Defense and Veterans Brain Injury Center "Head to Head" Study: A Psychometric Comparison of Brief Computerized Neuropsychological Assessment Batteries

December 10, 2015; 1-2:30 p.m. (ET)

Presenters

Jacques P. Arrieux, M.A.
Senior Clinical Research Associate,
Contract Support to Defense and Veterans Brain Injury Center (DVBIC), Department of Brain Injury Medicine, Womack Army Medical Center,
Fort Bragg, North Carolina

Wesley R. Cole, Ph.D.
Senior Clinical Research Director,
Contract Support to DVBIC, Department of Brain Injury Medicine,
Womack Army Medical Center,
Fort Bragg, North Carolina

Moderator

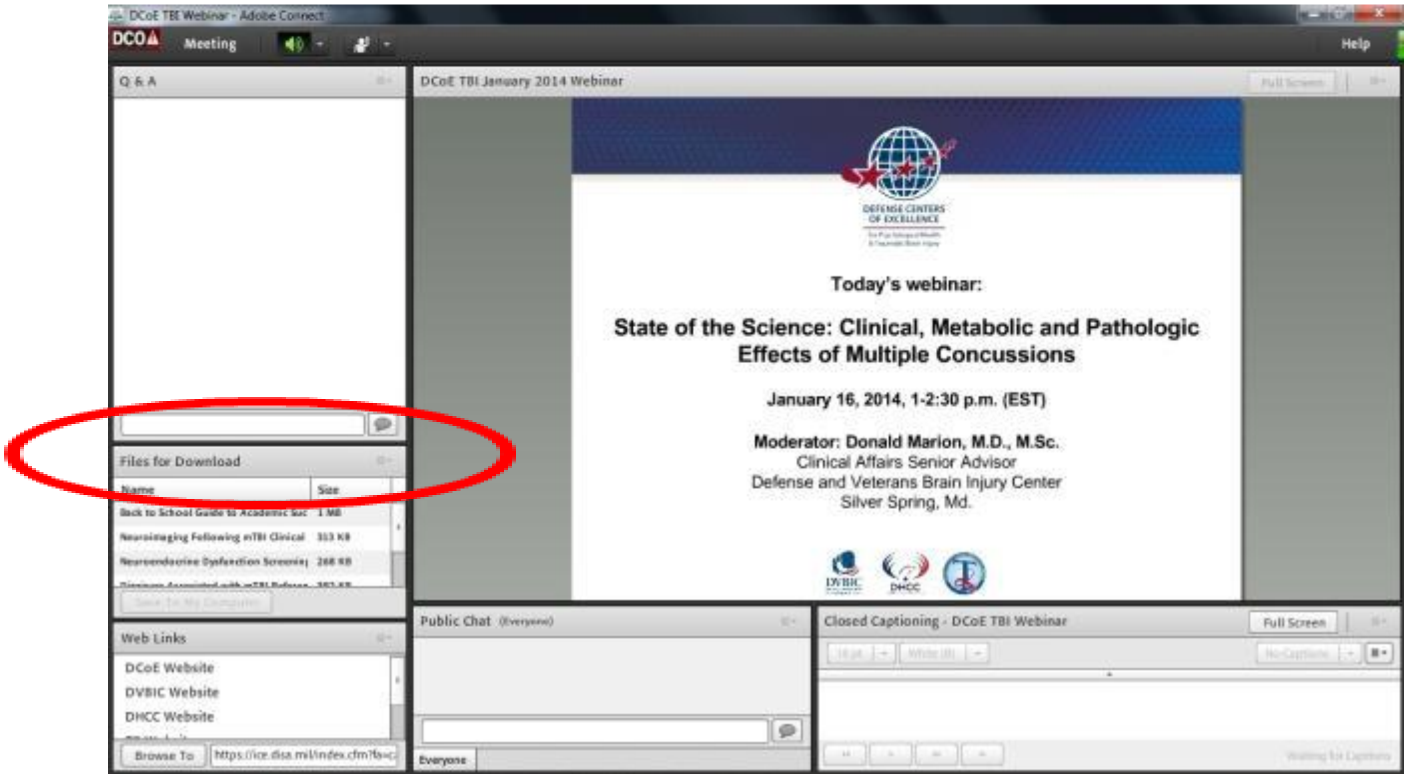
Emma Gregory, Ph.D.
Research Scientist, Contract Support to DVBIC, Silver Spring, Maryland

Webinar Details

- Live closed captioning is available through Federal Relay Conference Captioning (see the “Closed Captioning” box)
- Webinar audio is **not** provided through Adobe Connect or Defense Connect Online
  - Dial: CONUS **888-455-0936**; International **773-799-3736** Use participant pass code: **1825070**
- Question-and-answer (Q&A) session
  - Submit questions via the Q&A box

Resources Available for Download

Today’s presentation and resources are available for download in the “Files” box on the screen, or visit **dvbic.dcoe.mil/online-education**



Continuing Education Details

- DCoE’s awarding of continuing education (CE) credit is limited in scope to health care providers who actively provide psychological health and traumatic brain injury care to active-duty U.S. service members, reservists, National Guardsmen, military veterans and/or their families.

- The authority for training of contractors is at the discretion of the chief contracting official.
  - Currently, only those contractors with scope of work or with commensurate contract language are permitted in this training.

Continuing Education Accreditation

- This continuing education activity is provided through collaboration between DCoE and Professional Education Services Group (PESG).
- Credit Designations include:
  - 1.5 AMA PRA Category 1 credits
  - 1.5 ACCME Non Physician CME credits
  - 1.5 ANCC Nursing contact hours
  - 1.5 CRCC
  - 1.5 APA Division 22 contact hours
  - 0.15 ASHA Intermediate level, Professional area
  - 1.5 NASW contact hours
  - 1.5 CCM hours
  - 1.5 AANP contact hours
  - 1.5 AAPA Category 1 CME credit

Continuing Education Accreditation

Physicians
This activity has been planned and implemented in accordance with the essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME). Professional Education Services Group is accredited by the ACCME as a provider of continuing medical education for physicians. This activity has been approved for a maximum of 1.5 hours of *AMA PRA Category 1 Credits* ™. Physicians should only claim credit to the extent of their participation.

Nurses
Nurse CE is provided for this program through collaboration between DCOE and Professional Education Services Group (PESG). Professional Education Services Group is accredited as a provider of continuing nursing education by the American Nurses Credentialing Center's Commission on Accreditation. This activity provides a maximum of 1.5 contact hours of nurse CE credit.

Occupational Therapists
(ACCME Non Physician CME Credit) For the purpose of recertification, The National Board for Certification in Occupational Therapy (NBCOT) accepts certificates of participation for educational activities certified for AMA PRA Category 1 Credit ™ from organizations accredited by ACCME. Occupational Therapists may receive a maximum of 1.5 hours for completing this live program.

Physical Therapists
Physical Therapists will be provided a certificate of participation for educational activities certified for AMA PRA Category 1 Credit ™. Physical Therapists may receive a maximum of 1.5 hours for completing this live program.

Psychologists
This Conference is approved for up to 1.5 hours of continuing education. APA Division 22 (Rehabilitation Psychology) is approved by the American Psychological Association to sponsor continuing education for psychologists. APA Division 22 maintains responsibility for this program and its content.

Continuing Education Accreditation

Rehabilitation Counselors
The Commission on Rehabilitation Counselor Certification (CRCC) has pre-approved this activity for 1.5 clock hours of continuing education credit.

Speech-Language Professionals
This activity is approved for up to 0.15 ASHA CEUs (Intermediate level, Professional area)

Social Workers
This Program is approved by The National Association of Social Workers for 1.5 Social Work continuing education contact hours.

Case Managers
This program has been pre-approved by The Commission for Case Manager Certification to provide continuing education credit to CCM® board certified case managers. The course is approved for up to 1.5 clock hours. PESG will also make available a General Participation Certificate to all other attendees completing the program evaluation.

Nurse Practitioners
Professional Education Services Group is accredited by the American Academy of Nurse Practitioners as an approved provider of nurse practitioner continuing education. Provider number: 031105. This course if offered for 1.5 contact hours (which includes 0 hours of pharmacology).

Physician Assistants
This Program has been reviewed and is approved for a maximum of 1.5 hours of AAPA Category 1 CME credit by the Physician Assistant Review Panel. Physician Assistants should claim only those hours actually spent participating in the CME activity. This Program has been planned in accordance with AAPA's CME Standards for Live Programs and for Commercial Support of Live Programs.

Other Professionals
Other professionals participating in this activity may obtain a General Participation Certificate indicating participation and the number of hours of continuing education credit.

Questions and Chat

- Throughout the webinar, you are welcome to submit technical or content-related questions via the Q&A pod located on the screen. **Please do not submit technical or content-related questions via the chat pod**.
- The Q&A pod is monitored during the webinar; questions will be forwarded to presenters for response during the Q&A session.
- Participants may chat with one another during the webinar using the chat pod.
- The chat function will remain open 10 minutes after the conclusion of the webinar.

Summary and Learning Objectives

With more than 300,000 service members diagnosed with traumatic brain injury (TBI) since 2000, a need for fast and easy assessment of cognitive functioning has arisen. Numerous computerized neurocognitive assessment tools (NCATs) have emerged from this need. Companies creating these tests often tout them as suitable alternatives to traditional pencil and paper tests. However, emerging research suggests this may not be true, and the issue is not as straightforward as once believed.

Investigators at Fort Bragg, North Carolina recently completed a two-phase study of the psychometric properties of four NCATs: ANAM4, CNS-Vital Signs, CogState and ImPACT. The first phase investigated the test-retest reliability of the NCATs by comparing examinees' scores over a 30-day interval. The second phase investigated the validity of the NCATs by comparing the performance of healthy service members and service members with acute mild TBI to their performance on traditional tests. In the context of this study, this webinar will present the state of the literature regarding NCATs, their clinical utility and future directions.

At the conclusion of this webinar, participants will be able to:

- Identify key concepts when considering computerized neurocognitive testing as an alternative to traditional pencil and paper neuropsychological tests
- Describe the current state of the literature regarding computerized neurocognitive testing, to include recently completed research at Fort Bragg, North Carolina
- Articulate potential issues and future directions with regard to the evaluation of computerized neurocognitive tests for future use in clinical populations

Wesley R. Cole, Ph.D.

Wesley R. Cole, Ph.D.

- Senior clinical research director and neuropsychologist with the Defense and Veterans Brain Injury Center (DVBIC) at the Womack Amy Medical Center at Fort Bragg, North Carolina
- Completed pre- and post-doctoral training in counseling and neuropsychology at the Kennedy Krieger Institute, an affiliate of Johns Hopkins School of Medicine
- Education
  - Ph.D., Clinical Psychology, University of South Carolina
  - M.A., Psychology, University of South Carolina
  - B.S., Psychology, James Madison University

Disclosures

- This work was funded by the DVBIC, in part, through contract support provided by the Henry M. Jackson Foundation for the Advancement of Military Medicine, Inc. and General Dynamics Information Technology.

- The views expressed herein are those of the presenter and do not reflect the official policy of the Department of the Army, Department of Defense, or DVBIC.

- The presenter does not intend to discuss the off-label/investigative (unapproved) use of commercial products or devices.

- The presenter has no relevant financial relationships to disclose.

Polling Question #1

My discipline is:

- ❑ Primary care provider
- ❑ Rehabilitation provider
- ❑ Behavioral health provider
- ❑ Nurse
- ❑ Social worker/case manager
- ❑ Other

Polling Question #2

I primarily work with:

- ❑ Service members (SM)
- ❑ Veterans
- ❑ Civilians – Athletes
- ❑ Civilians – Non-athletes
- ❑ Civilians – Both athletes and non-athletes

Polling Question #3

I currently use or interpret scores from computerized test batteries.

- ❑ Yes
- ❑ No

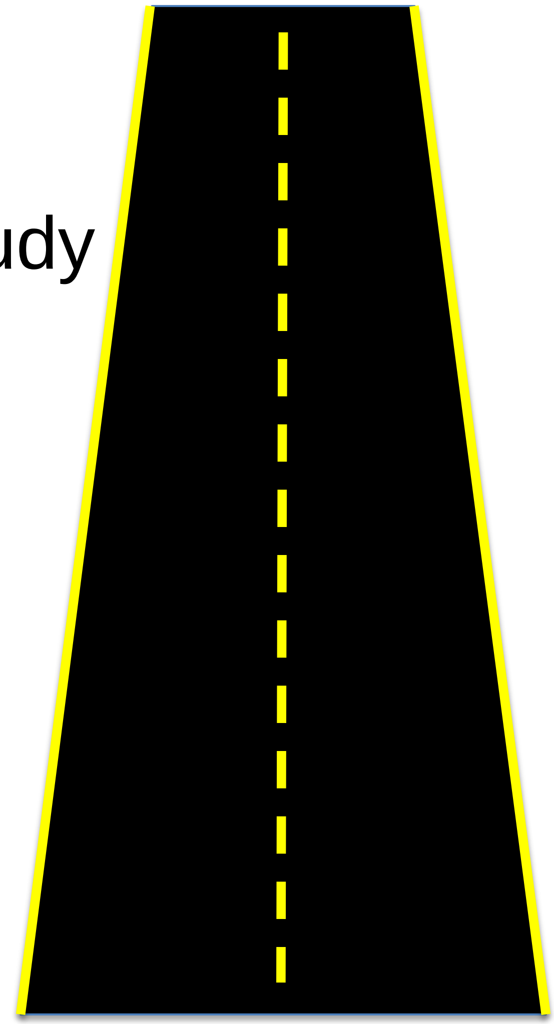
Polling Question #4

I consider myself familiar with the following computerized cognitive tests (please select all that apply):

- ❑ ANAM
- ❑ CNS Vital Signs
- ❑ Axon Sports CogState
- ❑ ImPACT
- ❑ None of these
- ❑ Other

Presentation "Roadmap"

- Overview of neurocognitive testing
  - Pros and cons of computerized testing
- An overview of our Head to Head study
  - Test-retest reliability
  - Validity
- In depth review of NCATs
- Results and conclusions from our study
- Broader implications for NCAT research and clinical use



Current Testing Standard

- Neurocognitive testing is often a standard component of care after TBI.
- Includes face-to-face measures of intelligence, memory, attention, executive functioning, etc.
- Tests are typically “paper and pencil” measures, administered by a neuropsychologist or trained technician.
- Measures are well established and have been deemed valid and reliable.

Image source: U.S. Army photo by Patricia Deal, CRDAMC Public Affairs. (2011). [Photograph of WAIS-IV Block Design]. https://www.dvidshub.net/image / 487658/behavioral-healthcare-benefits-affect-soldiers-quality-life#.Vk5GNlKVWko

TBI in the Military

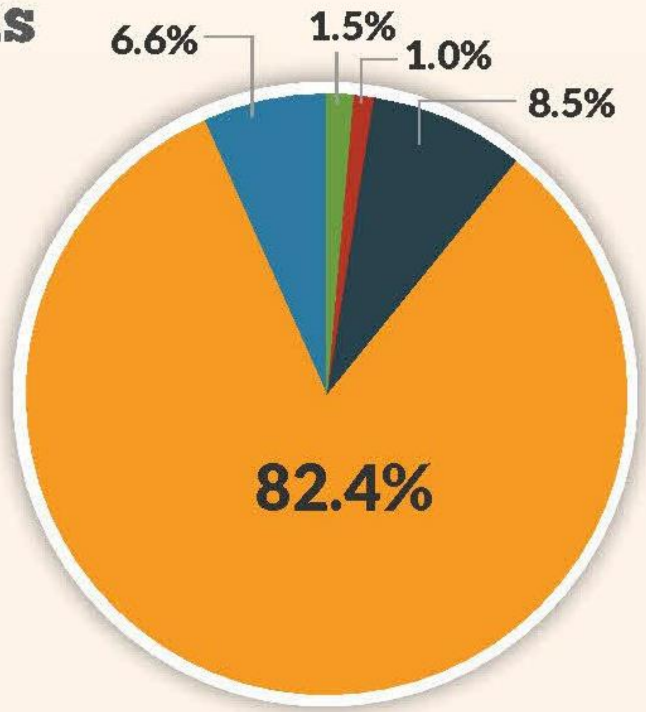
DoD Numbers for Traumatic Brain Injury
Worldwide – Totals

2000-2015 Q1-Q2

Penetrating	4,904
Severe	3,463
Moderate	28,192
Mild	274,568
Not Classifiable	22,042
Total - All Severities	**333,169**

Source: Defense Medical Surveillance System (DMSS), Theater Medical Data Store (TMDS) provided by the Armed Forces Health Surveillance Center (AFHSC)

Prepared by the Defense and Veterans Brain Injury Center (DVBIC)



2000-2015 Q1-Q2 , as of Aug 18, 2015

(Defense and Veterans Brain Injury Center, 2015)

Why Use Computerized Tests?

- Often shorter duration than a traditional test battery
  - 20-30 minutes vs. hours of testing
- Delivery can be standardized without extensive training.
  - Test proctor vs. neuropsychologist or psychometrist
- Ability to administer to larger groups
- Potential for almost unlimited alternate forms
  - Beneficial for post-injury repeated assessments
- Precise measurements, e.g., reaction time
- Rapid availability of results
- Centralized data storage, analysis and reporting
  - Norms can be constantly updated

Why NOT Use Computerized Tests?

- Cost
- Access
  - Equipment
  - Proprietary nature of many features of tests
- Hardware and software issues
- Loss of qualitative data from behavioral observations
- Auto-generated reports may result in faulty conclusions.
- Precise measurements, e.g., reaction time
- Limited psychometric properties in the literature

How Are NCATs Currently Used?

They are NOT used to "diagnose concussion."

With civilians:

- ImPACT is the most widely used test.
- Preseason baseline assessments
- Post-TBI evaluations
  - The goal is to identify a return to baseline.
- Clinical testing, ideally as a supplement

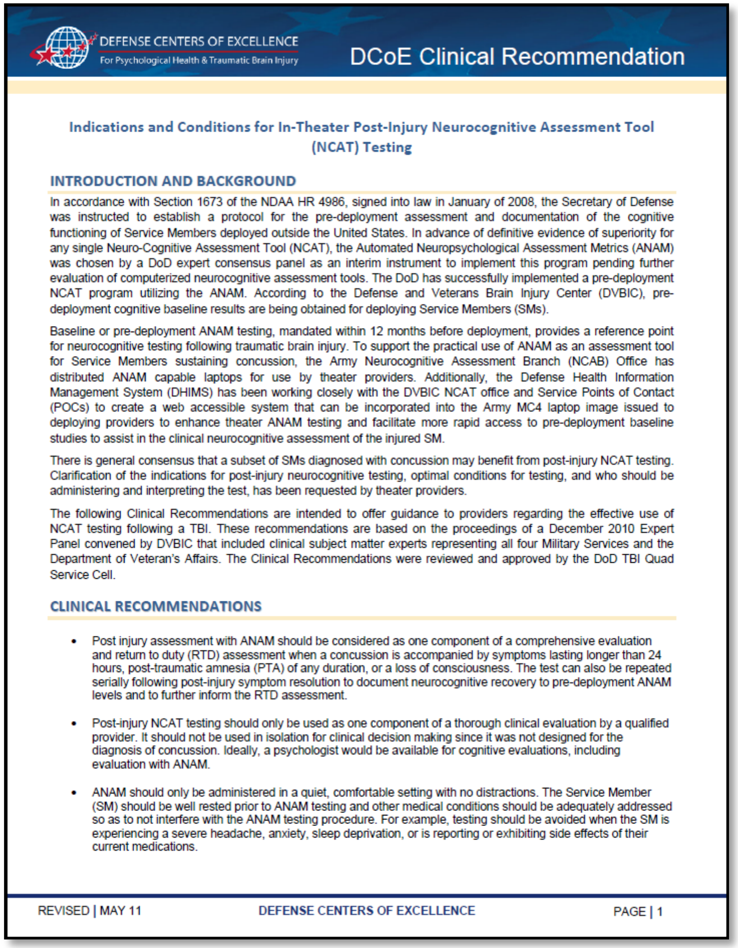
With SMs:

- ANAM is typically used.
  - Army Special Forces use ImPACT.
- Pre-deployment baseline evaluations
- Post-TBI evaluations
  - Assist with return-to-duty (RTD) decisions

DCoE NCAT Clinical Recommendation

Key recommendations:

- NCAT should be one component of post-TBI assessment.
- Not sufficient alone for RTD determinations
- Administer in a quiet, comfortable setting with minimal distractions.
- SMs with concussion and rapidly resolving symptoms do not typically benefit from NCAT administration.
- Attempt to administer within 24-72 hours of injury.
- Repeat every 3-4 days as symptoms persist.
- Consult with a psychologist/ neuropsychologist for interpretation.



DEFENSE CENTERS OF EXCELLENCE
For Psychological Health & Traumatic Brain Injury
DCoE Clinical Recommendation

Indications and Conditions for In-Theater Post-Injury Neurocognitive Assessment Tool (NCAT) Testing

INTRODUCTION AND BACKGROUND

In accordance with Section 1673 of the NDAA HR 4986, signed into law in January of 2008, the Secretary of Defense was instructed to establish a protocol for the pre-deployment assessment and documentation of the cognitive functioning of Service Members deployed outside the United States. In advance of definitive evidence of superiority for any single Neuro-Cognitive Assessment Tool (NCAT), the Automated Neuropsychological Assessment Metrics (ANAM) was chosen by a DoD expert consensus panel as an interim instrument to implement this program pending further evaluation of computerized neurocognitive assessment tools. The DoD has successfully implemented a pre-deployment NCAT program utilizing the ANAM. According to the Defense and Veterans Brain Injury Center (DVBIC), pre-deployment cognitive baseline results are being obtained for deploying Service Members (SMs).

Baseline or pre-deployment ANAM testing, mandated within 12 months before deployment, provides a reference point for neurocognitive testing following traumatic brain injury. To support the practical use of ANAM as an assessment tool for Service Members sustaining concussion, the Army Neurocognitive Assessment Branch (NCAB) Office has distributed ANAM capable laptops for use by theater providers. Additionally, the Defense Health Information Management System (DHIMS) has been working closely with the DVBIC NCAT office and Service Points of Contact (POCs) to create a web accessible system that can be incorporated into the Army MC4 laptop image issued to deploying providers to enhance theater ANAM testing and facilitate more rapid access to pre-deployment baseline studies to assist in the clinical neurocognitive assessment of the injured SM.

There is general consensus that a subset of SMs diagnosed with concussion may benefit from post-injury NCAT testing. Clarification of the indications for post-injury neurocognitive testing, optimal conditions for testing, and who should be administering and interpreting the test, has been requested by theater providers.

The following Clinical Recommendations are intended to offer guidance to providers regarding the effective use of NCAT testing following a TBI. These recommendations are based on the proceedings of a December 2010 Expert Panel convened by DVBIC that included clinical subject matter experts representing all four Military Services and the Department of Veteran's Affairs. The Clinical Recommendations were reviewed and approved by the DoD TBI Quad Service Cell.

CLINICAL RECOMMENDATIONS

- Post injury assessment with ANAM should be considered as one component of a comprehensive evaluation and return to duty (RTD) assessment when a concussion is accompanied by symptoms lasting longer than 24 hours, post-traumatic amnesia (PTA) of any duration, or a loss of consciousness. The test can also be repeated serially following post-injury symptom resolution to document neurocognitive recovery to pre-deployment ANAM levels and to further inform the RTD assessment.
- Post-injury NCAT testing should only be used as one component of a thorough clinical evaluation by a qualified provider. It should not be used in isolation for clinical decision making since it was not designed for the diagnosis of concussion. Ideally, a psychologist would be available for cognitive evaluations, including evaluation with ANAM.
- ANAM should only be administered in a quiet, comfortable setting with no distractions. The Service Member (SM) should be well rested prior to ANAM testing and other medical conditions should be adequately addressed so as to not interfere with the ANAM testing procedure. For example, testing should be avoided when the SM is experiencing a severe headache, anxiety, sleep deprivation, or is reporting or exhibiting side effects of their current medications.

REVISED | MAY 11 DEFENSE CENTERS OF EXCELLENCE PAGE | 1

(Defense Centers of Excellence for Psychological Health & Traumatic Brain Injury, 2011)

Fort Bragg "Head to Head" Study

- Assess the psychometrics of multiple computerized NCATs in a homogenous sample of SMs
- Four NCATs used
  - ANAM4 (version 4.3.01)
  - CNS Vital Signs (CNS VS) (version 3.2.0.51)
  - CogState (version 5.6)
  - ImPACT (version 3, standalone for the Army)
- Phase 1: Test-retest Reliability
- Phase 2: Validity

Test-Retest Reliability

- The stability in test scores over multiple test sessions
- On a reliable test, without significant medical events between sessions, scores will remain stable.
- Low reliability suggests instability of the test due to testing error.
- High reliability suggests any changes will be due to changes in the trait being measured.
- Statistics commonly used to assess reliability
  - Pearson *r* correlation coefficients
  - Intra-class coefficients (ICC)

Reliability Primer

Very High = .90+

High = .80 - .89

Adequate = .70 - .79

Marginal = .60 - .69

Low = <.59

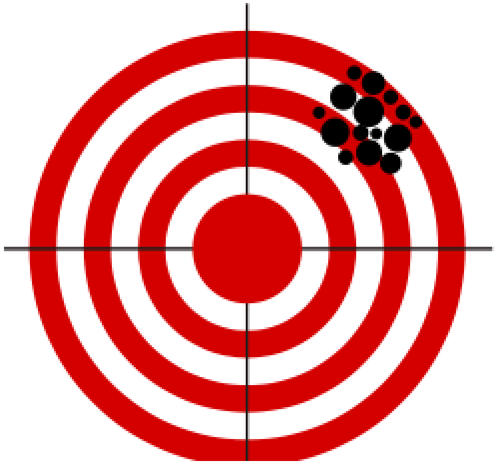


Image source: @Nevit Dilmen found at Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Reliability_and_validity.svg

(Lezak et al., 2012)

Validity

- Validity is operationally defined as the extent to which a test measures what it purports to measure.

- Criterion validity
  - Describes the test's ability to assess a criterion that is external to the test itself
    - Concurrent and predictive

- Construct validity
  - Describes the functional relationships between variables
    - Convergent and divergent

Validity Primer

Criterion and Construct Validity

- *Concurrent* – How well a test performs against a benchmark or “gold standard”
- *Predictive* – How well a test predicts future abilities
- *Convergent* – Constructs expected to be related are actually related
- *Discriminant/Divergent* – Constructs expected to have little to no relationship are unrelated

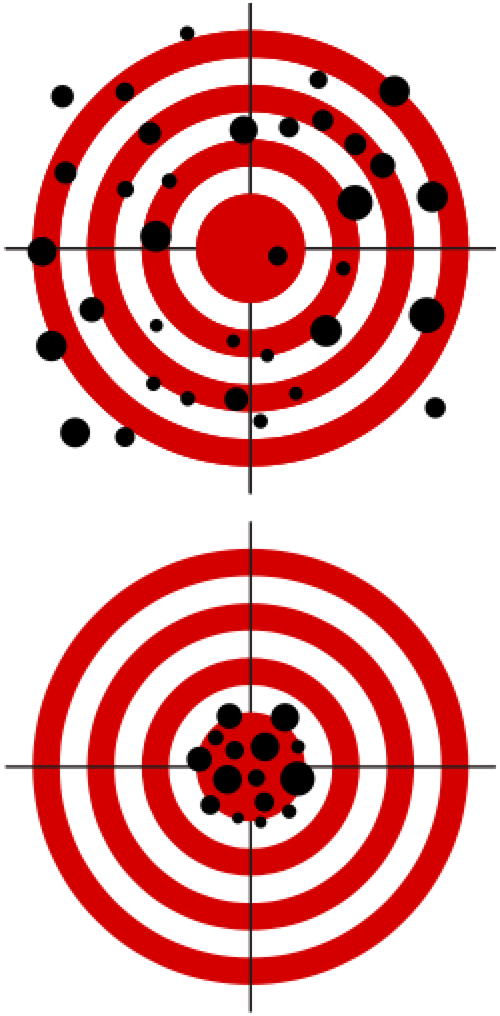
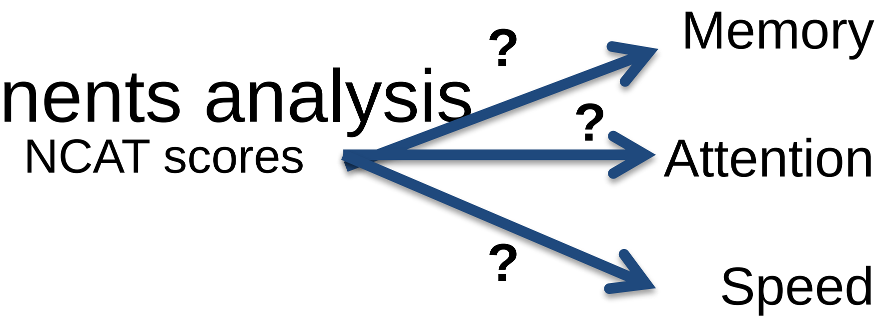


Image source: @Nevit Dilmen found at Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Reliability_and_validity.svg

Validity Common Statistics

- Correlations
  - What is the relationship between NCATs and traditional tests?
- Regression analyses
  - What amount of variance in a specific trait do NCAT scores account for?
- “Classification analyses”
  - i.e., Receiver Operating Curve, Sensitivity and Specificity
  - How accurate are NCATs at classifying patients in specific categories, e.g., diagnosis, cognitive functioning, etc.?
- Principal components analysis



Validity Definitions

"All of these labels for distinct categories of validity are ways of providing different types of evidence for validity and are not, in and of themselves, different types of validity as some sources might claim."

(Strauss, Sherman, & Spreen, 2006, p. 18)

Jacques P. Arrieux, M.A.

Jacques P. Arrieux, M.A.

- Senior clinical research associate with DVBIC at WAMC at Fort Bragg
- Previous positions at WAMC including administering and scoring neuropsychological tests as a psychometrist
- Education
  - M.A., Experimental Psychology, Fayetteville State University
  - B.S., Psychology, University of North Carolina at Pembroke

Disclosures

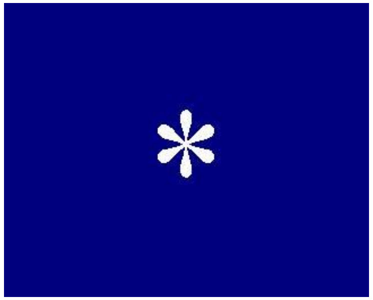
- The views expressed herein are those of the presenter and do not reflect the official policy of the Department of the Army, Department of Defense, or DVBIC.
- The presenter does not intend to discuss the off-label/investigative (unapproved) use of commercial products or devices.
- The presenter has no relevant financial relationships to disclose.

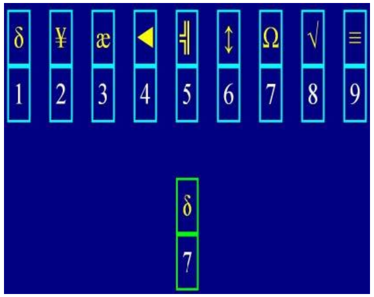
ANAM

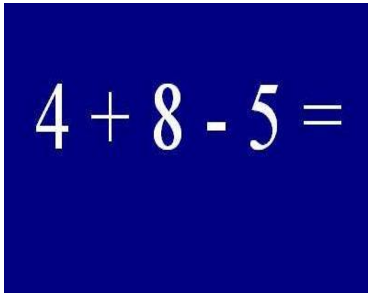
(Cognitive Science Resource Center (CSRC), 2014)

ANAM4 TBI-MIL

- Primary Subtests
  - Simple Reaction Time (SRT)
  - Simple Reaction Time [R] (SRT,R)
  - Procedural Reaction Time (PRO)
  - Code Substitution - Learning (CDS)
  - Code Substitution - Delayed (CDD)
  - Mathematical Processing (MTH)
  - Matching to Sample (M2S)





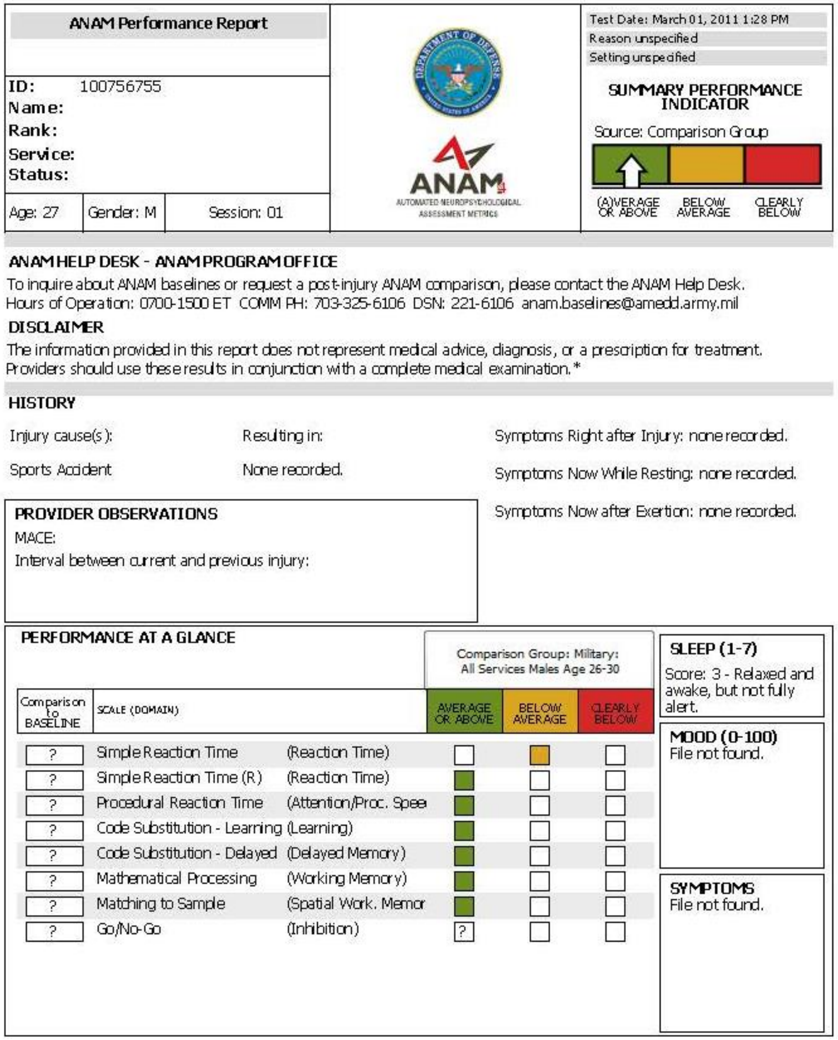


(CSRC, 2014)

ANAM Primary Scores

- Throughput
  - Throughput = number of correct responses per unit of available response time:
    [NumCorr/((NumCorr+NumInc)*MeanRT+NumLapse*Timeout)]
- Composite Score
  - Sum the Standard Scores for Throughput for each of the seven ANAM performance tests
  - Convert sum of Throughput to a z-score using normative sample
- Impaired performance
  - ANAM composite score < -1.28

ANAM Performance Report



ANAM Performance Report		Test Date: March 01, 2011 1:28 PM
ID: 100756755	ANAM AUTOMATED NEUROPSYCHOLOGICAL ASSESSMENT METRICS	Reason unspecified
Name:		Setting unspecified
Rank:		SUMMARY PERFORMANCE INDICATOR
Service:		Source: Comparison Group
Status:		(A)VERAGE OR ABOVE / BELOW AVERAGE / CLEARLY BELOW
Age: 27 / Gender: M / Session: 01		

ANAM HELP DESK - ANAM PROGRAM OFFICE

To inquire about ANAM baselines or request a post-injury ANAM comparison, please contact the ANAM Help Desk.
Hours of Operation: 0700-1500 ET COMM PH: 703-325-6106 DSN: 221-6106 anam.baselines@amedd.army.mil

DISCLAIMER

The information provided in this report does not represent medical advice, diagnosis, or a prescription for treatment. Providers should use these results in conjunction with a complete medical examination.*

HISTORY

Injury cause(s):	Resulting in:	Symptoms Right after Injury: none recorded.
Sports Accident	None recorded.	Symptoms Now While Resting: none recorded.
		Symptoms Now after Exertion: none recorded.

PROVIDER OBSERVATIONS

MACE:
Interval between current and previous injury:

PERFORMANCE AT A GLANCE

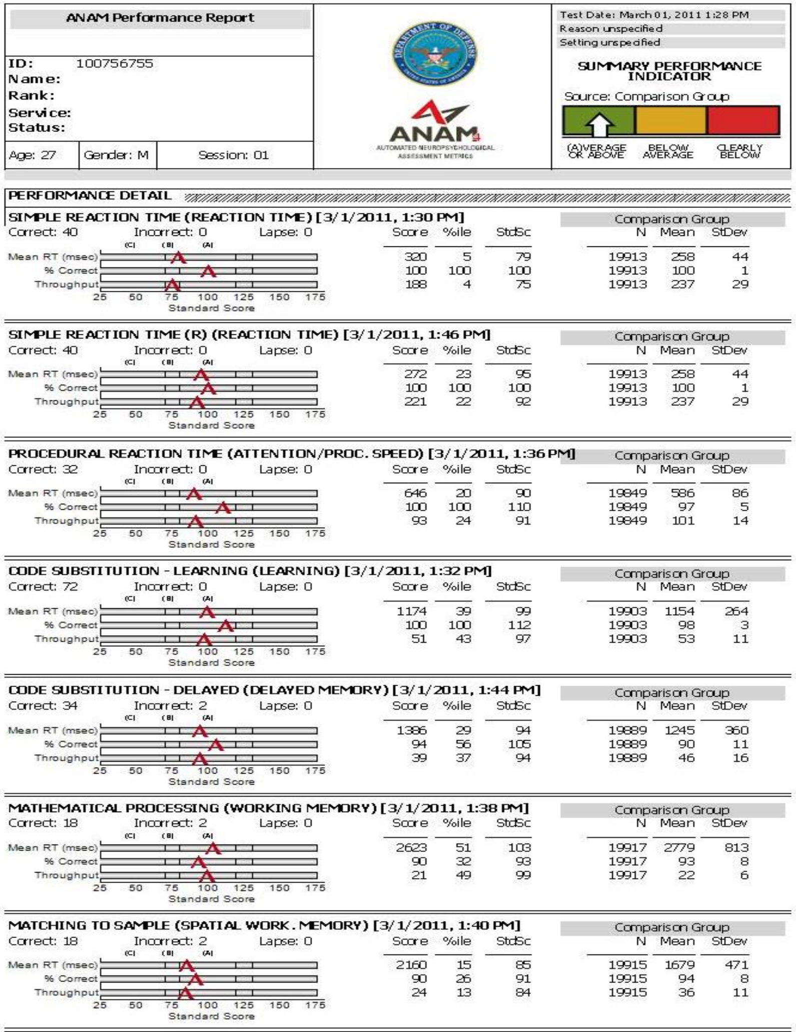
Comparison Group: Military: All Services Males Age 26-30

Comparison to BASELINE	SCALE (DOMAIN)		AVERAGE OR ABOVE	BELOW AVERAGE	CLEARLY BELOW
?	Simple Reaction Time	(Reaction Time)	□	■	□
?	Simple Reaction Time (R)	(Reaction Time)	■	□	□
?	Procedural Reaction Time	(Attention/Proc. Spee	■	□	□
?	Code Substitution - Learning	(Learning)	■	□	□
?	Code Substitution - Delayed	(Delayed Memory)	■	□	□
?	Mathematical Processing	(Working Memory)	■	□	□
?	Matching to Sample	(Spatial Work. Memor	■	□	□
?	Go/No-Go	(Inhibition)	?	□	□

SLEEP (1-7)
Score: 3 - Relaxed and awake, but not fully alert.

MOOD (0-100)
File not found.

SYMPTOMS
File not found.



ANAM Performance Report		Test Date: March 01, 2011 1:28 PM
ID: 100756755	ANAM AUTOMATED NEUROPSYCHOLOGICAL ASSESSMENT METRICS	Reason unspecified
Name:		Setting unspecified
Rank:		SUMMARY PERFORMANCE INDICATOR
Service:		Source: Comparison Group
Status:		(A)VERAGE OR ABOVE / BELOW AVERAGE / CLEARLY BELOW
Age: 27 / Gender: M / Session: 01		

PERFORMANCE DETAIL

SIMPLE REACTION TIME (REACTION TIME) [3/1/2011, 1:30 PM]
Correct: 40 Incorrect: 0 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	320	5	79	19913	258	44
% Correct	100	100	100	19913	100	1
Throughput	188	4	75	19913	237	29

SIMPLE REACTION TIME (R) (REACTION TIME) [3/1/2011, 1:46 PM]
Correct: 40 Incorrect: 0 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	272	23	95	19913	258	44
% Correct	100	100	100	19913	100	1
Throughput	221	22	92	19913	237	29

PROCEDURAL REACTION TIME (ATTENTION/PROC. SPEED) [3/1/2011, 1:36 PM]
Correct: 32 Incorrect: 0 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	646	20	90	19849	586	86
% Correct	100	100	110	19849	97	5
Throughput	93	24	91	19849	101	14

CODE SUBSTITUTION - LEARNING (LEARNING) [3/1/2011, 1:32 PM]
Correct: 72 Incorrect: 0 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	1174	39	99	19903	1154	264
% Correct	100	100	112	19903	98	3
Throughput	51	43	97	19903	53	11

CODE SUBSTITUTION - DELAYED (DELAYED MEMORY) [3/1/2011, 1:44 PM]
Correct: 34 Incorrect: 2 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	1386	29	94	19889	1245	360
% Correct	94	56	105	19889	90	11
Throughput	39	37	94	19889	46	16

MATHEMATICAL PROCESSING (WORKING MEMORY) [3/1/2011, 1:38 PM]
Correct: 18 Incorrect: 2 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	2623	51	103	19917	2779	813
% Correct	90	32	93	19917	93	8
Throughput	21	49	99	19917	22	6

MATCHING TO SAMPLE (SPATIAL WORK. MEMORY) [3/1/2011, 1:40 PM]
Correct: 18 Incorrect: 2 Lapse: 0

	Score	%ile	StdSc	N	Mean	StDev
Mean RT (msec)	2160	15	85	19915	1679	471
% Correct	90	26	91	19915	94	8
Throughput	24	13	84	19915	36	11

(Comparison Group: N, Mean, StDev; chart axis: Standard Score 25–175, markers (C) (B) (A))

(CSRC, 2014)

ANAM Reliability

Author	Sample	Retest interval	Statistics	Test retest
Register-Mihalik et al. 2012	38 healthy college athletes	2 – 8 weeks	ICC, *r*	0.14 – 0.86
Cole et al. 2013	50 healthy active duty military	4 – 6 weeks	ICC, *r*	0.40 – 0.79
Segalowitz et al. 2007	29 healthy adolescents	1 week	ICC, *r*	0.44 – 0.72
Cernich et al. 2007	18 healthy USMA cadets	166 days	*r*	0.38 – 0.87
Dretsch et al. 2014	102 healthy active duty military	8 days	ICC, *r*	0.57 – 0.86
Kaminski et al. 2009	25 healthy college students	5x over 2 weeks	ICC	0.75 – 0.96
Hawkins et al. 2012	72 Parkinson's Disease (PD) patients & 26 controls	1 – 3 weeks	*r*	0.60 – 0.86

ANAM Validity

Author	Methods	Results
Woodhouse et al. 2013	-30 neurologically impaired & 113 controls -Logistic Regression to determine accurate impairment status based on RBANS	Sensitivity = 81% Specificity = 89.1% Classification Rate = 87.9%
Kelly et al. 2012	-71 with acute mTBI & 166 controls -ROC curve and sensitivity and specificity -With and without baseline data	Without Baseline Data: Area under curve = 0.73 Discriminant ability = 71%, Sensitivity = 59% Specificity = 82% With Baseline Data: Area under curve = 0.79 Discriminant ability = 75% Sensitivity = 53% Specificity = 98%
Register-Mihalik et al. 2012	-38 Healthy controls -132 mTBI within 5 days of injury -Administered ANAM, GSC (Graded Symptom Checklist, and SOT (Sensory Organizational Test) -Reliable Change Index at 95%, 90%, and 80% CI	ANAM alone: Sensitivity=9.3% Specificity=95.2% Including ANAM, SOT, and GSC: Sensitivity=50% Specificity=96.7%

ANAM Validity

Author	Methods	Results
Norris et al. 2013	-165 soldiers with mTBI -Administered ANAM at days 3 and 5 post injury -Demographics and injury characteristics on Return to Duty (RTD) time	Per SRT2 2nd administration: -lowest 25% took 19 days to recover -top 25% recovered in 7 days (Kaplan–Meier plot)
Coldren et al. 2012	-47 mTBI (<72 hours post injury) &108 healthy controls -Administered ANAM while deployed -Compared group performance of pre-deployment baseline ANAM to testing at $\leq$3, 5+, and 10+ day intervals	-Significant differences between most scores at $\leq$ 3 days post injury -Minimal differences found at 5+ or 10+ day interval
Bleiberg et al. 2000	-122 healthy students (adolescence and young adults) -Administered ANAM and traditional NP battery (WAIS-R, TMT, FTT, ACT, PASA, HVLT, COWAT, and Stroop)	-PCA revealed a 4 factor structure that the ANAM and traditional battery account for 66% of variance. -Stepwise regression showed ANAM MTH & STN best predicted traditional NP scores

ANAM Validity

Author	Methods	Results
Jones et al. 2008	-77 healthy college students -Administered ANAM and WJ-III (cognitive)	Stepwise regression: -ANAM scores best predicted WJ-III numbers reversed -PCA revealed a 3 factor solution that accounts for 70% of total variance
Kabat et al. 2001	-191 Veterans referred for outpatient NP testing -Compared ANAM to traditional NP battery (WAIS-R, Trails, CVLT, and Heaton Story/Figure Loss)	-ANAM score with highest correlation was also best predictor of traditional test score -CDS and MTH RT accounted for 45% of WAIS DS Coding scores -PCA revealed a 3 factor solution accounting for 62% of total variance
Guskiewiecz et al. 2011	-100 college athletes (<72 hours post mTBI) -administered ANAM, GSC, and SOT	-McNemar tests of paired proportions indicated 22%-52% disagreement between measures of impairment
Hawkins et al. 2012	-72 Parkinson's Disease (PD) patients & 26 controls -Administered ANAM and traditional NP battery (FTT,GPB, WAIS-III PSI, Graphic Sequencing, Verbal Fluency, Clock drawing, Hooper VOT, and WCS)	-Significant difference on ANAM Cognitive Efficiency Score between PD and controls -ANAM accurately classified as impaired 83.3% & non-impaired 86.1%

ANAM Validity

Author	Methods	Results
Meier et al. 2015	-17 college football athletes with mTBI & 27 healthy controls -Cerebral Blood Flow (CBF) imaging conducted at 1 day, 1 week, and 1 month post concussion.	-SRT1&2 subtests demonstrated a significant main effect for time ($p<0.001$) -t-tests showed that all subtests demonstrating a main effect were worse at time 1 ($p<0.001$) -Longer recovery associated with CBF in right insular and superior temporal cortex.

ANAM Validity Correlations

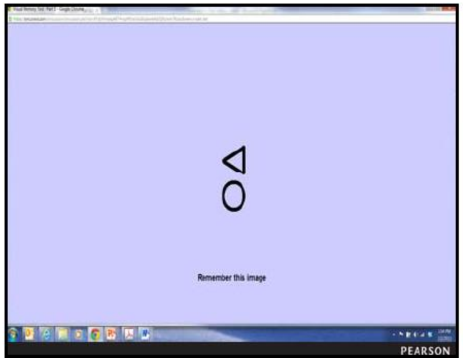
Author	Methods	Results
Bleiberg et al. 2000	-122 healthy students (teens and young adults) -Administered ANAM and traditional NP battery (WAIS-R, TMT, FTT, ACT, PASA, HVLT, COWAT, and Stroop)	-Throughput (TP) scores most correlated with traditional NP tests. -MTH and STN most correlated 0.66, 0.41 -Correlations ranged form -0.50 – 0.66
Jones et al. 2008	-77 healthy college students -Administered ANAM and WJ-III (cognitive)	-ANAM Logical Reasoning (LGR) most correlated with WJ-III *g* (0.77) -Correlations ranged from -0.24 – 0.55
Kabat et al. 2001	-191 Veterans referred for outpatient NP testing -Compared ANAM to traditional NP battery (WAIS-R, Trails, CVLT, and Heaton Story/Figure Loss)	-Highest correlations between CDS RT and TMT B (0.66) -Correlations ranged from -0.64 – 0.66
Cernich et al. 2007	-Woodard et al 2002 dataset -Compared healthy controls to mTBI on ANAM and traditional tests (HVLT, COWAT, WAIS DS, Brief test of attention)	-Highest correlation between ANAM MTH and Symbol Search (0.61) -Significant correlations ranged from 0.40 – 0.82
Hawkins et al. 2012	-26 healthy controls -Administered ANAM and traditional NP battery (FTT,GPB, WAIS-III PSI, Graphic Sequencing, Verbal Fluency, Clock drawing, Hooper VOT, and WCS)	-Highest correlation was between ANAM Cognitive Efficiency Score (CES) and WAIS-III PSI (0.75) -Significant correlations ranged from -0.48 – 0.75

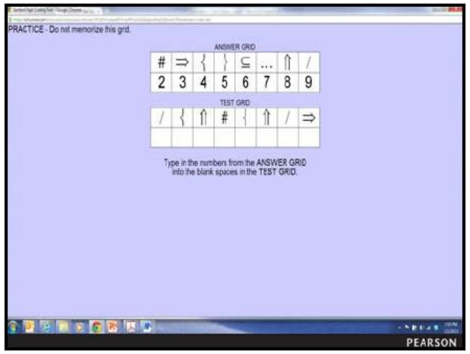
CNS Vital Signs

(CNS Vital Signs, 2015)

CNS Vital Signs Subtests

- **Subtests**
  - Verbal Memory Test (Immediate & Delayed)
  - Visual Memory Test (Immediate & Delayed)
  - Finger Tapping Test
  - Symbol Digit Coding Test
  - Stroop Test
  - Shifting Attention Test
  - Continuous Performance Test





(Resch, 2013)

CNS Vital Signs

- Domain Scores
  - NCI (Neurocognitive Index)
  - Composite memory
  - Verbal Memory
  - Visual Memory
  - Psychomotor Speed
  - Reaction Time
  - Complex Attention
  - Cognitive Flexibility
  - Processing Speed
  - Executive Function
  - Simple Attention
  - Motor Speed

How are the cognitive domains calculated?

Clinical Domains	Domain Score Calculations
Neurocognition Index - NCI	Average of five domain scores: Composite Memory, Psychomotor Speed, Reaction Time, Complex Attention , and Cognitive Flexibility ; representing a form of a global score of neurocognition
Composite Memory	VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay + VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay
Verbal Memory	VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay
Visual Memory	VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay
Psychomotor Speed	FTT Right Taps Average + FTT Left Taps Average + SDC Correct Responses
Reaction Time	(ST Complex Reaction Time Correct + Stroop Reaction Time Correct) / 2
Complex Attention	Stroop Commission Errors + SAT Errors + CPT Commission Errors + CPT Omission Errors
Cognitive Flexibility	SAT Correct Responses - SAT Errors - Stroop Commission Errors
Processing Speed	SDC Correct Responses - SDC Errors
Executive Function	SAT Correct Responses - SAT Errors
Simple Attention	Continuous Performance (CPT) Correct Responses minus CPT Commission Errors
Motor Speed	Finger Tapping Test Right Taps Average + Finger Tapping Test Left Taps Average

Abbreviations Defined: VBM - Verbal Memory Test; VIM - Visual Memory Test; SDC - Symbol Digit Coding Test; SAT - Shifting Attention Test; FTT - Finger Tapping Test; ST - Stroop Test; CPT - Continuous Performance Test; 4PCPT - Four Part CPT; POET - Perception of Emotions Test; NVR - Non- verbal Reasoning Test.

(CNS Vital Signs, 2015)

CNS Vital Signs Clinical Report

CNS Vital Signs Clinical Report	Test Date: February 22 2011 13:15:53
Subject Reference/ID: 106708269	Administrator:
Language: English (United States)	Age: 31

Patient Profile:	Percentile Range				> 74	25 - 74	9 - 24	2 - 8	< 2
	Standard Score Range				> 109	90 - 109	80 - 89	70 - 79	< 70
Domain Scores	**Subject Score**	**Standard Score**	**Percentile**	**VI****	**Above**	**Average**	**Low Average**	**Low**	**Very Low**
Neurocognition Index (NCI)	NA	100	50	Yes		x			
Composite Memory	90	83	13	Yes			x		
Verbal Memory	46	80	9	Yes			x		
Visual Memory	44	93	32	Yes		x			
Processing Speed	71	116	86	Yes	x				
Executive Function	52	104	61	Yes		x			
Psychomotor Speed	216	125	95	Yes	x				
Reaction Time*	680	88	21	Yes			x		
Complex Attention*	5	102	55	Yes		x			
Cognitive Flexibility	51	103	58	Yes		x			
Total Test Time (min:secs)	26:11				Total time taken to complete the tests shown.				

Domain Dashboard: Above average domain scores indicate a standard score (SS) greater than 109 or a Percentile Rank (PR) greater than 74, indicating a high functioning test subject. Average is a SS 90-109 or PR 25-74, indicating normal function. Low Average is a SS 80-89 or PR 9-24 indicating a slight deficit or impairment. Below Average is a SS 70-79 or PR 2-8, indicating a moderate level of deficit or impairment. Very Low is a SS less than 70 or a PR less than 2, indicating a deficit and impairment. Reaction times are in milliseconds. An * denotes that "lower is better", otherwise higher scores are better. Subject Scores are raw scores calculations generated from data values of the individual subtests.

VI** – Validity Indicator: Denotes a guideline for representing the possibility of an invalid test or domain score. "No" means a clinician should evaluate whether or not the test subject understood the test, put forth their best effort, or has a clinical condition requiring further evaluation.

(CNS Vital Signs, 2015)

CNS Vital Signs Clinical Report

Verbal Memory Test (VBM)	Score	Standard	Percentile	
Correct Hits - Immediate	13	104	61	Verbal Memory test: Subjects have to remember 15 words and recognize them in a field of 15 distractors. The test is repeated at the end of the battery. The VBM test measures how well a subject can recognize, remember, and retrieve words e.g. exploit or attend literal representations or attribute. "Correct Hits" refers to the number of target words recognized. Low scores indicate verbal memory impairment.
Correct Passes - Immediate	12	63	1	
Correct Hits - Delay	10	94	34	
Correct Passes - Delay	11	49	1	
Visual Memory Test (VIM)	**Score**	**Standard**	**Percentile**	
Correct Hits - Immediate	12	100	50	Visual Memory test: Subjects have to remember 15 geometric figures, and recognize them in a field of 15 distractors. The test is repeated at the end of the battery. The VIM test measures how well a subject can recognize, remember, and retrieve geometric figures e.g. exploit or attend symbolic or spatial representations. "Correct Hits" refers to the number of target figures recognized. Low scores indicate visual memory impairment.
Correct Passes - Immediate	12	102	55	
Correct Hits - Delay	11	98	45	
Correct Passes - Delay	9	85	16	
Finger Tapping Test (FTT)	**Score**	**Standard**	**Percentile**	
Right Taps Average	76	123	94	The FTT is a test of motor speed and fine motor control ability. There are three rounds of tapping with each hand. The FTT test measures the speed and the number of finger-taps with each hand. Low scores indicate motor slowing. Speed of manual motor activity varies with handedness. Most people are faster with their preferred hand but not always.
Left Taps Average	69	118	88	
Symbol Digit Coding (SDC)	**Score**	**Standard**	**Percentile**	
Correct Responses	72	116	86	The SDC test measures speed of processing and draws upon several cognitive processes simultaneously, such as visual scanning, visual perception, visual memory, and motor functions. Errors may be due to impulsive responding, misperception, or confusion.
Errors*	1	98	45	

Stroop Test (ST)	Score	Standard	Percentile	
Simple Reaction Time*	263	103	58	The ST measures simple and complex reaction time, inhibition / disinhibition, mental flexibility or directed attention. The ST helps assess how well a subject is able to adapt to rapidly changing and increasingly complex set of directions. Prolonged reaction times indicate cognitive slowing / impairment. Errors may be due to impulsive responding, misperception, or confusion.
Complex Reaction Time Correct*	580	97	42	
Stroop Reaction Time Correct*	779	83	13	
Stroop Commission Errors*	1	96	40	
Shifting Attention Test (SAT)	**Score**	**Standard**	**Percentile**	
Correct Responses	54	100	50	The SAT measures executive function or how well a subject recognizes set shifting (mental flexibility) and abstraction (rules, categories) and manages multiple tasks simultaneously. Subjects have to adjust their responses to randomly changing rules. The best scores are high correct responses, few errors and a short reaction time. Normal subjects may be slow but accurate, or fast but not so accurate. Attention deficit may be apparent.
Errors*	2	110	75	
Correct Reaction Time*	1108	94	34	
Continuous Performance Test (CPT)	**Score**	**Standard**	**Percentile**	
Correct Responses	40	104	61	The CPT measures sustained attention or vigilance and choice reaction time. Most normal subjects obtain near-perfect scores on this test. A long response time may suggest cognitive slowing and/or impairment. More than 2 errors (total) may be clinically significant. More than 4 errors (total) indicate attentional dysfunction.
Omission Errors*	0	104	61	
Commission Errors*	2	65	1	
Choice Reaction Time Correct*	376	104	61	

(CNS Vital Signs, 2015)

CNS Vital Signs Reliability

Author	Sample	Retest interval	Statistics	Test retest
Cole et al 2013	39 Active duty military	3-6 weeks	ICC, *r*	0.29 – 0.79
Gualtieri et al 2006	99 Healthy controls	62 days	*r*	0.31 – 0.87
Littleton et al 2015	40 Healthy controls	3 sessions 1 week apart	ICC, *r*	T1-T2 0.10 – 0.85 T2-T3 0.45 – 0.82 T1-T3 0.22 – 0.86

CNS Vital Signs Validity

Author	Methods	Results
Gualtieri et al. 2006	-144 patients with psychiatric disorders & 36 controls -Administered CNS VS and a traditional NP battery (RAVLT, WMS, FTT, Stroop, Trails B, CPT, and Verbal Fluency)	MANOVA: -significant differences between mTBI group and controls ($P < 0.05$)
Lanting et al. 2012a	-50 patients with mTBI & 31 trauma controls (orthopedic injury) -Administered CNS VS 6-8 weeks after injury	MANOVA: - non-significant differences in scores and small effect sizes -scores below 1 SD were more prevalent in the mTBI group
Gualtieri et al. 2015	-3420 healthy controls -Compare scores on demographic factors -Evaluate the factor structure in the normative reference group	-Age and education contributed to performance ($p<0.0001$) -EFA and CFA indicated 3 primary factors: memory, processing speed, and attention (RMSEA=0.065; CFI=0.961)
Gualtieri et al. 2015	-3420 healthy controls, 4084 ADHD, & 694 TBI -Compare scores on different clinical groups	-Neither stepwise or logistic regression were able to identify a specific pattern of response for the 4 groups

CNS Vital Signs Validity Correlations

Author	Methods	Results
Gualtieri et al. 2006	-144 patients with psychiatric disorders and 36 controls -Administered CNS VS and a traditional NP battery (RAVLT, WMS, FTT, Stroop, Trails B, CPT, and Verbal Fluency)	-Best correlation was between WAIS DSST and VBM *r* = 0.79 -Overall ranged from -0.52 – 0.79
Lanting et al. 2012b	-50 patients with mTBI -Administered CNS VS and a traditional battery (NAB, RIST, and WTAR) 6-8 weeks after injury	-Best correlation was between NAB Memory Index and CNS VS Psychomotor speed *r* = 0.58 -Overall ranged from 0.29 – 0.58).
Gualtieri et al. 2015	-convenience sample of 179 -were assessed with both CNS VS and WAIS-III or IV -evaluated for ADD, LD, or MCI	-Best correlations were between VIM and VIQ *r* =0.53; SAT and FSIQ r = 0.59 -Overall ranged from -0.27 – 0.59

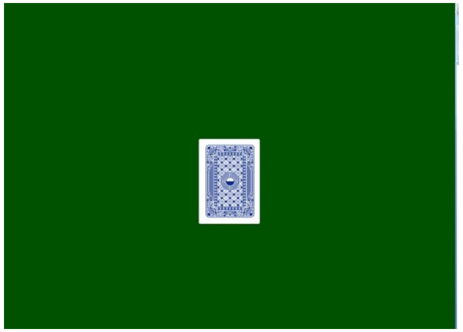
CogState

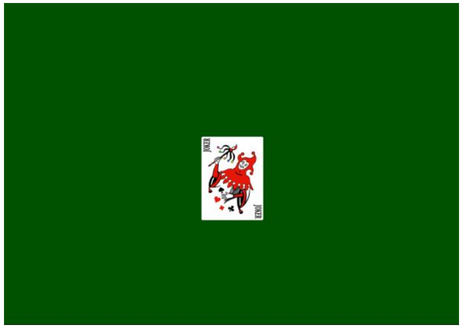
CogState
ClinicalTrials

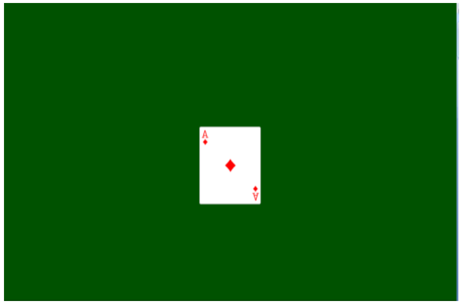
(CogState, 2008)

CogState Subtest

- Detection Task (DET)
- Identification Task (IDN)
- One Card Learning Task (OCL/LN1T)
- One Back Task (OBK)







(CogState, 2008)

CogState Scores Overview

Summary scores were generated by CogState which produced the z-scores for each of the following subtest scores:

Test	Primary outcome measure	Other outcome measures	z-score computed on	Data integrity on
Detection	Speed of performance	Accuracy of performance	Speed of performance	Accuracy > 90%
Identification	Speed of performance	Accuracy of performance	Speed of performance	Accuracy > 80%
One Back	Speed of performance	Accuracy of performance	Speed of performance	Accuracy > 80%
One Card Learning [2]	Accuracy of performance	Speed of performance	Accuracy of performance	Accuracy > 50%
Composite	-	-	Average of 4 subtests' z-scores then compared to norms	2 or more subtests with suboptimal effort

(CogState, 2012)

CogState Reliability

Author	Sample	Retest interval	Statistic	Test retest
Cole et al. 2013	53 active duty military	3 – 6 weeks	ICC, *r*	0.22 – 0.79
Felleti et al. 2006	45 healthy controls	4 administrations,10 minutes apart & 1 week later	ICC	-RT scores were better than ACC, ranged from 0.35 – 0.94 -1 week ranged from 0.51 – 0.82
Louey et al. 2014	235 healthy controls	7 days	ICC	0.83 – 0.93
Collie et al. 2003	60 healthy controls	1 hour and 1 week	ICC	-RT ranged from 0.60 – 0.90 -ACC ranged from -0.08 – 0.51
MacDonald et al. 2015	108 healthy high school	1 year	ICC	Ranged from 0.405 – 0.672
Hammers et al. 2011	23 healthy controls, 20 MCI & 52 Alzheimer's	2 hours	*r*	MCI -0.19 – 0.73, AD 0.59 – 0.80, Controls 0.23 – 0.79,
Lim et al. 2013	105 healthy older adults 48 adults with MCI 42 adults with AD	4 administrations, 1 month apart	ICC	-Controls ranged from 0.77 – 0.93 -MCI ranged from 0.79 – 0.95 -AD ranged from 0.70 – 0.95

CogState Validity

Author	Methods	Results
Maruff et al. 2009	-215 healthy controls -Compared performance on CogState with traditional battery (GPB, TMT, SDMT, BVMT, RCFT, Spatial Span Subtest form WMS-III) -Pearson r Correlations	-Best correlation was between OCL and BVMT *r* = 0.83 -Correlations ranged form 0.49 – 0.83
Collie et at. 2003	-240 healthy athletes -Compared scores on CogState, DSMT, and TMT -Pearson *r* Correlations	-TMT and CogState RT scores ranged from 0.23 – 0.44 -DSMT and CogState RT scores ranged from 0.42 – 0.86
Louey et al. 2014	-29 acute mTBI compared to 260 normal controls -Compared baseline to norms on classification of abnormal performance -ANCOVA & Diagnostic accuracy by CCR (correct classification rate)	Controls performed better than mTBI group on all scores (p <0.001) Baseline Sensitivity=97% Specificity=87% CCR=88% Normative Sensitivity=69% Specificity=91.5% CCR=89%

CogState Validity

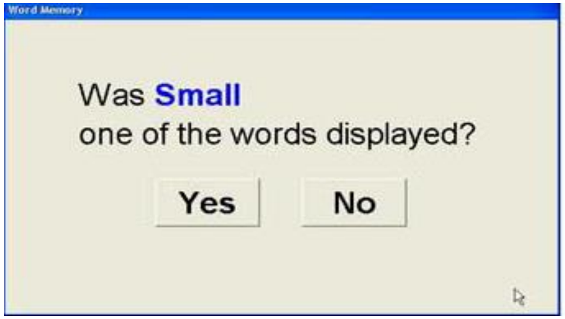
Author	Methods	Results
Makdissi et al. 2001	-6 mTBI & 7 controls (pro football players, < 3 days post injury) -Administered CogState, DSMT, and TMT -ANOVA comparing group & by test	-DET was worse in mTBI group -In contrast, performance increased in controls (p<0.02)
Collie et al 2006	-61 mTBI (25 symptomatic/36 asymptomatic, <11days post injury) & 84 controls -Administered CogState, TMT, and DSMT -Compared to baseline scores -ANOVA and Z change statistics	-Post-injury CogState scores declined in symptomatic group -On traditional NP tests the symptomatic group showed no decline in scores, while the controls improved
Maruff et al. 2009	-50 mTBI, 50 Schizophrenia, 20 AIDS Dementia Complex (ADC) & Case matched controls for each clinical group -Compared the impairment between groups -Independent samples t-tests, Cohen's *d*, & Non-overlap statistic (%n-OL)	-T-tests were significant for all measures and groups -mTBI group, p<0.0001, d ranged from -1 to -1.8 -%n-OL ranged from 41% DET (in ADC group) and 78% OCL (in mTBI group)
Lim et al. 2013	-105 healthy older adults, 48 adults with MCI, & 42 adults with AD -Compared performance between groups across 3 months (4 CogState administrations, 1 month apart) with LMM ANCOVA & Cohen's *d*	-Magnitude of difference between clinical groups vs controls was generally large (*d* ranged from 0.60 – 2.62).

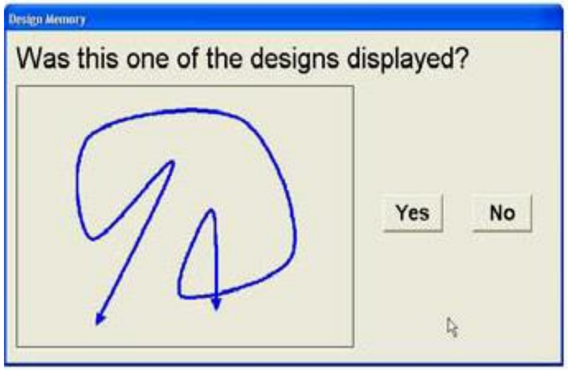
ImPACT

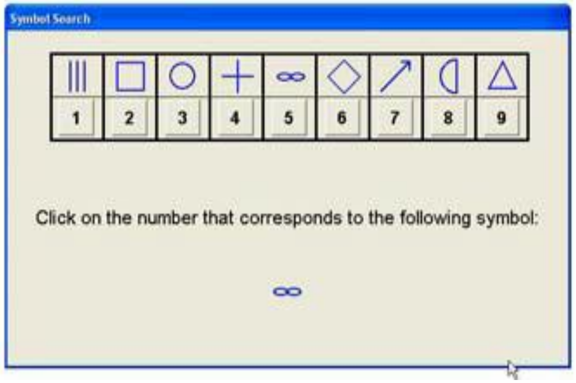
(ImPACT Applications, Inc., 2010)

ImPACT Subtests

- Subtests
  - Word Memory (Immediate)
  - Design Memory (Immediate)
  - Xs and Os
  - Symbol Match
  - Color Match
  - Four Letters
  - Word Memory (Delay)
  - Design Memory (Delay)







(ImPACT Applications, Inc., 2010)

ImPACT Composite Scores

- Verbal Memory
- Visual Memory
- Visual Motor Speed
- Reaction Time
- Impulse Control

(ImPACT Applications, Inc., 2015)

ImPACT Sample Report

Word Memory				
Hits (Immediate) - Trial 1	11	12		
Correct distractors (immed.) - Trial 1	12	12		
Learning percent correct - Trial 1	96%	100%		
Hits (Immediate) - Trial 2	11	10		
Correct distractors (immed.) - Trial 2	12	10		
Learning percent correct - Trial 2	96%	83%		
Hits (delay)	9	12		
Correct distractors (delay)	12	9		
Learning percent correct (delay)	88%	88%		
Total percent correct	93.33%	90.33%		

Design Memory				
Hits (Immediate) - Trial 1	9	10		
Correct distractors (immed.) - Trial 1	8	8		
Learning percent correct - Trial 1	71%	75%		
Hits (Immediate) - Trial 2	9	8		
Correct distractors (immed.) - Trial 2	10	12		
Learning percent correct - Trial 2	79%	83%		
Hits (delay)	10	9		
Correct distractors (delay)	8	9		
Learning percent correct (delay)	75%	75%		
Total percent correct	75%	77.67%		

X's and O's		
Total correct (memory)	3	6
Percentage correct (memory)	33.33%	66.67%
Correct hits (interference)	12	12
Incorrect hits (interference)	0	0
Average correct time (interference)	1.2	1.05
Average incorrect time (interference)	0	0

ImPACT™ Clinical Report 139798163

Symbol Match				
Total correct (visible)	27	27		
Average correct reaction time (visible)	1.88	2.44		
Total correct (hidden)	7	8		
Average correct reaction time (hidden)	2.63	2.27		

Color Match				
Total correct	9	9		
Average correct reaction time	0.3	0.25		
Total commissions	0	0		
Average commissions reaction time	0	0		
Color Blind	No	No		

Four Letters				
Total sequence correct	2	2		
Total letters correct	11	10		
Percentage of total letters correct	91.67%	83.33%		
Average timeof first click	0.22	0.34		
Average counted	15.33	15		
Average counted correctly	15.33	15		

Composite Scores				
Memory composite (verbal)	94	54%	88	26%
Memory composite (visual)	54	12%	73	62%
Visual motor speed composite	27.33	66%	27	64%
Reaction time composite	0.71	99%	0.7	99%
Impulse control composite	0		0	
Total Symptom Score	0		0	

(ImPACT Applications, Inc., 2015)

ImPACT Reliability

Author	Sample	Retest interval	Statistics	Test retest
Cole et al. 2013	44 healthy active duty military	4-6 weeks	ICC, *r*	0.53 – 0.83
Nakayama et al. 2014	96 healthy college students	45 and 50 days	ICC, *r*	T1-T2 0.67 – 0.87 T2-T3 0.66 – 0.88 T1-T3 0.60 – 0.85 Overall 0.74 – 0.91
Broglio et al. 2007a	73 healthy college students	45 and 50 day	ICC, *r*	T1-T2 0.23 – 0.39 T2-T3 0.39 – 0.61
Bruce et al. 2014	283 Healthy NHL players	1 year	ICC	0.45 – 0.76
Elbin et al. 2011	369 High School athletes	1 year	ICC	0.57 – 0.85
Iverson et a.l 2003	56 High School and College athletes	5.8 days	*r*	0.67 – 0.86
Register-Mihalik et al. 2012	40 College and High School athletes	1.8 and 1.6 days (3 administrations)	ICC, *r*	0.29 – 0.71
Resch et al. 2013	46 college students (Ireland) 45 college age (USA)	7 and 14 days 45 and 50 days	ICC	0.41 – 0.88 0.37 – 0.76
Schatz 2010	95 College athletes	2 years	ICC	0.43 – 0.74
Schatz & Ferris 2013	25 College students	1 month	ICC, *r*	0.60 – 0.88

ImPACT Validity Correlations

Author	Methods	Results
Iverson et al. 2005	-72 athletes with mTBI -Compared performance on ImPACT to SDMT -Pearson *r* correlation	-Best correlation was Processing Speed and SDMT -Ranged from -0.60 – 0.70
Schatz et al. 2006	-30 healthy college students -Compared performance on ImPACT to TMT and SDMT with Pearson *r* correlation	-ImPACT Complex Reaction Time and Trails (A=0.64, B=0.44) -Ranged from -0.51 – 0.64
Allen et al. 2011	-100 healthy college students -Compared performance on ImPACT to NFL traditional NP battery (HVLT-R, BVMT-R, TMT, COWA, and 3 subtests from the WAIS-III) -Pearson *r* correlation	-Best correlation was Visual Motor Speed and WAIS Coding (*r*=0.43) -Ranged from -0.38 – 0.43
Maerlender et al 2010	-54 healthy college athletes -Compared performance on ImPACT to traditional NP battery (CVLT-II, BVMT-R, CPT, DKEFS (TMT, VF, and CWI), GPB, and PASAT. -Pearson *r* correlation & Canonical Correlations	-Best correlation was between ImPACT and NP Visual Memory domains (*r*=0.59) -Ranged from -0.39 – 0.59 -Canonical correlations indicated a strong correlation between batteries Dimension 1 = 0.80, *p*=0.0043) Dimension 2 = 0.73, *p*=0.0409)

ImPACT Validity

Author	Methods	Results
Maerlender et al. 2013	-54 healthy college athletes (same sample from 2010) -Compared performance on ImPACT to traditional NP battery to evaluate discriminant validity -Point-Biserial Correlations	-ImPACT did not discriminate between dissimilar measures. -3 of 4 ImPACT domains were correlated with dissimilar traditional NP measures ($p<0.05$) -3 of 4 traditional NP domain correlations were not correlated with dissimilar measures ($p>0.05$)
Allen et al. 2011	-100 healthy college students -ImPACT and NFL traditional NP battery scores -PCA	-NFL battery, 4-factor solution explaining 70% of variance -ImPACT, 5 factor solution explaining 69% of variance
Schatz et al. 2006	-72 High School Athletes with mTBI, 66 healthy controls -Administered ImPACT <72 hours post injury -MANOVA & Stepwise discriminant analysis	-Groups differed on all indices except Impulse control ($p=0.0001$, Partial Eta^2 0.19 – 0.31) -ImPACT cognitive and symptoms measures combined predicted group membership with sensitivity/NPV = 81.9% and specificity/PPV = 89.4%

ImPACT Validity

Author	Methods	Results
Schatz et al. 2012	-81 symptomatic athletes with mTBI assessed within 72 of injury, 37 asymptomatic athletes with mTBI (suspected of hiding mTBI), demographically matched healthy controls -Compared pre and post season assessments -Prediction of group membership	-In symptomatic group, data indicated 91.4% sensitivity and 69.1% specificity -In asymptomatic group, data indicated 94.6% sensitivity and 97.3% specificity
Broglio et al. 2007b	-24 College athletes -Compared baseline ImPACT to post-injury test within 24 hours of injury, symptom inventory, and NeuroCom SOT. -Incidence of mTBI identified as impaired	-ImPACT alone was sensitive to cognitive decline after mTBI in 79.2% of participants. When combined with postural control and symptom assessment sensitivity increased to 91.7% -Traditional tests were sensitive to decline in 43.5% of participants. When combined with postural control and symptom assessment sensitivity increased to 95.7%

Fort Bragg “Head to Head” Study

- Phase 1: Test-retest Reliability
  - Study design
  - Results
  - Summary of findings
- Phase 2: Validity
  - Study design
  - Results
  - Summary of findings
- General conclusions

Phase 1 Test-Retest Reliability

- “Healthy control” SMs
- Randomly assigned to take one of four NCATs over two testing sessions
- Total n = 419; 215 returned in one month
  – Median 31 days
- 186 with adequate effort included in analyses

ANAM4:	n = 50
CNS VS:	n = 39
CogState:	n = 53
ImPACT:	n = 44

- Groups were equivalent on demographics

(Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013)

Statistics

- Analyses conducted by a third party company, blinded to the NCATs
- Poor testing effort was excluded.
  - Determined by each NCAT's criteria
- Intraclass correlations (ICC)
  - SAS software procedure Generalized Linear Model (GLM)
  - Variability of the observed scores → within-person and between-person variance
  - ICC coefficient = Ratio of between person variability to the total variance (range of 0 to 1)

(Cole et al., 2013)

ANAM4

ANAM4 N = 50			
Variable	r	ICC	Sdiff
Simple Reaction Time	.65	.60	10.11
Simple RT (Repeated)	.41	.40	12.77
Procedural RT	.62	.51	12.77
Math Processing	**.70**	**.70**	**11.67**
Code Subst Learning	**.79**	**.79**	**9.56**
Code Subst Memory	.68	.59	13.07
Matching to Sample	.69	.67	11.10

Very High = .90+ High = .80 - .89 Adequate = .70 - .79 Marginal = .60 - .69 Low = <.59

(Cole et al., 2013)

DEFENSE CENTERS OF EXCELLENCE
For Psychological Health & Traumatic Brain Injury

CNS Vital Signs

CNS VITAL SIGNS N = 39			
Variable	r	ICC	Sdiff
Memory	.53	.54	14.97
Psychomotor	**.77**	**.72**	**10.43**
Speed	**.78**	**.75**	**8.79**
Reaction Time	**.79**	**.79**	**12.52**
Complex Attention			
Cognitive Flexibility	.71	.62	11.35
Processing Speed	.68	.63	13.39
Executive Functioning	.73	.64	10.96
Neurocognitive Index	**.76**	**.70**	**7.11**

Very High = .90+ High = .80 - .89 Adequate = .70 - .79 Marginal = .60 - .69 Low = <.59

DEFENSE CENTERS OF EXCELLENCE
For Psychological Health & Traumatic Brain Injury

(Cole et al., 2013)

CogState

CogState N = 53			
Variable	r	ICC	Sdiff
DET Speed	**.77**	**.78**	**.64**
IDN Speed	**.78**	**.77**	**1.01**
OCL Accuracy	.25	.22	.94
OBK Speed	**.76**	**.74**	**.78**
Composite	**.80**	**.79**	**.64**

Very High = .90+ High = .80 - .89 Adequate = .70 - .79 Marginal = .60 - .69 Low = <.59

(Cole et al., 2013)

ImPACT

ImPACT N = 44			
Variable	r	ICC	Sdiff
Verbal Memory	.61	.60	12.66
Visual Memory	.49	.50	16.17
Reaction Time	.53	.53	.08
Visual Motor Speed	**.86**	**.83**	**2.01**

Very High = .90+ High = .80 - .89 Adequate = .70 - .79 Marginal = .60 - .69 Low = <.59

(Cole et al., 2013)

DEFENSE CENTERS OF EXCELLENCE
For Psychological Health & Traumatic Brain Injury

Reliability Summary

	Low <.59	Marginal .60-.69	Adequate .70-.79	High .80-.89	Very High >.90
ANAM4	3	2	2	0	0
CNS VS	3	3	4	0	0
CogState	1	0	4	0	0
ImPACT	2	1	0	1	0

(Cole et al., 2013)

Summary of Reliability Findings

- Generally consistent with other test-retest reliability studies
  - For summaries, see: Broglio, et al., 2007; Schatz & Ferris, 2013; Cole, et al., 2013; Nakayama, et al., 2014
- All NCATs had at least one subtest in the *adequate* or higher range.
- CogState had the highest proportion of *adequate* or higher scores.
- Measures of response speed tended to have the highest reliabilities.
- However, reliabilities are lower than desired for clinical decision making.
- These results are not sufficient to select a “best test.”

(Cole et al., 2013)

Phase 2 Validity

- Two comparison groups (enlisted SMs only):
  - Healthy controls (n = 139; 51-79 took each NCAT)
  - Acute mild TBI (n = 216; 81-101 took each NCAT)
- Randomly assigned to take two of four NCATs
  - Order of administration was counter-balanced.
- "Traditional" neuropsychological test battery
  - Participant Effort (CARB)
  - IQ (WAIS-IV)
  - Verbal & Visual Processing (WAIS-IV)
  - Working Memory (WAIS-IV)
  - Processing Speed (WAIS-IV)
  - Verbal Learning & Memory (CVLT-II)
  - Visual Learning & Memory (Rey Complex Figure)
  - Executive Functioning, (DKEFS)
  - Attention (CPT-II)

*findings not yet published

Validity Analyses

1) **Effect of order of administration**
   a) NCAT scores at time 1 vs. same NCAT at time 2
   b) One-way ANOVA to compare time 2 scores, grouped by which NCAT was received at time 1
2) **Correlations: NCATs with traditional tests**
   a) Primary scores of interest for NCATs and traditional tests were used
3) **T-tests: Control vs. mTBI**
4) **Logistic regression: "Cognitive impairment"**
   a) Evaluates how well the NCAT as well as demographic and injury history variables predict classification as "cognitively impaired"

*findings not yet published

Validity Order Effects

- No differences between time 1 and time 2 scores on ANAM4 or ImPACT ($p > .05$).
- Potential slight to moderate order effects for CNS VS and CogState ($p < .05$; Cohen's $d > .40$).
- Although several comparisons (especially CNS VS) were no longer statistically significant after controlling for false discovery rate, effect sizes remain moderate ($d > .40$).
- Although not a universal order effect, there may be an order effect for some scores.
- Researchers administering multiple NCATs should take steps to account for order.
  - Counter-balancing order of administration
  - Control in statistical analyses

*findings not yet published

Validity Correlations

Correlations between NCAT scores and traditional tests purported to assess similar cognitive domains

	ANAM4	CNS-VS	CogState	ImPACT
Proc. Speed	.378	**.434**	.301, .356	**.511**
Attention	**-.454** to -.124	-.354 to -.061	-.103 to -.399	.065 to .292
Working Mem.	.319, **.440**	.174, .247	.274, .300	.357, .374
Verbal Memory	.239 to **.400**	.277 to **.491**	.064 to .267	.244 to **.430**
Visual Memory	.349 to **.406**	.262 to .286	.204 to .252	.292, .340
Visual Scanning	.184	-.023, .089	.105, .141	.288
Motor Speed	.280 to .373	.207, .253	.197, .249	-.186, .229
Exec. Func.	.183 to .359	.272 to **.562**	N/A	N/A

*findings not yet published

Validity T-tests

ANAM4 Throughput scores for subtests					
Subtest	Control Mean (SD)	mTBI Mean (SD)	t-score (df)	p-value	Cohen's d
Simple Reaction Time	87.38 (15.44)	79.06 (22.17)	2.88 (166.80) †	.007	.44
Simple Reaction Time 2	89.15 (14.28)	75.50 (26.04)	4.36 (156.78) †	.000	.65
Procedural RT	96.70 (14.66)	87.40 (19.91)	3.50 (166.84) †	.001	.53
Code Subst. Learning	105.54 (18.19)	99.70 (14.70)	2.30 (167)	.023	.35
Code Subst. Memory	101.27 (18.11)	95.92 (16.04)	2.03 (167)	.044	.31
Math Processing	101.34 (15.83)	94.45 (13.64)	3.03 (167)	.003	.47
Matching to Sample	102.96 (18.14)	92.16 (15.80)	4.12 (167)	.000	.64
ANAM4 Composite	-0.25 (1.26)	-1.14 (1.46)	4.15 (167)	.000	.65

†t-statistic corrected for unequal variances

p-value is significant at α=.05, 2-tailed test

Cohen's d effect sizes: small = >.20-.49; medium = .50-.79; large = >.80

*findings not yet published

Validity T-tests

CNS-Vital Signs Standardized scores for indices					
Index	Control Mean (SD)	mTBI Mean (SD)	t-score (df)	p-value	Cohen's d
Memory	102.87 (16.10)	93.08 (19.81)	3.21 (146)	.002	.54
Psychomotor Speed	101.13 (15.24)	89.47 (16.14)	4.35 (146)	.000	.74
Reaction Time	93.38 (15.26)	78.84 (26.14)	3.95 (146)	.000	.68
Complex Attention	94.08 (17.97)	83.39 (24.89)	2.90 (146)	.004	.49
Cognitive Flexibility	97.17 (18.27)	87.07 (20.19)	3.13 (146)	.002	.53
Processing Speed	97.97 (14.87)	90.20 (16.75)	2.93 (146)	.004	.49
Executive Functioning	98.13 (18.22)	88.44 (19.43)	3.08 (146)	.002	.51
Verbal Memory	99.56 (18.10)	90.75 (22.14)	2.58 (146)	.011	.44
Visual Memory	105.17 (14.68)	97.21 (16.35)	3.06 (146)	.003	.51
Simple Attention	92.27 (25.94)	76.42 (35.82)	3.12 (145.94) †	.002	.51
Motor Speed	102.49 (14.38)	92.46 (15.80)	3.97 (146)	.000	.66
Composite	97.73 (12.50)	86.41 (15.82)	4.70 (146)	.000	.79

†t-statistic corrected for unequal variances

p-value is significant at α=.05, 2-tailed test

Cohen's d effect sizes: small = ≥.20-.49; medium = .50-.79; large = ≥.80

*findings not yet published

Validity T-tests

CogState z-scores for subtests					
Subtest	Control Mean (SD)	mTBI Mean (SD)	t-score (df)	p-value	Cohen's d
Detection Speed	-0.77 (1.14)	-1.56 (1.74)	3.49 (162.76) †	.001	.53
Identification Speed	-0.18 (0.82)	-1.36 (1.68)	6.03 (154.99) †	.000	.90
One Card Learn Accuracy	0.05 (0.72)	-0.01 (0.71)	.453 (163)	.651	.07
One Back Speed	-0.60 (0.85)	-1.53 (1.34)	5.43 (162.99) †	.000	.83
Composite	-0.46 (0.77)	-1.39 (1.46)	5.35 (158.56) †	.000	.80

ImPACT Standardized scores for Indices					
Index	Control Mean (SD)	mTBI Mean (SD)	t-score (df)	p-value	Cohen's d
Verbal Memory	92.54 (9.13)	88.12 (10.48)	2.60 (138)	.010	.45
Visual Memory	72.75 (13.27)	69.36 (14.17)	1.43 (138)	.154	.25
Visual Motor Speed	27.27 (4.59)	25.90 (4.33)	1.80 (138)	.074	.31
Reaction Time	0.64 (0.12)	0.60 (0.08)	1.77 (138)	.078	.30

†t-statistic corrected for unequal variances

p-value is significant at α=.05, 2-tailed test

Cohen's d effect sizes: small = ≥.20-.49; medium = .50-.79; large = ≥.80

*findings not yet published

Validity: T-tests Summary

Controls scored significantly better on:

- 7 of the 8 of **ANAM4** subtests
  - Small to medium effect sizes
- All 12 of the **CNS VS** indices
  - Medium effect sizes
- 4 of the 5 **CogState** subtests
  - Medium to large effect sizes
- 1 of the 4 **ImPACT** indices
  - Small effect sizes

*findings not yet published

Validity Cognitive Impairment

- Logistic Regression: Evaluates how well classify "cognitive impairment"
  - Controlling for: Age, gender, education level, marital status, number of past concussions, and WAIS Full Scale IQ
- "Cognitive impairment" based on scoring < 2 standard deviations below the mean on one traditional test

	ANAM4	CNSVS	CogState	ImPACT
Prevalence	44.8%	40.4%	37.0%	39.4%
Sensitivity	66.7%	43.6%	52.6%	66.0%
Specificity	85.9%	84.0%	88.7%	88.3%
PPV	79.3%	64.9%	73.2%	78.6%
NPV	76.0%	68.7%	76.1%	80.0%

*findings not yet published

Validity Results Summary

- Small to medium correlations with traditional tests, even among similar cognitive domains
  - No clear pattern of higher correlations among “like” cognitive domains
- Healthy soldiers performed better on NCATs than soldiers with mTBI.
  - In a manner consistent with traditional tests
  - There may be variable and limited clinical utility.
  - CogState, followed by ANAM4 amd CNS VS, performed the best in these analyses. ImPACT did not perform well.
- NCATs predict impairment on traditional tests relatively well.
  - ANAM4 and ImPACT performed the best in these analyses.

*findings not yet published

Limitations and Critiques

- Relatively small n for reliability phase
  - Well within the range of other published studies
  - Sufficient power for analyses
- Same computer platform used for all four NCATs
  - Input received from all NCAT companies during study design
  - At time of study, no specific requirement for standard platform
  - Any recommended post hoc data corrections were used.
- Is it truly "Head to Head" (i.e., all four NCATs were not administered to all participants)?
  - Broglio et al., 2007, criticized for administering more than one NCAT (Nakamaya et al., 2014; Schatz et al., 2010)
  - Groups were statistically equivalent across NCATs.

*findings not yet published

Broader Conclusions

- Test-retest reliability is lower than desired.
- There appears to be poor convergent validity.

HOWEVER…

- There is potential utility at distinguishing between controls and injured patients for some tests.
- There may be some clinical utility at identifying patients as "Not Impaired."

SO?

- There is still not a "best test" that emerges, and that may be the wrong question to be asking.
- The type of analysis utilized can paint a different picture.
- ANAM4 performs adequately in comparison to other NCATs.
- NCATs still remain best suited as a screening tool.

“Apples to Oranges”

- Comparisons of NCATs vs. traditional tests and NCATs vs. NCATs can be “apples to oranges.”
  - Different stimulus delivery and response methods
  - The same cognitive domain can be measured in different ways, impacting direct comparisons.
  - Impairment can be defined differently.
  - Participant effort is assessed differently.

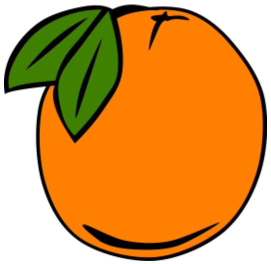


Image source: www.openclipart.org

"Apples to Oranges"

"…test batteries are in fact measuring very different and unique characteristic traits of neurocognitive functioning…
…not all neuropsychological test batteries are created equal."

(Kaminski, et al., 2009, p. S-29)

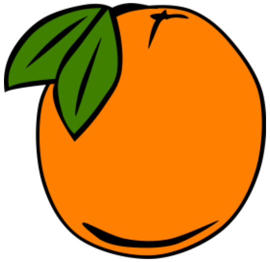


Image source: www.openclipart.org

Future Directions

- Our data
  - Slow and methodical “deep dive” into this issue
  - Further look at demographic and medical history items
- Reliability
  - Reliable change indices
  - Regression based measures
- Validity
  - Clarify some of the “apples to oranges” comparisons via:
    - Factor analyses
    - Multivariate base rate analyses
- In general
  - Baseline scores vs. normative comparisons
  - Alternative psychometric criteria?
  - Alternative methods of investigating psychometrics

Questions?

Jacques P. Arrieux
jacques.p.arrieux.ctr@mail.mil

Dr. Wes Cole
wesley.r.cole.ctr@mail.mil

References

Allen, B. J., & Gfeller, J. D. (2011). The Immediate Post-Concussion Assessment and Cognitive Testing battery and traditional neuropsychological measures: A construct and concurrent validity study. *Brain injury*, *25*(2), 179-191.

Alsalaheen, B., Stockdale, K., Pechumer, D., & Broglio, S. P. (2015). Measurement error in the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT): Systematic review. *The Journal of Head Trauma Rehabilitation*, published ahead of print

Bleiberg, J., Kane, R. L., Reeves, D. L., Garmoe, W. S., & Halpern, E. (2000). Factor analysis of computerized and traditional tests used in mild brain injury research. *The Clinical Neuropsychologist*, *14*(3), 287-294.

Broglio, S. P., Ferrara, M. S., Macciocchi, S. N., Baumgartner, T. A., & Elliott, R. (2007a). Test-retest reliability of computerized concussion assessment programs. *Journal of Athletic Training*, *42*(4), 509.

Broglio, S. P., Macciocchi, S. N., & Ferrara, M. S. (2007b). Sensitivity of the concussion assessment battery. *Neurosurgery*, *60*(6), 1050-1058.

References

Bruce, J., Echemendia, R., Meeuwisse, W., Comper, P., & Sisco, A. (2014). 1 year test–retest reliability of ImPACT in professional ice hockey players. *The Clinical Neuropsychologist*, *28*(1), 14-25.

Cernich, A., Reeves, D., Sun, W., & Bleiberg, J. (2007). Automated neuropsychological assessment metrics sports medicine battery. *Archives of Clinical Neuropsychology*, *22*, 101-114.

CogState (Version 5.6) [Computer software]. (2008). New Haven, CT: CogState Inc.

CogState Inc. (2012). *CogState Analyser Specification*. CogState Inc., New Haven, CT.

Coldren, R. L., Russell, M. L., Parish, R. V., Dretsch, M., & Kelly, M. P. (2012). The ANAM lacks utility as a diagnostic or screening tool for concussion more than 10 days following injury. *Military Medicine*, *177*(2), 179-183.

Collie, A., Maruff, P., Makdissi, M., McCrory, P., McStephen, M., & Darby, D. (2003). CogSport: Reliability and correlation with conventional cognitive tests used in postconcussion medical evaluations. *Clinical Journal of Sport Medicine*, *13*(1), 28-32.

References

Collie, A., Makdissi, M., Maruff, P., Bennell, K., & McCrory, P. (2006). Cognition in the days following concussion: Comparison of symptomatic versus asymptomatic athletes. *Journal of Neurology, Neurosurgery & Psychiatry*, *77*(2), 241-245.

Cole, W. R., Arrieux, J. P., Schwab, K., Ivins, B. J., Qashu, F. M., & Lewis, S. C. (2013). Test–retest reliability of four computerized neurocognitive assessment tools in an active duty military population. *Archives of Clinical Neuropsychology*, *28*(7), 732-742.

CNS Vital Signs. (2015). *CNSVS-Brief Interpretation Guide*. CNS Vital Signs, Morrisville, NC.

CNS Vital Signs. (2015). Frequently asked questions. Retrieved from https://www.cnsvs.com/FAQs.html.

CSRC. (2014) *ANAM Military Battery: Administration Manual*. Cognitive Science Research Center, University of Oklahoma, Norman, OK.

References

Defense and Veterans Brain Injury Center. (2015). DoD numbers for traumatic brain injury. Defense and Veterans Brain Injury Center. Retrieved from http://dvbic.dcoe.mil/dod-worldwide-numbers-tbi

Defense Centers of Excellence for Psychological Health & Traumatic Brain Injury. (2011). Indications and conditions for in-theater post-injury neurocognitive assessment tool (NCAT) testing clinical recommendation. Retrieved from https://dvbic.dcoe.mil/material/indications-and-conditions-theater-post-injury-neurocognitive-assessment-tool-ncat-testing

Dilmen, Nevit. (2012). [Photograph of File:Reliability and validity.svg]. Retrieved from https://commons.wikimedia.org/wiki/File:Reliability_and_validity.svg

Dretsch, M., Parish, R., Kelly, M., Coldren, R., & Russell, M. (2015). Eight-day temporal stability of the Automated Neuropsychological Assessment Metric (ANAM) in a deployment environment. *Applied Neuropsychology: Adult*, *22,* 304-310.

References

Elbin, R. J., Schatz, P., & Covassin, T. (2011). One-year test-retest reliability of the online version of ImPACT in high school athletes. *The American Journal of Sports Medicine*, *39*(11), 2319-2324.

Falleti, M. G., Maruff, P., Collie, A., & Darby, D. G. (2006). Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. *Journal of Clinical and Experimental Neuropsychology*, *28*(7), 1095-1112.

Gualtieri, C. T., & Johnson, L. G. (2006). Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs. *Archives of Clinical Neuropsychology*, *21*(7), 623-643.

Gualtieri, C. T., & Hervey, A. S. (2015). The structure and meaning of a computerized neurocognitive test battery. *Frontiers*, *4*(2), 11-21.

Guskiewicz, K. M., & Register-Mihalik, J. K. (2011). Postconcussive impairment differences across a multifaceted concussion assessment protocol. *PM&R*, *3*(10), S445-S451.

References

Hammers, D., Spurgeon, E., Ryan, K., Persad, C., Heidebrink, J., Barbas, N., ... & Giordani, B. (2011). Reliability of repeated cognitive assessment of dementia using a brief computerized battery. *American Journal of Alzheimer's Disease and Other Dementias*, *26*(4), 326-333.

Hawkins, K. A., Jennings, D., Vincent, A. S., Gilliland, K., West, A., & Marek, K. (2012). Traditional neuropsychological correlates and reliability of the automated neuropsychological assessment metrics-4 battery for Parkinson's disease. *Parkinsonism & Related Disorders*, *18*(7), 864-870.

ImPACT Applications Inc. (2010). *ImPACT: Technical manual, psychometric data and normative values*. ImPACT Applications Inc., Pittsburg, PA.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2003). Interpreting change on ImPACT following sport concussion. *The Clinical Neuropsychologist*, *17*(4), 460-467.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2005). Validity of ImPACT for measuring processing speed following sports-related concussion. *Journal of Clinical and Experimental Neuropsychology*, *27*(6), 683-689.

References

Jones, W. P., Loe, S. A., Krach, S. K., Rager, R. Y., & Jones, H. M. (2008). Automated neuropsychological assessment metrics (ANAM) and Woodcock-Johnson III tests of cognitive ability: A concurrent validity study. *The Clinical Neuropsychologist*, *22*(2), 305-320.

Kabat, M. H., Kane, R. L., Jefferson, A. L., & DiPino, R. K. (2001). Construct validity of selected Automated Neuropsychological Assessment Metrics (ANAM) battery measures. *The Clinical Neuropsychologist*, *15*(4), 498-507.

Kaminski, T. W., Groff, E. R., & Glutting, J. J. (2007). Comparing ANAM and ImPACT computerized neuropsychological test scores derived from a group of uninjured intercollegiate athletes. Free Communications, Oral Presentations: Mild Brain Injury and Neurocognitive Testing. *Journal of Athletic Training, 42*(2), S29.

References

Kaminski, T. W., Groff, R. M., & Glutting, J. J. (2009). Examining the stability of Automated Neuro-psychological Assessment Metric (ANAM) baseline test scores. *Journal of Clinical and Experimental Neuropsychology*, *31*(6), 689-697.

Kelly, M. P., Coldren, R. L., Parish, R. V., Dretsch, M. N., & Russell, M. L. (2012). Assessment of acute concussion in the combat environment. *Archives of Clinical Neuropsychology*, *27*(4), 375-388.

Lanting, S. C., Iverson, G. L., & Lange, R. T. (2012 a). Comparing patients with mild traumatic brain injury to trauma controls on CNS Vital Signs. Presented at American Congress of Rehabilitation Medicine Conference, Vancouver.

Lanting, S. C., Iverson, G. L., & Lange, R. T. (2012 b). Concurrent validity of CNS Vital Signs in patients with mild traumatic brain injury. Presented at American Congress of Rehabilitation Medicine Conference, Vancouver.

Lezak, M. D. (2004). *Neuropsychological assessment*. Oxford University Press.

References

Lim, Y. Y., Jaeger, J., Harrington, K., Ashwood, T., Ellis, K. A., Stöffler, A., . . . & Maruff, P. (2013). Three-month stability of the CogState brief battery in healthy older adults, mild cognitive impairment, and Alzheimer's disease: Results from the Australian imaging, biomarkers, and lifestyle-rate of change substudy (AIBL-ROCS). *Archives of Clinical Neuropsychology*, *28*(4), 320-330.

Littleton, A. C., Register-Mihalik, J. K., & Guskiewicz, K. M. (2015). Test-Retest Reliability of a computerized concussion test CNS Vital Signs. *Sports Health: A Multidisciplinary Approach, 7*(5), 443-447.

Louey, A. G., Cromer, J. A., Schembri, A. J., Darby, D. G., Maruff, P., Makdissi, M., & Mccrory, P. (2014). Detecting cognitive impairment after concussion: sensitivity of change from baseline and normative data methods using the CogSport/Axon cognitive test battery. *Archives of Clinical Neuropsychology*, *29*(5), 432-441.

MacDonald, J., & Duerson, D. (2015). Reliability of a computerized neurocognitive test in baseline concussion testing of high school athletes. *Clinical Journal of Sport Medicine*, *25*(4), 367-372. doi: 10.1097/JSM.0000000000000139

References

Maerlender, A., Flashman, L., Kessler, A., Kumbhani, S., Greenwald, R., Tosteson, T., & McAllister, T. (2010). Examination of the construct validity of ImPACT™ computerized test, traditional, and experimental neuropsychological measures. *The Clinical Neuropsychologist*, *24*(8), 1309-1325.

Maerlender, A., Flashman, L., Kessler, A., Kumbhani, S., Greenwald, R., Tosteson, T., & McAllister, T. (2013). Discriminant construct validity of ImPACT™: A companion study. *The Clinical Neuropsychologist*, *27*(2), 290-299.

Makdissi, M., Collie, A., Maruff, P., Darby, D. G., Bush, A., McCrory, P., & Bennell, K. (2001). Computerised cognitive assessment of concussed Australian rules footballers. *British Journal of Sports Medicine*, *35*(5), 354-360.

Maruff, P., Thomas, E., Cysique, L., Brew, B., Collie, A., Snyder, P., & Pietrzak, R. H. (2009). Validity of the CogState brief battery: Relationship to standardized tests and sensitivity to cognitive impairment in mild traumatic brain injury, schizophrenia, and AIDS dementia complex. *Archives of Clinical Neuropsychology*, *24*(2), 165-178.

References

Meier, T. B., Bellgowan, P. S., Singh, R., Kuplicki, R., Polanski, D. W., & Mayer, A. R. (2015). Recovery of cerebral blood flow following sports-related concussion. *JAMA Neurology*, *72*(5), 530-538.

Nakayama, Y., Covassin, T., Schatz, P., Nogle, S., & Kovan, J. (2014). Examination of the test-retest reliability of a computerized neurocognitive test battery. *The American Journal of Sports Medicine*, *42*(8), 2000-2005.

Norris, J. N., Carr, W., Herzig, T., LaBrie, D. W., & Sams, R. (2013). ANAM4 TBI reaction time-based tests have prognostic utility for acute concussion. *Military Medicine*, *178*(7), 767-774.

Nunnally, J. C., Bernstein, I. H., & Berge, J. M. T. (1967). *Psychometric theory* (Vol. 226). New York: McGraw-Hill.

Register-Mihalik, J. K., Kontos, D. L., Guskiewicz, K. M., Mihalik, J. P., Conder, R., & Shields, E. W. (2012). Age-related differences and reliability on computerized and paper-and-pencil neurocognitive assessment batteries. *Journal of Athletic Training*, *47*(3), 297.

References

Register-Mihalik, J. K., Guskiewicz, K. M., Mihalik, J. P., Schmidt, J. D., Kerr, Z. Y., & McCrea, M. A. (2013). Reliable change, sensitivity, and specificity of a multidimensional concussion assessment battery: Implications for caution in clinical practice. *The Journal of Head Trauma Rehabilitation*, *28*(4), 274-283.

Resch, J., Driscoll, A., McCaffrey, N., Brown, C., Ferrara, M. S., Macciocchi, S., . . . & Walpert, K. (2012). ImPACT test-retest reliability: Reliably unreliable?. *Journal of Athletic Training*, *48*(4), 506-511.

Resch, J. E. (2013). Pearson's Concussion Webinar Series, Testing the Test: An Evaluation of Computerized Neurocognitive Assessment. Retrieved from http://images.pearsonassessments.com/images/PDF/webinar/CVShandouts.pdf

Schatz, P. (2010). Long-term test-retest reliability of baseline cognitive assessments using ImPACT. *The American Journal of Sports Medicine*, *38*(1), 47-53.

Schatz, P., & Ferris, C. S. (2013). One-month test–retest reliability of the ImPACT test battery. *Archives of Clinical Neuropsychology*, *28*(5), 499-504

References

Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., & Podell, K. (2006). Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Archives of Clinical Neuropsychology*, *21*(1), 91-99.

Schatz, P., & Putz, B. O. (2006). Cross-validation of measures used for computer-based assessment of concussion. *Applied Neuropsychology*, *13*(3), 151-159.

Schatz, P., & Sandel, N. (2013). Sensitivity and specificity of the online version of ImPACT in high school and collegiate athletes. *The American Journal of Sports Medicine*, *41*(2), 321-326.

Segalowitz, S. J., Mahaney, P., Santesso, D. L., MacGregor, L., Dywan, J., & Willer, B. (2007). Retest reliability in adolescents of a computerized neuropsychological battery used to assess recovery from concussion. *NeuroRehabilitation, 22*(3), 243.

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. Oxford University Press, USA.

References

Woodhouse, J., Heyanka, D. J., Scott, J., Vincent, A., Roebuck-Spencer, T., Domboski-Davidson, K., . . . & Adams, R. (2013). Efficacy of the ANAM general neuropsychological screening battery (ANAM GNS) for detecting neurocognitive impairment in a mixed clinical sample. *The Clinical Neuropsychologist*, *27*(3), 376-385.

Questions?

- Submit questions via the Q&A box located on the screen.
- The Q&A box is monitored and questions will be forwarded to our presenters for response.
- We will respond to as many questions as time permits.

How to Obtain CE Credit

1. After the webinar, go to URL http://dcoe.cds.pesgce.com
2. Select the activity: **10 Dec 2015TBI** Webinar
3. This will take you to the log in page. Please enter your e-mail address and password. If this is your first time visiting the site, enter a password you would like to use to create your account. Select Continue.
4. Verify, correct, or add your information AND Select your profession(s).
5. Proceed and complete the activity evaluation
6. Upon completing the evaluation you can print your CE Certificate. You may also e-mail your CE Certificate. Your CE record will also be stored here for later retrieval.
7. The website is open for completing your evaluation for **14 days.**
8. After the website has closed, you can come back to the site at any time to print your certificate, but you will not be able to add any evaluations.

Webinar Evaluation/Feedback

We want your feedback!

- Please complete the Interactive Customer Evaluation which will open in a new browser window after the webinar, or visit: https://ice.disa.mil/index.cfm?fa=card&sp=134218&s=1019&dep=*DoD&sc=11
- Or send comments to usarmy.ncr.medcom-usamrmc-dcoe.mbx.dcoe-monthly@mail.mil

Chat and Networking

Chat function will remain open 10 minutes after the conclusion of the webinar to permit webinar attendees to continue to network with each other.

Save the Date

Next DCoE Traumatic Brain Injury Webinar:

Do Head Injuries Cause Chronic Traumatic Encephalopathy?

January 14, 2016; 1-2:30 p.m. (ET)

Next DCoE Psychological Health Webinar:

Year in Review, Clinical Practice Guideline: 2016 Post-traumatic Stress Disorder

January 28, 2015; 1-2:30 p.m. (ET)

DCoE Contact Info

DCoE Outreach Center

866-966-1020 (toll-free)

dcoe.mil

resources@dcoeoutreach.org