Published in final edited form as:

J Abnorm Psychol. 2011 May ; 120(2): 427–442. doi:10.1037/a0021405.

Does Attention-Deficit/Hyperactivity Disorder Have a Dimensional Latent Structure? A Taxometric Analysis

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Abstract

An understanding of the latent structure of attention-deficit/hyperactivity disorder (ADHD) is essential for developing causal models of this disorder. Although some researchers have presumed that ADHD is dimensional and others have assumed that it is taxonic, there has been relatively little research directly examining the latent structure of ADHD. The authors conducted a set of taxometric analyses using data from the NICHD Study of Early Child Care and Youth Development (*n*s between 667–1078). The results revealed a dimensional latent structure across a variety of different analyses and sets of indicators, for inattention, hyperactivity/impulsivity, and ADHD. Furthermore, analyses of correlations with associated features indicated that dimensional models demonstrated stronger validity coefficients with these criterion measures than dichotomous models. These findings jibe with recent research on the genetic basis of ADHD and with contemporary models of ADHD.

Keywords

ADHD; taxometric analysis; latent structure

ADHD is one of the most commonly diagnosed childhood disorders, affecting approximately 8% of school-age children (Centers for Disease Control and Prevention, 2005). The *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM-IV-TR*; American Psychiatric Association, 2000) distinguishes among three subtypes of ADHD: predominantly inattentive, predominantly hyperactive-impulsive, and combined type. Although there has been progress in diagnosing, understanding, and treating ADHD, researchers are far from a comprehensive etiological model of the disorder and a number of issues remain unresolved. For example, is ADHD best understood as arising from a single core deficit (e.g., Barkley, 1997) or can it be better explained by a multiple pathway model (e.g., Sonuga-Barke, 2002)? Although ADHD is frequently comorbid with other conditions such as conduct problems, the precise relation between ADHD and these related conditions remains in question (e.g., Waschbusch, 2002). Also unresolved is whether ADHD is a qualitatively distinct category (i.e., a taxon) or whether it is better understood as existing on a continuum, which is the focus of this investigation.

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There has been ongoing debate about whether childhood disorders, in general, are better conceptualized dimensionally or as categories. Beauchaine (2003) noted that developmental psychopathologists generally prefer dimensional models for a variety of reasons, including that dimensional systems may better capture developmental processes (as opposed to categories that identify presumptively immutable outcomes) and because categories may minimize the importance of situational influences. It is, however, worth noting that some developmental processes, such as puberty, may be categorical, and situational influences can contribute to taxonic conditions (e.g., cancers resulting from a combination of a genetic diathesis and an environmental carcinogen). In terms of assessment, Achenbach and McConaughy (1997) advocated for classifying childhood disorders quantitatively and Achenbach's (1991a) Child Behavior Checklist (CBCL) is a frequently used dimensional measure of child psychopathology. Consistent with a dimensional approach, Fergusson and Horwood (1995) found that continuous measures of externalizing behaviors were better predictors of subsequent substance abuse and delinquent behaviors, than were DSM-III-R diagnoses. However, Cantwell (1996) defended the value of categorical approaches both for identifying rare disorders and for their pragmatic value. Ultimately, whether a specific "disorder represents a discrete entity is an empirical question that cannot be settled through methodological convention or philosophical debate" (Beauchaine, 2003, p. 503), or as noted by Sonuga-Barke (1998), "particular categories of disorder should be seen as scientific hypotheses that can be tested using taxometric analysis" (p. 116).

Sonuga-Barke (2005) noted that knowing whether ADHD is a discrete category or a continuous trait is critical to identifying causal models for ADHD. Many experts believe that ADHD is best understood dimensionally (e.g., "the dimensional approach to ADHD seems most consistent with the available evidence" Barkley, 2006, p. 96). Additionally, multiple pathway models of ADHD (e.g., Nigg, Goldsmith, & Sachek, 2004; Sonuga-Barke, 2005) are likely to be more consistent with a dimensional latent structure than with a taxonic latent structure. A number of studies provide indirect support for a dimensional conceptualization. Delays and variability in processing speed are linearly distributed from typical controls, to children with borderline ADHD, to those with ADHD (Kalff et al., 2005). A meta-analysis on genetic and environmental influences on ADHD symptoms stated that "examination of behavioral dimensions as opposed to diagnostic subtype categories may provide a more clear and consistent answer as to potential etiological differences between" symptoms of inattention and hyperactivity (Nikolas & Burke, 2010, p. 2).

Nevertheless, these findings do not address the question of latent structure directly. Although it appears that various indicators of ADHD (e.g., processing speed, inattention, response inhibition) are continuously distributed, dimensional indicators can be symptoms of a taxonic condition (e.g., fever as an indicator of influenza). Furthermore, ADHD may have a taxonic latent structure even if there are varying levels of severity within the taxon (e.g., mild and severe cases of influenza may be caused by the same pathogen). In fact, there appears to be consensus that the question of whether ADHD is categorical or continuous is both important and unresolved (e.g., Levy, McStephen, & Hay, 2001; Nigg et al., 2002; Sonuga-Barke, 1998; Stevenson et al., 2005).

Some studies have used latent class analysis (LCA) to examine the structure of ADHD. The primary aim of these studies has been to clarify the subtypes of ADHD (e.g., is there a pure hyperactive-impulsive subtype?), and only a few of these studies have explicitly addressed the question of whether ADHD or its subtypes are categorical or dimensional. Hudziak et al. (1998) examined the latent structure of ADHD symptoms in a sample of female adolescent twins. They analyzed parent reports of DSM-IV ADHD symptoms and found evidence of three separate dimensions (inattention, hyperactivity-impulsivity, and combined). Each dimension was continuously distributed and there was no evidence to suggest that ADHD or any of these subtypes were categorical. In their LCA of parent interview data, Neuman et al. (1999) found evidence of inattentive and combined subtypes. Both subtypes were continuously distributed in their sample, again suggesting that ADHD is not taxonic. However, Todd et al. (2001) found greater heritability within than across latent class ADHD subtypes, which they took as possible evidence that the various latent classes may be categorical.

Ultimately, LCA is useful for identifying subgroups, but because researchers are left to interpret whether the latent classes are qualitatively or quantitatively distinct, LCA does not directly test whether a construct is taxonic or dimensional. In contrast, Meehl's (e.g., Ruscio, Haslam, & Ruscio, 2006; Waller & Meehl, 1998) taxometric method appears to be a more accurate method for identifying a construct's latent structure. There have been two prior taxometric analyses of ADHD. Haslam et al. (2006) examined the latent structure of ADHD in two large epidemiological samples, one of children and one of adolescents. They used two taxometric procedures to analyze indicators drawn from parent reports on the CBCL and the Diagnostic Interview Schedule for Children. A clear majority of the findings were more consistent with a dimensional than a taxonic structure, and overall, this study provided support that ADHD has a dimensional latent structure.

Frazier, Youngstrom, and Naugle (2007) examined the latent structure of ADHD symptoms in a clinical sample of individuals referred for ADHD evaluations, 72% of whom were subsequently diagnosed with ADHD. The taxometric analyses used a range of indicators including parent reports, intelligence and achievement test results, and results from the Connors' Continuous Performance Task (CPT). Frazier et al.'s analytic strategy involved performing separate taxometric analyses for each domain of symptoms (e.g., one set of analyses for CPT performance and another set for IQ indexes), as well as analyses using a mixture of indicators across domains. Consistent with Haslam et al. (2006), Frazier and colleagues concluded that ADHD has a dimensional structure.

Despite the lack of evidence to fully support qualitatively distinct subgroups of individuals with or without ADHD, the conceptualization and treatment of ADHD as categorical is still held strongly within much current research—particularly in fields, such as genetic and psychiatric research (e.g., Acosta et al., 2008; Althoff et al., 2006). For example, Elia and colleagues (2009) identified six ADHD phenotypes via LCA that they described as homogenous groups that could be used in future genetic research. Similarly, a categorical conceptualization remains the way that ADHD is diagnosed clinically based on the current DSM-IV-TR and the proposal criteria for the DSM-V (American Psychiatric Association, 2010). Thus, based on extant research it may be that categorical views of ADHD have been disproportionately influential on shaping ADHD research and diagnosis and additional research on the latent structure of ADHD is needed to clarify existing ideas and practices.

The present study bridges the gap between the Haslam et al. and Frazier et al. studies by using (a) indicators drawn from a wide range of domains and methods with (b) a general population sample of individuals. We conducted a set of taxometric analyses using parent and teacher ADHD symptom reports and measures of cognitive and executive functions as indicators. These data were collected as part of a multi-site population-based study. In addition, we tested the validity of our taxometric findings by comparing the utility of dimensional versus categorical models of ADHD on their ability to predict features associated with ADHD (for the importance of validating taxometric findings see Waldman & Lilienfeld, 2001; Watson, 2006). More specifically, we examined whether continuous scoring of ADHD symptoms or dichotomous classification systems accounted for more variance in known correlates of ADHD.

Method

Participants

Data were provided by the 1078 families who participated in Phase III of the NICHD Study of Early Child Care and Youth Development (SECCYD), a longitudinal study that runs from birth through sixth grade. Data for Phase III of the study were collected from the second through the sixth grade from a diverse sample of children born in 1991 in ten locations across the United States. The taxometric analyses were conducted using data collected when the children were in third grade. Details about the sample can be found in NICHD ECCRN (2005). Because of missing data, the actual number of cases for each analysis ranged from 667 to 1078.

Measures for Taxometric Analyses

Primary indicators were drawn from instruments used to diagnose ADHD. However, because indicators may be any variables that discriminate between members of the taxon and of the complement (Waller & Meehl, 1998), secondary indicators that do not involve DSM-IV-TR symptoms but that differentiate between children with and without ADHD were also included. Although the secondary measures are not specific to ADHD, they all have demonstrated sensitivity and, in combination with our primary measures, are likely to be diagnostic of ADHD. Furthermore, many of the secondary indicators are laboratory-based measures or standardized tests and, thus, have the advantage of avoiding some rater effects and biases that can influence a latent structure analysis (Beauchaine & Waters, 2003). By combining measures that have specificity and sensitivity for ADHD with others that are merely sensitive, the chances of revealing the true latent structure of ADHD is maximized. The following indicators were considered primary:

***Child Behavior Checklist* (CBCL; Achenbach, 1991a)—**The CBCL is a rating scale completed by parents, yielding eight clinical scales. Composites of items measuring inattention and hyperactivity-impulsiveness from the Attention Problems scale (based on mother report) were primary indicators of ADHD. The Attention Problems scale is often used in the diagnosis of ADHD and discriminates children with ADHD from those without ADHD (e.g., Hudziak, Copeland, & Stanger, 2004).

***Teacher Report Form* (TRF; Achenbach, 1991b)—**The TRF is a rating scale completed by teachers. Composites of items from the Attention Problems scale were primary indicators of ADHD. The Attention Problems scale from the TRF also discriminates between children with and without ADHD (Achenbach, 1991b).

***Disruptive Behavior Disorders Questionnaire* (DBQ; Pelham, Gnagy, Greenslade, & Milich, 1992)—**This scale includes all 18 symptoms of ADHD rated on a Likert scale. Two versions of the DBQ—parent (mother as informant) and teacher—were used as primary indicators of ADHD. These ratings can determine whether a parent and/or teacher endorses a clinically significant number of symptoms required for an ADHD diagnosis (i.e., at least 6 of 9 inattention symptoms endorsed for ADHD-Predominantly Inattentive Type; at least 6 of 9 hyperactive-impulsive symptoms endorsed for ADHD-Predominantly Hyperactive/Impulsive Type; or at least 6 of 9 symptoms in *both* categories endorsed for ADHD-Combined Type).

The following indicators were considered secondary:

***Classroom Observation System* (COS)—**The COS tracks discrete child behaviors. The disruptive behavior scale was use as an indicator. Coding behaviors provides a more behaviorally-defined measure of ADHD symptoms than would be available from just parent and teacher reports, which are based on global symptom ratings (e.g., Leach & Brewer, 2005).

***Continuous Performance Task* (CPT; Connors, 1994)—**The CPT measures sustained attention. Two of the error types yielded, errors of omission (indicative of inattention) and errors of commission (indicative of impulsivity), were used as secondary ADHD indicators, given that both are found to be higher among children with ADHD when compared to their peers (e.g., Barry, Klinger, Lyman, Bush, & Hawkins, 2001).

***Tower of Hanoi* (TOH)—**The TOH measures planning, problem-solving, and executive functioning, which have been found to be impaired in children with ADHD (e.g., Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). The TOH total efficiency score was used as an indicator.

***Woodcock-Johnson Test of Achievement-Revised* (WJ-R; Woodcock & Mather, 1989–1990)—**Children with ADHD typically show a pattern of low academic achievement (Frazier, Demaree, & Youngstrom, 2004). Therefore, an average of the Broad Reading and Broad Math standard scores of the WJ-R was used as an indicator.

Measures to Examine the Associated Features of ADHD (Criterion Measures)

Other measures available in the SECCYD data set were used to examine whether the dichotomous or continuous ADHD scores were better correlated with associated features of ADHD. These included academic impairment, other externalizing behaviors, internalizing symptoms, and social functioning. Specifically, the remaining seven clinical scales from the CBCL (mother report) and TRF were used in these analyses. The Oppositional and Defiant Disorder (ODD) symptoms scores from the mother and teacher version of the DBQ were also included. Additional information from the COS was used to examine externalizing behaviors commonly associated with ADHD (engaged in classroom, negative/aggressive toward peers, negative toward teacher). Residualized academic achievement scores, based on regressing WJ-R Broad Reading and Broad Math standard scores on the Wechsler Abbreviated Scales of Intelligence (WASI; The Psychological Corporation, 1999) Full Scale IQ score served as a measure of academic underachievement. The Social Skills composite from the Social Skills Rating System (SSRS; Gresham & Elliott, 1990) was used as a measure of social functioning based on both parent and teacher report. The teacher version also includes a standardized Academic Competence scale.

Taxometric Analyses

The taxometric analyses included three nonredundant procedures: Means Above Minus Below a Cut (MAMBAC; Meehl & Yonce, 1994), MAXimum EIGenvalue (MAXEIG; Waller & Meehl, 1998), and Latent Mode (L-Mode; Waller & Meehl, 1998). MAMBAC requires at least two indicators, one of which serves as the input and the other as the output. Cuts are made along the input indicator (100 cuts in the current analyses, based on our large sample sizes). At each cut the difference between the mean score on the output indicator for the cases below the cut and the mean score for the cases above the cut are graphed on the *y*-axis. Prototypically, a taxonic construct will have a peak near the score that separates the taxon group from the complement. For the current set of analyses, all indicators scores were standardized, one indicator served as the output for each graph and the remaining indicators were summed to create the input indicator.

MAXEIG is a multivariate extension of Meehl and Yonce's (1996) MAXCOV procedure. One indicator serves as the input and the remaining indicators contribute to the output. The sample is divided into a set of overlapping windows along the input indicator. All of the remaining indicators are subjected to a principle component analysis and the eigenvalue of the first principal component, which represents the multivariate analogue of the covariance, is plotted on the *y*-axis for each window. Taxonic data will prototypically yield a graph that peaks at the window with the subsample most evenly divided between members of the taxon and complement because this is the subsample with the greatest variance, which therefore yields the maximum eigenvalue. In the current MAXEIG analyses, we used 100 windows with .90 overlap except for the samples with 667 cases, which used 50 windows with .90 overlap. There is Monte Carlo evidence that .90 overlap generates more accurate results than using discrete intervals (Walters & Ruscio, in press) and this combination of windows and overlap yielded a minimum of 76 cases per window, which should generate stable results.

In L-Mode all of the indicators are factor analyzed and the distribution of scores on the first principal factor is graphed. Taxonic data prototypically yield bimodal graphs and dimensional data yield unimodal graphs. We only conducted L-Mode analyses when at least four indicators were available (Waller & Meehl, 1998).

Because the shape of taxometric curves can be influenced by factors other than the latent structure of the construct being assessed (e.g., the skew of the indicators, the base rate of the putative taxon), taxometric analyses do not always yield prototypic curves. Simulated comparison data that varies whether the latent structure is taxonic or dimensional while reproducing many of the features of the research data has proven useful for interpreting taxometric graphs (Ruscio, Ruscio, & Meron, 2007). These sets of simulation data are entered into MAMBAC, MAXEIG, and L-Mode analyses and the graphs produced by the simulation data can be compared to the graphs from the research data.

The extent to which results for the actual data are more similar to the taxonic or dimensional comparison data can be quantified by computing a Comparison Curve Fit Index (CCFI) that ranges from 0 (strong support for dimensional structure) to 1 (strong support for taxonic structure). Values in the .45 to .55 range are indeterminate (Ruscio, 2007). There is considerable evidence that CCFI values discriminate between taxonic and dimensional data with a high degree of accuracy across a range of data conditions (Ruscio & Marcus, 2007; Ruscio et al., 2007), particularly when the procedures yield consistent CCFIs. For example, Ruscio, Walters, Marcus, and Kaczetow (2010) generated 50,000 categorical and 50,000 dimensional data sets. When MAMBAC, MAXCOV, and L-Mode all yielded CCFIs less than .45 or greater than .55, the latent structure was correctly identified 99.9% of the time. The taxometric analyses were conducted using programs written by Ruscio (2009b) for R.

Results

We conducted three sets of taxometric analyses. The first set used combinations of indicators of inattention to examine whether attention problems are dimensional or categorical. The second set used examined the latent structure of hyperactivity/impulsivity. Finally, because it is possible for inattention and hyperactivity/impulsivity to each have a dimensional latent structure, yet for the unique combination of these two dimensions to be taxonic, we combined indicators of inattention and hyperactivity/impulsivity to examine the latent structure of ADHD.

The correlations among the primary and secondary indicators of ADHD are provided in Table 1. Because indicator skew can influence the shape of taxometric curves (e.g., Ruscio & Ruscio, 2002), the skew of each indicator is also provided in this table. All of the indicators were positively skewed except for the TOH and WJR, which were the only two variables in which higher scores indicated higher functioning. These two variables were reverse scored in the taxometric analyses.

Taxometric analyses require valid indicators and Meehl (1995) recommended that they should demonstrate at least 1.25 standard deviation units (SDU) of separation between taxon and complement groups. Unfortunately, the SECCYD data set did not include formal diagnoses of ADHD. More importantly, there is no reason to presuppose that the diagnosis of ADHD would be isomorphic with a presumptive taxon; therefore, we used two strategies to estimate the validity of the various indicator sets. First, we presumed a taxon base rate of 7%, which is consistent with the population base rate of ADHD and also consistent with the participants' scores on the DBQ (see below). Second, the MAMBAC and MAXEIG procedures provide base rate estimates based on the shape of the taxometric curves and these base rate estimates were used to compute indicator validities, by combining the indicators and using this composite to divide the sample according to the base rate. With the exception of a few individual indicators (see below), all of the indicator sets yielded validity coefficients above 1.25 SDUs (Table 2).

Ideally, the indicators for a taxometric analysis are correlated with one another in the full sample, but there is smaller covariance among the indicators within the taxon and complement groups (i.e., low nuisance covariance). Table 2 also reports the average full sample and nuisance correlations for each set of indicators, once again presuming a 7% taxon base rate. The full sample correlations are .30 or greater for all but one of the reported sets of analyses. There was generally little evidence of nuisance covariance.[1]

The indicators for the primary taxometric analyses for inattention, hyperactivity/impulsivity, and ADHD used the relevant DBQ items, because they map directly onto the DSM-IV-TR diagnostic criteria. The mother and teacher DBQs were analyzed separately and they were also combined across teacher and mother responses. If the teacher and mother both provided a report, these items were averaged; otherwise, the response provided was used. The rationale for averaging the mother and teacher responses was because children behave differently in different situations so these raters have access to separate types of information and because raters may interpret the same behavior differently (Pelham, Fabiano, Massetti, 2005). Although average ratings are not the same as having independent reports as is required for comprehensive ADHD assessments (Pelham et al., 2005), these average ratings were a way to use information from both the mother and teacher and can be considered a compromise between the "or" and the "and" rule for combining multi-informant data (Gizer et al., 2008). In the interest of succinctness and because there is no rationale for assigning the separate mother or teacher ratings primacy, we provide detailed reports of the results from the average of the mother and teacher responses (and the corresponding graphs), but also provide the results from the separate analyses of the mother and teacher reports in Table 2.

Inattention

The average of the mother and teacher DBQ inattention items demonstrated strong validity: On the basis of the base rates yielded by the subsequent MAMBAC and MAXEIG analyses, the average degrees of separation for these nine indicators were 2.17 and 2.52[2] SDUs,

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[1]Given that the results of the taxometric analyses were consistent with a dimensional latent structure, technically these validity and nuisance covariance estimates were based on arbitrary cuts along a continuum and not on an actual separation of a taxon and complement group. Although this method is less than ideal, it does demonstrate that the various indicators used were related to one another in a manner that meets the requirements for taxometric analyses.

[2]We do not report base rate estimates or indicator validities based on the base rate estimates from the L-Mode analyses because when L-Mode yields dimensional results the base rate is usually around 50%.

respectively. For the MAMBAC analyses, each item served as the output indicator for one graph, with the remaining 8 items summed to create the input indicator. All nine graphs exhibited a rising cusp on the right side of the graph that could either be indicative of a low baserate taxon or positively skewed indicators.[3] The average of the nine curves was more similar to the dimensional comparison data than to the taxonic comparison data (Figure 1, top graph), with a CCFI of .406 (Table 2). None of the nine individual MAXEIG curves displayed a clear peak consistent with taxonic structure. The average of the nine MAXEIG curves was more similar to the dimensional comparison data than to the taxonic comparison data (Figure 1, middle graph), with a CCFI of .304. The L-Mode curve for the actual data was unimodal (CCFI = .379), unlike the L-Mode Curve for the simulated taxonic data, which was bimodal (Figure 1, bottom graph). We conducted the same set of analyses separately for the mother and teacher DBQ forms. All of these results were consistent with a dimensional latent structure (Table 2).

Next, we used indicators that operationalized inattention using diverse methods. The four indicators for these analyses were (a) observer rated inattention problems (the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the CBCL), (b) academic achievement (average Broad Reading and Math scores on the WJ-R), (c) omissions on the CPT, and (d) TOH. Because these diverse operationalizations do not share method variance, they did not cohere as strongly as indicators all derived from the same methodology. As a result, the average degrees of separation for these four indicators, based on the base rates derived from the subsequent MAMBAC and MAXEIG analyses, were 1.41 and 1.52 SDUs, respectively, which is adequate but less than ideal.

Two of the MAMBAC graphs exhibited a rising cusp on the right side of the graph that could be indicative of a low base-rate taxon or positively skewed indicators, whereas the other two graphs had right side peaks suggestive of a taxon. However, the average of the four curves was more similar to the dimensional comparison data than to the taxonic comparison data, (CCFI= .429, Table 2). The MAXEIG analyses were consistently dimensional. The four MAXEIG curves were flat and the average MAXEIG curve was more similar to the dimensional comparison data than to the taxonic comparison data, (CCFI = .328; Table 2). The L-Mode graph was unimodal and more similar to the dimensional comparison data (CCFI = .273). Finally, because the CPT omissions yielded the lowest indicator validity, we repeated the MAMBAC and MAXEIG analyses with the three remaining indicators. These analyses yielded better average indicator validities (1.59 for MAMBAC; 1.74 for MAXEIG), and dimensional results for MAMBAC (CCFI = .287) and MAXEIG (CCFI = .348). Across almost all of the analyses using the various combinations of inattention indicators, there was strong evidence that inattention problems have a dimensional latent structure.

Hyperactivity/Impulsivity

The average of the mother and teacher DBQ hyperactivity/impulsivity items also yielded acceptable validity coefficients: On the basis of the base rates yielded by the subsequent MAMBAC and MAXEIG analyses, the average degrees of separation for these nine indicators were 1.93 and 2.31 SDUs, respectively. All nine MAMBAC curves exhibited a

[3]Although we describe the shapes of the individual curves (these graphs and all subsequent results and graphs that are not provided in this paper are available from David K. Marcus), our interpretations of the analyses are primarily based on the comparisons between the average curves and the simulated taxonic and dimensional data sets, and the resulting CCFIs. The rationale for this strategy is that there is considerable Monte Carlo evidence that the CCFIs generated by averaged graphs provide an accurate method for assessing latent structure (e.g., Ruscio, 2007; Ruscio & Marcus, 2007). In contrast, there is no evidence that the visual interpretation of individual curves, especially when analyzing skewed data, can yield more accurate findings than the CCFI method (Ruscio et al., 2010). Additionally, a recent Monte Carlo study found that the CCFI method was superior to visual interpretation of taxometric graphs when the indicators are skewed (Ahmed, 2010).

rising cusp on the right side of the graph. Overall, the average MAMBAC curve was closer to the simulated dimensional data than to the simulated taxonic data (CCFI = .426; Figure 2, top graph). Only two of the nine MAXEIG curves displayed a clear peak consistent with a taxonic structure. The average of the nine MAXEIG curves was clearly more similar to the dimensional comparison data than to the taxonic comparison data (Figure 2, middle graph), CCFI = .272. The L-Mode curve for the actual data was unimodal, (Figure 2, bottom graph), and the CCFI (.376) was more consistent with a dimensional latent structure. We also ran separate sets of taxometric analyses for the mother and teacher forms of the DBQ. These analyses also yielded consistently dimensional results (Table 2).

Next, we used indicators that operationalized hyperactivity/impulsivity using diverse methods. Specifically, the three indicators for these analyses were (a) observer rated hyperactivity/impulsivity problems (the hyperactivity/impulsivity ratings averaged across both the mother and teacher DBQ, the TRF, and the CBCL), (b) classroom disruptive behavior as rated by an observer, and (c) commission errors on the CPT. The average degrees of separation for these three indicators, based on the base rates derived from the subsequent MAMBAC and MAXEIG analyses, were 1.41 and 2.23 SDUs, respectively.

Two of the MAMBAC graphs exhibited a rising cusp on the right side of the graph, whereas the other graph had a right side peak consistent with a taxon. However, the average of the three curves was much more similar to the dimensional comparison data than to the taxonic comparison data, CCFI = .285 (Table 2). The average MAXEIG curve was clearly more similar to the dimensional comparison data than to the taxonic comparison data, CCFI = .378 (Table 2). Overall, it appears that hyperactivity/impulsivity has a dimensional latent structure.

ADHD

We used multiple sets of indicators to examine whether an ADHD taxon emerged from the combination of inattention and hyperactivity/impulsivity problems. The first analyses used the total DBQ inattention score and total DBQ hyperactivity/impulsivity score (each averaged across mother and teacher reports when both were available) as the two indicators. Because there were only two indicators for this analysis, we were limited to MAMBAC. Both curves had a rising cusp on the right. The average of the two curves was considerably more similar to the curve from the simulated dimensional data than the curve produced by the simulated taxonic data (CCFI = .370). Separate MAMBAC analyses with just the mother DBQ and teacher DBQ reports also yielded dimensional results (Table 2).

Separate factor analyses of the ADHD items from the TRF and the mother report CBCL, yielded inattention and hyperactivity/impulsivity factors for the TRF, but only a single combined ADHD factor for the CBCL. Based on the subsequent MAMBAC (2.02 SDUs) and MAXEIG (2.42 SDUs) analyses, these three scales had good indicator validity. This set of indicators also yielded results that were consistent with a dimensional latent structure (MAMBAC CCFI = .236; MAXEIG CCFI = .291).

Finally, we used indicators that operationalized ADHD using diverse methods. The five indicators for these analyses were (a) observer rated inattention problems (the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the CBCL), (b) observer rated hyperactivity/impulsivity problems (the hyperactivity/impulsivity ratings averaged across both the mother and teacher DBQ, the TRF, and the CBCL), (c) academic achievement (average Broad Reading and Math scores on the WJ-R), (d) omission errors on the CPT,[4] and (e) TOH. The average degrees of separation for these five indicators, based on the base rates derived from the subsequent MAMBAC and MAXEIG analyses, were 1.42 and 1.57 SDUs, respectively, which is adequate.

One of the five MAMBAC curves had a clear peak, but the other four were ambiguous (two had a rising cusp and two had multiple peaks). The average of the five curves was more similar to the dimensional comparison data than to the taxonic comparison data, (CCFI = .359; Figure 3, top graph). All five MAXEIG curves were flat and the average MAXEIG curve was more similar to the dimensional comparison data than to the taxonic comparison data (CCFI = .418; Figure 3, middle graph). The L-Mode graph was unimodal and more similar to the dimensional comparison data (CCFI = .278; Figure 3, bottom graph; Table 2). Finally, because the CPT omissions yielded the lowest validity scores, we ran the analyses with just the other four ADHD indicators. These analyses yielded greater separation (1.57 and 1.79 SDUs), and the results remained dimensional (see Table 2).

Comparison of Dimensional and Dichotomous Models

Examination of features associated with ADHD provides a further test of the relative merits of taxonic versus dimensional models of the construct (Watson, 2006). To examine the utility of these alternative models, we computed correlations between dimensional and categorical ADHD scores (based on two sets of scores) and numerous associated features. First, because the DBQ items map directly onto the DSM-IV-TR criteria, DBQ case assignments were considered positive if (a) mother and teacher reports both met the six-symptom cut off for either inattention or hyperactivity/impulsivity symptoms, or (b) either the mother or teacher report met the criteria for both inattention and hyperactivity/impulsivity. These criteria yielded a 7% rate of ADHD, consistent with population base rates.[5] The second set of scores combined the data from the inattention and hyperactivity/impulsivity measures from the DBQ-mother, DBQ-teacher, TRF, and CBCL (total of eight scales converted to *z*-scores and averaged). Composite case assignments were made, splitting the sample into two groups matching the putative taxon base rate across all of the analyses that examined the latent structure of ADHD (26.7%). Based on Monte Carlo simulations Ruscio (2009a) concluded that case assignment based on the estimated taxon base rate is at least as accurate as other methods such as using Bayes' theorem. The DBQ and Composite continuous scores were the average scores of the respective measures.

The correlations among the dimensional scores and the associated features were consistently higher than the correlations among the dichotomous scores and the associated features, (Table 3). In fact, the DBQ-based case assignments accounted for 7.6% of the variance (on average) in the associated features, whereas the continuous DBQ score accounted for 17.4% of the variance in the associated features. Likewise, the composite case assignments accounted for an average of 6.5% of the variance in these variables, compared to 18.8% of the variance accounted for when treating the composite scores continuously. Overall, treating ADHD continuously accounted for 2.6 times as much variance as treating ADHD categorically. Finally, we compared the differences in the correlations between the associated features and the DBQ continuous and case assignment scores, as well as the differences in the correlations between the associated features and the composite continuous and case assignment scores. Steiger's (1980) method for comparing two dependent correlations (i.e., those sharing one common variable—the associated feature) was used. These results (Table 3) indicated that correlations in which ADHD was treated continuously were significantly larger for 42 of 48 comparisons.

[4]Commissions from the CPT were not included in this analysis because it yielded sub-optimal indicator validity coefficients.
[5]More stringent diagnostic criteria (i.e., requiring both mother and teacher reports to meet the ADHD diagnostic criteria) resulted in a considerably lower rate of ADHD in the sample (3%).

Discussion

There was consistent evidence that inattention, hyperactivity/impulsivity, and ADHD symptoms all have a dimensional latent structure. The analyses generated graphs that were more similar to simulated dimensional data than to simulated taxonic data: Not one of the 39 different taxometric analyses reported in Table 2 yielded a CCFI greater than .45. Given the findings from Ruscio et al.'s (2010) Monte Carlo study, which found that when MAMBAC, MAXEIG, and L-Mode all yielded CCFIs less than .45, there was a 99.9% chance that the construct was correctly identified as dimensional, we can have considerable confidence in the current findings.

The results of the current study were consistent with the conclusions from the two prior studies that used Meehl's taxometric method to examine ADHD (Frazier et al., 2007; Haslam et al., 2006). Furthermore, the current study complemented these previous studies in a number of ways. Unlike Haslam et al., which was based entirely on indicators that used a single method, the current set of taxometric analyses included analyses using a variety of raters and methods. Unlike Frazier et al., the current sample was drawn from the general population and was not clinic referred. Taken together, these results provide strong and consistent evidence that ADHD symptoms are best represented using a dimensional latent variable. [6]

We also conducted secondary analyses to examine the practical consequences of these dimensional findings. Overall, scoring the ADHD measures on a continuum predicted theoretically relevant associated features of ADHD with greater accuracy than did group classification, despite our use of multiple cut-scores. Such findings are consistent with Achenbach's (1991a) dimensional approach to assessing childhood psychopathology and with Fergusson and Horwood's (1995) findings that dimensional measures of externalizing behavior are better predictors of subsequent problems than are categorical diagnoses.

Although the present study was not designed to test etiological models of ADHD, our dimensional findings are consistent with the underlying assumptions of most contemporary models of ADHD, such as those proposed by Nigg and colleagues (2004) and Sonuga-Barke (2005), both of which presuppose that ADHD has a dimensional structure. Furthermore, these dimensional findings are consistent with the results of a recent meta-analysis (Nikolas & Burt, 2010), which found that each component of ADHD could be best explained as arising from a multi-locus genetic basis with a mix of additive and non-additive effects, along with nonshared environmental influences. Such a genetic model is likely to be more consistent with a dimensional latent structure than with a taxonic one, because each influence may add to the severity of the disabilities along a continuum from subclinical to meeting diagnostic threshold. Of course these findings do not rule out the possibility that there are sub-groups of ADHD with alternative transmission patterns.

Limitations

Our study is not without limitations. It is possible that we may have missed a very low base rate ADHD taxon. Given the size of the sample and the expected base rate of ADHD in the general population, this possibility is unlikely. If, however, the DSM-IV-TR criteria are too liberal and there actually is a very small subset of children with a qualitatively distinct impairment, it is possible that such a taxon may have been missed because the sample only contained a few taxon members.[7] If this unlikely possibility were to be the case, it would

[6]Of course, future research using other latent variable modeling approaches may yield more complex multi-class structures.

[7]Recent Monte Carlo research suggests that even at low base rates (*P* < .06), the CCFI method appears to be accurate as long as there are sufficient taxon members in the sample (see Ruscio et al., 2010, Figure 5).

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require a significant shift in how ADHD is conceptualized and diagnosed. Furthermore, the Frazier et al. (2007) study, with its clinical sample, should have identified such a putative taxon.

One of the strengths of the current study was that, unlike the majority of taxometric studies which have relied on a single methodology for deriving indicators, the current study used indicators drawn from a variety of sources. A downside to this approach, however, was that when indicators were derived from different methodologies, the indicator validity coefficients were sometimes less than ideal. This trade-off between methodological variation and indicator validity is probably not unique to the current study, because shared method variance is likely to inflate validity coefficients. Our analytic strategy was to conduct both mono-method analyses, which had indicator validity coefficients far exceeding the values suggested by Meehl, and multi-method analyses. The results were complementary, with both sets of analyses consistently yielding dimensional results.

Acknowledgments

Funding for this project was provided by National Institute of Child Health and Human Development Grant 1R03HD054667-01A1 awarded to David K. Marcus and Tammy D. Barry. This study was conducted by the NICHD Early Child Care Research Network supported by NICHD through a cooperative agreement that calls for scientific collaboration between the grantees and the NICHD staff.

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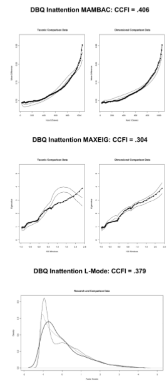

Figure 1.

Average MAMBAC, MAXCOV, and L-Mode curves for the research data along with taxonic and dimensional comparison data for the nine DBQ inattention indicators. To stabilize the shape of the curves, the analyses were replicated 10 times by randomly shuffling the cases with equal scores on the input indicator and recalculating the output indicator, with the average values across the 10 replications serving as the final results (Ruscio et al., 2006). Dark lines on the curves represent the actual data and the lighter lines represent one standard deviation above and below the average for each type of comparison data. CCFI = Comparison Curve Fit Index.

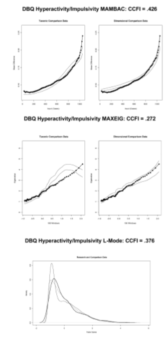

Figure 2.
Average MAMBAC, MAXCOV, and L-Mode curves for the nine DBQ hyperactivity/impulsivity indicators.

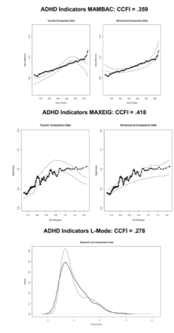

Figure 3.
Average MAMBAC, MAXCOV, and L-Mode curves for the five ADHD indicators.

Table 1

Correlations among primary and secondary indicators of ADHD [a].

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. CBCL-I	(1.15)	.71***	.55***	.42***	.88***	.61***	.35***	.51***	−.22***	.11**	.12**	.12***	−.29***
2. CBCL-HI		(1.18)	.41***	.52***	.64***	.89***	.46***	.38***	−.20***	.18***	.10**	.11**	−.24***
3. TRF-I			(1.32)	.65***	.47***	.35***	.54***	.92***	−.26***	.16***	.22***	.25***	−.39***
4. TRF-HI				(1.59)	.35***	.47***	.93***	.65***	−.19***	.30***	.23***	.16***	−.21***
5. DBQ-M-I					(2.08)	.61***	.29***	.45***	−.16***	.10**	.06	.09**	−.24***
6. DBQ-M-HI						(1.80)	.43***	.34***	−.18***	.20***	.08*	.06	−.21***
7. DBQ-T-I							(1.79)	.59***	−.16***	.31***	.19***	.15***	−.17***
8. DBQ-T-HI								(2.16)	−.23***	.18***	.19***	.21***	−.32***
9. TOH									(−0.17)	−.07*	−.21***	−.24***	.32***
10. COS-DB										(5.76)	.11**	.02	−.14***
11. CPT-C											(4.78)	.36***	−.27***
12. CPT-O												(3.51)	−.36***
13. WJR													(−1.03)

Note: CBCL = Child Behavior Checklist; TRF = Teacher Report Form; DBQ = Disruptive Behavior Disorders Questionnaire; M = Mother; T = Teacher; I = Inattention; HI = Hyperactivity/Impulsivity; TOH = Tower of Hanoi (total planning efficiency across tasks); COS-DB = Classroom Observation System – Disruptive Behavior; CPT-C = Continuous Performance Task (commission errors); CPT-O = Continuous Performance Task (omission errors); WJR = average Broad Reading and Math scores on the Woodcock Johnson-Revised Tests of Achievement. Pairwise exclusion used in calculation of correlation coefficients; sample size ranged from 810 to 1013 for each pair. [a] Skew showed in the diagonal.

* $p < .05$;

** $p < .01$;

*** $p < .001$.

Table 2

Summary of the Taxometric Analyses Examining the Latent Structure of Inattention, Hyperactivity, and ADHD

							MAMBAC			MAXEIG			L-Mode	Mean
Indicators	***n***	***k***	**skew**	***r***	r_n	d^a	***d***	**CCFI**	**BR**	***d***	**CCFI**	**BR**	**CCFI**	**CCFI**
I. Inattention														
DBQ Inattention Items Combined Mother & Teacher	1078	9	1.14	.65	.35	2.65	2.17	.406	.27	2.52	.304	.14	.379	.363
DBQ Inattention Items Mother Form	957	9	0.98	.51	.23	2.32	1.69	.314	.29	2.00	.322	.15	.351	.329
DBQ Inattention Items Teacher Form	945	9	1.41	.66	.30	2.83	2.52	.200	.22	2.74	.223	.14	.429	.284
Combined Mother & Teacher Ratings, Achievement, & Neuropsychological Measures	667	4[b]	1.37	.30	.04	1.96	1.41	.429	.36	1.52	.328	.27	.273	.343
Combined Mother & Teacher Ratings, Achievement, & Neuropsychological Measures	667	3[c]	0.74	.34	.00	2.02	1.59	.287	.37	1.74	.348	.22		.318
II. Hyperactivity														
DBQ Hyperactivity Items Combined Mother & Teacher	1075	9	1.30	.55	.27	2.47	1.93	.426	.26	2.31	.272	.13	.376	.358
DBQ Hyperactivity Items Mother Form	957	9	1.12	.39	.15	1.96	1.52	.184	.25	1.75	.269	.14	.300	.251
DBQ Hyperactivity Items Teacher Form	945	9	1.75	.60	.29	2.92	2.54	.253	.15	2.77	.174	.11	.443	.290
Combined Mother & Teacher Ratings, Classroom Behavior, & CPT	667	3[d]	3.91	.20	−.12	2.39	1.41	.285	.28	2.23	.378	.09		.332
III. ADHD														
DBQ Hyperactivity Scale & Inattention Scale Combined Mother & Teacher	1072	2	1.24	.67	.20	3.06	2.53	.370	.30					
DBQ Hyperactivity Scale & Inattention Scale Mother Form	833	2	1.07	.69	.29	3.00	2.44	.413	.30					
DBQ Hyperactivity Scale & Inattention Scale Teacher Form	833	2	1.54	.64	.17	3.26	2.68	.311	.27					
TRF Inattention, TRF Hyperactivity, & Mother CBCL ADHD	928	3	1.43	.51	.08	2.62	2.02	.236	.32	2.42	.291	.19		.264
Combined Mother & Teacher Ratings, Achievement, & Neuropsychological Measures	667	5[e]	1.38	.32	.06	1.87	1.42	.359	.34	1.57	.418	.24	.278	.352
Combined Mother & Teacher Ratings, Achievement, & Neuropsychological Measures	667	4[f]	0.91	.35	.04	2.10	1.57	.295	.35	1.79	.396	.21	.191	.294

Note: n = sample size; k = number of indicators; skew = average skew of the indicators; r = average correlation among the indicators in the full sample; r_n = average nuisance covariance (estimated 7% taxon base rate); d = indicator validity in *SD* units; CCFI = Comparison Curve Fit Index; BR = estimated taxon base rate; DBQ = Disruptive Behavior Disorders Questionnaire; TRF = Teacher Rating Form; CBCL = Child Behavior Checklist. MAMBAC analyses all used 100 cuts. MAXEIG analyses used 100 windows with .90 overlap except for the samples with 667 cases, which used 50 windows with .90 overlap.

[a] Validity coefficients in this column were computed presupposing a 7% taxon base rate.

[b] The 4 indicators were (1) the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (2) average Broad Reading and Math scores on the Woodcock Johnson, (3) omissions on the Continuous Performance Test, and (4) Tower of Hanoi.

[c] The 3 indicators were (1) the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (2) average Broad Reading and Math scores on the Woodcock Johnson, and (3) Tower of Hanoi.

[d] The 3 indicators were (1) the hyperactivity ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (2) the Classroom Observation Scale, disruptive behavior, and (3) commissions on the Continuous Performance Test.

[e] The 5 indicators were (1) the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (2) the hyperactivity ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (3) average Broad Reading and Math scores on the Woodcock Johnson, (4) omissions on the Continuous Performance Test, and (5) Tower of Hanoi.

[f] The 4 indicators were (1) the inattention ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (2) the hyperactivity ratings averaged across both the mother and teacher DBQ, the TRF, and the Mother's CBCL, (3) average Broad Reading and Math scores on the Woodcock Johnson, and (4) Tower of Hanoi.

Table 3

Correlations comparing the dimensional and dichotomous variables with outcome variables.

	n	DBQ Case Assignment[a]	DBQ Continuous[b]	*t*[c]	Composite Case Assignment[d]	Composite Continuous[e]	*t*[f]
Academic							
WJR Broad Reading (residualized)[g]	770	−.07	−.15***	−2.57*	−.09*	−.15***	−1.86*
WJR Broad Math (residualized)[g]	772	−.09*	−.13***	−1.28	−.11**	−.13***	−0.62
Academic Competence (SSRS-T)	833	−.32***	−.54***	−8.88***	−.38***	−.56***	−6.85***
COS Engaged	801	−.17***	−.26***	−3.10***	−.18***	−.25***	−2.23*
Other Externalizing Problems							
Aggressive Behavior (CBCL)	832	.33***	.47***	5.39***	.29***	.51***	8.04***
Aggressive Behavior (TRF)	832	.45***	.66***	9.50***	.32***	.62***	12.03***
Delinquent Behavior (CBCL)	832	.25***	.41***	5.95***	.28***	.44***	5.60***
Delinquent Behavior (TRF)	832	.40***	.59***	7.99***	.29***	.58***	11.21***
ODD Symptoms (DBQ-M)	833	.30***	.51***	8.30***	.40***	.51***	4.06***
ODD Symptoms (DBQ-T)	833	.41***	.61***	8.57***	.30***	.57***	10.34***
COS Negative/Aggressive with Peers	801	.13***	.18***	1.69	.06	.18***	3.77***
COS Negative Toward Teacher	801	.23***	.27***	1.39	.11**	.24***	4.13***
Internalizing Symptoms							
Withdrawn (CBCL)	832	.08*	.22***	4.89***	.21***	.30***	2.97***
Withdrawn (TRF)	832	.25***	.34***	3.25***	.19***	.40***	7.21***
Anxious/Depressed (CBCL)	832	.17*	.28***	3.89***	.20***	.33***	4.33***
Anxious/Depressed (TRF)	832	.22***	.24***	0.70	.13***	.28***	4.91***
Somatic Complaints (CBCL)	832	.06	.15***	3.09***	.18***	.19***	0.32
Somatic Complaints (TRF)	832	.25***	.30***	1.78*	.19***	.33***	4.66***
Social and Other Problems							
Social Problems (CBCL)	832	.25***	.41***	5.95***	.25***	.48***	8.24***
Social Problems (TRF)	832	.41***	.61***	8.57***	.33***	.63***	12.15***
Social Skills (SSRS-M)	833	−.25***	−.43***	−6.77***	−.34***	−.45***	−3.89***

	n	DBQ Case Assignment[a]	DBQ Continuous[b]	t[c]	Composite Case Assignment[d]	Composite Continuous[e]	t[f]
Social Skills (SSRS-T)	826	$-.36^{***}$	$-.63^{***}$	-11.79^{***}	$-.38^{***}$	$-.64^{***}$	10.59^{***}
Thought Problems (CBCL)	832	$.24^{***}$	$.35^{***}$	3.99^{***}	$.24^{***}$	$.43^{***}$	6.61^{***}
Thought Problems (TRF)	832	$.36^{***}$	$.46^{***}$	3.84^{***}	$.22^{***}$	$.50^{***}$	10.21^{***}

Note: WJR = Woodcock-Johnson-Revised; M = Mother; T= Teacher; DBQ = Disruptive Behavior Disorders Questionnaire; CBCL = Child Behavior Checklist (mother report); TRF = Teacher Rating Form; SSRS = Social Skills Rating System; COS = Classroom Observation System.

[a] DBQ Case Assignment = met ADHD criteria for inattention and hyperactivity/impulsivity (by either mother or teacher) or inattention only (by both mother and teacher) or hyperactivity/impulsivity only (by both mother and teacher) on the DBQ.

[b] DBQ Continuous = average of the inattention and hyperactivity/impulsivity scales for both mother and teacher ratings on the DBQ.

[c] Significance test of correlation differences comparing DBQ (Continuous and Case Assignment); N-3 degrees of freedom (Steiger, 1980).

[d] Composite Case Assignment = met the cut-score for a base rate of 26.7% (based on taxometric analyses) on the average of the inattention and hyperactivity/impulsivity scales for the DBQ-mother, DBQ-teacher, CBCL, and TRF.

[e] Composite Continuous = average of the inattention and hyperactivity/impulsivity scales for the DBQ-mother, DBQ-teacher, CBCL, and TRF.

[f] Significance test of correlation differences comparing Composite (Continuous and Case Assignment); N-3 degrees of freedom.

[g] Academic achievement scores are residualized scores based on regressing WJ-R Broad Reading and Broad Math standard scores on WASI Full Scale IQ.

$^{*}p < .05$;

$^{**}p < .01$;

$^{***}p < .001$