Construct Validity of NeuroTrax™: Comparison with Paper-Based Tests

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Introduction

The NeuroTrax software uses tests of cognitive performance that measure similar cognitive functions to traditional paper-based tests. Indeed many of the computerized tests are based upon established paper-based tests that have been used to assess cognitive performance for decades. Additionally, like the NeuroTrax tests, these paper-based tests provide standardized results in order to allow for comparison between the individual test-taker and a reference population.

In order to confirm that the NeuroTrax tests are comparable to traditional paper-based cognitive examinations designed to measure similar cognitive functions, i.e. construct validity, correlations have been computed between the computerized and paper-based tests in multiple cohorts. As a general rule, correlations of greater than 0.3 are taken to indicate a meaningful relationship among measures (Hinkle et al., 1988), those greater than 0.4 as indicating a moderate degree of correlation, and those above 0.6 as reflecting a marked degree of correlation (Franzblau, 1958). As a benchmark for the expected range of correlation among tests of a similar construct, tests of executive function, including Trail Making B and Stroop Color and Word tests yielded correlations ranging from 0.34 to 0.55 (Chaytor et al., 2006). Another study (Duff et al., 2005) found correlations ranging from 0.23 to 0.70 among outcomes from different tests of memory and 0.28 to 0.52 for tests of executive function.

As described below, correlations between NeuroTrax and corresponding paper-based tests reflect meaningful relationships that are generally moderate to marked and are considered significant based on a *p*-value of less than 0.05, reflecting good correspondence between computerized and paper-based tests. Note that the sign of an *r*-value measurement is not related to the strength of the correlation; rather an *r*-value of 0 indicates no correlation and *r*-value of either 1 or -1 indicates perfect correlation.

A. Older Adults

In a cohort of 54 community-based elderly patients (from Dwolatzky et al., *BMC Geriatrics*, 2003), NeuroTrax tests were compared with paper-based tests including subtests of the Weschler Memory Scale, 3rd Edition (WMS-III), the Weschler Adult Intelligence Scale, 3rd Edition (WAIS-III), the Rey Auditory-Verbal Learning Test (RAVLT) and the Stroop test, as well as the Controlled Oral Word Association and Boston Naming tests. Results are shown in Table 1 and demonstrate good comparability between NeuroTrax and paper-based tests.

Table 1. Construct Validity of NeuroTrax in Older Adults (*N*=54)

***NeuroTrax* Test (outcome parameter)**	**Traditional Paper-Based Measures**	**Correlation r-value[A]**
Verbal Memory	WMS-III Logical Memory II	0.73
(accuracy, final repetition, immediate	WMS-III Logical Memory I	0.70
recognition test)	WMS-III Visual Reproduction II	0.70
Non-Verbal Memory	RAVLT Short Term Retention	0.77
(accuracy, final repetition, immediate	WMS-III Visual Reproduction II	0.72
recognition test)	WAIS-III Visual Reproduction II	0.71
	RAVLT Delayed Recall	0.70
	WMS-III Logical Memory I	0.70
	WMS-Logical Memory II	0.70
	WMS-III Visual Reproduction I	0.68
	RAVLT Total Learning	0.61
Go-NoGo	Stroop Word Time	-0.81
(composite score)	Stroop Color Word Time	-0.71
	Controlled Oral Word Association A	0.69
	WAIS-III Digit Symbol	0.68
Stroop Phase III	Stroop Color Word Time	-0.52
(composite score)	Controlled Oral Word Association A	0.50
	WAIS-III Letter-Number Sequencing	0.47
Visual Spatial Imagery	WAIS-III Digit Symbol	0.60
(accuracy)	WMS-III Mental Control	0.57
	WAIS-III Spatial Span	0.57
Verbal Rhyming	Controlled Oral Word Association A	0.64
(weighted accuracy)	Boston Naming Test	0.62
	WMS-III Logical memory I	0.62
	Controlled Oral Word Association FS	0.61
Staged Information Processing	WMS-III Mental Control	0.76
(overall composite score)		
Problem Solving	WAIS-III Block Depn	0.66
(accuracy)	WAIS-III Similarities	0.61
'Catch' Game	WAIS-III Block Depn	0.60
(weighted accuracy)	WAIS-III Digit Symbol	0.51

[A] $p<0.05$ for all reported correlations

In a separate study, 20 elderly patients (from Doniger et al., *Neurology,* 2005) completed both NeuroTrax and a battery of paper-based neuropsychological tests at an inner-city memory clinic. Correlations between computerized and paper-based tests measuring comparable cognitive domains appear in Table 2. Good correspondence was shown in this cohort as well, attesting to the generalizability of NeuroTrax construct validity across cohorts of varying ethnicity and socioeconomic status.

Table 2. Construct Validity of NeuroTrax in Urban Black Memory Clinic Cohort (*N*=20)

NeuroTrax Test	**Outcome Parameter**	**Paper-Based Test**	***r*-value**
Go-NoGo	Composite Score	Symbol Digit Modalities (written)	0.56*
		Trails – Number/Letter Switching	-0.69**
		Card Sorting Test (Delis-Kaplan)	0.68**

Verbal Memory	Accuracy, All Repetition Trials	California Verbal Learning Test	0.69**
	Accuracy, Repetition 1	Digit Span	0.69**
Problem Solving	Accuracy	Wechsler Test of Adult Reading (WTAR)	0.65*
		Clock Drawing Test	0.65**
		Symbol Digit Modalities (written)	0.68**
		Trails – Number/Letter Switching	-0.75**
		Card Sorting Test (Delis-Kaplan)	0.68**
Stroop	SD of Reaction Time, Interference Phase	Clock Drawing Test	-0.59*
Catch Game	Total Score	Clock Drawing Test	0.91**
Staged Information Processing Speed	Accuracy, Level 1.1	Trails – Number Sequencing	-0.77*
	Accuracy, Level 2.2	Digit Span	0.68**
	SD of Reaction Time, Level 2.1	Digit Span	-0.77**
Verbal Function	Accuracy, Naming	Clock Drawing Test	0.68**
		Wechsler Test of Adult Reading (WTAR)	0.65**
		Boston Naming Test	0.93**
		Verbal Fluency: F, A, S	0.64**
		Category Fluency (Animals, Boys' Names)	0.69**
	Accuracy, Rhyming	Wechsler Test of Adult Reading (WTAR)	0.54*
		Boston Naming Test	0.82**
		Verbal Fluency: F, A, S	0.61**
		Category Fluency (Animals, Boys' Names)	0.62**
		Trails – Letter Sequencing	-0.63**

SD: Standard deviation
*p<0.05
**p<0.01

Comparability between NeuroTrax and paper-based tests was also evaluated in a cohort of 37 older patients (age: 60.3±13.4 years; education: 13.6±2.4 years; 10 female; MMSE: 28.3±2.3). Results from this study (Doniger et al., *Movement Disorders*, 2006) are presented in Table 3 and Figures 1 & 2. NeuroTrax showed good correspondence with traditional neuropsychological tests.

Table 3. Construct Validity of NeuroTrax in Older Adults (*N*=37)

Cognitive Domain	NeuroTrax Test	Paper-based Test	Correlation, p-value
MEMORY	Verbal Memory	Hopkins Verbal Learning	r=0.72, p=0.001
		Brief Visuospatial Memory Test-Revised	r=0.66, p=0.003
	Non-Verbal Memory	Brief Visuospatial Memory Test-Revised	r=0.84, p<0.001
		Hopkins Verbal Learning	r=0.71, p<0.001
		Wechsler Memory Scale III (WAIS-3)	r=0.64, p<0.001
EXECUTIVE FUNCTION	Go-NoGo	Trails B	r=0.63, p<0.001
		WAIS-3 Digit Symbol	r=0.63, p<0.001
	Stroop Interference	WAIS-3 Digit Symbol	r=0.63, p<0.001
	Catch Game	Trails B	r=0.70, p<0.001
		WAIS-3 Digit Symbol	r=0.65, p<0.001
VISUAL SPATIAL	Visual Spatial	Judgment of Line Orientation	r=0.70, p<0.001
VERBAL FUNCTION	Verbal Function: Naming	Boston Naming test	r=0.66, p=0.002
		Hopkins Verbal Learning	r=0.69, p=0.001
		Brief Visuospatial Memory Test-Revised	r=0.77, p<0.001
	Verbal Function: Rhyming	Hopkins Verbal Learning	r=0.76, p<0.001
		Brief Visuospatial Memory Test-Revised	r=0.67, p=0.002
ATTENTION	Go-NoGo (RT variability)	Trails B	r=0.74, p<0.001
	Catch Game (RT variability)	Trails B	r=0.65, p<0.001
MOTOR SKILLS	Finger Tapping (inter-tap interval)	Trails A	r=0.60, p<0.001
		Trails B	r=0.60, p<0.001
INFORMATION PROCESSING SPEED	Information Processing: Medium Speed, High Load	Hopkins Verbal Learning	r=0.71, p<0.001
	Information Processing: Fast Speed, Low Load	WAIS-3 Digit Symbol	r=0.70, p<0.001
	Information Processing: Fast Speed, Medium Load	Trails B	r=0.65, p<0.001

Figure 1. Construct Validity in Memory Domain.

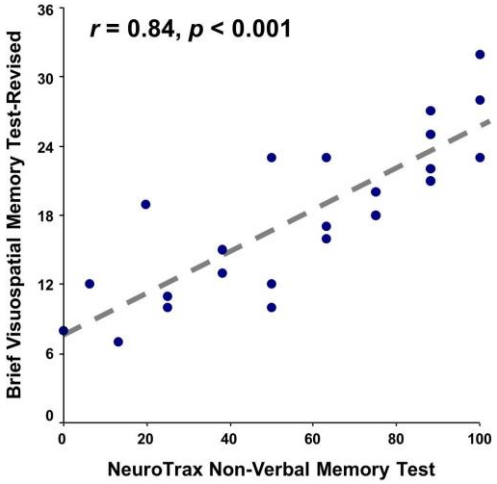
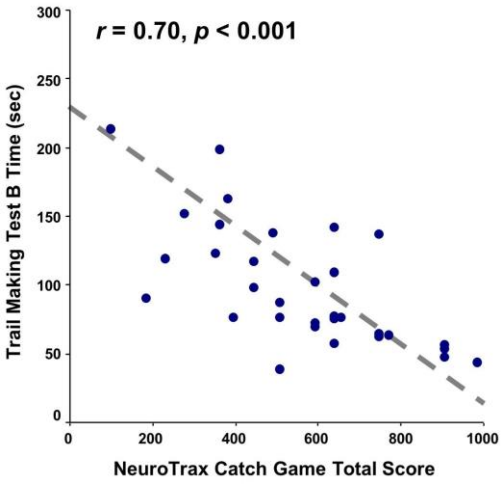
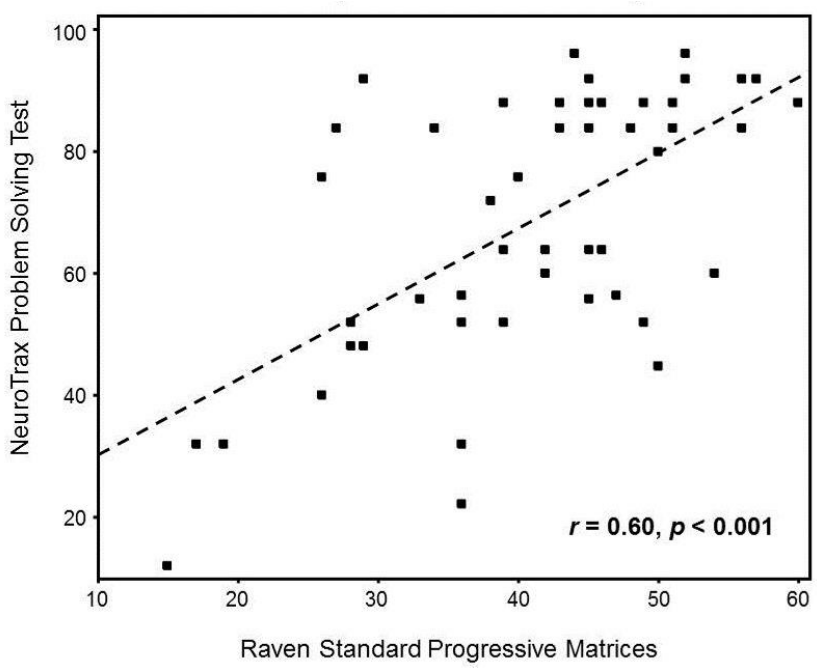


Figure 2. Construct Validity in Executive Function Domain.



Recently, construct validity of the NeuroTrax Problem Solving test, a test of non-verbal reasoning modeled on the paper-based Raven's Standard Progressive Matrices test was evaluated in a cohort of older adults (*N*=49; age: 73.3±14.2 years; education: 13.6±2.4 years; 24 female) (Doniger et al., submitted). A correlation of 0.60 ($p<0.001$) was obtained between the computerized and paper-based measures (Figure 3), attesting to the construct validity of the NeuroTrax test as a measure of non-verbal intelligence.

Figure 3. Scatterplot demonstrating a significant positive linear relationship between raw NeuroTrax Problem Solving test and raw Raven Standard Progressive Matrices score in a cohort of older adults (*N*=49), attesting to the construct validity of the NeuroTrax test.



B. Young Adults

32 adults (age: 30.6±9.7 years; 13 female) were tested with NeuroTrax and with traditional neuropsychological tests (Ben-Harush, masters thesis). Pearson correlations between computerized and paper-based tests are given in Table 4. Good construct validity was demonstrated.

Table 4. Construct Validity of NeuroTrax in Young Adults (*N*=32)

NeuroTrax Test	*Outcome Parameter*	*Paper-Based Test*	*r-value, p-value*
Verbal Memory	Accuracy- delayed memory	RAVLT Immediate Recall 2	r=.611, p=.000
		RAVLT Delayed Recall	r=.581, p=.001
		RAVLT Recognition	r=.528, p=.002
Verbal Function	Accuracy- naming	WAIS III- VIQ	r=.521, p=.003
		WAIS III- Verbal Comprehension Index	r=.545, p=.002
		WAIS III- Information	r=.572, p=.001
		Naming Test	r=.621, p=.003
	Accuracy- rhyming	WAIS III- Verbal Comprehension Index	r=.618, p=.000
		WAIS III- Vocabulary	r=.530, p=.004
		WAIS III- Similarities	r=.567, p=.001
		Naming Test	r=.547, p=.010
Problem Solving	Accuracy	WAIS III- FSIQ	r=.638, p=.000
		WAIS III- VIQ	r=.639, p=.000
		WAIS III- PIQ	r=.459, p=.008
		WAIS III- Verbal Comprehension Index	r=.603, p=.000
		WAIS III- Perceptual Organization Index	r=.514, p=.003
		WAIS III- Vocabulary	r=.594, p=.001
		WAIS III- Letter- Number Sequencing	r=.546, p=.004
		WAIS III- Matrix Reasoning	r=.648, p=.000
		WAIS III- Symbol Search	r=.608, p=.001
Visual Spatial Processing	Accuracy	WAIS III- FSIQ	r=.525, p=.003
		WAIS III- Similarities	r=.510, p=.004
		WAIS III- Picture Completion	r=.509, p=.004
Staged Information Processing	Composite score- level 1.3	WAIS III- Digit span	r=.586, p=.001
	Composite score- level 2.3	WAIS III- Arithmetic	r=.508, p=.004
	Composite score- level 3.2	WAIS III- Working Memory Index	r=.595, p=.001
		WAIS III- Digit span	r=.566, p=.001
		WAIS III- Block Design	r=.529, p=.002

Construct validity of NeuroTrax relative to paper-based tests measuring similar cognitive functions was also examined in a cohort of 37 young adults (Elstein et al., *Genetics in Medicine*, 2005). Results appear in Table 5. As in the above cohorts, good construct validity was shown between the computerized and traditional neuropsychological tests.

Table 5. Construct Validity of NeuroTrax in Young Adults (*N*=37)

NeuroTrax Test	Outcome Parameter	Paper-Based Test	*r*-value
Go-NoGo	Commission Errors	Tower of Hanoi (time)	0.51**
Verbal Memory	Accuracy, All Repetition Trials	Rey Auditory Verbal Learning Test	0.56**
Problem Solving	Accuracy	Trail Making Test B	0.87**
		Wisconsin Card Sorting Test (perseverative errors)	0.66**
		Wisconsin Card Sorting Test (responses of conceptual level)	0.57**
Stroop	Reaction Time, Interference Phase	Trail Making Test B	0.56**
	SD of Reaction Time, Interference Phase	Trail Making Test B	0.62**
Non-Verbal Memory	Accuracy, All Repetition Trials	Rey Osterreith Complex Figure Test (recall)	0.67**
Finger Tapping	Inter-Tap Interval	Trail Making Test A	0.56**
	SD of Inter-Tap Interval	Trail Making Test A	0.62**
Catch Game	Total Score	Trail Making Test B	0.51**
	SD of Time to First Move	Tower of Hanoi (time)	0.52**
Staged Information Processing Speed	Accuracy, Level 2.2	Trail Making Test A	0.52**
Verbal Function	Accuracy, Rhyming	Verbal Fluency: Animals	0.54**
Visual Spatial Processing	Accuracy	Rey Osterreith Complex Figure Test (copy)	0.55**
		Rey Osterreith Complex Figure Test (recall)	0.52**

SD: Standard deviation
*p<0.05
**p<0.01

C. Children

Finally, in a construct validity study of NeuroTrax versus paper-based tests in children (*N*=40; age: 11.01±1.27 years; education: 5.12±1.3 years; 22 female), moderate-to-high correlations were generally found between computerized and paper-based measures of comparable cognitive functions (Ohana, masters thesis; Table 6).

Table 6. Construct Validity of NeuroTrax in Healthy Children (N=40)

Cognitive Domain	Paper-based Test	NeuroTrax Test	*r*-value	*p*-value
Attention	TMT-A (time)	Go-NoGo (composite score)	-.550	<0.001
		Go-NoGo (reaction time)	.575	<0.001
		Go-NoGo (SD of reaction time)	.661	<0.001
		Staged Information Processing low load, medium speed (SD of reaction time)	.501	.001
		Staged Information Processing low load, high speed (SD of reaction time)	.671	<0.001
		Staged Information Processing medium load, high speed (SD of reaction time)	.632	<0.001
	Number Cancellation (592-time)	Stroop (reaction time, non-interference: meaning)	.546	<0.001
		Stroop (composite score, non-interference: meaning)	-.524	.001
Psychomotor Planning	TMT-B (time)	Catch Game (time to first move)	.469	.002
Verbal Function	COWA (5 phases)	Verbal Function (naming, accuracy)	.408	.009
Verbal Memory	RAVLT (trials 1 to 5)	Verbal Memory (accuracy, all repetition trials)	.462	.007
	RAVLT (List A after List B)	Verbal Memory (accuracy, all repetition trials)	.405	.01
	RAVLT (delayed)	Verbal Memory (accuracy, all repetition trials)	.465	.003
	RAVLT (List A after List B)	Verbal Memory (accuracy, delayed recognition)	.404	.01
	RAVLT (delayed)	Verbal Memory (accuracy, delayed recognition)	.490	.002
Non-Verbal Memory	Rey Complex Figure (immediate)	Non-Verbal Memory (accuracy, all repetition trials)	.516	.001

SD: Standard deviation
TMT: Trial Making Test
COWA: Controlled Oral Word Association
RAVLT: Ray Auditory Verbal Learning Test

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