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Development and validation of a World-Wide-Web-based neurocognitive assessment battery: WebNeuro

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Assessment of neurocognitive functioning is a critical task in many clinical, educational, service, and industrial settings. We report on descriptive and validation data of a new, World-Wide-Web-based, comprehensive battery of neurocognitive functioning, WebNeuro, that can be used in both applied and research contexts. Fifty healthy control participants completed both WebNeuro, and an established non-Internet-based computerized cognitive assessment battery, IntegNeuro, that uses a touchscreen platform. Results indicated comparability across the two batteries, in terms of critical single test scores, factor analysis derived indices, overall performance scores, and sex differences. These results support the validity of WebNeuro as a neurocognitive assessment measure. Advantages of its use in applied and research settings are discussed.

Neurocognitive assessment is a critical aspect of standard practice in a number of professional domains, including the medical, educational, service, and industrial fields. In educational contexts, for example, assessment of functioning plays a key role in determination of the nature and extent of learning disability, which can be used to guide the development of individualized education plans. In service and industrial settings, cognitive functioning is often assessed in the evaluation of the suitability of potential employees for positions across a number of sectors, including law enforcement and the airline industry (e.g., pilot and air traffic controller selection).

Traditionally, the most common use of neurocognitive testing has been in the areas of clinical practice and research with patients with neuropsychiatric or neurological disorders. In many such disorders, cognitive impairment precedes the onset of behavioral symptoms, and cognitive decline is a major factor contributing to functional disability (e.g., Bobholz & Rao, 2003; Brandt, Shpritz, Codori, Margolis, & Rosenblatt, 2002; Green, 2006; Mindt et al., 2003). Practical applications of neurocognitive assessment include, but are not limited to (1) detection of decline in memory function in cases of suspected Alzheimer's dementia; (2) detection of decline in memory and motor speed in cases of suspected HIV-dementia and other subcortical dementias; (3) describing the extent of cognitive recovery, whether spontaneous or from a cognitive rehabilitation intervention, in cases of traumatic brain injury and stroke; (4) monitoring the effects of pharmacologic intervention in a wide range of disorders; and (5) assess-

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ing the nature and extent of cognitive impairment, both statically and over time, in psychiatric conditions such as depression, attention-deficit hyperactivity disorder, and schizophrenia. The latter condition serves as an exemplar of why a comprehensive neurocognitive assessment is necessary. In schizophrenia, cognitive impairments are often found in multiple areas, including visual information processing (Green, 1998; Knight & Silverstein, 1998); attention (Nuechterlein, 1991; Silverstein, Light, & Palumbo, 1998); working memory (Docherty et al., 1996; Park & Holzman, 1992); short-term memory and learning (Calev, Karin, Kugelmass, & Lerer, 1987; Silverstein, Osborn, & Palumbo, 1998); executive functioning (Goldberg, Weinberger, Berman, Pliskin, & Podd, 1987); speed of processing (Braff & Saccuzzo, 1982); reasoning and problem solving (Chan, Chen, Cheung, Chen, & Cheung, 2004); context processing (Cohen, Barch, Carter, & Servan-Schreiber, 1999; Cohen & Servan-Schreiber, 1992; Silverstein, Matteson, & Knight, 1996); and social perception and cognition (Green, Olivier, Crawley, Penn, & Silverstein, 2005; Silverstein, 1997). While no single profile of cognitive deficits has been found to characterize all schizophrenia patients, the majority have impaired ability in at least one area of functioning (Morice & Delehunty, 1996; Palmer et al., 1997). As with other neuropsychiatric and neurological conditions, the impairments in schizophrenia wax and wane over time and can be affected by environmental conditions, psychological interventions, and pharmacologic treatment (Silverstein & Wilkniss, 2004). Therefore, a standardized platform for assessing neurocognitive functioning is an important aspect of comprehensive treatment and research for this and other conditions.

Traditionally, cognitive assessment has made use of standardized paper-and-pencil batteries such as the Nebraska–Luria and Halstead–Reitan, which were developed to identify cases of "organic" brain disturbance. These are no longer in widespread use, and have generally been replaced by more diagnosis-specific batteries that are supported by research data. For example, in the area of schizophrenia, such batteries include the Repeatable Battery for the Neuropsychological Assessment of Schizophrenia (RBANS) (Gold, Queern, Iannone, & Buchanan, 1999; Hobart, Goldberg, Bartka, & Gold, 1999), the Brief Assessment of Cognition in Schizophrenia (BACS) (Keefe et al., 2004), and the Measurement and Treatment Research to Improve Cognition in Schizophrenia (MATRICS) Cognitive Consensus Battery (MCCB) (Green & Nuechterlein, 2004). All of the above mentioned batteries consist solely of paper and pencil tests of specific cognitive domains (e.g., working memory, executive function) known to be impaired in many people with schizophrenia, with the exception of the MCCB, which incorporates a computerized measure of sustained attention.

Recently, computerized versions of neuropsychological assessments have increasingly received recognition as valuable research and clinical tools. The American Psychological Association (APA) recognized the value of computerized psychological testing and published guidelines in 1986 (APA, 1986) to assist in the development and interpretation of computerized test results. In that publication, the APA identified six major benefits of computerized assessment, including (1) automation of data collection and storage, (2) greater efficiency of use, (3) freeing of the clinician from test administration to focus on treatment, (4) a greater sense of mastery and control for the client, (5) reduced negative self-evaluation among clients that experience difficulty on the computer, and (6) greater ability to measure performance parameters that are not easily acquired through traditional paper-and-pencil tests (e.g., response latency, strength, variability).

Despite their promise, initial efforts to computerize cognitive tests focused mainly on individual measures, and the validity of these outcomes varied (for a review, see Kane & Kay, 1992). In addition, many early versions of computerized assessment were characterized by poor visual graphics, inadequate sound quality and inconsistencies in recording of responses. These limitations have been overcome with substantial improvements and developments in computing hardware and software. Computerized methods now exist for accurate and reliable timing of stimulus presentation, response recording, and multidimensional display of information (Paul et al., 2005).

A number of computerized cognitive batteries have been developed in recent years subsequent to advancements in computing power. Four computerized batteries frequently cited in the literature include the Cambridge Automated Neuropsychological Test Battery (CANTAB; Morris, Evenden, Sahakian, & Robbins, 1986), the MicroCog (Devivo, Rothland, Price, & Fein, 1999), the Neurobehavioral Evaluation System (NES; Baker et al., 1985), and CogState (Cysique, Maruff, Darby, & Brew, 2006). These computerized batteries have provided significant contributions to the research literature. There are, however, aspects of these batteries that restrict their utility, including the absence of language measures on the CANTAB, NES 3, and CogState, and the assessment of cognitive constructs that differ from standardized clinical assessment (e.g., MicroCog—Elwood, 2001). As such, there is a need for the development of cognitive programs that capitalize on the advancements of computing technology to allow assessment of standard cognitive skills including language and verbal memory (Paul et al., 2005).

Recently, a touchscreen-based computerized cognitive assessment battery (IntegNeuro) was developed as part of the standardized methodology used with the Brain Resource International Database (BRID; Gordon, 2003; Gordon, Cooper, Rennie, Hermens, & Williams, 2005). IntegNeuro consists of automated stimulus presentation and response recording protocols which involve a touchscreen platform and voice recording software. The tests are designed to assess the same core cognitive constructs as existing neuropsychological tests known to be sensitive to brain dysfunction. Attractive features of the battery include standardized instructions using both auditory explanations and visual examples, practice trials prior to test trials, its independence from mouse or keyboard familiarity, and largely automated scoring procedures. In addition, the battery includes both language and nonlanguage paradigms. The battery was developed by a consortium of scientists involved in the first standardized international brain database (Gordon et al., 2005). Test–retest reliability for each of the cognitive tests is acceptable for all measures (Paul et al., 2005; Williams et al., 2005).

The purpose of the BRID project is to develop standardized testing methodologies which enable the integration of normally independent sources of data, spanning psychological, cognitive, psychophysiological, neuroimaging, genetic and clinical data. Data are acquired internationally using standardized testing protocols and hardware, with a centralized, industrial-strength database infrastructure for storage and manipulation of these data into a database. As of this writing, this database contains data from over 10,000 people, ages 6–100, with a large normative cohort and well as various diagnostic groups, such as schizophrenia, ADHD, Alzheimer's disease, depression, PTSD, and mild cognitive impairment (secondary to traumatic brain injury) (Gordon et al., 2005).

The BRID and standardized methodologies are used in discovery science projects, in studies establishing the validity of specific biomarkers, and in clinical trial evaluations of pharmaceutical compounds and markers of treatment response. The cognitive battery, called *IntegNeuro*, and the psychophysiological battery, called *NeuroMarker*, are currently being used in these applications in North America, Europe, Australia, and Africa. Discovery projects and trials are also linking IntegNeuro markers to genetic data. In each case, the database provides a normative framework and matched comparison samples not previously available. The BRID also provides an additional resource for independent scientific discovery, under the independently coordinated scientific network BRAINnet (www.brainnet.net). BRAINnet oversees access to scored BRID data for hypothesis-driven projects for publication by its scientist members.

A potential constraint on the use of specialized hardware systems is that they require specific hardware to implement. This issue applies to a number of available products, including CogTest[1] and IntegNeuro, which uses an IBM touch-screen-based system. Therefore, despite their advantages for rapid and automated testing and scoring, the use of these batteries may not be feasible for some clinics on a restricted budget and/or in cases where patients are assessed at multiple locations. In an effort to produce an equivalent battery for use in such situations, the developers of IntegNeuro (Brain Resource Company) produced a Web-based neurocognitive assessment battery that mirrors IntegNeuro but that can be run on a typical computer. This new battery is called WebNeuro.

The World-Wide Web has been an increasingly popular and useful tool in the field of behavioral sciences. An obvious advantage to developing precise psychological testing for delivery via the Web is the facilitation and standardization of measurements and parameters across multiple testing sites, including clinical situations. Additional advantages include the elimination of the need for special hardware and software on local computers as well as the greater possibilities for large and rapid data collection efforts on new paradigms, both for norming and testing purposes.

The primary aim of this study is to determine the comparability of WebNeuro to the more established IntegNeuro battery. If it is demonstrated that the WebNeuro battery generates scores that are comparable to those from the IntegNeuro battery, this would support using the Web-based computerized WebNeuro battery, with the advantages described above, in clinical practice and clinical trials of treatments for neuropsychiatric and neurologically disordered patients, as well as in the educational, service, and industrial sectors as described earlier.

METHOD

Participants

Potential participants who expressed interest in the study were interviewed to inform them of its goals and the tasks and time commitment involved. Those interested in participating then read an IRB-approved consent form and HIPAA Authorization form. Data collection began immediately, unless the participant needed to schedule the actual testing visit on another day. A total of 50 healthy adults (28 females and 22 males) completed both the IntegNeuro and the WebNeuro neuropsychological batteries. Participants were between 18 and 55 years of age, in good general physical health, without a diagnosable major Axis-I psychiatric condition and were able to give informed consent. They were divided between Caucasian ($n = 40$; 80%), African-American ($n = 4$; 8%), and Asian ($n = 6$, 12%) subgroups as well as between males ($n = 22$; 44%) and females ($n = 28$; 56%). Exclusion criteria included any mental or physical condition with the potential to influence cognitive performance, including a personal history of mental illness, physical brain injury, neurological disorder, genetic disorder, or other medical condition (hypertension, diabetes, cardiac disease, thyroid disease), and/or a personal history of drug or alcohol addiction.

Procedure

A Web-based questionnaire was used to acquire demographic data including age, sex, years of education and current mood state in terms of depression, anxiety, and stress (assessed using an abbreviated version of the Depression Anxiety Stress Scale [DASS]; Lovibond & Lovibond, 1995).

IntegNeuro was administered in a sound-attenuated testing room, with participants seated in front of a touch-screen computer (NEC MultiSync LCD 1530V). The touch-screen computer was used to record nonverbal responses and a microphone was connected to collect the verbal responses. All test instructions were delivered by prerecorded instructions through the headphones. WebNeuro was also administered in a sound-attenuated testing room, with participants seated in front of the testing computer. Test instructions for WebNeuro were presented on the computer screen prior to each test. Each subtest of both WebNeuro and IntegNeuro included at least one practice trial prior to the test trials. Participants were required to pass the practice trial(s) accurately before completing the test trials. In the event that an individual was unable to perform the practice trial(s) without error, the test was terminated and the individual was automatically forwarded to the next test in the battery. In the present study, all participants were capable of passing the practice trials. In most cases, participants completed both test batteries during the same visit.

In half of the cases, the IntegNeuro battery was administered first, followed by WebNeuro. In the other half of the cases WebNeuro was completed first, followed by IntegNeuro. The order of administration (IntegNeuro vs. WebNeuro) was determined by random assignment to avoid an order effect.

TEST BATTERIES

IntegNeuro

IntegNeuro tests tap the following domains of cognitive function: sensorimotor, verbal and language, memory, executive planning and attention. A "spot the real word" test is also included to assess intelligence. Scoring of responses was conducted using an automated software program for most tests, and by hand-scoring for .wav files.

Hand scoring was required for the two language tests and the verbal memory test. Trained research assistants conducted the hand scoring of the .wav files and oversight was implemented to monitor accuracy. The measures in each of these domains are described below.

Sensorimotor Domains

Simple motor tapping task. Participants were required to tap a circle on the touch-screen with their index finger, as fast as possible for 60 sec. The dependent variable was total number of taps with the dominant hand.

Choice reaction time task. Participants were required to attend to the computer screen as one of four target circles was illuminated in pseudorandom sequence over a series of trials. For each trial, the participant was required to place their index finger in preparation on a start circle displayed on the touchscreen. On each trial, the participant then had to touch the illuminated circle as quickly as possible following presentation. Twenty trials were administered with a random delay between trials of 2–4 sec. The dependent variable was the mean reaction time across trials.

Attention Domain

Span of visual memory test. This test is a computerized adaptation of the Spatial Span test from the Wechsler Memory Scale (III; Wechsler, 1997). Participants were presented with squares arranged in a random pattern on the computer screen. The squares were highlighted in a sequential order on each trial. Participants were required to repeat the order in which the squares were highlighted by touching the squares with their forefinger. Both forward and reverse trials are conducted. The total correct was the dependent variable.

Digit span test. Participants were presented with a series of digits on the touchscreen (e.g., 4, 2, 7, etc., 500-msec presentation), separated by a one second interval. The participant was then immediately asked to enter the digits on a numeric keypad on the touch-screen. In the first part of the test, participants were required to recall the digits in forward order (digits forward); in the second part, they were required to recall them in reverse order (digits backward). In each part, the number of digits in each sequence was gradually increased from 3 to 9, with two sequences at each level. The dependent measure for each part was the maximum number of digits the participant recalled without error.

Continuous performance test. To assess sustained attention, a series of letters (B, C, D, or G) were presented to the participant on the computer screen (for 200 msec), separated by an interval of 2.5 sec. If the same letter appeared twice in a row, the participant was asked to touch a designated area of the screen with an index finger. Speed and accuracy of response were equally stressed in the task instructions. There were 125 stimuli presented in total, 85 being nontarget letters and 20 being target letters (i.e., repetitions of the previous letter). The dependent variables were the number of errors of omissions and false positives.

Switching of attention test. This test is a computerized adaptation of the Trail Making test (Reitan, 1958). It consists of two parts. In the first part, the participant was presented with a pattern of 25 numbers in circles and asked to touch them in ascending numerical sequence (i.e., 1 2 3 . . .). As each number is touched in correct order, a line is drawn automatically to connect it to the preceding number in the sequence. This allowed the participant to visualize the path touched. This task tests psychomotor speed and the basic ability to hold attention on a simple task. The second part of the test is described below. The dependent variable was time to completion.

Executive Function Domain

Switching of attention task, Part II. In the second part of this task, the participant was presented with a pattern of 13 numbers (1–13) and 12 letters (A–L) on the screen and was required to touch numbers and letters alternatively in ascending sequence (i.e., 1 A 2 B 3 C . . .). This part is more difficult than the first part and reflects the requirement to switch attention between mental tasks, in this case number and letter sequence checking, and thereby alternate between the respective mental sets induced. The dependent variable was time to completion.

Verbal interference task. This task taps the ability to inhibit automatic and irrelevant responses and has similarities to the Stroop task (Golden, 1978). The participant was presented with colored words presented serially, one at a time. Each word was drawn from the following set of lowercase words: red, yellow, green and blue. The color of each word is drawn from the following set of colors: red, yellow, green and blue. Below each colored word is a response pad with the four possible words displayed in black and in fixed format. The test has two parts. In Part 1, the participant is required to identify the name of each word as quickly as possible after it is presented on the screen. In Part 2, the participant is required to name the color of each word as quickly as possible. Each part lasts for 1 min. Responses are made on the screen by touching the appropriate word on the response pad. The dependent variable in each part was the number of words correctly identified.

Maze task. This task was a computerized adaptation of the Austin Maze (Walsh, 1985). The participant was presented with a grid (8 × 8 matrix) of circles on the computer screen. The object of the task was to identify the hidden path through the grid, from the beginning point at the bottom of the grid to the end point at the top. The participant is able to navigate around the grid by pressing arrow keys (up, down, left, right). A total of 24 consecutive correct moves were required to complete the maze. The participant is presented with one tone (and a red cross at the bottom of the screen) if they made an incorrect move, and a different tone (and a green tick at the bottom of the screen) if they made a correct move. The purpose of the task was therefore to assess how quickly the participant learned the route through the maze and their ability to remember that route. Only one maze was presented across trials, and the test ended when the participant completed the maze twice without error or after 10 min had elapsed. The dependent variable was the total maze time. It should be noted that while this measure is identified as a test of executive function, the requirement to retain the maze in memory for two successive trials introduces an added memory component to the task, and therefore this measure taps memory in addition to executive function.

Language Domain

Letter fluency test. Participants were required to generate (by speech) words that began with the letters F, A, and S. Sixty seconds were allowed for each letter and proper nouns were not allowed. Responses were recorded via the microphone and hand scored. Intrusive or perseverative responses were not included in the total number correct. The total number of correct words generated across the three trials was the dependent measure.

Animal fluency. Participants were required to name animals as quickly as possible for 60 sec. Intrusions and perseverative responses were not allowed. Total correct served as the dependent variable.

Memory Domain

Verbal list-learning test. The participants were read a list of 12 words, which they were asked to memorize. The list contained 12 concrete words from the English language. Words are closely matched on concreteness, number of letters and frequency. The list was presented orally four times (and received by the participant using headphones). On each of the four trials, the participant was required to recall as many words as possible by speaking directly into the attached microphone. The participant was then presented with a list of distractor words and asked to recall them after presentation. Immediately following this, the participant was asked to recall the 12 words from the original list (short-delay recall trial). A long delayed recall trial was completed approximately 20 min later after a number of intervening tasks. A recognition trial was then completed after the delayed trial. The dependent variables were the number of words correctly recalled across the four learning trials, the immediate recall trial and the delayed recall trial, and the total number of correctly identified words on the recognition trial.

Social Cognition Domain

Emotion perception test.[2] This is a test of emotional recognition. Participants are presented with a series of faces with different

Table 1
Factor Score Algorithms

IntegNeuro
I_Vigilance = mean.1(ZI_wmrt, ZI_wmerr)
I_ManualDex = -ZI_rhtapn
I_WMCapacity = -ZI_digitot
I_InfoProcSpeed = mean.3(ZI_Swoadur2, -ZI_vi_sco1, -ZI_vi_sco2, ZI_chavrt)
I_VisuoSpatial = mean.1(ZI_emzerr, ZI_emzcomp)
I_OverallPerformance = mean.3(I_Visuospatial, I_InfoProcSpeed, I_WMCapacity)
I_OverallPerformance2 = mean.5(ZI_Swoadur2, -ZI_vi_sco1, -ZI_vi_sco2, ZI_chavrt,ZI_emzerr, ZI_emzcomp,-ZI_digitot)
WebNeuro
W_Vigilance = mean.1(ZW_wmrt, ZW_wmerr)
W_ManualDex = -ZW_rhtapn
W_WMCapacity = -ZW_digitot
W_InfoProcSpeed = mean.3(ZW_Swoadur2, -ZW_vi_sco1, -ZW_vi_sco2, ZW_chavrt)
W_VisuoSpatial = mean.1(ZW_emzerr, ZW_emzcomp)
W_OverallPerformance = mean.3(W_Visuospatial, W_InfoProcSpeed, W_WMCapacity)
W_OverallPerformance2 = mean.5(ZW_Swoadur2, -ZW_vi_sco1, -ZW_vi_sco2, ZW_chavrt, ZW_emzerr, ZW_emzcomp,-ZW_digitot)

emotional expressions (fear, disgust, happy, neutral). Participants are required to use the mouse and identify the correct emotional valence presented by the face. The dependent variable is the total correct.

Intelligence

Spot-the-word test. This task is a computerized adaptation of the Spot the Real Word test (Baddeley, Emslie, & Nimmo-Smith, 1993). On each trial of this task, participants were presented with two words on the touch-screen. One of the two words was a valid word in the English language (“true” target word), and the second was a nonword foil. Participants were required to identify, by touching the screen, which of the two words was the true target. The total correct score was the dependent measure.

WebNeuro

WebNeuro taps the following domains of cognitive function: sensorimotor, memory, executive planning, attention, and emotion perception (social cognition). A “spot the real word” test is also included to assess intelligence. Scoring of responses was conducted using an automated software program for most tests. No .wav files are produced with WebNeuro. The measures in each domain are described below.

Sensorimotor Domains

Simple motor tapping test. Participants are required to tap the space bar on the keyboard with their index finger as fast as possible for 60 sec. The dependent variable is total number of taps with the dominant hand.

Choice reaction time test. Participants are required to attend to the computer screen as one of four target circles is illuminated in pseudorandom sequence over a series of trials. For each trial, the participant is required to use the mouse and click on the illuminated circle as quickly as possible following presentation. Twenty trials are administered with a random delay between trials of 2–4 sec. The dependent variable is the mean reaction time across trials.

Attention Domain

Digit span test. Participants are presented with a series of digits on the computer screen, separated by a one second interval. The participant is immediately asked to enter the digits using the mouse. In the first part of the test, participants are required to recall the digits in forward order. In the second part, they are required to recall them in reverse order. In each part, the number of digits in each sequence is gradually increased from 3 to 7, with two sequences at each level. The dependent measure for each part is the maximum number of digits the participant recalled without error.

Continuous performance test. To tap sustained attention, a series of similar looking letters (B, C, D, or G) are presented to the participant on the computer screen (for 200 msec), separated by an interval of 2.5 sec. If the same letter appears twice in a row, the participant is required to press the space bar. Speed and accuracy of response are equally stressed in the task instructions. There are 125 stimuli presented in total, 85 being nontarget letters and 20 being target letters (i.e., repetitions of the previous letter). The dependent variables are the number of errors of omissions and false positives.

Executive Function Domain

Switching of attention test. This task is a computerized adaptation of the “Trail Making Test” Part B (Reitan, 1958). The participant is presented with a pattern of 13 numbers (1–13) and 12 letters (A–L) on the screen and is required to click inside the appropriate circles for numbers and letters alternatively in ascending sequence (i.e., 1 A 2 B 3 C . . .). As each number or letter is clicked in correct order, a line is drawn automatically to connect it to the preceding number or letter in the sequence. This allows the participant to visualize the path touched. This task tests the ability of the participant to switch attention between mental tasks, in this case number and letter sequence checking, and thereby alternate between the respective mental sets induced. The dependent variable is time to completion.

Verbal interference test. This task taps the ability to inhibit automatic and irrelevant responses and has similarities to the Stroop task (Golden, 1978). The participant is presented with colored words, one at a time. Each word is drawn from the following set of words: *red*, *yellow*, *green*, and *blue*. Below each colored word is a response pad with the four possible words displayed in black and in fixed format. The test has two parts. In Part 1, the participant is required to identify the name of each word as quickly as possible. In Part 2, the participant is required to name the color of each word as quickly as possible. Each part lasts for 1 minute. Responses are made on the screen by clicking the mouse on the appropriate word on the response pad. The dependent variable in each part is the number of words correctly identified.

Maze test. This is identical to the version in IntegNeuro, with the exception that the participant is able to navigate around the grid by using the arrow keys on the keyboard. The dependent variable is the total number of errors.

Table 2
Correlations Between IntegNeuro and WebNeuro Factor and Overall Performance Scores

Factor	Validity Coefficient	Interpretation
Vigilance	.75	high
Manual dexterity	.56	moderately high
Working memory capacity	.74	high
Information processing speed	.75	high
Executive function (visuospatial)	.84	extremely high
Overall performance	.86	extremely high

Table 3
Correlations Between IntegNeuro and WebNeuro Critical Scores for Each Test

Test Score	Validity Coefficient	Interpretation
Sensorimotor tapping (average number)	.56	moderately high
Switching of attention duration	.73	high
Visual interference accuracy	.65	high
Verbal interference accuracy	.45	moderate
Spot the Word accuracy	.70	high
Digit span forward accuracy	.74	high
Working memory RT	.43	moderate
Working memory accuracy	.87	extremely high
Executive maze duration	.79	high

Note—RT, reaction time (in milliseconds).

Go–no-go test. The color of the word PRESS is frequently presented in green (go) and infrequently in red (no-go). The participant is required to inhibit keypress responses on red. This task measures target detection rate; response time; errors of commission and omission. It is used to assess inhibition, the capacity for suppressing well learned, automatic responses.

Memory Domain

Memory recognition/verbal list-learning task. The participants are presented with 12 words, which they are asked to memorize and later recognize from memory. The list contains 12 concrete words from the English language. Words are closely matched on concreteness, number of letters and frequency. The list is presented four times. After each trial, the participant is required to recognize as many words as possible by choosing between 20 sets of word pairs on the screen. One is correct and the other a distractor word. A delayed memory recognition trial is completed approximately 10 min later after a number of intervening tasks. The dependent variables are the number of words correctly recognized across the four learning trials and the delayed trial.

Social Cognition Domain

Emotion perception test (see note 2). This is a test of emotional recognition. Participants are presented with a series of faces with different emotional expressions (fear, disgust, happy, neutral). Participants are required to use the mouse and identify the correct emotional valence presented by the face. The dependent variable is the total correct.

Intelligence

Spot-the-word test. This is the same test that is included in IntegNeuro, but using the keyboard rather than the touch screen to respond.

DATA ANALYSIS

Both IntegNeuro and WebNeuro data were scored using standardized and automated algorithms according to established criteria. To avoid any potential scoring bias, evaluation of test performance on WebNeuro was completed without prior knowledge of the participant's performance on IntegNeuro. Validity was first assessed by assessing the degree of similarity in performance on the IntegNeuro and WebNeuro tests using correlational analyses. Two sets of correlational analyses were done. The first was based

Table 4
Descriptive Data on Factor Score and Critical Indicators From Each Test

Descriptions*	Variables	*n*	Min	Max	*M*	*SD*
WebNeuro						
Factors						
Vigilance	W_Vigilance	50	−2.08	3.23	−0.01	0.96
Manual dexterity	W_ManualDex	47	−1.98	2.39	0.00	1.00
Working memory capacity	W_WMCapacity	50	−1.91	2.13	0.00	1.00
Information processing speed	W_InfoProcSpeed	48	−1.90	2.34	0.02	0.86
Executive function (visuospatial)	W_VisuoSpatial	50	−0.81	4.47	0.00	0.95
Overall performance	W_OverallPerformance	48	−1.25	2.71	0.02	0.75
Tests						
Switching of attention (duration)	W_swoadur2	50	19,562.00	60,016.00	41,101.06	11,486.07
Visual interference (score)	W_vi_sco1	49	6.00	30.00	19.92	5.81
Verbal interference (score)	W_vi_sco2	48	7.00	24.00	15.48	3.39
Spot the Real Word (score)	W_spotscor	49	36.00	55.00	46.94	4.82
Digit span (total correct)	W_digitot	50	4.00	14.00	9.28	2.47
Working memory (RT)	W_wmrt	49	283.21	631.14	462.96	86.52
Working memory (errors)	W_wmerr	47	0.00	12.00	1.96	3.11
Executive maze (duration)	W_emzcomp	50	63,372.00	682,328.65	199,945.57	115,484.47
IntegNeuro						
Factors						
Vigilance	I_Vigilance	45	−1.19	2.25	−0.01	0.84
Manual dexterity	I_ManualDex	48	−2.01	2.45	0.00	1.00
Working memory capacity	I_WMCapacity	48	−1.56	2.10	0.00	1.00
Information processing speed	I_InfoProcSpeed	50	−1.66	1.63	0.01	0.72
Executive function (visuospatial)	I_VisuoSpatial	50	−0.73	4.78	0.00	0.94
Overall performance	I_OverallPerformance	48	−1.11	2.02	−0.02	0.67
Tests						
Switching of attention (duration)	I_swoadur2	50	19,046.00	60,006.00	34,520.38	11,482.18
Visual interference (score)	I_vi_sco1	50	14.00	29.00	21.08	3.72
Verbal interference (score)	I_vi_sco2	44	3.00	24.00	14.84	4.46
Spot the Real Word (score)	I_spotscor	48	38.00	58.00	50.02	4.99
Digit span (total correct)	I_digitot	48	4.00	13.00	9.17	2.46
Working memory (RT)	I_wmrt	45	492.12	1,238.44	844.82	199.19
Working memory (errors)	I_wmerr	44	0.00	21.00	3.52	5.03
Executive maze (duration)	I_emzcomp	50	72,723.00	576,137.00	188,807.98	115,454.83

Note—RT, reaction time (in milliseconds). *Factor scores are standardized scores.

on factor analysis-derived cognitive factor scores. These were previously identified based on a factor analysis of IntegNeuro scores in a sample of 1,000 healthy control participants already in the BrainNet database. Formulas for calculation of the factor scores can be found in Table 1. The five factors are (1) vigilance (defined by the working memory CPT scores), (2) manual dexterity (defined by the tapping scores), (3) working memory capacity (defined by forward digit span), (4) information processing speed (defined by visual/verbal interference scores, switching of attention Part II, and choice RT), and (5) executive function (visuospatial; executive maze). In addition to these factor scores, a variable representing overall performance was also derived. Correlations between factor scores and the overall performance index across the IntegNeuro and WebNeuro batteries are reported in Table 2. The second set of correlational analyses involved the critical performance index from each WebNeuro test. Each of these indices was correlated with its comparable score from IntegNeuro. The resulting correlations are displayed in Table 3.

Table 5
Separate Performance Data for Men and Women on All Tests in Both Batteries

Description	*N*			*M*			*SD*				
	Female	Male	Total	Female	Male	Total	Female	Male	Total	*F*	Sig.
IntegNeuro											
Switching of Attention											
Duration II	29	21	50	33,527.14	35,892.00	34,520.38	11,174.06	12,033.29	11,482.18	0.512	.48
Errors II	28	21	49	.39	.48	.43	.83	.87	.84	0.115	.74
Verbal Interference											
Errors	29	20	49	.79	.50	.67	.94	.89	.92	1.202	.28
Scores	24	20	44	14.25	15.55	14.84	4.37	4.58	4.46	0.925	.34
Visual Interference											
Errors	28	20	48	.21	.15	.19	.42	.37	.39	0.305	.58
Score	29	21	50	21.10	21.05	21.08	4.06	3.29	3.72	0.003	.96
Spot-the-Word Scores	29	19	48	49.21	51.26	50.02	4.95	4.92	4.99	1.993	.17
Digit Span Scores	28	20	48	8.93	9.50	9.17	2.64	2.21	2.46	0.624	.43
Choice RT											
Variability	26	13	39	77.23	87.86	80.77	57.77	78.50	64.55	0.230	.63
Time	27	21	48	590.36	570.29	581.58	72.92	84.22	77.86	0.781	.38
Right Hand Tapping											
Number of taps	27	21	48	160.85	180.67	169.52	19.95	27.00	25.08	8.559	.01**
Variability	27	20	47	95.07	79.85	88.60	26.34	19.41	24.61	4.757	.03**
Working Memory											
RT	25	20	45	890.72	787.44	844.82	197.12	191.21	199.19	3.132	.08*
RT variability	25	20	45	188.34	180.12	184.69	83.90	76.62	79.95	0.115	.74
False alarms	24	20	44	1.46	1.40	1.43	3.12	3.98	3.49	0.003	.96
Misses	25	20	45	2.04	2.05	2.04	2.75	2.31	2.53	0.000	.99
Total errors	24	20	44	3.58	3.45	3.52	4.23	5.97	5.03	0.007	.93
Executive Maze											
Errors	29	21	50	53.97	30.19	43.98	86.92	24.56	68.59	1.478	.23
Time to complete	29	21	50	215,217.41	152,337.81	188,807.98	123,310.87	94,669.78	115,454.83	3.821	.06*
WebNeuro											
Switching of Attention											
Duration II	29	21	50	41,215.07	40,943.62	41,101.06	11,089.99	12,288.20	11,486.07	0.007	.94
Errors II	28	21	49	.57	.76	.65	1.35	1.58	1.44	0.21	.65
Verbal Interference											
Errors	29	21	50	.72	.62	.68	0.65	0.86	0.74	0.24	.63
Scores	28	20	48	15.64	15.25	15.48	3.41	3.43	3.39	0.15	.70
Visual Interference											
Errors	28	19	47	.14	.16	.15	0.36	0.37	0.36	0.02	.90
Scores	28	21	49	19.93	19.90	19.92	5.99	5.72	5.81	0.00	.99
Spot-the-Word Scores	29	20	49	46.48	47.60	46.94	4.16	5.70	4.82	0.63	.43
Digit Span Scores	29	21	50	9.48	9.00	9.28	2.50	2.47	2.47	0.46	.50
Choice RT											
Variability	14	7	21	55.53	40.22	50.43	27.88	18.66	25.78	1.70	.21
Time	14	7	21	270.70	260.81	267.40	40.37	41.65	40.03	0.27	.61
Right Hand Tapping											
Number of taps	28	19	47	178.93	195.37	185.57	22.38	19.19	22.46	6.83	.01**
Variability	26	19	45	24.04	24.95	24.42	8.23	9.80	8.83	0.11	.74
Working Memory											
RT	29	20	49	483.38	433.36	462.96	74.33	95.97	86.52	4.22	.50*
RT variability	28	21	49	128.91	126.76	127.99	52.35	58.08	54.30	0.02	.90
False alarms	29	18	47	1.38	1.50	1.43	2.93	2.66	2.80	0.02	.89
Misses	28	19	47	0.39	0.26	0.34	0.69	0.65	0.67	0.42	.52
Total errors	29	18	47	1.86	2.11	1.96	2.91	3.50	3.11	0.07	.79
Executive Maze											
Errors	29	21	50	64.07	34.29	51.56	105.09	15.86	81.45	1.65	.21
Time to complete	29	21	50	222,770.50	168,425.42	199,945.57	132,789.02	78,677.31	115,484.47	2.80	.10

Note—RT, reaction time (in milliseconds); Sig., significance. $^*p < .10$. $^{**}p < .05$.

Below is a guide to interpretation of the magnitude of correlations between tests with $n = 50$. Validity coefficients range from 0 to 1, such that

0 indicates no validity,
$<$.3 indicates minimal validity,
.3–.45 indicates moderately low validity,
.45–.5 indicates moderate validity,
.5–.65 indicates moderately high validity,
.65–.8 indicates high validity,
$>$.8 indicates extremely high validity, and
1.0 indicates perfect validity.

In addition to these analyses, we examined sex differences on scores for each test in both batteries, to determine if males and females performed similarly on each test, and if not, if the performance differences were similar across both batteries. Finally, we examined the effects of age and education level on performance.

RESULTS

Descriptive data for the cognitive measures are included in Table 4. Note that data were missing for two participants on several measures, as indicated by the participant numbers in each case. Degrees of freedom for analysis of correlation coefficients was $n - 1$ for each measure.

In general, correlations between the WebNeuro and IntegNeuro tests were high, indicating excellent convergent validation for WebNeuro (see Tables 2 and 3). This was true whether overall score, factor scores or critical indices from individual tests were considered as independent variables.

The correlation between the IntegNeuro and WebNeuro factor scores exceeded .56 in all cases, reflecting a statistically significant degree of overlap between the two variables. The average factor score across the five factors was .73. The correlation between the index of overall performance on both measures was .86. In the case of critical scores from individual tests, correlations exceeded .43 in all cases, and averaged .66 across the nine scores.

Analysis of sex differences indicated that males and females performed similarly on most WebNeuro and IntegNeuro tests. However, on both batteries, there were differences (or trends toward differences) between males and females for performance on the tapping task, working memory RT and time to complete the mazes task. Full data on performance of male and female subgroups are presented in Table 5.

Relationships with age were explored using correlations between each measure and the natural logarithm of age. This transformation was used because age-score relationships were characterized by an inverted U shape, and so a standard linear model would mis-fit the trends. These data are reported in Table 6. Relationships with education were explored using partial correlations to control for age (log). This is because age and education are quite collinear, particularly for people under 25. The partial correlations thus give a measure of the association between measures and education level, over and above the effect of age. These data are presented in Table 7.

The combined impact of age and education level was also assessed. This was done using the following regression model for each WebNeuro DV: DV = const + b1 × age + b2 × ln(age) + b3 × education). The total R^2 for these models is reported in Table 8, indicating the proportion of variance in these measures explainable via age and education effects.

Table 6
Pearson Correlations Between WebNeuro Test Scores and Log Age

Pearson Correlation	N	r	Significance	p
Switching of Attention				
Duration II	50	.35	.01	.22
Errors II	49	.06	.69	.04**
Verbal Interference				
Errors	50	.12	.39	.04**
Scores	48	−.69	.00	.52
Visual Interference				
Errors	47	.12	.41	.12
Scores	49	−.64	.00	.54
Spot-the-Word Scores	49	−.24	.10	.22
Digit Span Scores	50	−.28	.05	.11
Choice RT				
Variability	21	.17	.47	.04**
Time	21	.57	.01	.42
Right Hand Tapping				
Number of taps	47	−.11	.46	.03**
Variability	45	.05	.76	.02**
Working Memory				
RT	49	.20	.16	.04**
Variability	49	.19	.20	.06*
False alarms	47	−.01	.96	.05*
Misses	47	.08	.58	.02**
Total errors	47	.05	.76	.09*
Executive Maze				
Errors	50	.23	.10	.08*
Time to complete	50	.43	.00	.20

Note—RT, reaction time (in milliseconds). $^{*}p < .10$. $^{**}p < .05$.

Table 7
Partial Correlations Between WebNeuro Test Scores and Education (in Years), Controlling for Log Age

Correlation	r	Significance	df
Switching of Attention			
Duration II	−.29	.05*	47
Errors II	−.19	.19	46
Verbal Interference			
Errors	−.01	.95	47
Scores	.10	.52	45
Visual Interference			
Errors	−.27	.07*	44
Scores	.36	.01**	46
Spot-the-Word Scores	.35	.01**	46
Digit Span Scores	.17	.23	47
Choice RT			
Variability	.09	.71	18
Time	−.12	.62	18
Right Hand Tapping			
Number of taps	−.08	.61	44
Variability	−.01	.95	42
Working Memory			
RT	.02	.89	46
Variability	.06	.68	46
False alarms	.02	.87	44
Misses	.03	.83	44
Total errors	−.03	.83	44
Executive Maze			
Errors	−.10	.48	47
Time to complete	−.11	.45	47

Note—RT, reaction time (in milliseconds). $^{*}p < .10$. $^{**}p < .05$.

Table 8
Total Variance Explained by Age and Education for Each WebNeuro Measure via Model R^2 for Regressions

	R^2	Variance Explained (%)
Switching of Attention		
Duration II	.22	22
Errors II	.04	4
Verbal Interference		
Errors	.04	4
Scores	.52	52
Visual Interference		
Errors	.12	12
Scores	.54	54
Spot-the-Word Scores	.22	22
Digit Span Scores	.11	11
Choice RT		
Variability	.04	4
Time	.42	42
Right Hand Tapping		
Number of taps	.03	3
Variability	.02	2
Working Memory		
RT	.04	4
Variability	.06	6
False alarms	.05	5
Misses	.02	2
Total rrors	.09	9
Executive Maze		
Errors	.08	8
Time to complete	.20	20

Note—DV = const ± b1 × age ± b2 × ln(age) ± b3 × education. RT, reaction time (in milliseconds).

DISCUSSION

The results of the study provide preliminary support for the use of WebNeuro to assess cognitive function. The correlational analyses revealed strong relationships between WebNeuro and IntegNeuro, in terms of overall performance, cognitive factor scores, and individual key test scores for each battery. Therefore, the battery appears to capture essential elements of standardized cognitive assessments including language-based measures. The standardization of task procedures and instructions, and the ability to assess patients/participants on any computer with an Internet connection offer a significant benefit to multisite studies and research initiatives.

In addition to the expected pattern of correlations across comparable tests from the two batteries, sex differences in performance were nearly identical across the batteries, further supporting the validity of WebNeuro, in terms of producing similar results to the more established IntegNeuro battery. Both age and education level (controlling for age) were significantly correlated with scores on the switching of attention (Part II) and visual interference indices. For the most part, however, test scores were not significantly correlated with age or education.

Additional information regarding the reliability of WebNeuro, the utility of alternate forms of the tests, the sensitivity of the tests to clinical indications, and differences in performance as a function of computer familiarity and other variables will be important next steps to determine the broader utility of the battery for research and clinical applications. We are currently collecting data from populations of people with schizophrenia and people with mood disorders, and will soon be able to determine the degree to which group differences (e.g., compared to healthy controls) revealed by IntegNeuro scores are replicated with WebNeuro. We are also about to begin a project examining changes in cognitive functioning with normal aging.

WebNeuro is the first comprehensive neurocognitive assessment battery available for use over the Internet. Its ease of use and automated scoring and reporting (to be described in a future paper) processes can significantly reduce cost and personnel burden in clinical and research settings by not requiring the use of a psychometrician, paper-and-pencil testing, hand scoring, or proprietary hardware use. The data presented above, demonstrating comparability to scores on an older computerized battery that had previously demonstrated validity with traditional paper-and-pencil tests, is consistent with data that Web-based cognitive measures produce results comparable to those in traditional experimental testing situations (Kozma-Wiebe et al., 2006; Krantz & Dalal, 2000).

Further time and cost savings can be realized by using WebNeuro in combination with online self-report measures of demographic and personal history information. Participants in this study completed such a measure, which is typical during IntegNeuro administration for clinical and research purposes. Research data indicate comparability of online and paper-and-pencil self-report methods (Luce et al., 2007). Therefore, complete automation of personal and neurocognitive data is now possible, leading to greater efficiency in both research settings and in the context of providing individualized evidence-based treatment for people with neurocognitive impairment.

AUTHOR NOTE

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NOTE

1. CogTest has been used in a number of studies, especially in clinical trials of schizophrenia. However, as of this writing, there are no published studies on the reliability or validity of the complete battery.

2. This test was added to both batteries subsequent to data collection for this project, and therefore no comparisons between scores on the two batteries are reported here.

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