT scales and composites between concussed and controls: Cognitive performance (F[7,67] = 2048; P = .001; partial η^2 = .99). - **Stepwise DFA**: 91.4 % of concussed group and 69.1 of control group were correctly classified - **Stepwise DFA**: 94.6% of asymptomatic concussed group and 97.3% of control group were correctly classified **- Symptomatic- Chi square:** no significant findings
Broglio, Macciocchi (2007)	N=75	**Correct Classification**	**Correct Classification:** 65.2% of athletes were identified correctly using just cognitive variables. Correct classification increases to 79.2% when symptom inventory included.

Incremental validity of ImPACT compared with self-reported symptoms

In a recent study, van Kampen, Lovell, Pardini, Collins, & Fu. (2006) assessed the added value neuropsychological testing ImPACT relative to symptom self-report in a group of 122 concussed and 72 non-concussed high school and collegiate athletes who had completed the ImPACT test battery. Both male and female athletes were included. This study found that the addition of ImPACT resulted in an increase in sensitivity of 19% relative to symptom monitoring alone. 93% percent of the concussed athlete group was correctly identified as being concussed in this study. In contrast, symptom data alone correctly classified only 64 percent of the sample. This study highlighted the frequent “disconnect” between self-reported symptoms and more objective neuropsychological test results. In addition, this study found that although none (0 percent) of the control group had both abnormal ImPACT neurocognitive performance and elevated symptoms relative to baseline (determined by RCI scores, relative to baseline test results). In contrast, 93 percent of the concussed group had either poorer ImPACT test scores or elevated symptoms.

Construct and concurrent validity

One of the first studies to look at the construct validity of ImPACT was completed by Iverson, Lovell and Collins (2005) who administered ImPACT to the Symbol Digits Modalities Test (Smith, 1982). A sample of 72 athletes randomly selected from a larger sample were administered both scales. All athletes had successfully completed an ImPACT baseline test prior to participation and at a later time were determined to have suffered a concussion by a physician or an ATC. Correlational analysis, t-tests and Principle Components Factor Analysis were completed. The SDMT was found to correlate .70 with Processing Speed and -.60 with Reaction Time. Pairwise T-tests revealed strongest relationships were between SDMT and Processing Speed and Reaction Time versus Verbal, or Visual Memory or Total Symptoms. The PCFA confirmed a three-factor solution of Speed/Reaction Time Memory and Total Symptoms as the solution best fitting the data.

Schatz and Putz (2006) studied 30 college student volunteers who were administered the Trail Making Test A &B (TMT) and the Digit Symbol subtest of the Wechsler Adult Intelligence Scale–Revised (WAIS–R). These researchers found that Reaction time was significantly correlated with Trails A-B (.61, .44 respectively) and Digit Symbol from the WAIS (.46). Digit Symbol was also significantly correlated with ImPACT Processing Speed Index -.51

In the most extensive independent study published to date, Maerlender (2010) examined the correlations of ImPACT with a traditional comprehensive test battery. These authors' test battery was comprised of tests of verbal (California Verbal Learning Test [CVLT]) and visual memory (Brief Visuospatial Test-Revised [BVMT-R™]); cognitive speed (Trail Making Tests- A and B, Verbal Fluency, Delis-Kaplan Executive Function System [DKEFS] Color Word Memory); reaction time (Conners Continuous Performance Test [CPT]) and working memory (Paced Auditory Serial Addition Test [PASAT]). They concluded that "the present study demonstrates that cognitive domains represented by ImPACT have good construct validity with standard neuropsychological tests that are sensitive to cognitive functions associated with mild TBI". They highlighted that ImPACT is best used as a screening tool along with other neuropsychological tests.

Allen and Gfeller (2011) compared ImPACT to a standard "paper and pencil" test battery. In this study, 100 neurologically intact college students completed ImPACT and a more traditional test battery that was previously used throughout the National Football League (NFL). Tests were administered in counter balanced order. A factor analysis was completed and correlations between the two batteries were presented. The authors found significant overlap between the batteries' assessed constructs, but noted slightly different factor structures for them.

Table 4-3 Summary of study results supporting construct validity of ImPACT

Study	Sample	Analysis	Results
Iverson, Lovell (2005)	N=72.	Comparison to the Symbol Digit Modalities Test (SDMT) Correlational analysis, t-tests Principle Components Factor Analysis	SDMT correlated with: Processing Speed (r=.70, p<.01), Reaction Time r=-0.60, p=0.01; Verbal Memory r=.46, p=<.01; Visual Memory r=.37, p=<.01 Pairwise T-tests revealed strongest relationships between SDMT and Processing Speed (t = 2.69, p < .01), and Reaction Time (t = 2.24, p < .05). The PCFA confirms a three-factor solution of Speed/Reaction Time Memory and Total Symptoms: (1) *Speed/Reaction Time*: SDMT .87, Processing Speed Composite .85, and Reaction Time Composite -.76; (2) *Memory*: Verbal Memory Composite .87 and Visual Memory Composite .80; (3) *Total symptoms* .93
Maerlender (2010)	N=54.	Correlational analysis relating ImPACT Composites and Neuropsychological domains	Overall ImPACT was shown to have good convergent and discriminant validity. Significant correlations were found between traditional pencil and paper neuropsychological testing domains and all ImPACT domain (composite) scores except for the Impulse Control factor. ImPACT composites correlated with the experimental neuropsychological measures, Processing Speed and Reaction Time measures were inter-correlated; the experimental Working Memory task was related to three of the five ImPACT composites, as well as NP Working Memory.
Schatz & Putz (2006)	N=30	Correlational analysis relating ImPACT Composites to Trail Making A-B, D-2 test and Digit Symbol from WAIS-R	ImPACT Reaction time was significantly correlated with Trails A (r=.64, p=<.05), Trails B (r=.44, p=<.01), and Digit Symbol from the WAIS (p=.46, p=<.01). Digit Symbol was also significantly correlated with ImPACT Processing Speed Index r=-.51, p=<.004.
Allen & Gfeller (2011)	N=100	Correlational analysis with ImPACT and NFL Battery (HVLT-R, BVMT-R, Trail Making Test A-B, COWA and Symbol Search and Digit Span Forward and Backward from the WAIS-III	Significant correlations were obtained between many of the ImPACT composite scores and components of the NFL battery. Correlations tended to be in the .3 to .45 range and likely could have been suppressed by a restricted range in the sample.

Summary

The evidence presented in this chapter provides substantial support for the reliability and validity of ImPACT. The results obtained from this tool have been found to be stable over time and to be consistent with what one would expect from a test of memory and reaction time. Additional research is being conducted to augment these findings and support the conclusions that have been drawn.

Appendix A. References

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