Archives of Clinical Neuropsychology 21 (2006) 623–643

Archives of CLINICAL NEUROPSYCHOLOGY

Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs

C. Thomas Gualtieri [a,*], Lynda G Johnson [b]

[a] *Department of Neuropsychiatry, North Carolina Neuropsychiatry Clinics, 400 Franklin Square, 1829 East Franklin Street, Chapel Hill NC 2751, United States*

[b] *Department of Neuropsychology, North Carolina Neuropsychiatry Clinics, Chapel Hill NC 2751, United States*

Accepted 31 May 2006

Abstract

CNS Vital Signs (CNSVS) is a computerized neurocognitive test battery that was developed as a routine clinical screening instrument. It is comprised of seven tests: verbal and visual memory, finger tapping, symbol digit coding, the Stroop Test, a test of shifting attention and the continuous performance test. Because CNSVS is a battery of well-known neuropsychological tests, one should expect its psychometric properties to resemble those of the conventional tests upon which it is based.

1069 subjects age 7–90 participated in the normative database for CNSVS. Test-retest reliability (TRT) was evaluated in 99 Ss who took the battery on two separate occasions, separated, on the average, by 62 days; the results were comparable to those achieved by equivalent conventional and computerized tests. Concurrent validity studies in 180 subjects, normals and neuropsychiatric patients, indicate correlations that are comparable to the concurrent validity of similar tests. Discriminant validity is supported by studies of patients with mild cognitive impairment and dementia, post-concussion syndrome and severe traumatic brain injury, ADHD (treated and untreated) and depression (treated and untreated). The tests in CNSVS are also sensitive to malingerers and patients with conversion disorders.

The psychometric characteristics of the tests in the CNSVS battery are very similar to the characteristics of the conventional neuropsychological tests upon which they are based. CNSVS is suitable for use as a screening instrument, or as a serial assessment measure. But it is not a substitute for formal neuropsychological testing, it is not diagnostic, and it will have only a limited role in the medical setting, absent the active participation of consulting neuropsychologists.

Keywords: Test development; Reliability; Concurrent validity; Normative data; Computerized test; Memory; Psychomotor speed; Reaction time; Complex attention; Cognitive flexibility; CNS Vital Signs

Computerized neurocognitive tests (CNT's) are well suited to a new and developing arena of mental testing: measuring relatively mild degrees of neurocognitive impairment in circumstances where speed, efficiency and low cost are important. Theoretically, at least, CNT's can increase productivity, efficiency and knowledge. But like every technology, computerized testing has limitations. Many computerized batteries are relatively stunted in terms of their psychometric development.

* Corresponding author. Tel.: +919 933 2000x106; fax: +919 933 2830.
E-mail address: tg@ncneuropsych.com (C.T. Gualtieri).

0887-6177/$ – see front matter © 2006 Published by Elsevier Ltd on behalf of National Academy of Neuropsychology.
doi:10.1016/j.acn.2006.05.007

CNT's have a few advantages compared to conventional psychological testing. These include consistency in administration and scoring, the ability to generate numerous alternative forms suitable for repeated testing, precise stimulus control, the ability to track various components of subjects' responses, increased cost efficiency in testing, and the ability to develop large and accurate databases. Published reports emphasize the feasibility of the technology, its acceptability to patients, and the reliability of the data thus generated.

CNS Vital Signs (CNSVS) is a CNT battery that was developed as a brief clinical evaluation tool. In contrast to many CNT batteries, for which new and untried tests were developed, CNSVS is comprised of familiar and well-established tests: verbal and visual memory, finger tapping, symbol digit coding, the Stroop Test, a test of shifting attention and the continuous performance test. Since it was designed as a brief clinical evaluation tool instrument, it is easy to set up and to use.

Because CNSVS is a battery of well-known neuropsychological tests, one presumes that its psychometric properties are similar to the conventional tests upon which it is based. But that is only a presumption; the PC, after all, is a novel vehicle for the administration of mental tests. We have gathered data, therefore, on the normative structure of CNSVS, its test-retest reliability, concurrent validity, and discriminant validity in three conditions associated with mild degrees of cognitive impairment: attention deficit/hyperactivity disorder (ADHD), early dementia and traumatic brain injury. We have also examined the properties of the test battery in individuals who sought to manipulate the results.

1. Methods

A series of studies have been done to investigate the reliability and validity of the CNSVS test battery: test performance in normal subjects, test-retest reliability and concurrent validity compared to other CNT's and to conventional psychological tests. Discriminant validity studies of patients with attention deficit/hyperactivity disorder, mild cognitive impairment and dementia, depression and brain injury have been published elsewhere, but are restated here in a new format.

1.1. The CNSVS battery

The CNS Vital Signs brief clinical evaluation battery contains seven tests. The test battery is composed of tests that are widely used by neuropsychologists and known to be reliable and valid. The tests embrace an appropriate span of cognitive domains, and are known to be sensitive to most of the causes of mild cognitive dysfunction.

Verbal memory (VBM) and visual memory (VIM) are adaptations of the Rey Auditory Verbal Learning Test and the Rey Visual Design Learning Test. VBM and VIM are recognition tests, however, not tests of recall. Correct responses from VBM and VIM are summed to generate a composite memory or memory domain score.

The finger Tapping Test (FTT) is one of the core tests of the Halstead–Reitan Battery, but similar tests were used by 19th century psychologists like Wundt, Galton and Cattell. Symbol digit coding (SDC) is based on the Symbol Digit Modalities Test, itself a variant of the Wechsler digit symbol substitution test. The total of right and left taps from the FTT and total correct responses on the SDC generates a composite score for "psychomotor speed."

The Stroop Test (ST) (Stroop, 1935) in CNSVS has three parts that generate simple and complex reaction times. Averaging the two complex reaction time scores from the Stroop Test generates a domain score for "reaction time." It might be more precise to refer to this domain as "information processing speed."

The Shifting Attention Test (SAT) measures the subject's ability to shift from one instruction set to another quickly and accurately. Other computerized batteries, like the NES2, CogState and CANTAB have Shifting Attention Tests. Color-shape tests like the SAT have been used in cognitive imaging studies. A domain score for cognitive flexibility is generated by taking the number of correct responses on the SAT and subtracting the number of errors on the SAT and the Stroop Test.

The Continuous Performance Test is a measure of vigilance or sustained attention. A domain score for "complex attention" is generated by adding the number of errors committed in the CPT, the SAT and the Stroop.

Because the presentation of stimuli is randomized, no two presentations of CNSVS are ever the same; so, the test battery is appropriate for serial administration. Several of the tests draw stimuli from a "reservoir" of words or figures (VBM, VIM, SDC). Several tests record reaction times with millisecond accuracy (VBM, VIM, FTT, ST, SAT, CPT).

A medical office assistant can initiate the test, and a child with a fourth grade reading level can take the test battery, unassisted. The visual arrays are simple and easy to read, even to someone who is color-blind. It does not use a mouse,

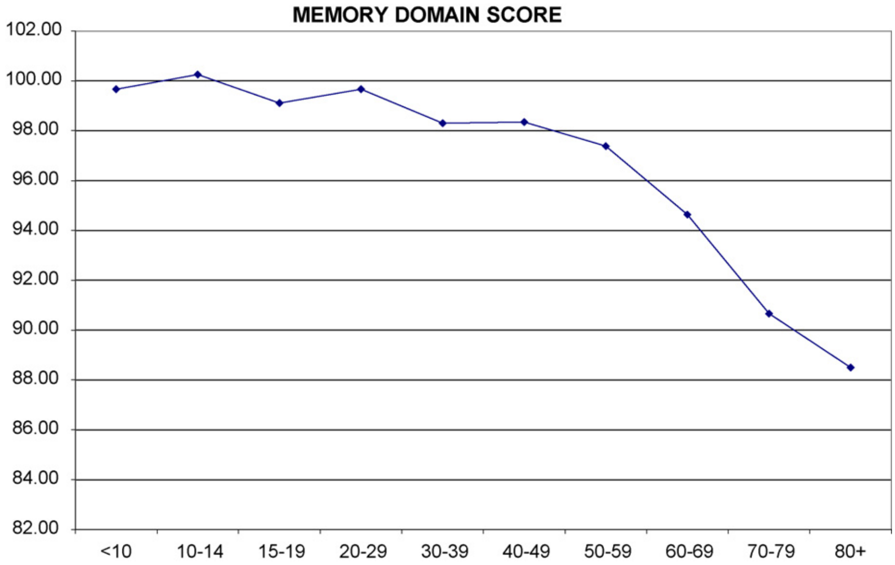

Fig. 1. Composite memory from age 7 to 90 in normal subjects.

a joystick or a touchscreen, because those devices introduce an unacceptable level of instability to its millisecond accuracy. A minimum number of keys are in play, so keyboard skills have minimal influence on performance. The test is administered on an ordinary, Windows-based PC, and takes about 30 min. A report is generated by the machine as soon as the test is completed.

A more complete description of the tests and scoring is presented in Appendix A.

2. Normative data

2.1. Subjects

One thousand sixty nine normal volunteers participated in the normative study of CNS Vital Signs battery. They were in good health, without past or present psychiatric or neurological disorders, head injury, learning disabilities, etc.; and free of any centrally acting medications. The subjects ranged in age from 7 to 90.

2.2. Results

The data were summarized in ten age groups: less that 10 years old, 10–14, 15–19; in deciles to 79, and finally, 80 years or older. Demographic statistics and normative data are presented in Appendix B. Graphic data are presented in Figs. 1 and 2, for the domains of composite memory (VBM + VIM) and psychomotor speed (FTT + SDC). Peak performance is achieved during the third decade of life, and declines gradually thereafter.

3. Test-retest reliability

TRT was evaluated in CNSVS in 99 Ss who took the entire battery on two separate occasions, separated, on the average, by 62 days. The test-retest interval ranged from 1 to 282 days, with a median interval of 27 days.

3.1. Subjects

Normal volunteers ($n = 40$) and neuropsychiatric patients ($n = 59$), who were clinically stable on the same medications on two consecutive visits.

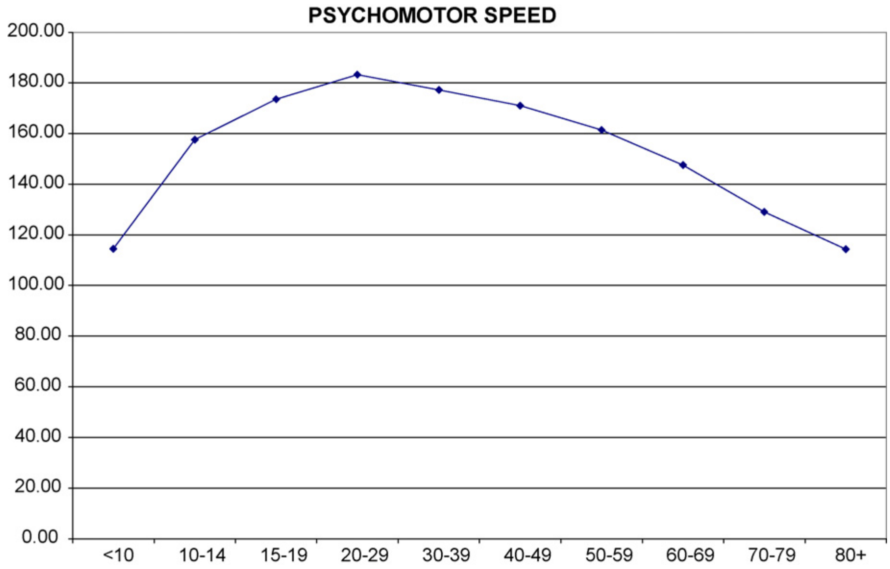

Fig. 2. Psychomotor speed from age 7 to 90 in normal subjects.

3.2. Results

Results are presented in Table 1. In previous studies, we found that the results of the various tests in the Vital Signs battery are normally distributed, save two: correct responses and errors on the continuous performance test. Pearson's r was calculated for all of the tests except those that were not normally distributed, for which Spearman's

Table 1
Correlation coefficients for CNS Vital Signs tests

Test/domain	r
Memory	0.726
Psychomotor speed	0.869
Reaction time	0.795
Cognitive flexibility	0.744
Complex attention	0.645
Verbal memory, total correct	0.611
Visual memory, total correct	0.668
Immediate memory, total correct	0.667
Delayed memory, total correct	0.625
Finger tapping, right	0.804
Finger tapping, left	0.776
Finger tapping, total	0.831
Symbol digit coding, correct	0.840
Symbol digit coding, errors	0.623
Stroop, simple reaction time	0.569
Stroop, complex reaction time	0.554
Stroop color-word reaction time	0.868
Stroop Test, errors	0.314
Shifting attention, correct	0.773
Shifting attention, errors	0.697
Shifting attention, reaction time	0.803
Shifting attention, efficiency	0.694
Continuous performance, correct	0.452[a]
Continuous performance, errors	0.565[a]
Continuous performance, Reaction time	0.874

[a] Spearman's *rho*.

rho was used. The correlation coefficients are given for the individual tests and the domain scores (caps) in Table 1.

Neither age nor clinical status had any bearing on reliability. There was no difference in reliability among children/adolescents, young adults and older adults. The reliability of the test in patients was as least as good as normal subjects. There was a small decrement in reliability relative to the interval between tests (see Appendix C).

4. Concurrent validity

A series of studies were done, comparing the performance of subjects on CNSVS to their performance on conventional neuropsychological tests and on another computerized neurocognitive test, the NES2 (Baker et al., 1985). The conventional tests were the Rey Auditory Verbal Learning Test, Logical Memory and Facial Recognition from the Wechsler Memory Test, a mechanical finger tapper, the Stroop Test, Trails B and the Verbal Fluency Test. From the NES2, the comparison tests were Finger Tapping, Switching Attention, and the Continuous Performance Test.

4.1. Subjects

One hundred forty-four patients with various neuropsychiatric disorders and 36 normals subjects; 102 males and 78 females; age 10–85 years, mean age 34.8.

4.2. Results

Correlation coefficients are presented in Table 2. When the tests in CNSVS were compared to conventional neuropsychological tests, moderate correlations were found in tests of memory, perceptual-motor speed (coding) and executive function. CNSVS tests were moderately well correlated with tests of psychomotor speed (finger tapping

Table 2
CNSVS in normal controls and neuropsychiatric patients

	N	Age	MEM	PMS	RT*	ATT*	CF
Mild cognitive impairment and early dementia							
Controls	88	63.7	94.86	140.97	711.14	12.75	31.48
MCI	37	66.4	86.91	119.24	783.69	34.04	12.89
EDEM	52	61.9	76.46	102.15	885.96	35.29	0.57
F			90.27	35.62	26.03	33.01	51.22
P<			0.0000	0.0000	0.0000	0.0000	0.0000
Post-concussion syndrome and severe brain injury							
Controls	143	42.0	98.43	172.08	647.49	7.60	44.53
PCS	13	47.4	90.70	139.07	816.15	17.77	21.38
STBI	84	42.1	86.69	124.78	883.01	29.52	10.60
F			2.47	3.92	2.49	2.74	4.48
P<			0.0318	0.0023	0.0306	0.0192	0.0009
Children and adolescents with ADHD, treated and untreated							
Controls	101	12.35	100.65	155.14	712.07	17.24	28.49
ADHD-treated	177	13.08	96.67	149.60	707.39	29.32	23.29
ADHD-untreated	95	13.54	97.35	146.81	749.26	25.59	19.47
F			8.39	7.56	6.50	8.86	7.10
P<			0.0000	0.0000	0.0000	0.0000	0.0000
Patients with depression, treated and untreated							
Controls	68	41.30	98.47	171.42	642.73	8.11	43.77
DEP-treated	31	43.55	99.19	163.39	665.03	8.48	41.42
DEP-untreated	37	38.11	96.68	164.52	665.43	15.22	34.30
F			0.49	3.60	0.61	5.54	3.06
P<			0.6866	0.0153	0.6114	0.0013	0.0307

MEM, memory domain score; PMS, psychomotor speed domain; RT, reaction time domain; ATT, complex attention domain; CF, cognitive flexibility domain. An asterisk (*) following RT and ATT indicates that lower scores are better.

Table 3
Malingerers and patients with conversion disorders compared to severely impaired neuropsychiatric patients

	N	Age	MEM	PMS	RT*	ATT*	CF
Dementia	52	61.9	76.46	102.15	885.96	35.29	0.57
SEVTBI	84	42.1	86.69	124.78	883.01	29.52	10.60
Mild MR	17	29.4	75.29	98.25	845.13	36.33	−5.13
Conversion	16	41.3	73.94	107.31	825.06	35.75	0.38
Malinger	18	43.0	56.29	76.59	694.68	45.82	−2.71

and coding) and executive function on the NES2. Correlations between the CPT in CNSVS and the NES2 were low. CNSVS finger tapping was significantly correlated with finger tapping in the NES2 but not with the mechanical tapper.

5. Discriminant validity

The most common causes of cognitive impairment in developed countries are attention deficit/hyperactivity disorder, traumatic brain injury and dementia. The data in Table 2 have been presented elsewhere, in papers describing performance on the CNSVS battery in patients with mild cognitive impairment (MCI) and early dementia (Gualtieri & Johnson, 2006a); post-concussion syndrome (PCS) and severe traumatic brain injury (Gualtieri & Johnson, 2005; Gualtieri & Johnson, submitted for publication); and ADHD (Gualtieri & Johnson, Ms subm). In each study, the patients were compared to subjects in the CNSVS normative database, who were randomly selected and matched for age, race and gender. Patients with depression are added as a comparison group (Gualtieri & Johnson, 2006c). The *F* statistics in Table 2 were generated by MANOVA.

Another criterion for test validity in the clinical setting is to evaluate the relative performance of patients with real neurocognitive impairment to those who are feigning impairment (malingerers) or whose problems are exaggerated for psychological reasons (conversion disorder). In Table 3, we present CNSVS data from patients with dementia, severe traumatic brain injury and mild mental retardation, compared to patients with conversion disorders and malingerers. The diagnoses were established independent of CNSVS by formal neuropsychological/neuropsychiatric assessments. Malingerers performed worst of all.

6. Discussion

Although CNT's have been employed since the days of microcomputers, they have been used mainly in research, or in specialized clinical areas, like aerospace medicine and concussion management. In these areas, the usual practice has been to compare subjects' performance at baseline to their performance after they have been administered an experimental drug, for example, or after they have been concussed on the playing field. Tests thus developed are known as "performance assessment batteries." The developers of such tests have taken pains to demonstrate test-retest reliability and sensitivity to drugs, neurotoxins, concussion, etc., but have not necessarily attended to psychometric issues of interest to clinicians (Kane & Kay, 1992; Weber et al., 1998; Epstein et al., 2001; Forbes, 1998; Levin et al., 2001; Lopez et al., 2001; Riccio et al., 2001; McGee et al., 2000; Rohlman et al., 2000). Since the CNSVS battery was designed to be used as a clinical battery, it was necessary to standardize the instrument in a more conventional way: to demonstrate not only its reliability over time, but also its normative structure, its comparability to established tests and its sensitivity to a wide range of clinical conditions associated with cognitive impairment.

The normative data from age 8 to 90 is taken from 1069 normal subjects, a respectable number, and sufficient to capture the known changes in cognition that occur with maturation and ageing. The database needs to be expanded, especially in these age groups: <10 years old, 15–19, and 80+. With larger numbers, it will be possible to standardize scores within narrower age parameters. The database also needs to be expanded among minority Americans. Since CNSVS has been translated into 52 languages (see Appendix D), it will also be necessary to generate normative data in each language. Similar improvements, however, would be welcome for most neurocognitive tests, especially computerized tests.

With respect to test-retest (in fact, alternate forms) reliability, CNSVS is a reliable battery of tests. All of the reliability coefficients in Table 1 are significant ($P < .05$) and are comparable to those reported for similar, traditional tests and to similar tests in other computerized test batteries. Of the 25 test scores in Table 4, seven exceed the

Table 4
Correlations of CNSVS with the NES2 and conventional neuropsychological tests

Comparison Tests		CNS VS		
	N	VBMtot	VIMtot	MEM
Rey Immediate Total	131	0.54	0.49	0.56
Rey Delayed Recall	131	0.52	0.50	0.53
Logical Memory Immed	49	0.45	0.26	0.35
Logical Memory Delay	49	0.56	0.18	0.33
Facial Recog Immed	49	0.30	0.06	0.29
Facial Recog Delay	49	0.35	0.21	0.36
		FTT-R	FTT-L	Total
FTT R (NES)	74	0.50	0.49	0.51
FTT L (NES)	74	0.44	0.52	0.50
Total Taps (NES)	74	0.41	0.41	0.48
FTT R (M)	49	0.23	0.24	0.26
FTT L (M)	49	0.13	0.17	0.17
Total Taps (M)	49	0.19	0.22	0.23
		SDCC		
SDC (NES)	74	0.60		
DSST (WAIS)	49	0.79		
		ST3rt	Sterr	
SwATT (side) (NES)	74	0.51	0.06	
SwATT (direction) (NES)	74	0.54	0.17	
SwATT Errors (NES)	74	0.16	0.55	
Stroop 3	49	0.51	0.08	
Stroop Errors	49	0.24	0.25	
Trails B	49	0.25	0.45	
Verbal Fluency Total	49	-0.39	0.11	
		SATcorr	SATerrs	SATrt
SwATT (side) (NES)	74	0.34	0.26	0.08
SwATT (direction) (NES)	74	0.17	0.06	0.18
SwATT Errors (NES)	74	0.54	0.55	0.05
Stroop 3	49	-0.52	0.54	0.31
Stroop Errors	49	-0.37	0.50	0.06
Trails B	49	-0.22	0.29	0.03
Verbal Fluency Total	49	0.45	-0.28	-0.53
		CPTcorr	CPTerr	CPTrt
Correct Responses (NES)	74	0.04	0.20	0.30
Errors (NES)	74	0.14	0.26	0.28
Reaction Time (NES)	74	0.04	0.08	0.47

Shaded boxes indicate that correlation is significant at $P < 0.05$.

conventional standard for a "good" correlation ($r > 0.8$), and six the standard for "moderate" ($r > 0.7$). Only five scores have correlation coefficients lower than 0.6. Reliability coefficients for the five domain scores range from 0.65 to 0.87.

The CPT data generate low correlations, but this is not a problem unique to CNSVS. Rather, it a problem inherent to the CPT itself. Two commonly used commercial CPT's fare little better. The TOVA (Tests of Variables of Attention), does not even *report* TRT, but rather, split-half reliability. The Conners CPT-II does report TRT, but only on 23 normal subjects; and not, as we have, on raw scores, but on composite scores, which always tend to be more reliable. If one scores the CPT data in CNSVS as "normal" or "abnormal" based on a cutoff score (>2 SD's from the mean), and measures percent agreement, the CPT in CNS Vital Signs has 87.5% agreement on test-retest with the NES2 CPT (TRT using cutoff scores for "normal" and "abnormal" is how reliability was determined for the computerized test, MicroCog).

The reliability coefficients for the tests in CNSVS were compared to data on equivalent neuropsychological tests published in textbooks, test manuals and articles, as cited. A summary of the data is presented in Appendix E. The tests in CNSVS are comparable, in this respect, to other tests (Table 5).

Table 5
Test-retest reliability of conventional tests, computerized tests, and CNS Vital Signs

Tests/domains	Conventional		Computerized		CNSVS
	N	*r*	*N*	*r*	*r*
Memory	713	0.67–0.71	1801	0.65–0.69	0.66
Psychomotor speed	1159	0.78–0.65	2228	0.72–0.79	0.88
Finger tapping	596	0.75–0.83	310	0.74–0.79	0.78
Coding	563	0.87–0.88	629	0.78–.85	0.82
Stroop Test	224	0.64	471	0.74	0.75
Cognitive flexibility	139	0.68–0.74	746	0.68–0.74	0.71
Attention	554	0.70–0.73	1578	0.60–0.63	0.65
Reaction time	78	0.82	621	0.66–0.68	0.75

The simplicity and stability of CNT batteries like CNSVS suggest that they should have high levels of test-retest reliability. On the other hand, there is reason to suspect that CNT batteries might be *less* reliable than conventional psychological tests, which can provide highly reliable scores, particularly when stable traits, such as verbal skills or personality traits are at issue. CNT batteries usually measure psychological traits that are relatively unstable. Memory, attention, reaction time and processing speed, psychomotor speed and fine motor coordination are intrinsically unreliable, because they can be affected by external factors (drugs, disease states, time-of-day) as well an internal factors (motivation, fatigue, mood, level of alertness). Nevertheless, the data in Table 5 indicate broad comparability in the reliability of conventional and computerized tests.

CNSVS took a conservative approach to content and construct validity. The tests in the battery are computerized versions of neuropsychological tests that have been used for years. The presumption of equivalence is supported, but only to a degree, by the concurrent validity studies summarized in Table 4. Five of the tests in the CNSVS battery are as well correlated with their conventional equivalents as conventional tests are with each other. The FTT in CNSVS correlates moderately well with the computerized FTT in the NES2, but not with the mechanical tapper; a digital tapper would probably have been a better comparator. The CPT, as we have indicated above, is problematic.

In Appendix F, we present data from concurrent validity studies of various conventional and computerized neurocognitive tests. The median low–high correlations for tests of memory reported in the literature is 0.4–0.46; for tests of psychomotor speed, 0.28–0.40; for tests of executive function, 0.41–0.48; for tests of attention, 0.24–0.56; and for reaction time tests, 0.5–0.6. Correlations between mental tests are expected to be high if the tests are equivalent, but low if the modality of stimulus presentation is different; for example, verbal presentation by an examiner, visual presentation by the computer; or when the response modality is different, for example, word recall in response to an examiner, word recognition in response to a computer (Krengel et al., 1996). As it happens, whether a test is administered on a PC or in person does not appear to effect concurrent validity.

Computerized tests are well suited to be used as brief clinical evaluation instruments for common causes of neurocognitive impairment. Conditions like ADHD, dementia and mild brain injury afflict millions of patients. Patients with these disorders are usually treated (if at all) by physicians, who rely on patient reports, subjective data from rating scales, or gross tests like the TOVA or the Mini-Mental State Exam. Cheap, efficient and reliable computerized tests have the potential to lend at least a degree of objectivity to diagnosis and patient management.

Our data, and the literature to date, indicate that computerized neurocognitive tests are sensitive to virtually all of the causes of mild cognitive dysfunction. Computerized tests are used widely in pharmaceutical research and studies of environmental/industrial neurotoxins. They are used in multi-center, international studies to measure the cognitive impact of procedures like coronary artery bypass grafting. Clinically, they are used to manage concussion in professional athletes; computerized CPT's are used widely by psychologists and physicians who treat patients with ADHD.

The fact that the tests in CNSVS are sensitive to the conditions listed in Table 2 is only to be expected. Patients with early dementia score worse than patients with mild cognitive impairment, who, in turn, score worse than normal controls. Patients with severe traumatic brain injuries score worse than patients who have been concussed and the latter score worse than normal controls. Children and adolescents with ADHD perform less well in the untreated state than they do when treated; but that treated ADHD patients still perform less well than normal controls. Similarly, depressed patients perform better after they have been treated successfully, although their performance does not "normalize." These data support the criterion validity of the test battery.

CNSVS is also sensitive to the manipulations of individuals who are "faking bad." Malingers, as a group, score worse than patients with dementia, mental retardation and severe brain injury. The memory tests in CNSVS are, in fact, "forced choice" tests. Pressing the space bar for every stimulus generates a score of 60; not pressing the space bar at all scores 60; responding randomly scores about 60. Malingerers, as a group, scored 56.3 on the memory tests.

These data do not, however, establish that CNSVS is a "diagnostic" test. The diagnostic utility of any test requires an entirely different kind of analysis, and no computerized test has yet met that standard. In the case of ADHD, for example, the diagnostic utility of tests like the Conners CPT and the TOVA has been criticized (Dulcan & Popper, 1991). One would be ill-advised to diagnose ADHD entirely on the basis of "below average" scores in the complex attention domain of CNSVS; or to diagnose mild cognitive impairment simply because a patient score poorly on the tests of memory. On the other hand, the tests do indicate a patient's level of function at a point in time, and they do so precisely, and as reliably as any other test. Interpreting the meaning of that information, however, is the responsibility of a skilled clinician. Diagnosis is a clinical exercise that relies on data from many different sources.

The results of computerized tests like CNSVS do not have the specificity necessary to qualify as diagnostic tools. They are highly sensitive to mild cognitive dysfunction, though, and that makes them suitable to be used as brief clinical evaluation instruments. But this also raises a red flag. CNT's generate massive amounts of precise data that can be misinterpreted or misused by poorly trained clinicians. In our communications with psychiatrists and neurologists who have used the test in their practices, we have not always been impressed by their facility at judging exactly what the test means and what to do next. The widespread use of computerized testing by unqualified professionals would be cause for concern. On the other hand, widespread detection of mild cognitive dysfunction by the medical community represents an opportunity for neuropsychologists to play a more active role in consultation, as patients are identified with cognitive impairments that most physicians are ill-equipped to understand or to deal with.

In conversations with neuropsychologists, we have met a few who seemed to be threatened by the idea of computers doing what they do at a fraction of the cost. This is an understandable reaction, but it is unfounded. One of us (TG) is old enough to remember neurologists' reaction to the CT scanner— "They're not going to need neurologists any more." In fact, neurology has thrived since the advent of scanning. So has neuropsychology. No one uses neuropsychological tests to localize a cerebral lesion, as we did in the fifties and sixties. The discipline has become more oriented towards functional analysis and treatment. This has been a positive change.

What computerized tests like CNSVS afford the neuropsychologist is an intermediate tool: an instrument that is more precise than patients' subjective complaints, but less definitive than a diagnostic neuropsychological battery. Since it is easier to apply at frequent intervals than conventional testing, it is ideal for serial testing, for example, of patients recovering from stroke or brain injury. In our clinic, CNSVS is used to complement the neuropsychological assessment, and then serially, to evaluate the effects of treatment. When physicians use CNSVS as a brief clinical evaluation tool in our clinics, they frequently discover problems that require consultation with a neuropsychologist.

The psychometric characteristics of the tests in the CNSVS battery are very similar to the characteristics of the conventional neuropsychological tests upon which they are based. The reliability of CNSVS in particular, and computerized tests in general is similar to that of conventional neuropsychological tests to which they correspond. CNSVS has a respectable normative database. It is sensitive to the most common causes of cognitive impairment. But it is not the same as formal neuropsychological testing, it is not diagnostic, and it will have only a limited role in the medical setting, absent the active participation of consulting neuropsychologists.

Acknowledgements

Dr. Gualtieri and Dr. Johnson are two of the developers of the CNS Vital Signs screening battery. Dr Gualtieri has conducted clinical trials on behalf of Astra-Zeneca, Bristol-Myers Squibb, Celltech, Cephalon, Eli Lilly, Glaxo-Smith-Kline, Medeva, Organon, Shire, Wyeth-Ayerst, and UCB. He has been a speaker for and/or consultant to Eli Lilly, GSK, Pfizer, Shire and Wyeth. This research was supported by North Carolina Neuropsychiatry Clinics in Chapel

Hill and Charlotte. No external support was sought or received on behalf of this research. *Disclosure:* Some of the data presented in this paper were presented at the annual meeting of the International Neuropsychological Society in Baltimore, February, 2004 and at the American Neuropsychiatric Association meeting in Mziami, March, 2004.

Appendix A. The CNS Vital Signs battery

A.1. Verbal Memory Test (VBM) and Visual Memory Test (VIM)

Vital Signs includes parallel tests of verbal memory (word list learning) and visual memory (figure learning). The tests are virtually identical, but one uses words as stimuli, the other, geometric shapes.

The verbal memory test (VBM) is an adaptation of the Rey Auditory Verbal Learning Test (Rey, 1964; Taylor, 1959). It is a recognition test, however, not a test of recall. In the CNS Vital Signs version, fifteen words are presented, one by one, on the screen. A new word is presented every two seconds. The subject is asked to remember these words. Then a list of thirty words is presented. The fifteen target words are mixed randomly among fifteen new words. When the subject recognizes a word from the original list, he or she presses the space bar. After this trial of thirty stimuli, the subject goes on to do the next six tests. At the end of the battery, about 20 min later, the fifteen target words appear again, mixed with 15 new non-target words.

The Visual Memory Test (VIM) in CNS Vital Signs is based on the Rey Visual Design Learning Test; the latter is, in turn, a parallel to the Rey Auditory Verbal Learning Test, using geometric figures rather than words, and requiring the subject to draw the figures from memory. In CNS Vital Signs, the visual memory test is just like the verbal memory test. Fifteen geometric figures are presented; the subject has to identify those figures nested among fifteen new figures. Then, after five more tests, there is a delayed recognition trial.

The VBM draws from a “reservoir” of 120 words selected from word-frequency tables. The VIM draws from a reservoir of 120 simple geometric designs. The scoring is correct hits and correct passes, immediate and delayed. Correct responses from VBM and VIM are summed to generate a composite memory or memory domain score. The highest score one can attain is 120; the lowest is 60. Scores below 60 suggest willful exaggeration.

A.2. Finger Tapping Test (FTT)

The FTT is one of the most commonly used tests in neuropsychology, because of its simplicity and reliability, and because it generates relevant data about fine motor control, which is based on motor speed as well as kinesthetic and visual-motor ability (Mitrushina et al., 1999). It was one of the core tests of the Halstead–Reitan Battery, which dates to the 1940’s, but similar tests were used by nineteenth century psychologists like Wundt, Galton and Cattell. The FTT is believed to be one of the most sensitive neuropsychological tests for determining brain impairment (Mitrushina et al., 1999).

In CNS Vital Signs, the FTT is a very simple test. Subjects are asked to press the Space Bar with their right index finger as many times as they can in 10 s. They do this once for practice, and then there are three test trials. The test is repeated with the left hand. The score is the average number of taps, right and left.

A.3. Symbol Digit Coding (SDC)

The Symbol Digit Modalities Test (SDMT) (Smith & Jones, 1982) is a variant of the Wechsler DSST, but the position of symbols and digits is reversed. The clinical and psychometric properties of the SDMT are similar to those of the DSST. Although the SDMT may be a “harder” test, and thus more sensitive to neurotoxicity, performance on the SDMT and the DSST are highly correlated (Lezak, 1994). Smith maintained that the SDMT was “usually the most sensitive (test) to the presence of acute or chronic ‘organic’ cerebral dysfunction” (Smith, 1982).

In the CNS Vital Signs SDC, the subject is given a training session to learn how to link numbers to digits. The test itself consists of serial presentations of screens, each of which contains a bank of eight symbols above and eight empty boxes below. The subject types in the number that corresponds to the symbol that is highlighted. Only the digits from 2 through 9 are used; this to avoid the confusion between “1” and “I” on the keyboard. The test lasts for 120 s. The goal is to type in as many correct numbers as one can in 120 s.

Neither the SDMT nor the DSST are suitable for repeated administration, because subjects are able to remember the code and thus accelerate their performance (Hindmarch, 1980). Modifications in the test are necessary if it is to be used repeatedly; for example, changing the code in a random way on successive administrations. The SDC in CNS Vital Signs draws from a reservoir of 32 symbols. Each time the test is administered, the program randomly chooses eight new symbols to match to the eight digits

Scoring is the number of correct responses generated in 2 min. The total of right and left taps from the FTT and total correct responses on the SDC generates a composite score for "psychomotor speed".

A.4. The Stroop Test

There have been several versions of the Stroop test over the years. The modification adopted for CNS Vital Signs uses only four colors/color words (red, green, yellow, blue), and only one key is in play, the space bar. The test has three parts. In the first, the words RED, YELLOW, BLUE and GREEN (printed in black) appear at random on the screen, and the subject presses the space bar as soon as he or she sees the word. This generates a simple reaction time score.

In the second part, the words RED, YELLOW, BLUE and GREEN appear on the screen, printed in color. The subject is asked to press the space bar when the color of the word matches what the word says. This generates a complex reaction time score.

In the third part, the words RED, YELLOW, BLUE and GREEN appear on the screen, printed in color. The subject is asked to press the space bar when the color of the word does not match what the word says. This part also generates a complex reaction time score, called the "color-word reaction time". The color-word reaction time is, on average 120 ms longer than the complex reaction time generated in part two of the test (range, 78–188 ms) (the "Stroop effect"). Part three also generates an error score.

Averaging the two complex reaction time scores from the Stroop test generates a domain score for "reaction time". It might be more precise to refer to this domain as "information processing speed".

A.5. The Shifting Attention Test (SAT)

The Shifting Attention Test (SAT) measures the subject's ability to shift from one instruction set to another quickly and accurately. In the SAT test, subjects are instructed to match geometric objects either by shape or by color. Three figures appear on the screen, one on top and two on the bottom. The top figure is either a square or a circle. The bottom figures are a square and a circle. The figures are either red or blue; the colors are mixed randomly. The subject is asked to match one of the bottom figures to the top figure. The rules change at random. For one presentation, the rule is to match the figures by shape, for another, by color. This goes on for 90 s. The goal is to make as many correct matches as one can in the time allotted. The scores generated by the SAT are: correct matches, errors, and response time in milliseconds. *A domain score for cognitive flexibility is generated by taking the number of correct responses on the SAT and subtracting the number of errors on the SAT and the Stroop test*.

There is not a precise parallel to the SAT in the compendium of conventional neuropsychological tests, although Trails B and the Wisconsin Cart Sort are sometimes considered to be tests of shifting attention. Computerized tests, however, like the NES2, CogState and CANTAB have shifting attention tests that are not dissimilar to the SAT, and color-shape tests like the SAT have been used in cognitive imaging studies (Le, Pardo, & Hu, 1998; Nagahama et al., 1998).

A.6. The Continuous Performance Test (CPT)

The CPT is a measure of vigilance or sustained attention or attention over time (Rosvold & Delgado, 1956). It has been a popular test because of its robust relationship to psychiatric disorders. Poor performance on the CPT has been reported in ADHD (Epstein et al., 2001; Sykes et al., 1971), learning disabilities (Lindsay et al., 2001; McGee et al., 2000), patients with epilepsy (Mirksy & van Buren, 1965) and schizophrenics (Vadhan et al., 2001; Wohlberg & Kornetsky, 1973). It is sensitive to CNS dysfunction in general, and is not specific to any particular condition (Riccio & Reynolds, 2001).

The CPT is also sensitive, for better or worse, to the effects of various drugs. In ADHD children, performance on the CPT is reliably improved by stimulant medications (Barkley, 1977; Riccio et al., 2001). Alcohol consumption

(Dougherty et al., 2000) adversely affects performance on the CPT, but nicotine tends to improve performance on the test (Levin et al., 2001). Certain anticonvulsant medications impair performance on the CPT (Hutt et al., 1968).

The CPT in Vital Signs is a conventional version of the test, although it is shorter than some other versions. In the Vital Signs CPT, the subject is asked to respond to target stimulus “B” but not to any other letter. In 5 min, the test presents 200 letters. Forty of the stimuli are targets (the letter “B”), 160 are non-targets (other letters). The stimuli are presented at random, although the target stimulus is “blocked” so it appears eight times during each minute of the test.

Scoring is correct responses, commission errors (impulsive responding), and omission errors (inattention). The CPT also reports subjects’ choice reaction time for each variable. A domain score for “complex attention” is generated by adding the number of errors committed in the CPT, the SAT and the Stroop.

Appendix B. Normative data for CNS Vital Signs

See Tables B.1 and B.2.

Table B.1
Normative data, age 7–39

Group	<10		10–14		15–19		20–29		30–39	
N	25		112		48		153		172	
Gender (% males)	28.0		53.6		56.3		31.5		36.1	
Race										
White	18		93		39		126		139	
Black	3		13		5		18		13	
Hispanic	0		1		1		3		6	
Asian	3		5		3		1		4	
Other	0		0		0		4		0	
Handedness (% *R*)	100.0		89.7		91.7		89.5		87.0	
Computer familiarity										
Frequent	28.6		56.7		92.0		94.6		76.9	
Some	0.0		0.0		0.0		0.0		1.3	
Never	71.4		43.3		8.0		5.4		21.8	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	8.0	1.3	12.6	1.5	16.9	1.5	24.3	3.1	34.9	2.9
Memory	99.7	5.4	100.3	8.1	99.1	6.8	99.7	7.7	98.3	7.9
Psychomotor speed	114.5	27.4	157.6	26.8	173.6	25.6	183.3	24.2	177.2	25.2
Reaction time	814.9	139.3	690.5	108.2	638.8	70.6	601.3	87.3	613.3	85.9
Complex attention	29.4	18.7	15.2	9.0	8.9	4.2	6.8	6.5	5.7	5.6
Cognitive flexibility	12.5	16.3	32.3	15.6	44.1	9.9	49.3	10.1	48.2	11.4
Immediate memory	50.5	4.2	51.6	3.7	50.3	4.8	50.8	3.7	50.4	4.1
Delayed memory	47.7	4.3	48.7	5.0	47.9	4.9	48.7	5.0	47.9	4.6
Verbal memory	53.6	3.4	51.9	6.7	51.9	4.1	52.4	4.8	52.2	4.9
Visual memory	45.4	4.5	47.4	5.5	47.3	4.7	46.8	5.8	46.1	4.7
FTT right	42.3	9.6	56.0	10.1	57.8	13.3	61.0	9.7	59.1	11.3
FTT left	40.2	11.8	50.7	9.6	54.9	10.1	57.1	9.7	57.2	10.3
FTT total	82.8	19.3	106.7	18.0	112.6	21.7	118.1	18.1	116.3	20.7
SDC correct	32.0	11.6	50.8	12.3	61.0	11.8	65.1	11.6	60.9	11.0
STsrt	408.7	115.5	271.0	66.1	275.4	56.4	269.1	73.7	283.9	105.0
STcrt	757.4	103.3	631.2	97.6	594.6	68.1	550.1	94.0	564.9	79.7
STstrt	914.0	108.5	749.8	136.4	683.1	92.2	652.5	103.6	661.6	111.4
ST errors	1.3	3.2	0.7	1.7	0.8	1.1	0.5	1.0	0.5	1.0
SAT correct	34.2	10.7	45.2	8.9	52.3	7.4	55.0	7.0	53.4	7.7
SAT errors	21.4	11.0	12.6	8.3	7.1	3.6	5.2	5.1	4.7	5.2
SATRT	1146.5	309.7	1050.6	189.0	1005.7	121.0	988.2	156.3	1042.9	158.2
SAT efficiency (*q*)	2.0	0.8	1.4	0.3	1.2	0.2	1.1	0.2	1.1	0.2
CPT correct	37.8	4.1	39.4	3.0	39.8	0.7	39.8	0.7	39.9	0.4
CPT errors	6.0	6.8	2.6	3.8	0.9	1.3	1.1	3.1	0.5	1.6
CPTRT	550.8	62.8	431.7	45.8	404.8	52.4	399.5	55.6	392.6	48.8

Table B.2
Normative data, age 50–90

Group	40–49		50–59		60–69		70–79		80+	
N	212		160		87		74		26	
Gender (% males)	33.8		40.5		42.4		37.7		37.5	
Race										
White	189		141		72		71		25	
Black	15		9		10		3		0	
Hispanic	2		1		0		0		0	
Asian	1		4		1		0		0	
Other	1		1		0		0		6	
Handedness (% *R*)	94.1		92.0		92.5		81.3		92.3	
Computer familiarity										
Frequent	72.3		72.4		50.0		31.3		7.1	
Some	2.5		3.4		7.7		29.2		42.9	
Never	25.2		24.1		42.3		39.6		50.0	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	44.7	2.9	54.3	2.8	64.3	2.9	74.1	2.8	83.0	2.6
Memory	98.3	7.8	97.4	7.5	94.6	8.7	90.7	8.5	88.5	8.2
Psychomotor speed	171.0	19.9	161.4	20.5	147.5	27.7	129.1	20.2	114.4	25.8
Reaction time	646.1	96.2	669.1	94.0	709.4	129.0	768.4	149.9	880.8	126.3
Complex attention	7.2	6.5	8.3	15.8	10.9	9.3	15.3	10.9	25.6	43.5
Cognitive flexibility	43.9	12.8	43.1	12.1	35.8	18.4	24.5	23.6	14.3	20.9
Immediate memory	50.4	3.9	49.7	4.3	48.9	4.8	46.4	4.8	45.3	4.7
Delayed memory	48.0	4.7	47.3	4.9	45.6	4.8	43.9	5.1	42.3	4.8
Verbal memory	52.5	4.5	52.0	5.1	49.6	6.3	48.4	5.7	47.1	5.1
Visual memory	45.8	4.9	45.2	4.7	43.8	6.3	41.7	5.4	41.0	4.6
FTT right	58.2	9.0	56.0	8.5	52.4	11.3	45.8	9.0	42.9	12.5
FTT left	56.5	7.8	54.6	8.1	51.1	10.4	46.9	7.9	43.0	10.6
FTT total	114.7	15.5	110.5	15.6	103.5	20.8	92.7	15.9	86.0	22.6
SDC correct	56.3	10.1	50.7	9.8	43.7	11.3	36.1	10.2	29.0	8.7
STsrt	284.3	57.1	310.0	96.5	308.5	89.4	372.8	133.2	440.3	160.9
STcrt	600.0	108.3	609.3	100.8	652.6	123.1	706.1	143.2	821.5	149.1
STstrt	692.2	108.2	728.9	122.7	775.5	157.5	840.3	168.7	940.1	144.9
ST errors	0.7	1.5	0.7	1.2	1.3	3.0	1.0	1.5	0.6	1.2
SAT correct	50.5	8.1	49.8	7.7	45.7	11.1	38.5	14.6	30.9	11.6
SAT errors	5.9	5.9	6.0	5.9	8.6	8.5	12.9	10.8	16.0	9.6
SATRT	1101.6	161.3	1115.4	157.5	1149.2	204.6	1257.5	237.1	1312.7	211.9
SAT efficiency (q)	1.3	0.3	1.3	0.3	1.4	0.5	2.0	1.3	2.3	1.0
CPT correct	39.9	0.5	39.7	2.4	39.9	0.5	39.6	1.0	38.6	7.0
CPT errors	0.7	2.3	1.6	14.3	1.0	1.8	1.4	1.6	9.0	38.4
CPT RT	408.8	48.1	424.8	58.3	409.4	57.0	442.8	58.1	449.1	58.5

Appendix C. Effects of age, interval and clinical status on test-retest reliability

Although neither age nor interval between T1 and T2 had a significant bearing on practice effects, it was appropriate to determine whether they had any bearing on reliability. The advantage of an *N* of 99 is that the subjects could be divided into three equal groups for this analysis.

Reliability coefficients are presented in the next three tables for the five domain scores. In Table C.1, there appears to be no difference in reliability among the three groups: children/adolescents, young adults and older adults.

In Table C.2, we observe a small decrement in reliability relative to the interval between tests.

In Table C.3, we observe that the reliability of the test in patients is actually better than it is among normal subjects.

Table C.1
Reliability coefficients in three age groups

Age	MEM	PMS	IPS	CF	ATT	Average
13.9	0.723	0.819	0.781	0.785	0.627	0.747
31.4	0.689	0.871	0.627	0.794	0.655	0.727
53.9	0.784	0.865	0.897	0.632	0.561	0.748

Table C.2
Reliability coefficients by interval between tests

Interval	MEM	PMS	IPS	CF	ATT	Average
3	0.727	0.844	0.859	0.795	0.726	0.790
28	0.78	0.837	0.6	0.743	0.626	0.717
156	0.54	0.8	0.736	0.668	0.663	0.681

Table C.3
Reliability coefficients by clinical status

	MEM	PMS	RT	CF	ATT	Average
Normals	0.596	0.74	0.701	0.638	0.542	0.643
Patients	0.729	0.88	0.738	0.71	0.628	0.737

Appendix D. CNSVS translated into 54 languages

Language
Afrikaans
Arabic
Bengali
Bulgarian
Cebuano
Chinese Simplified (Malaysia)
Chinese Traditional
Chinses Simplified (China)
Croatian
Czech
Danish
Dutch
English (United Kingdom)
English (USA)
Finnish
French
French (Canada)
German
Greek
Gujarati
Hebrew
Hindi
Hungarian
Ilocano
Italian
Japanese
Kannada
Korean
Latvian
Malay

Appendix D (*Continued*)

Language
Malayalam
Marathi
Norwegian
Polish
Portuguese (Brazil)
Portuguese (Portugal)
Punjabi
Romanian
Russian
Serbian
Sesotho
Spanish (Latin America)
Spanish (Mexico)
Spanish (Spain)
Swedish
Tagalog
Tamil
Telugu
Thai
Turkish
Ukrainian
Urdu
Xhosa
Zulu

Appendix E. Test-retest correlation of conventional and computerized neurocognitive tests

Memory		References
Conventional tests	*r*	
Rey Auditory Verbal Learning Test	0.67–0.9	Shapiro & Harrison, 1990
	0.29–0.81	Lemay et al., 2004
	0.41–0.79	Mitrushina et al., 1991
Rey-Osterreith complex figure	0.57	Mitrushina et al., 1991
Recognition Memory Test	0.55–0.63	Coughlan & Hollows, 1984
	0.81	Soukup et al., 1999
	0.41–0.53	Bird et al., 2003
Buschke Selective Reminding Test	0.46–0.64	Dikmen et al., 1999
	0.39–0.7	Salinsky et al., 2001
Hopkins VLT	0.39–.056	Barr, 2003
WMS-III	0.62–0.88	Tulsky et al., 2001
Wechsler Memory Scale	0.62–0.81	Mitrushina et al., 1991
	0.58–0.7	Dikmen et al., 1991
	0.55–0.74	McCaffrey and Lynch, 1992
	0.47–0.69	McCaffrey and Lynch, 1992
Computerized Tests	*r*	
CANS-MCI	0.38–0.77	Tornatore et al., 2005
CANTAB	0.17–0.86	Lowe & Rabbitt, 1998
CDR (COGDRAS-D)	0.53–0.84	Simpson et al., 1991
CogState	0.26–0.69	Collie et al., JINS 2003
MicroCog	0.64–0.91	Elwood, Neuropsych Rev 2001
NES2	0.55–0.87	Letz, 1989
NEUROTRAX (Mindstreams)	0.84	Schweiger et al., Acta Neuropsych 2003

Appendix E (*Continued*)

Memory		References
Psychomotor speed		
Conventional Tests	*r*	
Digit symbol substitution	0.91	Salinsky et al., 2001
Digit coding (ISPOCD)	0.93	Lowe & Rabbitt, 1998
Symbol digit modalities	0.76–0.8	Smith and Jones, 1982
WAIS coding	0.86	Tulsky et al., 2001
Finger Tapping Test (FFT)	0.94	Gill et al., 1986
	0.86	Gill et al., 1986
	0.75	Bornstein et al., 1989
	0.71–0.76	Ruff & Parker, 1993
	0.04	Kelland et al., 1992
	0.64–0.87	Goldstein & Watson, 1989
	0.77–0.9	Dodrill & Troupin, 1975
	0.73	Ringendahl, 2002
	0.76	Salinksy et al., 2001
	0.58–0.93	Spreen & Strauss, 1991
Computerized Tests	*r*	
NES2 FTT	0.62–0.82	Letz, 1989
NEUROTRAX FTT	0.8	Schweiger et al., Acta Neuropsych 2003
NES2 symbol digit	0.7–0.92	Letz, 1989
NES 3 symbol digit	0.82	Letz et al., Neurotox 2003
Executive function		
Conventional Tests	*r*	
Trailmaking Test	0.41–0.65	Barr, 2003
Stroop Test	0.83–0.91	Salinsky et al., 2001
	0.22–0.53	Lowe & Rabbitt, 1998
	0.72–0.84	Lemay et al., 2004
	0.67–0.83	Franzen et al., 1987
	0.73–0.86	Golden, 1978
Computerized Tests	*r*	
CANS-MCI STROOP	0.8	Tornatore et al., 2005
NEUROTRAX STROOP	0.8	Schweiger et al., Acta Neuropsych 2003
CANTAB set shifting	0.09–0.7	Lowe & Rabbitt, 1998
CogState divided attention	0.31–0.72	Collie et al., JINS 2003
Attention and reaction time		
Conventional	*r*	
One-back Test (ISPOCD) RT	0.81	Lowe & Rabbitt, 1998
One-back Test (ISPOCD) No. Correct	0.28	Lowe & Rabbitt, 1998
Digit cancellation	0.9	Salinsky et al., 2001
WAIS Digit Span	0.83	Tulsky et al., 2001
Gordon diagnostic system	0.67–0.85	Kane & Kay, 1992
Auditory choice RT	0.85	Salinsky et al., 2001
Simple reaction time	0.82	Lemay et al., 2004
Choice reaction time	0.8	Lemay et al., 2004
Computerized	*r*	

Appendix F. Concurrent validity of various conventional and computerized neurocognitive tests

See Tables F.1–F.5.

Table F.1
Concurrent validity data of computerized and conventional tests of memory

Battery	Test/domain	Conventional test	*r*	Reference
CalCAP	Learning/memory	RAVLT, WMS Vis Repro	0.18–0.41	Gonzalez et al., 2002
CANS-MCI	Free Recognition I	WMS Logical Memory	0.56	Tornatore et al., 2005
CANS-MCI	Guided Recognition I (errors)	WMS Logical Memory	0.49	Tornatore et al., 2005
CANS-MCI	Free Recognition II	WMS Logical Memory I	0.46	Tornatore et al., 2005
CANS-MCI	Free Recognition I & II	WMS Logical Memory II	0.52	Tornatore et al., 2005
CANS-MCI	Free Recognition I & II	WMS Logical Memory	0.54	Tornatore et al., 2005
CDR	Word recognition	MMSE	0.95	Keith et al., Brain Inj 1998
CDR (COGDRAS-D)	Immediate word recognition	MMSE	0.64	Simpson et al., 1991
CDR (COGDRAS-D)	Immediate word recognition	Kew Test of memory, aphasia and parietal function	0.63	Simpson et al., 1991
CDR (COGDRAS-D)	Immediate word recognition	Kendrick Digit Copying	0.28	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed word recognition	MMSE	0.58	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed word recognition	Kew Test of memory, aphasia and parietal function	0.68	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed word recognition	Kendrick Digit Copying	0.34	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed picture recognition	MMSE	0.65	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed picture recognition	Kew Test of memory, aphasia and parietal function	0.65	Simpson et al., 1991
CDR (COGDRAS-D)	Delayed picture recognition	Kendrick Digit Copying	0.19	Simpson et al., 1991
CDR (COGDRAS-D)	Choice reaction time	MMSE	0.53	Simpson et al., 1991
CDR (COGDRAS-D)	Choice reaction time	Kew Test of memory, aphasia and parietal function	0.51	Simpson et al., 1991
CDR (COGDRAS-D)	Choice reaction time	Kendrick Digit Copying	0.28	Simpson et al., 1991
COGSCREEN	Visual assoc memory	Flight simulator	0.03–0.35	Taylor et al., 2000
COMP NCOG SCAN	Memory		0.53	Gur et al., 2001
CSI (HEADMINDER)	Memory	Buschke SRT	0.52	www.headminder.com
NES2	Pattern memory	WMS Visual Reproduction, immediate	0.37	Krengel et al., 1996
NES2	Pattern memory	WMS Visual Reproduction, delayed	0.35	Krengel et al., 1996
NES2	Pattern memory	Delayed Recog Span Test-Visual	0.47	Krengel et al., 1996
NES2	Associate learning	WMS Verbal Paired Associates	0.05–0.39	Krengel et al., 1996
NES2	Associate learning	WMS Memory Quotient	0.52	Krengel et al., 1996
NES2	Associate learning	WMS Delayed Recall	0.22	Krengel et al., 1996
NES2	Associate learning	Delayed Recog Span Test- Verbal	0.45	Krengel et al., 1996
NES2	Pattern memory	Benton Visual Retention Test	0.35	
NES2	Visual memory	Benton Visual Retention Test	0.34	
NES2	Pattern memory	Block Design	0.27	
NES2	Visual memory	Block Design	0.4	
NES2	Pattern memory	Memory Quotient	0.4	
NES2	Visual memory	Memory Quotient	0.3	
NES3	List learning	CVLT (immediate)	0.4	Proctor et al., 2000
NES3	List learning	CVLT short delay	0.38	Proctor et al., 2000
NES3	List learning	CVLT long delay	0.43	Proctor et al., 2000
NES3	List learning	PAL immediate	0.44	Proctor et al., 2000
NES3	List learning	PAL delay	0.51	Proctor et al., 2000
NES3	Pattern memory	WAIS-R Vis Rep immediate recall	0.14	Proctor et al., 2000
NES3	Pattern memory	WAIS-R Vis Rep delayed recall	0.25	Proctor et al., 2000
MicroCog	Memory		0.30–0.71	Elwood, 2001
WMS-III	Auditory immediate	CVLT Trials 1–5	0.33–0.74	Tulsky et al., 2001
WMS-III	Visual immediate	CVLT Short Delay	0.24–0.63	Tulsky et al., 2001
WMS-III	Immediate memory	CVLT Long Delay	0.07–0.53	Tulsky et al., 2001
WMS-III	Auditory delayed	Rey Osterreith	0.14–0.64	Tulsky et al., 2001
Average			0.449231	

Table F.2
Concurrent validity of computerized and conventional tests of psychomotor speed

Battery	Test/domain	Conventional test	*r*	Reference
CalCAP	Motor	Pegboard	0.22–0.40	Gonzalez et al., 2002
COGSCREEN	Motor coordination	Flight simulator	.08–0.25	Taylor et al., 2000
COMP NCOG SCAN	Sensorimotor		0.28	Gur et al., 2001
NES2	FTT	HRB FTT	0.69–0.74	Krengel et al., 1996
NES2	Symbol digit	WAIS-R Digit Symbol	0.45	Krengel et al., 1996
NES2	Symbol digit	Digit Symbol	0.47	
NES2	FTT	FTT	0.22	
NES2	Hand Eye Coordinatio	Purdue Pegboard	0.19–0.21	
NES3	FTT	HRB FTT	0.53–0.59	Proctor et al., 2000

Table F.3
Concurrent validity of computerized & conventional tests of executive function

Battery	Test/domain	Conventional test	*r*	Reference
CalCAP	Executive function	Categories, Trails B, Stroop	0.36–0.43	Gonzalez et al., 2002
CANS-MCI	Stroop	Digit Symbol	0.59	Tornatore et al., 2005
COGSCREEN	Tracking	Flight simulator	0.00–0.44	Taylor et al., 2000
COMP NCOG SCAN	Executive function		0.52	Gur et al., 2001
NES3	Sequences A	Trails A	0.44	Proctor et al., 2000
NES3	Sequences A	Trails B	0.6	Proctor et al., 2000
MicroCog	Analogies		0.41	Green et al., 1994
WAIS-III	Processing Speed	Trails B	0.4–0.66	Tulsky et al., 2001
WAIS-III	Processing Speed	WCST	0.3–0.48	Tulsky et al., 2001

Table F.4
Concurrent validity of computerized and conventional tests of attention

Battery	Test/domain	Conventional test	*r*	Reference
CalCAP	Attention/working memory	PASAT, Digit Span, WMS Vis Span	0.24–0.37	Gonzalez et al., 2002
CDR	Spatial working memory	MMSE	0.94	Keith et al., 1998
CDR (COGDRAS-D	Number vigilance	MMSE	0.27	Simpson et al., 1991
CDR (COGDRAS-D	Number vigilance	Kew Test of memory, aphasia & parietal function	0.25	Simpson et al., 1991
CDR (COGDRAS-D	Number vigilance	Kendrick Digit Copying	0.18	Simpson et al., 1991
COGSCREEN	Speed, working memory	Flight simulator	0.06	Taylor et al., 2000
CPT	Omission errors	WISC-R Coding	0.32	Klee & Garfinkel, 1983
CPT	Commission errors		0.25	Klee & Garfinkel, 1983
CPT	Total Errors		0.31	Klee & Garfinkel, 1983
CSI (HEADMINDER	Attention/working memory	Digit Span	0.62	www.headminder.com
NES2	Digit Span	WAIS-R Digit Span	0.34–0.79	Krengel et al., 1996
NES2	Digit Span forward	Digit Span forward	0.44	
NES2	Digit Span backward	Digit Span backward	0.49	
NES3	Symbol Digit	WAIS-R DSST	0.7	Proctor et al., 2000
NES3	Visual Span	WAIS-R Vis Rep immediate recall	0.2–0.35	Proctor et al., 2000
NES3	Visual Span	WAIS-R Vis Rep delayed recall	0.35–0.56	Proctor et al., 2000
MicroCog	Numbers forward &		0.43–0.56	Green et al., 1994
MicroCog	Attention Index		0.72–0.85	Elwood, 2001
Working memory T	Alphabet Span	Alphabet Span	0.23–0.47	Waters & Caplan, 2003
Working memory T	Backward Digit Span	Backward Digit Span	0.22–0.55	Waters & Caplan, 2003
Working memory T	Missing Digit Span	Missing Digit Span	0.14–0.27	Waters & Caplan, 2003
Working memory T	Subtract 2 Span	Subtract 2 Span	0.29–0.74	Waters & Caplan, 2003
Working memory T	Running Item Span	Running Item Span	0.17–0.61	Waters & Caplan, 2003
Working memory T	Sentence (simple)	Sentence (simple)	0.23–0.67	Waters & Caplan, 2003
Working memory T	Sentence (complex)	Sentence (complex)	0.18–0.77	Waters & Caplan, 2003
WAIS–III	Working memory	MicroCog Memory Index	0.15–0.55	Tulsky et al., 2001

Table F.5
Concurrent validity of computerized and conventional tests of reaction time

Battery	Test/domain	Conventional test	*r*	Reference
CalCAP	Information processing	SDM, RT	0.35–0.38	Gonzalez et al., 2002
CANS-MCI	General reaction time	Digit Symbol	0.53	Tornatore et al., 2005
CDR	Choice reaction time	MMSE	0.54	Keith et al., 1998
CDR (COGDRAS-D)	Choice reaction time	MMSE	0.6	Simpson et al., 1991
CDR (COGDRAS-D)	Choice reaction time	Kew Test of memory, aphasia and parietal function	0.7	Simpson et al., 1991
CDR (COGDRAS-D)	Choice reaction time	Kendrick Digit Copying	0.59	Simpson et al., 1991
CRI (Headminder)	Processing speed	Symbol Digit	0.66	Erlanger et al., 2003
CRI (Headminder)	Simple reaction time	Grooved Pegboard	0.46–0.6	Erlanger et al., 2003
CRI (Headminder)	Complex reaction time	Grooved Pegboard	0.59–0.7	Erlanger et al., 2003
CSI (Headminder)	Response speed	Trails A and B	0.73–0.74	www.headminder.com
CSI (Headminder)	Processing speed	Symbol Digit Modalities	0.58–0.65	www.headminder.com
MicroCog	Reaction time		0.59–0.85	Elwood, 2001
WAIS-III	Processing speed	Trails A	0.12–0.56	Tulsky et al., 2001

References

Baker, E. L., Letz, R. E., Fidler, A. T., Shalat, S., Plantamura, D., & Lyndon, M. (1985). A computer-based neurobehavioral evaluation system for occupational and environmental epidemiology: methodology and validation studies. *Neurobehavioral Toxicology & Teratology*, *7*, 369–377.

Barkley, R. A. (1977). A review of stimulant drug research with hyperactive children. *Journal of Child Psychology and Psychiatry*, *18*, 137–165.

Barr, W. B. (2003). Neuropsychological testing of high school athletes. Preliminary norms and test-retest indices. *Archives of Clinical Neuropsychology*, *18*, 91–101.

Bird, C. M., Papadopoulou, K., Ricciardelli, P., Rossor, M. N., & Cipolotti, L. (2003). Test-retest reliability, practice effects and reliable change indices for the recognition memory test. *British Journal of Clinical Psychology*, *42*, 407–425.

Bornstein, R. A., Miller, H. B., & Van Schoor, J. T. (1989). Neuropsychological deficit and emotional disturbance in head-injured patients. *Journal of Neurosurgery*, *70*, 509–513.

Collie, A., Maruff, P., Darby, D. G., & McStephen, M. (2003). The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test-retest intervals. *Journal of the International Neuropsychological Society*, *9*, 419–428.

Coughlan, A. K., & Hollows, S. E. (1984). Use of memory tests in differentiating organic disorder from depression. *British Journal of Psychiatry*, *145*, 164–167.

Dikmen, S. S., Temkin, N. R., Miller, B., Machamer, J., & Winn, H. R. (1991). Neurobehavioral effects of phenytoin prophylaxis of posttraumatic seizure. *Journal of the American Medical Association*, *265*, 1271–1277.

Dikmen, S. S., Heaton, R. K., Grant, I., & Temkin, N. R. (1999). Test-retest reliability and practice effects of expanded Halstead–Reitan Neuropsychological Test Battery. *Journal of the International Neuropsychological Society*, *5*, 346–356.

Dodrill, C. B., & Troupin, A. S. (1975). Effects of repeated administrations of a comprehensive neuropsychological battery among chronic epileptics. *Journal of Nervous and Mental Disease*, *161*, 185–190.

Dougherty, D. M., Marsh, D. M., Moeller, F. G., Chokshi, R. V., & Rosen, V. C. (2000). Effects of moderate and high doses of alcohol on attention, impulsivity, discriminability, and response bias in immediate and delayed memory task performance. *Alcohol and Clinical Experimental Research*, *24*, 1702–1711.

Dulcan, M. & Popper, C. (1991). *Concise Guide to Child and Adolescent Psychiatry*. Washington.

Elwood, R. W. (2001). MicroCog: Assessment of cognitive functioning. *Neuropsychology Review*, *11*, 89–100.

Epstein, J. N., Johnson, D. E., Varia, I. M., & Conners, C. K. (2001). Neuropsychological assessment of response inhibition in adults with ADHD. *Journal of Clinical & Experimental Neuropsychology*, *23*, 362–371.

Erlanger, D., Feldman, D., Kutner, K., Kaushik, T., Kroger, H., Festa, J., et al. (2003). Development and validation of a web-based neuropsychological test protocol for sports-related return-to-play decision-making. *Archives of Clinical Neuropsychology*, *18*, 316.

Forbes, G. B. (1998). Clinical utility of the Test of Variables of Attention (TOVA) in the diagnosis of attention-deficit/hyperactivity disorder. *Journal of Clinical Psychology*, *54*, 461–476.

Franzen, M. D., Tishelman, A. C., Sharp, B. H., & Friedman, A. G. (1987). An investigation of the test-retest reliability of the Stroop Color-Word Test across two intervals. *Archives in Clinical Neuropsychology*, *2*, 265–272.

Gill, D. M., Reddon, J. R., Stefanyk, W. O., & Hans, H. S. (1986). Finger tapping: Effects of trials and sessions. *Percept and Motor Skills*, *62*, 675–678.

Golden, C. J. (1978). *Stroop Color and Word Test: A Manual for Clinical and Experimental Uses*. Illinois: Stoelting Company.

Goldstein, G., & Watson, J. (1989). Test-restest reliability of the Halstead-Reitan Battery and the WAIS in a neuropsychiatric population. *Clinical Neuropsychologist*, *3*, 265–272.

Gonzalez, H., Mungas, D., & Haan, M. (2002). A verbal learning and memory test for English- and Spanish-speaking older Mexican-American adults. *Clinical Neuropsychologist*, *16*, 439–451.

Green, R. C., Green, J., Harrison, J. M., & Kutner, M. H. (1994). Screening for cognitive impairment in older individuals. Validation study of a computer-based test. *Archives of Neuropsychology*, *51*, 779–786.

Gualtieri, C., & Johnson, L. (2005). Allocation of Attentional Resources in Patients with ADHD:Maturational Changes from Age 10 to 29. *Journal of Attention Disorders*, *9*, 534–542.

Gualtieri, C., & Johnson, L. (2006). Neurocognitive testing supports a broader concept of mild cognitive impairment. *Journal of Alzheimers Related Dementia*, *20*, 359–366.

Gur, R. C., Ragland, J. D., Moberg, P. J., Turner, T. H., Bilker, W. B., Kohler, C., et al. (2001). Computerized neurocognitive scanning: I. Methodology and validation in healthy people. *Neuropsychopharmacology*, *25*, 766–776.

Hindmarch, I. (1980). Psychomotor function and psychoactive drugs. *British Journal of Clinical Pharmacology*, *10*, 189–209.

Hutt, S. J., Jackson, P. M., Belsham, A., & Higgins, G. (1968). Perceptual-motor behaviour in relation to blood phenobarbitone level: A preliminary report. *Developmental Medicine and Child Neurology*, *10*, 626–632.

Kane, R. L., & Kay, G. G. (1992). Computerized assessment in neuropsychology: A review of tests and test batteries. *Neuropsychology Review*, *3*, 1–117.

Keith, M. S., Stanislav, S. W., & Wesnes, K. A. (1998). Validity of a cognitive computerized assessment system in brain-injured patients. *Brain Injury*, *12*, 1037–1043.

Klee, S. H., & Garfinkel, B. D. (1983). The computerized continuous performance task: a new measure of inattention. *Journal of abnormal child psychology*, *11*, 487–495.

Krengel, M., White, R. F., Diamond, R., Letz, R., Cyrus, P., & Durso, R. (1996). A comparison of NES2 and traditional neuropsychological tests in a neurologic patient sample. *Neurotoxicology & Teratology*, *18*, 435–439.

Le, T. H., Pardo, J. V., & Hu, X. (1998). 4 T-fMRI study of nonspatial shifting of selective attention: Cerebellar and parietal contributions. *Journal of Neurophysiology*, *79*, 1535–1548.

Lemay, M., Bertram, C. P., & Stelmach, G. E. (2004). Pointing to an allocentric and egocentric remembered target. *Motor Control*, *8*, 16–32.

Letz, R., DiIorio, C. K., Shafer, P. O., Yeager, K. A., Schomer, D. L., & Henry, T. R. (2003). Further standardization of some NES3 tests. *Neurotoxicology*, *24*, 491–501.

Levin, E. D., Conners, C. K., Silva, D., Canu, W., & March, J. (2001). Effects of chronic nicotine and methylphenidate in adults with attention deficit/hyperactivity disorder. *Experimental and Clinical Psychopharmacology*, *9*, 83–90.

Lezak, M. D. (1994). Domains of behavior from a neuropsychological perspective: the whole story. *Nebraska Symposium on Motivation*, 41, 23–55.

Lindsay, R. L., Tomazic, T., Levine, M. D., & Accardo, P. J. (2001). Attentional function as measured by a continuous performance task in children with dyscalculia. *Journal of Developmental & Behavioral Pediatrics*, *22*, 287–292.

Lopez, S. J., Edwards, L. M., Floyd, R. K., Magyar-Moe, J., Rehfeldt, J. D., & Ryder, J. A. (2001). Note on comparability of MicroCog test forms. *Perceptual and Motor Skills*, *93*, 825–828.

Lowe, C., & Rabbitt, P. (1998). Test/re-test reliability of the CANTAB and ISPOCD neuropsychological batteries: theoretical and practical issues. Cambridge Neuropsychological Test Automated Battery. International Study of Post-Operative Cognitive Dysfunction. *Neuropsychologia*, *36*, 915–923.

McCaffrey, R. J., & Lynch, J. K. (1992). A methodological review of “method skeptic” reports. *Neuropsychology Review*, *3*, 235–248.

McGee, R. A., Clark, S. E., & Symons, D. K. (2000). Does the Conners’ continuous performance test aid in ADHD diagnosis? *Journal of Abnormal Child Psychology*, *28*, 415–424.

Mirksy, A. F., & van Buren, J. M. (1965). On the nature of the “absence” in centrencephalic epilepsy: a study of some behavioral, electroencephalographic and autonomic factors. *Electroencephalography and Clinical Neurophysiology*, *18*, 348.

Mitrushina, M., Satz, P., Chervinsky, A., & D’Elia, L. (1991). Performance of four age groups of normal elderly on the Rey Auditory-Verbal Learning Test. *Journal of Clinical Psychology*, *47*, 351–357.

Mitrushina, M. N., Boone, K. B., & D’Elia, L. F. (1999). *Handbook of Normative Data for Neuropsychological Assessment*. New York: Oxford University Press.

Nagahama, Y., Sadato, N., Yamauchi, H., Katsumi, Y., Hayashi, T., Fukuyama, H., et al. (1998). Neural activity during attention shifts between object features. *Neuroreport*, *9*, 2633–2638.

Proctor, S., Letz, R., & White, R. (2000). Validity of a computer-assisted neurobehavioral test battery in toxcant encephalopathy. *Neurotoxicology*, *21*, 703–714.

Rey, A. (1964). *L’examen clinique en psychologie*. Paris: Presses Universitaires de France.

Riccio, C. A., & Reynolds, C. R. (2001). Continuous performance tests are sensitive to ADHD in adults but lack specificity. A review and critique for differential diagnosis. *Annals of the New York Academy of Science*, *931*, 113–139.

Riccio, C. A., Waldrop, J. J., Reynolds, C. R., & Lowe, P. (2001). Effects of stimulants on the continuous performance test (CPT): implications for CPT use and interpretation. *Journal of Neuropsychiatry and Clinical Neuroscience*, *13*, 326–335.

Ringendahl, H. (2002). Factor structure, normative data and retest-reliability of a test of fine motor functions in patients with idiopathic Parkinson’s disease. *Journal of Clinical and Experimental Neuropsychology*, *24*, 491–502.

Rohlman, D. S., Bailey, S. R., Brown, M., Blanock, M., Anger, W. K., & McCauley, L. (2000). Establishing stable test performance in tests from the Behavioral Assessment and Research System (BARS). *Neurotoxicology*, *21*, 715–723.

Rosvold, H. E., & Delgado, J. M. (1956). The effect on delayed-alternation test performance of stimulating or destroying electrically structures within the frontal lobes of the monkey’s brain. *Journal of Comparative & Physiological Psychology*, *49*, 365–372.

Ruff, R. M., & Parker, S. B. (1993). Gender- and age-specific changes in motor speed and eye-hand coordination in adults: normative values for the Finger Tapping and Grooved Pegboard Tests. *Perceptual and Motor Skills*, *76*, 1219–1230.

Salinsky, M. C., Storzbach, D., Dodrill, C. B., & Binder, L. M. (2001). Test-retest bias, reliability, and regression equations for neuropsychological measures repeated over a 12–16-week period. *Journal of International Neuropsychological Society*, *7*, 597–605.

Schweiger, a., Doniger, G. M., Dwolatzky, T., Jaffe, D., & Simon, E. S. (2003). Reliability of a novel computerized neuropsychological battery for mild cognitive impairment. *Acta Neuropsychologica*, *1*, 407–413.

Shapiro, D. M., & Harrison, D. W. (1990). Alternate forms of the AVLT: a procedure and test of form equivalency. *Archives of Clinical Neuropsychology*, *5*, 405–410.

Simpson, P. M., Surmon, D. J., Wesnes, K. A., & Wilcock, G. K. (1991). The cognitive drug research computerized assessment system for demented patients: A validation study. *International Journal of Geriatric Psychiatry*, *65*, 95–102.

Smith, A. (1982). Symbol Digit Modalities Test (SDMT). Manual (Revised). Los Angeles, Western Psychological Services.

Smith, D. W. & Jones, K. L. (1982). *Recognizable Patterns of Human Malformation*. (3 ed.) Philadelphia: Saunders.

Soukup, V. M., Bimbela, A., & Schiess, M. C. (1999). Recognition memory for faces: Reliability and validity of the warrington Recognition Memory Test (RMT) in a neurological sample. *Journal of Clinical Psychology in Medical Settings*, *6*, 287–293.

Spreen, O., & Strauss, E. (1991). *A compendium of neuropsychological tests: administration, norms and commentary*. New York: Oxford University Press.

Sykes, D. H., Douglas, V. I., Weiss, G., & Minde, K. K. (1971). Attention in hyperactive children and the effect of methylphenidate (ritalin). *Journal of Child Psychology and Psychiatry*, *12*, 129–139.

Taylor, E. M. (1959). *The appraisal of children with cerebral deficits*. Cambridge, MA: Havard University Press.

Taylor, J. L., O'Hara, R., Mumenthaler, M. S., & Yesavage, J. A. (2000). Relationship of CogScreen-AE to flight simulator performance and pilot age. *Aviation, Space and Environmental Medicine*, *71*, 373–380.

Tornatore, J. B., Hill, E., Laboff, J. A., & McGann, M. E. (2005). Self-administered screening for mild cognitive impairment: initial validation of a computerized test battery. *Journal of Neuropsychiatry and Clinical Neurosciences*, *17*, 98–105.

Tulsky, D. S., Saklofske, D. H., Wilkins, C., & Weiss, L. G. (2001). Development of a general ability index for the Wechsler Adult Intelligence Scale–Third Edition. *Psychological Assessment*, *13*, 566–571.

Vadhan, N. P., Serper, M. R., Harvey, P. D., Chou, J. C., & Cancro, R. (2001). Convergent validity and neuropsychological correlates of the schedule for the assessment of negative symptoms (SANS) attention subscale. *Journal of Nervous and Mental Disease*, *189*, 637–641.

Waters, G. S. & Caplan, D. (2003). The reliability and stability of verbal working memory measures. *Behavior research methods, instruments, & computers: a journal of the Psychonomic Society, Inc.*, 35, 550–564.

Weber, B., Fritze, J., Schneider, B., Simminger, D., & Maurer, K. (1998). Computerized self-assessment in psychiatric in-patients: acceptability, feasibility and influence of computer attitude. *Acta Psychiatrica Scandinavica*, *98*, 140–145.

Wohlberg, G. W., & Kornetsky, C. (1973). Sustained attention in remitted schizophrenics. *Archives in General Psychiatry*, *28*, 533–537.