JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY
2007, 29 (1), 100–111

Psychology Press
Taylor & Francis Group

A clinical construct validity study of a novel computerized battery for the diagnosis of ADHD in young adults

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The cognitive profile of adult attention deficit hyperactivity disorder (ADHD) remains understudied despite difficulty in diagnosis. Further, no battery of neuropsychological tests has been shown valid in adult ADHD. Continuous performance tests are widely used for ADHD but provide limited information on cognitive functioning in general. The present study evaluated the construct and discriminant validity of Mindstreams® (NeuroTrax Corp., NY), a computerized battery assessing multiple cognitive domains. Twenty-nine young male adults with ADHD diagnosis completed a Mindstreams battery, including a multi-stage continuous performance ('Expanded Go-NoGo') test, and the Conners' CPT-II (Multi-Health Systems Inc., NY). Discriminant validity was assessed by comparisons with cognitively healthy controls of comparable age and education. Expanded Go-NoGo and corresponding CPT-II outcomes were significantly correlated in ADHD participants, and the Expanded Go-NoGo test exhibited excellent discriminant validity, with ADHD participants performing more poorly than controls. ADHD participants also performed more poorly on Stroop and Staged Information Processing Speed tests.

INTRODUCTION

Attention Deficit Hyperactivity Disorder is a developmental disorder (American Psychiatric Association, 1994) that continues into adulthood (Barkley, 1998; Wender, Wolf, & Wasserstein, 2001). Research suggests that one to two thirds of children diagnosed with ADHD will continue to present significant ADHD symptoms throughout adulthood (Biederman et al., 1996; Mannuzza et al., 1991; Wender et al., 2001). There is abundant research regarding the diagnostic process of children with ADHD, and numerous studies have examined neuropsychological and psychological tests for the diagnosis of ADHD in children (Barkley, Grodzinsky, & DuPaul, 1992; Frazier, Demaree, & Youngstrom, 2004; Hechtman, 2000). Nevertheless, the diagnostic process in *adult* ADHD is a controversial one, mainly because of the need for recollection of childhood events, difficulty in obtaining reliable informants and the high comorbidity rate (e.g., learning disabilities, anxiety disorders and depression) associated with adult ADHD (Barkley, 2003; Downey, Stelson, Pomerleau, & Giordani, 1997; Gallagher & Blader, 2001; Hechtman, 2000; Seidman, Biederman, Weber, Hatch, & Faraone, 1998; Wender et al., 2001). In light of these diagnostic difficulties, neuropsychological tests may play an important role in supporting the diagnosis of adult ADHD (Frazier, Demaree, & Youngstrom, 2004; Hervey, Epstein, & Curry, 2004; Johnson et al., 2001; Murphy & Gordon, 1998;

The research presented in this paper was submitted in partial fulfillment of the requirements for the Masters degree in psychology by the second author.
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http://www.psypress.com/jcen DOI: 10.1080/13803390500519738

Seidman et al., 1998). Gallagher and Blader (2001) argue that adults with ADHD may have a particular neuropsychological profile, and thus careful use of neuropsychological tests is warranted for this population.

As in childhood ADHD, investigators have found that adult subjects with ADHD appear to present deficiencies on executive functions tasks that are related to frontal lobe functional impairments (Barkley, 1997a, 1997b). Indeed research on neuropsychological functioning in adults diagnosed with ADHD indicates that these individuals show impairments in executive and attentional functions (Frazier, Demaree, & Youngstrom, 2004; Hervey et al., 2004; Johnson et al., 2001; Frazier, Demaree, & Youngstrom, 2004). In addition, both children and adults with ADHD were found to show impaired functioning in nonverbal working memory tasks (Barkley, 1998; Johnson et al., 2001; Lovejoy et al., 1999; Mariani & Barkley, 1997). Adult ADHD subjects also performed poorly on the Stroop test which measures response inhibition (Johnson et al., 2001; Rapport, Van Voorhis, Tzelepis, & Friedman, 2001; Walker, Shores, Trollor, Lee, & Sachdev, 2000). Further, the Stroop test appears to differentiate adults with ADHD from depressed adult patients, an observation reflecting good discriminant validity (Barkley, 1997b; Katz, Wood, Goldstein, Auchenbach, & Geckle, 1998). Additionally, children and adults with ADHD appear to perform poorly on arithmetic tasks (Ackerman, Anhalt, & Dykman, 1986; Biederman et al., 1993; Seidman et al., 1998; Walker et al., 2000) and on psychomotor performance speed tasks (Holdnack, Moberg, Arnold, Gur, & Gur, 1995; Seidman et al., 1998; Silverstein, Como, Palumbo, West, & Osborn, 1995; Walker et al., 2000).

Finally, studies show that adults with ADHD perform poorly on continuous performance tests (CPTs), especially on measures of reaction time (Holdnack et al., 1995; Kovner et al., 1998) and number of commission errors (Barkley et al., 1992; Barkley, Murphy, & Kwasnik, 1996; Epstein, Johnson, Varia, & Conners, 2001; Walker et al., 2000). In a recent review, Hervey et al. (2004) concluded that addition of distracters to a classic CPT task results in greater discriminant validity.

Nevertheless, in a different review, Riccio & Reynolds (2001) concluded that although continuous performance tests are widely used for the diagnosis of ADHD, they lack specificity to differentiate ADHD from other disorders (such as, for example, post traumatic stress disorder, anxiety, depression, and cluster A personality disorders). Therefore, there is a need to integrate data from different cognitive, affective and medical sources for the individuals in the process of assessing ADHD. In other words, the CPT-II is sensitive to attentional deficits which can be part of different diagnostic entities, of which ADHD is just one, albeit the most frequent, representative. As the Mindstreams battery provides data on different cognitive aspects of the examinee's cognition, the motivation for the present study is to validate its usefulness in detecting attentional deficits. If it is, it can provide the clinician with additional useful information that can be integrated with the results of attention testing.

In some ADHD studies, tests batteries were utilized which amalgamated a number of different tests, some paper-and-pencil and some computerized (Biederman et al., 1993; Epstein et al., 2001; Holdnack et al., 1995; Johnson et al., 2001; Lovejoy et al., 1999; Seidman et al., 1998; Walker et al., 2000). However, batteries comprised of multiple stand-alone tests might be impractical for clinical use due to length of administration and to possible use of different underlying (non-normal) scales. Furthermore, Frazier et al. (2004) suggest that the large variability in ADHD neuropsychological research results might stem from the unstandardized nature of these combined batteries.

There is a growing need not only for a standardized assessment instrument, but also for a user-friendly test battery, which can examine the totality of the cognitive functioning of adults suspected of having ADHD in a more comprehensive manner. Thus, the combination of a Go-NoGo test with additional tests of executive function and tests of other cognitive domains (e.g., short-term memory, naming ability) should be most useful, particularly when integrated into a single computerized tool. In the present study we sought to evaluate the construct validity of such a novel neuropsychological tool (Mindstreams®, NeuroTrax Corp., NY). Tests available with this tool assess a range of cognitive domains and include a Go-NoGo subtest. The computerized tests were administered both to individuals diagnosed with ADHD and cognitively healthy control participants. The present study represents an attempt to validate Mindstreams as a tool for assessing ADHD, while providing additional useful clinical information.

PARTICIPANTS

Twenty eight male undergraduate college students (mean age 28.5 years; $SD = 6.4$), enrolled in a special education program for students with learning disabilities at a college in northern Israel, volunteered to participate in this study. As ADHD is much more common in men (the ratio ranges from 4:1 to 9:1 depending on the settings, according to the *Diagnostic and Statistical Manual of Mental Disorders [DSM-IV]*; American Psychiatric Association, 1994), it was difficult to recruit women with pure ADHD in the program, so for the sake of uniformity we elected to use only males. All the participants gave their written consent to participate in the study and were not paid for their participation. Diagnoses were established by an experienced clinical neuropsychologist, and confirmed in all cases according to *DSM-IV* criteria. See further details under the 'Instruments' section. All participants who volunteered for the study had ADHD, but of the original 39 volunteers, 11 had an additional diagnosis of learning disabilities and were dropped from the sample. The remaining 28 participants with ADHD alone constituted the experimental group (mean age 26.68; *SD* = 2.96). For comparison, a control group of 49 neurologically intact males with mean age of 27.04 years (*SD* = 3.96) were tested on the Mindstreams tests. These normal, cognitively intact individuals were voluntarily recruited from the community for another research project aimed at evaluating the validity and reliability of the Mindstreams battery (deemed to be cognitively healthy by expert clinicians). Normative data was previously unavailable for the Mindstreams 'Expanded Go-NoGo test' which was newly developed for this study. As a reference group for this test, an additional group of 22 cognitively intact male students, with a mean age of 24.9 years (*SD* = 3.85) were administered only this revised Go-NoGo test. Participants for this control group were screened for and judged to be free of psychopathologies and learning disabilities by a clinical psychologist and received class credit for their participation. All participants in the control and the ADHD groups were medication free at the time of testing.

INSTRUMENTS

A *DSM-IV* based self report questionnaire was developed in the Hebrew language to facilitate diagnosis according to the standard *DSM-IV* criteria. Participants were asked to indicate whether or not they experience, or exhibit, behavioral symptoms which have persisted over the past six months and/or in their childhood (American Psychiatric Association, 1994). This is so because certain symptoms that are characteristic of ADHD in childhood are not seen typically in adulthood (e.g., breaking many toys). There were 20 'Combined' and 8 'Inattentive' types, but since a preliminary examination of the results did not yield significant differences between these two types, and due to the relatively small group, these two diagnostic groups were treated as the ADHD group for the purpose of this paper.

Conners' Continuous Performance test II (CPT-II)

The results of the Conners' Continuous Performance test II (Conners, 2000) were used to confirm (but not establish) the *DSM-IV* ADHD diagnosis. The Conners 'cutoff point' used for the evaluation of ADHD was a T-score over 60 in any one of the six primary indices, which is indicated in the CPT-II manual as being a high probability marker for attentional problems (Conners, 2000). The CPT-II is a computer based, sustained attention test. Respondents are required to press the mouse button when any letter except the target letter "X" appears. The CPT-II was administered using a laptop personal computer and took approximately 14 minutes to complete. The CPT-II has adequate reported reliability (Split half coefficients on all measures ranging from 0.73 to 0.95; Conners, 2000). In a reported comparison between a clinical ADHD group of adults and a non-clinical group, the ADHD clinical subjects performed significantly worse than the non-clinical group on all measures ($p < .001$; Conners, 2000). These results indicate that the CPT-II is sensitive to attentional deficits present in the ADHD population, and it was therefore chosen to be used as the external measure against which to assess the Mindstreams battery.

Mindstreams neuropsychological test battery

All participants completed a battery of Mindstreams® (NeuroTrax Corp., NY) tests designed for detection of mild cognitive impairment. A detailed treatment of the NeuroTrax system, including the computerized tests, data processing, normative data collection and usability considerations appears elsewhere (Dwolatzky et al., 2003; Mindstreams Cognitive Health Assessment, 2006). In brief, Mindstreams consists of custom software that resides on the local testing computer and serves as a platform for interactive cognitive testing that produces precise accuracy and reaction time (RT; millisecond timescale) data. Tests are adaptive, in that the level of difficulty is adjusted accordingly depending upon performance. This feature increases sensitivity, minimizes the prevalence of ceiling effects, and shortens administration time when appropriate as indicated by performance. Feedback is provided in the practice sessions, which precede each test, but not during the actual tests. Web-based administrative features allow for secure entry and storage of patient demographic data. Once testing is completed on the local computer, data are uploaded to a central sever, where calculation of outcome parameters from raw single-trial data and report generation occur. Most normative data for Mindstreams tests has been collected from individuals whose primary language is either English or Hebrew using appropriate language versions.

The Mindstreams test battery used for this study sampled a wide range of cognitive domains, including verbal memory, non-verbal memory, executive function, visual spatial processing, information processing speed, problem solving ability, and motor skills (cf. Table 1; about 45 to 60 minutes administration time). Administration time was about 35 minutes. All responses were made with the mouse or with the number pad on the keyboard. Participants were familiarized with these input devices at the beginning of the battery, and practice sessions prior to the individual tests prepared them for the specific types of responses required for each test.

Outcome parameters for each test included accuracies and RTs, and other test-specific parameters, as in Table 1. Given the speed-accuracy tradeoff (Cauraugh, 1990) a performance index (computed as [accuracy/RT]*100) was computed for timed Mindstreams tests in an attempt to capture performance both in terms of accuracy and RT. Test-retest reliability coefficients were assessed in a separate study and ranged from 0.64 to 0.84 (Schweiger, Doniger, Dwolatzky, Jaffe, & Simon, 2003). Following are brief descriptions of the Mindstreams tests that were included in the present study.

Non-Verbal Memory

Eight images are presented for 20 seconds, followed by a recognition test in which each image is presented together with similar images of three different orientations. Participants are required to remember the orientations of the originally presented objects. Four consecutive repetitions of the recognition test are administered during the 'learning' phase of the test. An additional recognition test is administered following a delay of approximately 10 minutes.

Expanded Go–NoGo test

A series of large colored stimuli are presented centrally at pseudo-random intervals. Participants are instructed to respond as quickly as possible by pressing a mouse button if the color of the stimulus is blue, white or green, but if the color is red, no response is to be made. The test consists of a baseline phase and three comparison phases, each with increasing difficulty relative to baseline in a different way: In the second phase, inter-stimulus interval (ISI) is shorter relative to baseline. In the third, additional red stimuli are presented. In the final phase, distracter stimuli are presented in the periphery. No break was given between the four phases, and the transitions between them were not marked in any way.

Mindstreams Stroop test

The Stroop is a well-established test of response inhibition (MacLeod, 1991). The Mindstreams Stroop test consists of three phases. Participants are presented with a pair of large colored squares, one on the left and the other on the right side of the screen. In each phase, participants are instructed to choose as quickly as possible which of the two squares is a particular color by pressing either the left or right mouse button, depending upon which of the two squares is the correct color. First, participants are presented with a general word that does not name a color in colored letters. In the next phase, participants are presented with a word that names a color in white letters. In the final phase (the Stroop phase), participants are presented with a word that names a color, but the letters of the word are in a color other than that named by the word. The instructions for the final phase are to choose the color of the letters, and not the color named by the word.

Verbal Function

Pictures of common objects of low and high familiarity are presented. Participants are instructed to select the name of the picture from four choices. In a related test, participants are instructed to select the word that best rhymes with the name of the picture.

Problem Solving

Pictorial puzzles of gradually increasing difficulty are presented. Each puzzle consists of a 2×2 array containing three black-and-white line drawings and a missing element. Participants must choose the best fit for the fourth (missing) element of the puzzle from among six possible alternatives. This subtest is somewhat similar to the familiar Raven's Standard Progressive Matrices Test and in fact, was found to correlate significantly with it in a separate study (forthcoming).

TABLE 1
Mindstreams outcome parameters used in this study

Mindstreams test	*Cognitive domains tested*	*Outcome parameters*
Expanded Go-NoGo Response Inhibition	Executive Function, Attention	Accuracy Mean RT Performance Index RT Standard Deviation Errors of Commission Errors of Omission RT for Errors of Commission
Non-Verbal Memory	Memory	*Immediate Recognition* Accuracy, Repetition 1 Accuracy, Repetition 2 Accuracy, Repetition 3 Accuracy, Repetition 4 Accuracy, Repetitions 1–4 *Delayed Recognition* Accuracy
Problem Solving	–	Accuracy (Non-Verbal IQ)
Stroop Interference	Executive Function, Attention	*No Interference: Letter Color [1]* Accuracy Mean RT Performance Index RT Standard Deviation *No Interference: Word Meaning [2]* Accuracy Mean RT Performance Index RT Standard Deviation *Interference: Letter Color vs. Word Meaning [3]* Accuracy Mean RT Performance Index RT Standard Deviation
Finger Tapping	Motor Skills	Inter-Tap Interval Tap Interval Standard Deviation
Catch Game	Executive Function, Motor Skills	Time to Make 1st Move Time to Make 1st Move Standard Deviation Average Direction Changes Per Trial Average Error Per Trial Total Score
Staged Information Processing Speed	Attention, Information Processing Speed	*SINGLE DIGIT* *Slow Speed [1.1]* Accuracy Mean RT Performance Index RT Standard Deviation *Medium Speed [1.2]* Accuracy Mean RT Performance Index RT Standard Deviation *Fast Speed [1.3]* Accuracy Mean RT Performance Index RT Standard Deviation

(Continued)

TABLE 1
(Continued)

Mindstreams test	*Cognitive domains tested*	*Outcome parameters*
		TWO-DIGIT ARITHMETIC
		Slow Speed [2.1]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
		Medium Speed [2.2]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
		Fast Speed [2.3]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
		THREE-DIGIT ARITHMETIC
		Slow Speed [3.1]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
		Medium Speed [3.2]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
		Fast Speed [3.3]
		Accuracy
		Mean RT
		Performance Index
		RT Standard Deviation
Verbal Function	Verbal Function	*Rhyming*
		Accuracy
		Picture Identification
		Accuracy
Visual Spatial Processing	Visual Spatial	Accuracy

Note: RT = Reaction Time.

Visual Spatial Processing

Computer-generated scenes containing a red pillar are presented. Participants are instructed to imagine viewing the scene from the vantage point of the red pillar. Four alternative views of the scene are presented as choices.

Staged Information Processing Speed test

This test comprises three levels of information processing load: single digits, two-digit arithmetic problems (e.g., 5 − 1), and three-digit arithmetic problems (e.g., 3 + 2 − 1). For each of the three levels, stimuli are presented at three different fixed rates, incrementally increasing in speed as testing continues. Participants are instructed to respond as quickly as possible by pressing the left mouse button if the digit or result is less than or equal to four and the right mouse button if it is greater than 4.

Finger Tapping

Participants receive two trials during which they are instructed to tap on the mouse button for 12 seconds, using their dominant hand.

Catch Game

The Catch game is a novel motor screen that assesses cognitive domains distinct from those in other Mindstreams tests. Participants must "catch" a rectangular white object falling vertically from the top of the screen before it reaches the bottom of the screen. Mouse button presses move a rectangular green "paddle" horizontally so that it can be positioned directly in the path of the falling object. The test requires hand-eye coordination, scanning and rapid responses.

PROCEDURE

All ADHD participants completed the CPT-II individually in a quiet room. Each participant was seated in front of the computer at their own comfortable distance and received instructions according the CPT-II standard guidelines (Conners, 2000). Following a 30-minute break, participants completed Mindstreams testing.

Statistical Analysis

Mindstreams performance of ADHD participants was compared with that of controls by utilizing a multivariate analysis of variance (MANOVA) of the main battery outcomes that are used clinically (Dwolatzky et al., 2003). Pearson correlations were used to examine the correspondence between CPT-II and Mindstreams variables in ADHD participants. The area under the curve (AUC) computed by receiver operating characteristic analysis was used to demonstrate the overall discriminabilty of the Mindstreams Expanded Go-NoGo test. In addition, a multivariate discriminant (canonical) function analysis (DFA) was conducted in order to examine the discriminability of all other Mindstreams' tests. Two-tailed statistics were used throughout, and $p < .05$ was considered significant. All statistics were computed with SPSS statistical software (SPSS, Chicago, IL).

RESULTS

A MANOVA was conducted to assess the overall difference between the ADHD group and controls on the ten Mindstreams variables presented in Table 2. The MANOVA showed an overall significant difference between the ADHD and non-ADHD groups [Hotelling's Trace = 0.796, $F(10, 67) = 5.335$, $p < .001$]. Subsequently, two multivariate discriminant function analyses (DFA) were conducted between the two groups. The first analysis was conducted between the ADHD and non-ADHD groups on the ten Mindstreams variables as dependent variables without the Expanded Go-NoGo subtest. The second analysis was conducted only with the six Expanded Go-NoGo variables as dependent variables.

Results show a robust significant discriminant effect between the ADHD and non-ADHD groups on the ten Mindstreams variables [Wilk's Lambda = .771, χ^2 (8) = 39.003, $p < .0001$]. Table 3 presents the DFA standardized discriminant function coefficients between the two groups. The resulting function was able to classify correctly 84.7% of the individuals in the sample. As can be seen from the Table 3, the performance index for the Staged Information Processing Speed subtest, which involves numerical challenge and working memory, has the highest weight in the discriminant equation.

TABLE 2
Multivariate analysis of variance (MANOVA) comparing performance of individuals with ADHD and normal controls on selected Mindstreams variables

	ADHD		*Controls*			
Mindstreams variables	*M*	*SD*	*M*	*SD*	*F*	*Cohen's d*
Non-Verbal Memory (Accuracy, Repetitions 1–4)	83.72	12.76	84.35	13.31	0.43	
Stroop Interference (Interference Level, PI)	18.9	7.44	23.95	4.85	11.39**	.75
Visual Spatial Processing (Accuracy)	70.17	12.88	73.91	11.89	1.7	
Verbal Function (Rhyming, Accuracy)	91.57	6.95	87.21	7.56	6.4*	.60
Staged Information Processing Speed (All Levels, PI)	9.45	1.28	10.68	1.5	13.37***	.87
Staged Information Processing Speed (All Levels, Mean RT)	915.97	114.33	842.42	98.56	8.99**	.69
Catch Game (Total Score)	856.34	138.59	873.33	140.48	0.27	
Catch Game (Average Direction Changes Per Trial)	0.1414	0.086	0.1284	0.071	0.521	
Finger Tapping (Inter-Tap Interval)	168.52	26.18	181.82	26.56	4.62*	.50
Finger Tapping (Tap Interval Standard Deviation)	45.17	27.35	80.51	114.24	2.67	

Notes. *$p < .05$, **$p < .01$, ***$p < .001$. PI = Performance Index; RT = Reaction Time. Descriptive statistics for timed parameters are given in milliseconds. Accuracies are given as percent correct. Reaction times computed for correct responses only.

TABLE 3
Standardized factor coefficients of the discriminant analysis (forced) performed on the ADHD vs. normal control groups using selected Mindstreams variables

Mindstreams variables	*Standardized function coefficients*
Staged Information Processing Speed (All Levels, PI)	1.785
Staged Information Processing Speed (All Levels, Mean RT)	.955
Finger Tapping (Inter-Tap Interval)	.663
Catch Game (Average Direction Changes Per Trial)	–.348
Catch Game (Total Score)	–.340
Stroop Interference (Interference Level, PI)	.319
Verbal Function (Rhyming, Accuracy)	–.187
Finger Tapping (Tap Interval Standard Deviation)	–.120
Non-Verbal Memory (Accuracy, Repetitions 1–4)	–.070
Visual Spatial Processing (Accuracy)	–.069

Notes: PI = Performance Index; RT = Reaction Time.

The second DFA yielded a robust significant discriminant effect between the ADHD and non-ADHD groups on the six Mindstreams Expanded Go-NoGo variables [Wilk's Lambda = .431, χ^2 (8) = 38.322, p < .0001]. Table 4 presents the DFA standardized discriminant function coefficients between the two groups. Using the resulting discriminant function, 92% of the individuals in the sample were classified correctly, using the Mindstreams Expanded Go-NoGo test alone.

A comparison between ADHD and control groups is presented in Table 2 using corrected univariate F tests from the MANOVA. The ADHD group performed significantly worse on the interference phase of the Mindstreams Stroop test (p < .001) and the Staged Information Processing Speed test (p < .001) and responded more slowly on the Staged Information Processing Speed test (p < .004). Other variables not shown in the table did not show differences between the groups. Interestingly, ADHD participants had a shorter inter-tap interval (p < .035) on the Finger Tapping test and were more accurate on the Verbal Function Rhyming test (p < .013). No significant differences were found between ADHD and control groups on the Non-Verbal Memory test, the Visual Spatial Processing test, or the Catch Game, nor was there a difference for standard deviation of inter-tap interval on the Finger Tapping test.

TABLE 4
Standardized factor coefficients of the discriminant analysis (forced) performed on the ADHD vs. normal control groups using Mindstreams Expanded Go-NoGo variables

Mindstreams Expanded Go-NoGo variables	*Standardized function coefficients*
PI ([accuracy/RT]*100)	2.117
Mean RT	1.380
RT Standard Deviation	.190
Errors of Omission	–.189
Accuracy	.112

Note: PI = Performance Index; RT = Reaction Time.

Table 5 presents correlations between four CPT variables and fourteen Mindstreams variables, including the corresponding variables from the Expanded Go-NoGo test. As four ADHD participants did not take the CPT-II, correlations were computed on the remaining 25 ADHD participants. Results show a strong correlation between the CPT-II total number of commission errors variable and the corresponding total number of commission errors variable from the Mindstreams Expanded Go-NoGo test (r = .792, p < .01). Similarly, a strong correlation was found between CPT-II mean RT and the corresponding Expanded Go-NoGo RT variable (r = .723, p < .05). A moderate correlation was found between CPT-II standard deviation of RT and the corresponding Mindstreams variable (r = .421, p < .05). The correlation between the CPT-II total number of omission errors variable and the corresponding Mindstreams variable was not significant. In contrast, the difference in the number of omission errors between ADHD and control groups was significant. No correlations were seen with other Mindstreams tasks such as memory and verbal subtests, as would be expected from subtests purporting to measure different constructs.

Table 6 presents the results of a MANOVA comparing the performance of ADHD participants and controls on Mindstreams Expanded Go-NoGo test variables. The MANOVA showed an overall significant difference between the ADHD and non-ADHD groups [Hotelling's Trace = 1.339, F(6, 43) = 9.593, p < .001]. The performance index for ADHD participants was significantly poorer than for controls [F(1,48) = 29.679, p < .001; AUC = .921, p < .001]. Accuracy for the ADHD group was significantly poorer (p = .014), RT was significantly slower (p = .007), and RT was significantly more variable (p = .012). Furthermore, participants in the ADHD group made significantly more errors of omission (p = .005). No

TABLE 5
Inter-correlations among selected CPT-II and Mindstreams variables

Mindstreams variables	*CPT-II Errors of Commission*	*CPT-II Errors of Omission*	*CPT-II Mean RT*	*CPT-II RT SD*
Expanded Go-NoGo (Errors of Commission)	**.792****	.019	**−.611****	−.250
Expanded Go-NoGo (Errors of Ommission)	.156	−.212	**−.341***	−.313
Expanded Go-NoGo (Mean RT)	**−.580****	.290	**.723***	**.394***
Expanded Go-NoGo (RT SD)	**−.371***	**.395***	**.874****	**.421***
Stroop Interference (Interference Level, PI)	−.125	.092	−.266	**−.375***
Non-Verbal Memory (Accuracy, Repetitions 1–4)	−.287	−.260	.237	.153
Finger Tapping (Inter-Tap Interval)	−.079	−.037	.062	.005
Finger Tapping (Tap Interval SD)	−.101	.086	.189	.028
Catch Game (Average Direction Changes Per Trial)	.106	−.123	−.303	−.157
Catch Game (Total Score)	.055	.047	−.289	−.303
Staged Information Processing Speed (All Levels, PI)	−.039	−.003	.041	.222
Staged Information Processing Speed (All Levels, Mean RT)	−.006	−.035	−.024	−.217
Verbal Function (Rhyming, Accuracy)	.199	.004	−.230	−.255
Visual Spatial Processing (Accuracy)	**−.367***	.016	**.384***	.267

Notes. *$p < .05$, **$p < .01$. PI = Performance Index; RT = Reaction Time; SD = Standard Deviation.

TABLE 6
MANOVA comparing performance of individuals with ADHD and normal controls on Mindstreams Expanded Go-NoGo variables

	ADHD		*Control*				
Mindstreams variables	*M*	*SD*	*M*	*SD*	*F*	*Sig.*	*Cohen's d*
Accuracy	92.3	6.2	95.9	2.1	6.56	.014	0.78
Mean RT	469.2	164.4	368.1	33.2	8.02	.007	0.85
PI ([accuracy/RT]*100)	21.2	4	26.4	2.2	26.68	.001	1.61
RT SD	105.1	59.1	70.8	18.1	6.9	.012	0.78
Errors of Omission	2.9	4.4	0.1	0.3	8.52	.005	0.9
Errors of Commission	6.4	5.6	4.9	2.4	1.28	.269	

Notes: PI = Performance Index; RT = Reaction Time; SD = Standard Deviation.

significant difference was found in errors of commission ($p = .269$).

DISCUSSION

The results of the present study establish that the Mindstreams test battery can be used to diagnose attentional deficits. That is, using a traditional continuous performance test (CPT-II) as the standard documentation of attentional deficits (Riccio & Reynolds, 2001), we provide data showing robust construct and discriminant validity in the assessment of attention and executive functions. Good correspondence was found between Mindstreams Expanded Go-NoGo variables and corresponding CPT-II variables. At the same time, the CPT-II variables do not correlate with other variables of the Mindstreams battery, such as the nonverbal memory and verbal tasks (see Table 5.) The results also indicate good discriminant validity of the Mindstreams Go-NoGo test in differentiating between ADHD and non-ADHD by identifying common aspects of attentional/impulsive deficits: more errors of commission (response to stimuli other than the target; Riccio & Reynolds, 2001), slowed RT, greater variability of RT, and reduced accuracy. Continuous performance tests have been shown to differentiate between normal adult individuals and adult individuals with attentional deficits (Barkley et al., 1992; Barkley et al., 1996; Epstein et al., 2001; Holdnack et al., 1995; Kovner et al., 1998; Walker et al., 2000). However, adults diagnosed with many other psychopathologies and frontal lobe disorders, such as traumatic brain injuries, also perform poorly on continuous performance tests (Riccio & Reynolds, 2001). In fact, in their review, Riccio & Reynolds (2001) discuss studies in which the differentiation between ADHD individuals and individuals with other disorders was not possible using continuous performance tests. Hence there is a need for additional neuropsychological testing to enhance discriminant validity in arriving at a diagnosis of adult ADHD.

One unexpected result of the present study was low correlation between CPT-II and Mindstreams number of omission errors (not responding to a target stimulus (Riccio & Reynolds, 2001)), despite a significant between-group difference for the Mindstreams variable. These findings may be explained on the basis of the sensitivity of omission errors to the test demands (e.g., the proportion of targets to distracters), resulting in large differential effects in clinical populations. The low correlation can be attributed to a differing proportion of target stimuli between the CPT-II and Mindstreams tests (i.e., proportionately fewer "go" trials on the CPT-II as compared with Mindstreams). Irrespective of these different task demands, Mindstreams omission errors discriminated between groups. Also unexpected was the significant correlation between CPT-II and Mindstreams errors of commission despite the lack of a between-groups difference. The significant correlation indicates a correspondence in commission errors across the two tests, but the presence of related performance doesn't necessitate a between-groups difference, especially with rather high within-group variance in both groups. Hence commission errors show the opposite pattern from omission errors—significant correlation between the two dependent measures of commission errors (on Mindstreams and CPT-II), but no significant difference between the clinical group and controls. These two opposing findings may reflect the increased variability seen in the performance of the ADHD group, which prevents detection of differences given the relatively small number of participants. The lack of correlation between the omission errors of the two batteries is also not surprising, given that the validity studies reported by the CPT-II manual showed omission errors to have little discriminatory incremental validity, and thus to be 'non-diagnostic' from the CPT-II's perspective; perhaps this is due again to the large variability. It is also the case that different frequencies of targets and distracters in the stimuli can affect accuracy of detection and of false alarms.

A review of studies employing neuropsychological test batteries to assess adult ADHD individuals resulted in a neuropsychological profile of adults with ADHD (Gallagher & Blader, 2001). This profile is consistent with the core executive function deficit associated with ADHD (Barkley, 1997a). On the other hand, adults with ADHD may not exhibit deficits on motor or verbal tests, whereas other populations of patients with attentional deficits, such as those with brain damage, often show them. Using the Mindstreams test battery we demonstrated that individuals with ADHD perform more poorly than normal individuals on the Mindstreams Stroop and Staged Information Processing Speed tests, consistent with core deficits in executive function and attention (Barkley, 1998; Barkley, 1997b). These results are consistent with a large body of research demonstrating the efficiency of the Stroop test in identifying executive function deficits (for a review, see Homack & Riccio, 2004). In addition, we found that adults with ADHD performed better on the Finger Tapping and Verbal Function Rhyming tests. These results indicate, in addition, that the current cohort did not suffer from general cognitive or motor decline that might otherwise explain the overall low performance on executive function and attentional variables. These results also indicate that significant depression and anxiety, which typically affect performance across the board, most likely were not a factor in the present study. Thus, Mindstreams provides additional information on tasks that could distinguish ADHD from other populations with cognitive deficits including attentional problems.

The present cohort of adults with ADHD may be somewhat unusual, in that all were able to pursue higher education despite academic problems and a probable history of behavioral problems. In addition to being well educated, as reflected by their superior Verbal Function Rhyming performance, the current cohort may have been highly motivated relative to the general adult ADHD population, and this may have contributed to their superior motor performance. However, this result may also be attributable to greater obsessive tendencies among the ADHD participants (Arnold, Ickowicz, Chen, & Schachar, 2005), who may try harder than normals to do well on the tests. Future studies should attempt to tease apart these two possibilities. Another aspect of the present study requiring further research is the use of only male participants. Future research along the present lines should include not only females, but also groups of varying ages and educational backgrounds.

There is relatively limited reliable information regarding the neuropsychological profile of adults with ADHD and more research is needed to elucidate whether or not adults with ADHD have a characteristic cognitive profile on standardized testing. Nevertheless, comprehensive information on all aspects of cognitive functioning of individuals suspected of suffering from ADHD is clearly needed in addition to clinical diagnosis to aid in therapeutic, academic and occupational planning for this population.

Whereas the present study confirms the validity of Mindstreams as a tool for assessing ADHD, further research is desirable to provide additional convergent data with other instruments used to diagnose ADHD, such as the Test of Variables of Attention (TOVA) or the Integrated Visual and Auditory Continuous Performance Test (IVA).

Original manuscript received 28 January 2005
Revised manuscript accepted 5 December 2005
First published online 10 November 2006

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