Comparative efficiency of a discrepancy analysis for the classification of Attention-Deficit/Hyperactivity Disorder in adults[☆]

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Abstract

The present study evaluated an alternative method of neuropsychological test interpretation for the classification of Attention-Deficit/Hyperactivity Disorder (ADHD) in adults. Specifically, an intra-individual discrepancy analysis was implemented in which differences between intellectual functioning and performance on a battery of six frontal/executive tests were examined within a homogeneous group of ADHD adults and matched normal controls. Significant group differences were identified between the ADHD adults and control sample on each of the dependent measures, with moderate diagnostic efficiency rates for the individual measures and a Discrepancy Impairment Index (DII). The discrepancy analysis approach generated significantly greater sensitivity in detecting the presence of ADHD as compared to a level of performance interpretive approach. Overall, these results provide support for the consideration of discrepancies between intellectual ability and frontal/executive

functioning for the assessment of adult ADHD. © 2002 National Academy of Neuropsychology. Published by Elsevier Science Ltd.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neuropsychiatric condition typically identified among the childhood behavioral and developmental disorders that manifests via a wide range of physiological, cognitive, and behavioral impairments (American Psychiatric Association, 1994; Barkley, 1998). While ADHD is widely hypothesized to be a neuro-behavioral syndrome, the precise etiology of the disorder has yet to be determined and may not be the result of a single factor (Zametkin & Ernst, 1999). Instead, the disorder likely reflects a final common pathway of select genetic, biological, and psychological components (Wender, 1995). Nevertheless, frontal lobe inefficiencies and related executive dysfunctions have proven to play a fundamental role in the etiology, development, and maintenance of the various cognitive and behavioral symptoms associated with ADHD (Faraone et al., 2000). Empirical evidence in support of the frontal lobe hypothesis arises from myriad investigations within neurochemistry, neuroanatomy, neuroimaging, and neuropsychology (e.g., Zametkin et al., 1990).

The signs and symptoms of ADHD were initially hypothesized to subside, or even disappear, with the onset of puberty and/or adulthood (Fargason & Ford, 1994). While a subgroup of children diagnosed with ADHD do not manifest clinically significant symptoms in adulthood, many are thought to maintain at least one disabling symptom throughout their lives (Weiss & Hechtman, 1993). In fact, clinical and empirical evidence indicates that between 30% and 50% of children diagnosed with ADHD continue to show impairment into adulthood (Mannuzza, Klein, & Addalli, 1991). Prevalence rates for adult ADHD range between 2% and 5% of the general population (Fargason & Ford, 1994).

Increased empirical and clinical interest in adult ADHD has heightened the need for more reliable and valid assessment techniques with enhanced diagnostic efficiency. In recent years, researchers have attempted to identify various neuropsychological instruments as useful means of identifying adults and children with ADHD (e.g., Lovejoy et al., 1999; Perugini, Harvey, Lovejoy, Sandstrom, & Webb, in press). A variety of investigations have demonstrated the ability of neuropsychological instruments to differentiate ADHD adults and controls on measures of attention, verbal fluency, list learning, abstract reasoning, and cognitive flexibility (e.g., Downey, Stelson, Pomeleau, & Giordani, 1997; Jenkins et al., 1998; Seidman, Biederman, Weber, Hatch, & Faraone, 1998; Walker, Shores, Trollor, Lee, & Sachdev, 2000). Yet there are presently no litmus tests for the diagnosis of ADHD.

Indeed, considering the variable levels of attention and cognitive efficiency found throughout this diagnostic group, there remains a high degree of inconsistency for specific instruments across studies evaluating the utility of assessment for ADHD in adulthood.

Patients diagnosed with ADHD often show sporadic or inconsistent attention/cognitive efficiency, which may be difficult to identify, particularly considering the increased structure often provided by one-to-one testing environments (Barkley, 1998). Moreover, the role of neuropsychological assessment in facilitating diagnostic accuracy has historically been problematic for disorders involving attentional systems (Reynolds, 1997). Thus, while neuropsychological testing may be indicated in particular instances, it has not provided sufficient diagnostic power for routine clinical use (Zametkin & Ernst, 1999). Taking into account the variable levels of sensitivity inherent to many individual tests, a battery approach has been hypothesized to heighten the clinician's ability to detect the presence ADHD in adults and children (Lovejoy et al., 1999; Perugini et al., in press).

1.1. Discrepancy analyses

The present study attempted to empirically validate an alternative neuropsychological interpretive technique for the assessment and classification of adult ADHD. This investigation also addressed controversial theoretical issues regarding the implications of discrepancies between intellectual ability and neuropsychological performance as an indicator of subtle brain dysfunction. More specifically, the present study sought to examine the notion that measured discrepancies between intellectual ability and frontal/executive functioning are indicative of subtle, domain-specific neuropsychological impairment and ultimately aid the practicing clinician in reaching more accurate diagnoses for adults suspected of having ADHD.

Neuropsychologists have traditionally relied upon level of performance analyses and standard published cutoff scores in classifying groups and reaching diagnostic conclusions: A tendency that is particularly evident in the burgeoning adult ADHD literature. However, the exclusive utilization of a level of performance analysis may predispose clinicians to ignore potentially useful aspects of neuropsychological data. Various authors (viz., Reitan & Wolfson, 1985) have taken great strides to incorporate alternate means of data interpretation into the general consciousness of clinical neuropsychologists. In addition to standard quantitative approaches, they have emphasized the consideration of various pathognomonic signs, patterns of performance (i.e., interrelationships between tests), and lateralizing indicators. For example, when coupled with good IQ scores, deficient scores on the four general indicators on the Halstead–Reitan Neuropsychological Test Battery [i.e., Halstead Impairment Index (HII), Category Test, Trail Making Test (TMT), Part B, and Tactual Performance Test] possess tremendous predictive power for the presence of brain impairment (Reitan & Wolfson, 1985).

The analysis of patterns of performance among neuropsychological tests is a familiar concept to most psychologists; yet this method of interpretation is inherently underutilized in day-to-day clinical practice (Macciocchi & Barth, 1996). Significant discrepancies between general intellectual functioning and particular neuropsychological domains are widely hypothesized to be indicative of brain dysfunction (Ivnik et al., 2000; Moses, Pritchard, & Adams, 1997). Discrepancy analyses are an alternate means of data interpretation that allow for the identification of patterns of neuropsychological strengths and weaknesses relative to an individual's global ability level. That is, average performance on neuropsychological

measures for patients demonstrating above-average to superior intellectual scores may, in fact, be indicative of a significant, albeit relative, impairment (viz., it does not represent what is to be expected by person-specific norms) (Cimino, 1994).

Lezak (1995) suggested that the use of absolute cutoff scores to determine the presence or absence of a given disorder creates a raised "floor effect" and invariably increases the likelihood of making a Type II error (i.e., false-negative). In an effort to avoid such serious interpretive errors, clinicians are widely encouraged to implement multiple means of data interpretation, including intra-individual comparisons, or discrepancy analyses (e.g., Reitan, 1985). As such, the interpretation of neuropsychological test profiles is undertaken with an adjusted expectation based in relation to higher levels of intellectual functioning (Reitan, 1985). Comparison of an individual's expected level of overall cognitive performance (i.e., intellectual ability) to domain-specific attentional and frontal/executive measures facilitates the delineation of specific patterns of dysfunction and ultimately renders more accurate diagnostic decisions (Slomka, 1998).

Myriad scientific investigations have provided empirical support for this approach to data interpretation. A variety of normative studies have demonstrated that the integration of corrections for such variables as educational level and intellectual functioning is not only feasible, but also preferable (e.g., Boone et al., 1993; Brittain et al., 1991; Heaton, Grant, & Matthews, 1991; Hermann, Wyler, Steenman, & Richey, 1988; Seidenberg, Giordani, Berent, & Boll, 1983; Wiens, Tindall, & Crossen, 1994). In 1985, Reitan reported significant correlations between control subjects' IQ level and the HII. In contrast, brain-damaged participants demonstrated a greater degree of intra-individual discrepancies between intellectual measures and neuropsychological performance. Participants exhibiting brain damage and higher IQ levels showed discrepancy impairments, whereas the total discrepancy between IQ and neuropsychological test scores were not substantial among normal controls. More recently, Ivnik et al. (2000) reported on the diagnostic utility of alternative approaches to neuropsychological test interpretation in a geriatric population. The results of this study indicated that comparisons of participants' neuropsychological test performance to their estimated overall premorbid ability level were diagnostically useful.

Still, various researchers contend that patients with above-average intelligence should not be expected to perform comparably on other neuropsychological measures (e.g., Dodrill, 1997). For example, is an individual who achieves a Full Scale IQ (FSIQ) of 125 and performs in the average range on a series of domain-specific neuropsychological measures displaying significant impairment? Citing evidence from an investigation using 181 control subjects, Dodrill (1997) reported that only limited improvements were appreciated on neuropsychological measures as the FSIQ scores rose above scores of 100. This phenomenon was explained by suggesting that, unlike intellectual abilities, many domains of neuropsychological functioning are not normally distributed; instead, scores on neuropsychological measures are likely to regress toward the mean. Thus, according to this point of view, average performance on neuropsychological tests for patients with above-average intellectual functioning would be considered normal, and consequently, not indicative of specific neurocognitive impairment.

However, this approach to data interpretation assumes that measures of general intellectual ability and specific tests of neuropsychological functioning are independent from one another

(Reitan, 1985). Critiques of the Dodrill (1997) study have noted that the percentage of impaired scores obtained by the control participants fell in correspondence with higher levels of intellectual functioning (Bell & Roper, 1998). Subsequent rejoinders also provide empirical evidence supporting the presence of a strong positive relationship between intellectual ability and complex neuropsychological functioning, particularly for individuals with above-average IQ scores (e.g., Horton, 1999; Tremont, Hoffman, Scott, & Adams, 1998). While intellectual assessment techniques and neuropsychological measures do not share a perfect correlative relationship, they invariably demonstrate a consistent positive relationship with one another and share a significant amount of the variance across studies (e.g., Moses et al., 1997).

1.1.1. Rationale for the present study

In light of recommendations to incorporate alternative means of data interpretation, the current investigation was undertaken as a direct follow-up analysis of the study published by Lovejoy et al. (1999). Using norm-referenced cut scores and a standard level of performance interpretive approach, Lovejoy et al. reported significant differences between a group of ADHD adults and matched normal controls on several measures of frontal/executive functioning. The highest rates of diagnostic accuracy were provided by a Summary Index (SI) that examined participants' performance across the entire battery of tests (n.b., abnormal scores were good predictors of ADHD, but normal scores were not necessarily indicative of the absence of ADHD).

In an effort to establish the validity of discrepancy analyses for the identification of ADHD in adults, the present study provided a reanalysis of the original Lovejoy et al. (1999) data using discrepancies between intellectual ability and frontal/executive functioning as an indicator of impairment. The use of a single sample was necessary to perform direct statistical comparisons of the classification rates and receiver-operating characteristic plots produced by the two interpretive techniques. By examining two unique test analysis strategies with the same population of subjects, one effectively avoids the variance inherent to comparisons across separate samples. It was hypothesized that, when compared to matched normal controls, the ADHD adults would demonstrate significantly greater discrepancies between intellectual functioning and scores on a battery of frontal/executive measures. Moreover, the incorporation of a discrepancy analysis was hypothesized to yield significantly more efficient, accurate, and sensitive classification rates as compared to the level of performance interpretive approach (Lovejoy et al. 1999).

2. Method

2.1. Participants

The 52 participants ($N = 52$) from the original Lovejoy et al. (1999) investigation were analyzed in the present follow-up study. The sample contained an equal number of males ($n = 26$) and females ($n = 26$), with an age range of 21 to 55 years. Twenty-six adults diagnosed

with ADHD were recruited from their respective treating psychiatrists using a brief informational notice ($n = 26$). All ADHD participants met DSM-IV diagnostic criteria for ADHD ($n = 25$ Combined Type; $n = 1$ Predominately Inattentive Type) as determined by a clinical interview performed by a board certified psychiatrist and the participants' endorsement of sufficient DSM-IV symptoms to meet criteria for ADHD. Stringent exclusionary criteria were implemented, including: (1) current or history of other Axis I diagnoses; (2) current prescriptions of psychoactive medications other than stimulants (i.e., methylphenidate and dextroamphetamine only); (3) scores less than 85 on a short-form intellectual estimate; (4) current or history of substance abuse; (5) history of neurological disease or head injury; and (6) previous diagnosis or special education remediation for a specific learning disability. Additionally, ADHD participants were included in the present study only if they reported that stimulant medications were "very helpful" in addressing their symptomatology. In an effort to negate the benefits attained from the medication, ADHD participants were evaluated only after a 12-hour reprieve from stimulants. Exclusionary criteria for the normal control participants included: (1) endorsement of greater than three symptoms of ADHD; (2) current or prior history of ADHD diagnosis; (3) scores less than 85 on a short-form intellectual estimate; (4) current or history of substance abuse; (5) history of neurological disease or head injury; and (6) previous diagnosis or special education remediation for learning disability. No significant between-group differences were identified on the basis of gender, age, education, or intellectual functioning (Lovejoy et al., 1999) (see Table 1). ADHD adults reported significantly more first-degree ADHD relatives and endorsed a greater total number of items on an ADHD symptom checklist adapted from DSM-IV.

2.2. Materials and procedure

Written informed consent was obtained from each participant following an explanation of the evaluation. The dependent measures were administered in strict accordance with their published standardized administration procedures. The tests were scored blindly using the available published scoring procedures and were subsequently transferred to a data summary sheet; the names were replaced with numerical codes for identification and

Table 1
Demographic information

| Variable | Group assignment | | | | |
| | ADHD ($n = 26$) | | Control ($n = 26$) | | |
	M	S.D.	M	S.D.	Range
Age	38.38	9.27	39.27	9.24	21–55
Education (years)	16.12	2.20	15.84	1.64	12–20
Estimated IQ	113.27	8.44	112.92	10.71	91–130
ADHD symptoms	11.92	3.00	0.46*	0.76	
ADHD relatives	17.00 (total)		2.00* (total)		

* $P < 0.05$.

subsequent data analysis. To facilitate intertest comparisons, the individual scores were converted to T-scores from their respective metrics.

2.2.1. Intellectual functioning

The Information and Picture Completion subtests from the Wechsler Adult Intelligence Scale — Revised (WAIS-R) were used to generate the IQ estimate (Kaufman, 1990; Wechsler, 1981). This dyad has an average reliability coefficient of .90 and excellent correlations with FSIQ scores in the WAIS-R standardization sample ($r = .88$) (Kaufman, 1990). The PC-I WAIS-R short form is particularly suited to the present methodology as it is calculated without subtests that may be sensitive to the effects of attentional disturbance (e.g., Digit Span) (Matochik, Rumsey, Zametkin, Hamburger, & Cohen, 1996). In fact, this short form has shown to be relatively unyielding to the effects of traumatic brain injury (Guilmette et al., 1999), schizophrenia (Missar, Gold, & Goldberg, 1994), and a mixed psychiatric sample (Boone, 1992).

2.2.2. Controlled Oral Word Association (COWA)

The COWA test was designed to assess letter fluency, phonetic association, and verbal organization (Spreen & Strauss, 1998). For the present study, participants were given 60 seconds to spontaneously generate rule-governed words beginning with a particular letter (i.e., C, F, and L). Interrater reliability for this instrument is nearly perfect, and test–retest reliability falls between .70 and .88 (Spreen & Strauss, 1998). The COWA maintains consistently strong correlations with intellectual estimates in healthy controls (e.g., Crawford, Moore, & Cameronn, 1992).

2.2.3. California Verbal Learning Test (CVLT)

The CVLT is a word list learning task that measures the various strategies and processes by which participants learn and remember verbal information (Delis, Kramer, Kaplan, & Ober, 1987). Consistent with administrative protocol, participants were presented with five trials of a shopping list containing 16 items grouped into four semantically similar categories: a distracter list, short-delay and long-delay free and cued recall trials, and a recognition trial. For the present study, the Short-Delay Free Recall index was chosen for analysis. Recent evidence suggests that mild deficits on similar verbal list learning tasks are associated with frontal lobe impairment and executive dysfunction (Spreen & Strauss, 1998; Stuss et al., 1994); furthermore, Lezak (1995) contends that the CVLT is a valid measure of concept formation, a process that relies heavily on executive functioning. Recall scores from this measure consistently demonstrate a positive relationship with IQ (e.g., Meehan, 1995; as cited in Spreen & Strauss, 1998). Split-half reliability CVLT falls within the moderate to high range and test–retest reliability coefficients range from .33 to .79 (Delis et al., 1987).

2.2.4. Stroop Neuropsychological Screening Test (SNST)

The SNST is a timed word- and color-naming task used as a measure of response inhibition, selective attention, and impulsivity (Trennery, Crosson, DeBoe, & Leber, 1988). Research has shown that Color–Word is a valid indicator of frontal/executive dysfunction

and provides solid classification accuracy rates in brain-injured populations (Trennery et al., 1988). Trennery et al. (1988) reported a test–retest reliability coefficient of .90 and no significant effects for gender. Intellectual level is a strong predictor of performance on this measure (e.g., Sherman, Strauss, Spellacy, & Hunter, 1995).

2.2.5. Trail Making Test, Parts A and B

TMT, Parts A and B are well-established measures of psychomotor speed, which also assess cognitive flexibility, divided attention, sequencing, and visual conceptual tracking (Reitan, 1992). Trails A and Trails B have shown to only correlate .49 with each other, suggesting that they are likely measuring different cognitive functions. Each of these tasks is supported by substantial body of empirical research and have consistently shown sensitivity to impairments in dorsolateral frontal deficits, as well as a wide range of brain impairment (Malloy, Cohen, & Jenkins, 1998). However, Part B is suggested to be the most sensitive to the presence of brain damage (Spreen & Strauss, 1998) and frontal/executive dysfunction (Heilbronner, Henry, Buck, Adams, & Fogle, 1991). Reliability coefficients for these tasks consistently fall between .60 and .90 (Spreen & Strauss, 1998). The interrater reliability for the TMTs is reported as .94 for Trails A, and .90 for Trails B (Fals-Stewart, 1992). The TMT also demonstrates strong correlations with FSIQ, particularly for Part B (Spreen & Strauss, 1998).

2.2.6. WAIS-R Freedom from Distractibility

The WAIS-R Freedom from Distractibility (FD) index was derived by averaging the age-adjusted scores from the Arithmetic and Digit Span subtests. The Arithmetic subtest provides a measure of the individual's faculty in mental arithmetic and is considered to be a sound measure of numerical reasoning ability, concentration, attention, and short-term memory. Similarly, Digit Span is a measure of short-term memory in which the participant is required to repeat a series of single-digit strings that increase over the duration of the subtest. Research on the construct validity of the FD suggests that it is primarily a measure of attention and, to a lesser extent, executive functioning (e.g., Sherman et al., 1995). Reliability coefficients for the FD factor are reported as .90 in adults (Kaufman, 1990). The Arithmetic and Digit Span subtests maintain .78 and .66 correlation coefficients with FSIQ, respectively (Wechsler, 1981).

2.2.7. The Summary Index (SI)

As previously reported, the six test scores used to create the SI included: (1) COWA total score; (2) CVLT Short-Delay Free Recall index; (3) the Color–Word score from the SNST; (4) total time to complete TMT A; 5) total time to complete TMT B; and (6) the average of the age-adjusted scores from the WAIS-R FD index (Lovejoy et al., 1999). The SI was calculated by summing the total number of scores falling in the impaired range for each participant as determined by the measures' respective published normative samples. SI scores ranged from 0 to 6.

2.2.8. The Discrepancy Impairment Index (DII)

The same six test scores used to create the SI were also used for the DII. However, scores for the DII were calculated by subtracting the individual T-score of each dependent variable

from the T-score achieved on the IQ estimate. Discrepancies falling greater than, or equal to, one standard deviation were deemed impaired (i.e., ≥ 10 T-score points). Thus, for a participant with an IQ estimate of 51T and an SNST of 36T, the SNST discrepancy score would equal -15, and would be included as impaired on the DII. However, for a participant exhibiting a 51T IQ estimate and an SNST of 50T, the discrepancy score would equal -1 and would not be included as impaired. Finally, the DII was calculated by summing the total number of scores falling in the impaired range for each individual participant; thus, DII scores ranged from a minimum of 0 to a maximum of 6.

3. Results

A one-way multivariate analysis of variance (MANOVA) was conducted to determine the effect of ADHD on difference scores between the dependent variables and estimated intellectual functioning (see Table 2). Significant differences were identified between the two groups on the dependent measures [Wilk's $\Lambda = 0.539$, $F(1,50) = 5.37$, $P < .001$], with a large multivariate strength of association ($\eta^2 = 0.461$). Follow-up analyses of variance (ANOVA) revealed significant differences on each of the seven dependent variables, with ADHD adults displaying greater discrepancies between their IQ estimates and measures of cognitive flexibility (SNST), verbal fluency (COWA), information processing speed (TMT A), divided attention (TMT B), freedom from distractibility (WAIS-R FD), and recall component of a word list learning task (CVLT Short-Delay Free Recall index).

3.1. Diagnostic efficiency of a discrepancy analysis for individual tests

Diagnostic classification rates were calculated for the individual measures in the DII (see Table 3). Overall predictive power for the individual measures ranged from 75% (SNST) to

Table 2
Results of the discrepancy analysis by group with *F*-test values and strength of association

| | Group assignment | | | | | |
| | ADHD ($n=26$) | | Control ($n=26$) | | | |
Measure	M	S.D.	M	S.D.	F	η^2
COWA	-17.27	13.75	-8.04	7.44	9.06**	0.153
CVLT	-17.96	15.55	-8.00	12.97	6.30*	0.112
SNST	-6.54	17.93	17.12	16.41	24.62***	0.330
Trails A	-12.31	10.78	-2.31	12.11	9.89**	0.165
Trails B	-11.58	10.92	-3.62	14.39	5.05*	0.092
WAIS-R FD	-6.54	7.81	-1.19	7.21	6.58*	0.116
Total score	-71.00	47.32	-4.15	46.78	26.24***	0.399
Overall MANOVA: [$F(1,50)=5.37$, $P<.001$; Wilk's $\Lambda = 0.539$; $\eta^2 = 0.461$].						

  * $P < .05$.
  ** $P < .01$.
  *** $P < .001$.

Table 3
Diagnostic classification rates for the individual tests using the discrepancy analysis technique

Dependent measures	Sensitivity	Specificity	PPP	NPP	FP	FN	OPP
COWA	0.81	0.65	0.70	0.77	0.30	0.23	0.73
CVLT	0.65	0.58	0.61	0.62	0.39	0.38	0.62
SNST	0.58	0.92	0.88	0.69	0.12	0.31	0.75
Trails A	0.73	0.73	0.73	0.73	0.27	0.27	0.73
Trails B	0.56	0.56	0.54	0.58	0.48	0.41	0.56
WAIS-R FD	0.39	1.00	1.00	0.62	0.00	0.38	0.69
Total difference score							
< -20 points	0.85	0.58	0.67	0.79	0.33	0.21	0.71
< -30 points	0.85	0.69	0.73	0.82	0.18	0.27	0.77
< -40 points	0.73	0.77	0.76	0.74	0.26	0.24	0.75
< -50 points	0.65	0.85	0.81	0.71	0.29	0.19	0.75

PPP = positive predictive power; NPP = negative predictive power; FP = false-positives; FN = false-negatives; OPP = overall predictive power.

56% (Trails B). Examination of the measures' operating characteristics revealed generally better specificity (56% to 100%) than sensitivity (56% to 81%). Of greater clinical interest, abnormal scores demonstrated adequate, but variable, abilities to predict the presence of ADHD (positive predictive power = 54–100%). Normal scores were also variable in predicting the absence of the disorder (negative predictive power = 58–77%). Finally, the rates of Type I (false-positives = 0–48%) and Type II (false-negatives = 23–41%) errors were somewhat high.

Diagnostic classification rates were also generated for a total score difference using the discrepancy analysis (see Table 3). The diagnostic efficiency for this method of test interpretation achieved adequate overall predictive power ranging from a low of 71% (20-point discrepancy) to a high of 77% (30-point discrepancy). Additionally, the total score discrepancy analysis achieved well-balanced levels of sensitivity and specificity, particularly at cutoff scores of −30 and −40, where sensitivity ranged from 73% to 85% and specificity ranged from 69% to 77%. Abnormal scores were sound predictors of ADHD (positive predictive power = 67–81%), and normal scores adequately predicted the absence of the

Table 4
Diagnostic classification rates for the DII

DII cutoff score	Sensitivity	Specificity	PPP	NPP	FP	FN	OPP
0 Measures impaired	0.00	0.77	0.00	0.44	1.00	0.57	0.39
>0 Measures impaired	1.00	0.23	0.57	1.00	0.43	0.00	0.62
>1 Measure impaired	0.87	0.54	0.66	0.82	0.34	0.18	0.71
>2 Measures impaired	0.69	0.76	0.75	0.71	0.25	0.29	0.73
>3 Measures impaired	0.57	0.92	0.88	0.69	0.11	0.31	0.75
>4 Measures impaired	0.38	1.00	1.00	0.62	0.00	0.38	0.69
>5 Measures impaired	0.19	1.00	1.00	0.55	0.00	0.45	0.60

PPP = positive predictive power; NPP = negative predictive power; FP = false-positives; FN = false-negatives; OPP = overall predictive power.

disorder (negative predictive power = 71–82%). Type I (false-negatives = 19–27%) and Type II (false-positives = 18–33%) errors were modest.

3.2. Discrepancy Impairment Index

The total number of measures determined as impaired using the discrepancy analysis technique was summed for each of the participants. To evaluate for group differences, a matched samples t test was conducted and revealed highly significant group differences $[t(46) = 5.29, P < .001]$ supporting the research hypotheses such that the ADHD participants demonstrated significantly more measures in the impaired range ($M = 3.73$, S.D. $= 1.71$) as compared to the reference control sample ($M = 1.54$, S.D. $= 1.24$). Moreover, the strength of association (i.e., eta square index) derived from this test was large, indicating that 35.9% of the variance of the test variable was accounted for by diagnostic status.

Diagnostic classification rates were subsequently calculated for the DII (see Table 4). The measured area under the Receiver-Operating Characteristic (ROC) curve (AU $= 0.8373$, S.E. $= 0.0539$) was highly significant ($z = 6.2628$, $P < .000001$) indicating that that the DII was significantly better than chance in correctly classifying observations in the ADHD and control groups (see Fig. 1). The general diagnostic efficiency for the DII at the various cutoff scores was highly variable (overall predictive power = 39–75%). The DII demonstrated levels of specificity ranging from a low of 23% (>0 measures impaired) to a high of 100% (>4
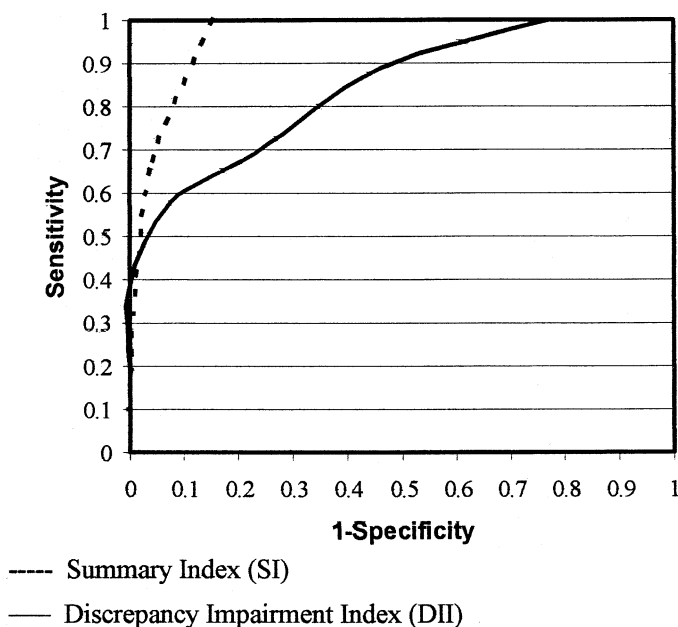

Fig. 1. The DII was highly significant ($z = 6.26$, $P < .000001$) in correctly categorizing observations in the ADHD and control groups. Although it was globally less efficient and specific than the SI, the DII interpretive technique nevertheless demonstrated significantly greater sensitivity in classifying observations in the ADHD sample.

Table 5
Statistical comparison of the sensitivity and specificity of the DII and SI interpretive techniques

Index cutoff score		DII	SI	χ^2
>0 Measures impaired	Sensitivity	1.00	0.96	0.50
	Specificity	0.23	0.85	12.50***
>1 Measure impaired	Sensitivity	0.87	0.69	4.17*
	Specificity	0.54	0.96	9.09**
>2 Measures impaired	Sensitivity	0.69	0.27	12.07***
	Specificity	0.76	1.00	4.17*
>3 Measures impaired	Sensitivity	0.57	0.08	12.07***
	Specificity	0.92	1.00	0.50
>4 Measures impaired	Sensitivity	0.38	0.00	8.10**
	Specificity	1.00	1.00	0.00
>5 Measures impaired	Sensitivity	0.19	0.00	3.20
	Specificity	1.00	1.00	0.00

DII = Discrepancy Impairment Index; SI = Summary Index.
  * $P < .05$.
  ** $P < .01$.
  *** $P < .001$.

measures impaired). Sensitivity of the DII interpretive technique was stronger at lower levels of impairment (sensitivity = 0–100%). Positive DII scores were highly efficient in predicting diagnostic status at greater levels of impairment (positive predictive power = 0–100%). Conversely, negative DII scores demonstrated greater efficiency at the lower reaches of impairment (negative predictive power = 44–100%). Finally, the rates of Type I (false-positives = 0–100%) and Type II (false-negatives = 0–57%) errors were variable.

3.3. Comparison of the DII and SI ROC curves

It was additionally hypothesized that the DII would yield superior diagnostic accuracy in classifying the ADHD and control groups as compared to the use of standard cutoff scores (i.e., the SI as described above in the original Lovejoy et al., 1999 study). To evaluate this hypothesis a matched z-test was calculated examining the area underneath the DII ROC curve and SI ROC curve with the associated probability (see Fig. 1). Counter to the initial research hypotheses, the SI demonstrated a greater overall level of diagnostic efficiency (AU = 0.96; $z = 2.18$; $P < .05$). Additionally, a McNemar's chi-square test indicated that the SI provided greater specificity than the DII in categorizing the control group at cutoffs score of greater than zero measures impaired, $[\chi^2(1, N = 52) = 12.50, P < .001]$, greater than one measure impaired, $[\chi^2(1, N = 52) = 9.09, P < .01]$, and greater than two measures impaired $[\chi^2(1, N = 52) = 4.17, P < .05]$ (Table 5).

Nevertheless, the DII demonstrated superior sensitivity. Results of the McNemar's chi-square test were significant in favor of the DII at cutoff scores of greater than one measure impaired $[\chi^2(1, N = 52) = 4.17, P < .05]$, greater than two measures impaired, $[\chi^2(1, N = 52) = 12.07, P < .001]$, greater than three measures impaired, $[\chi^2(1, N = 52) = 13.07, P < .001]$, and greater than four measures impaired $[\chi^2(1, N = 52) = 8.1, P < .05]$. A significant

trend was appreciated at a cutoff score of greater than five measures impaired [χ^2(1, $N = 52$) $= 3.2$, $P = .07$]. These final analyses are consistent with the original research hypotheses, suggesting that the discrepancy analysis is a more sensitive measure for identifying ADHD at these mid-range cutoff scores.

4. Discussion

Alternative approaches to neuropsychological test interpretation are commonly utilized in clinical practice to identify patterns of neurocognitive dysfunction. However, there is a paucity of research documenting the validity and diagnostic efficiency of such approaches in relation to specific diagnostic populations. As a clinical extension of literature supporting the use of discrepancy analyses for the identification of central nervous system dysfunction (e.g., Ivnik et al., 2000; Lezak, 1995; Moses et al., 1997; Reitan, 1985), the present study examined discrepancies between intellectual abilities and performance on a battery of frontal/executive measures in ADHD adults. It was hypothesized that the discrepancy analysis approach would differentiate ADHD adults and controls at the group level, and additionally demonstrate more efficient, accurate, and sensitive classification rates when compared to a standard level of performance interpretation (i.e., Lovejoy et al., 1999).

Significant group differences were identified between the ADHD adults and controls on each of the neuropsychological measures when data interpretations were based upon a discrepancy analysis. ADHD adults demonstrated greater discrepancies between their IQ estimates and measures of verbal fluency (COWA), timed cognitive flexibility, selective visual attention, and response disinhibition (SNST), visuomotor tracking and information processing speed (TMT A), divided attention (TMT B), attention/concentration (WAIS-R FD), and delayed free recall of a word list (CVLT Short-Delay). As predicted, a composite discrepancy score also differentiated the ADHD and control groups. The present findings were consistent with prior research demonstrating discrepancies between measures of intellectual ability and tests of attention/concentration for ADHD adults (e.g., Biederman et al., 1993; Brown, 1996). Importantly, these findings provide support for the theoretical contention that measured differences between intellectual ability and neuropsychological test performance can distinguish clinical and normal control samples at a group level. Moreover, these results highlight the utility of using alternative approaches to neuropsychological data interpretation in an effort to identify and characterize patterns of neurocognitive dysfunction in clinical populations.

Consistent with theoretical arguments supporting the use of discrepancy analyses in identifying neuropsychiatric disorders (e.g., Cimino, 1994), the individual measures within the DII provided overall adequate (albeit somewhat variable) classification rates in identifying the ADHD and normal control groups. Generally speaking, when a positive test score was present, the measure accurately identified the ADHD adults (i.e., positive predictive power). By and large, the individual measures were also accurate in capturing the control sample (i.e., specificity), but demonstrated generally lower sensitivity in capturing the ADHD participants (i.e., sensitivity). Discrepancies between IQ and performance on the

COWA provided the most efficient and well-balanced diagnostic accuracy rates. Overall, the diagnostic efficiency statistics were variable such that, while not all of the measures provided efficient operating characteristics, they each exhibited a unique pattern of relative strengths and weaknesses.

Except for the performance of the COWA, the individual measures did not always capture a large percentage of the ADHD participants. The most salient findings were the relatively weak performances of Trails B, WAIS-R FD, and the CVLT Short-Delay Free Recall index. These mixed findings are consistent with the erratic nature of individual tests reported across adult ADHD studies. It is possible that this variability reflects sampling error; yet variable diagnostic accuracy on these well-established measures also underscores the inconsistent nature of the attentional/executive impairment within the adult ADHD population. ADHD adults appear more likely to express their dysfunction across a battery of frontal/executive tasks, which reinforces the need for including multiple measures within this domain. It is generally recommended that neuropsychological assessment of frontal/executive functioning be undertaken using a broad battery of tests; in this way, the clinician is afforded the opportunity to assess multiple domains of functioning, as well as gain information from overlapping measures tapping different functional aspects within each domain (Malloy et al., 1998; Reitan & Wolfson, 1985).

Overall, this study also lends further support to the contention that ADHD is expressed through subtle, inconsistent dysfunction in the frontal/executive systems of the brain. Conclusions derived from this study are consistent with the various neuroimaging, neuro-chemical, and neuropsychological investigations evaluating the role of the frontal lobes and frontal/executive systems in the expression of ADHD in adult populations (Faraone et al., 2000). Importantly, however, it is not simply that this population is devoid of the capacity to perform well on complex frontal/executive measures. Instead, consistent with various other disorders resulting in disrupted attentional systems (Cohen, Jenkins, & Malloy, 1998), ADHD adults ostensibly maintain difficulty in harnessing their frontal/executive resources on a reliable basis over time. As mentioned above, such subtleties may be effectively evaluated via the use of multiple measures of attention/concentration and frontal/executive functioning, as well as the incorporation of complementary neuropsychological data interpretation techniques (e.g., patterns of performance).

The DII battery approach discriminated the ADHD adults and controls at the group level such that the ADHD population demonstrated significantly more measures in the impaired range. The DII additionally achieved highly significant operating characteristics, with particularly efficient diagnostic accuracy at the mid-range cutoff scores. Negative predictive value, which has been a significant weakness throughout the adult and pediatric ADHD literature (e.g., Barkley & Grodzinsky, 1994), was excellent at lower levels of impairment. Despite the technique's enhanced sensitivity, the DII sacrificed an element of specificity at these cut scores, suggesting that the DII reduced its capacity to efficiently capture the control participants. However, when evaluated at three or more measures impaired, the battery's operating characteristics reversed course, losing sensitivity, while gaining in specificity; likely due to the decreased prevalence of impairment at this cutoff level. In sum, the results of this preliminary analyses were generally consistent other studies that have evaluated discrepancies

between intellectual performance and domain-specific neuropsychological measures (e.g., Reitan, 1985) and support the incorporation of the DII technique as part of a broader diagnostic process.

While the DII provided highly significant operating characteristics when considered independently, it failed to achieve superiority over previously reported quantitative approach using strict cutoff scores based on normative samples (i.e., SI; Lovejoy et al., 1999). This finding ran counter to the initial research hypotheses and indicates that the SI is broadly more efficient in classifying ADHD adults and matched normal controls. However, the area measured under the ROC curve has been criticized as providing a limited representation of the entire ROC plot that does not appropriately account for the shape and variability of the curve (Hilden, 1991; Zweig & Campbell, 1993).

Upon closer analysis, the DII proved to be a more sensitive instrument at the mid-range cutoff scores (i.e., greater than two, three, and four measures impaired). This finding suggests that the consideration of discrepancy analyses is a valid interpretive methodology within the ADHD population and, in fact, is more sensitive in detecting the presence of ADHD than the SI uniform quantitative approach. Intuitively, this finding makes sense. The old adage "the absence of evidence is not evidence of absence" is particularly relevant to the existing adult ADHD neuropsychological literature and consistent findings of poor sensitivity and negative predictive power (e.g., Barkley & Grodzinsky, 1994; Lovejoy et al., 1999). The DII was created to account for the pervasiveness of a hypothesized floor effect and associated Type II error inherent to the strict quantitative approach to the neuropsychological assessment of adult ADHD. The issue of Type II error may be particularly salient for those patients who demonstrate above-average IQ scores; accordingly, the DII addressed this problem and demonstrated greater sensitivity to the presence of ADHD as compared to a level of performance approach.

However, what the DII interpretive approach gained in sensitivity, it comparably lost in specificity such that the SI was a more specific tool at lower cutoff scores (i.e., greater than zero, one, and two measures impaired). That is, a greater proportion of control participants were correctly identified when evaluated using the SI as compared to the DII technique. Thus, while an analysis of intellectual/executive discrepancies resulted in greater sensitivity to subtle brain dysfunction, the DII also heightened the risk of false positives (i.e., Type I error). The latter finding supports Dodrill's (1997) contention that the presence of discrepancies between IQ and neuropsychological performance are present in normal, healthy populations and are not necessarily specific to the presence of neuropsychological impairment.

Thus, in applying these interpretive approaches in clinical settings, it is vitally important to consider the practical implications of the Type I and Type II error rates in individual cases. The likelihood of arriving at inaccurate diagnoses within the ADHD population may be mitigated by reliance upon a comprehensive psychological evaluation, including an extensive clinical interview, developmental history questionnaire, objective rating scales, developmental, academic, social, familial history, measures of emotional adjustment, neuropsychological assessment, mental status exam, and a referral for a physical examination (Murphy, 1998). Ideally, clinicians will make efforts to attain information regarding patients' early history and

presenting complaints from diverse sources, including spouses, friends, coworkers, and additional family members. In this way, appropriate weight is provided to each of the assessment techniques, without undue emphasis on one method of evaluation to the exclusion of another.

4.1. Limitations and future directions

The generalizability of the present study is restricted by the presence of select methodological limitations, including sample composition and measurement techniques. Considerable efforts were made to ensure the relative homogeneity of the present ADHD sample; thus, diagnostic groups (e.g., learning disabilities, anxiety, depression) often comorbid with ADHD were not included. This limitation is particularly salient when considering that, consistent with the child literature, ADHD adults maintain elevated rates of comorbid psychiatric disorders (Spencer, Biederman, Wilens, & Faraone, 1998). Cross-validation with other ADHD and neuropsychiatric samples using this interpretive formula appears warranted. Relatedly, the discriminant validity of this index remains to be established as concerns to its ability to differentiate ADHD from other commonly encountered comorbid neuropsychiatric and/or neurological disorders that may present with similar complaints (e.g., anxiety and mood disorders, mild traumatic brain injury). An additional limitation of the present sample arises from the highly educated and intelligent nature of the participants; accordingly, the results from this investigation may not generalize to less educated samples. This limitation is particularly important considering the nature of the discrepancy analysis technique, which inherently relies upon a person's level of intellectual functioning.

Considerations regarding diagnostic gold standards and prevalence rates must be also taken into account when interpreting diagnostic efficiency and predictive statistics. It is widely established that there is no single litmus test for the diagnosis of ADHD; in fact, the diagnosis itself has undergone countless revisions and controversies over the past few decades (Barkley, 1998). Diagnostic gold standard issues are part and parcel with research on behavioral disorders. Nevertheless, in comparison to prior investigations, the present study incorporated rigorous standards with stringent inclusionary and exclusionary criteria. Continued evaluation of a combined, multimodal diagnostic approach may further facilitate the establishment of a reliable and valid set of gold standard diagnostic criteria for ADHD in adulthood.

Finally, while the results from the present investigation lend additional credence to the utility neuropsychological assessment techniques in reaching diagnostic conclusions with this population, very little is known about what, if any, unique contribution is provided by the neuropsychological evaluation. There is a continuing need to explore different interpretive methodologies and techniques for assessing ADHD patients that do not rely exclusively on either self-report and/or restricted methods of data interpretation, as both of these techniques are subject to bias. As such, future investigations may seek to evaluate the unique contribution and/or incremental validity of the neuropsychological evaluation to the overall diagnostic process.

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