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Replication and External Validation of a Bi-factor Parameterization of Attention Deficit/Hyperactivity Symptomatology

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Abstract

This study evaluated the fit and criterion validity of a recently proposed bi-factor structure for ADHD symptoms. Participants included N=1093 children, drawn from an ongoing prospective longitudinal study, whose ADHD symptoms were rated by parents and teachers when children were in 1st grade. The criterion validity of the bi-factor model was established using a range of school-based outcomes that included treatment utilization, teacher perceptions of the need for treatment, academic functioning, and peer and teacher relationship quality. Results indicated that a bi-factor model parameterization provided an equally good fit to parent, teacher, and combined reports of ADHD symptoms as did traditional 1-, 2-, and 3-factor. However, in contrast to traditional models, the bi-factor parameterization acknowledged both the unity and diversity of ADHD symptoms. The *general* ADHD latent factor explained the vast majority of the observed variation in every symptom. Whereas the general ADHD latent factor was significantly associated with all 15 outcomes, the *specific* Inattentive factor explained unique variation in 9 (primarily the academically-oriented) outcomes and the *specific* Hyperactive-Impulsive factor explained unique variation in 2 outcomes. The general ADHD factor was more strongly correlated with each of the observed ADHD symptom scores (total, inattentive, hyperactive-impulsive) than was either specific factor. Results are discussed with respect to how changes in the conceptualization of the factor structure correspond to recent changes to the diagnostic criteria for ADHD, as well as whether/how individual differences in inattention and hyperactivity-impulsivity might be used to differentiate children who are diagnosed with ADHD.

Keywords

attention deficit/hyperactivity disorder; bi-factor confirmatory factor analysis; school outcomes

The modern era of research on attention deficit/hyperactivity disorder (ADHD) was initiated with the publication of the third edition of the Diagnostic and Statistical Manual (DSM) by the American Psychiatric Association (APA, 1980). Over the ensuing three decades,

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substantial energy has been devoted to clarifying the factor structure of the core symptoms of hyperactivity, impulsivity, and inattention. As recently reviewed by Willcutt and colleagues, an extensive factor analytic literature involving parent, teacher, and self-report ratings of over 60,000 children has provided strong support for distinguishing inattentive (IN) from hyperactive-impulsive (HI) behaviors (Willcutt et al., 2012). The distinction between IN and HI symptoms is also evident from studies conducted in at least 15 different countries, increasing the generalizability of this conclusion (Bauermeister, Canino, Polanczyk, & Rohde, 2010).

Changing conceptualizations of the factor structure of ADHD symptoms have informed efforts about how to best subtype ADHD youth on the basis of their hyperactive, impulsive, and/or inattentive behaviors (see Frick & Nigg, 2012 for a brief historical review). In DSM-IV, children who were diagnosed with ADHD were characterized by one of three mutually exclusive subtypes—primarily inattentive, primarily hyperactive-impulsive, or combined (APA, 2000). Despite the close conformity between the DSM-IV subtyping efforts and the factor analytic literature of ADHD symptomatology, there were proposals to abandon efforts at subtyping ADHD youth on the basis of their IN or HI symptoms (Nigg, Tannock, & Rohde, 2010; Swanson, Wigal, & Lakes, 2009; Willcutt et al., 2012). The primary rationale for these proposals was evidence of the developmental instability of subtypes; youth who were clinically diagnosed with ADHD frequently moved "in and out" of subtypes across time (Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Todd et al., 2008; Valo & Tannock, 2010). To be clear, although continuous measures of IN and HI symptoms exhibited moderate across-time stability, membership in ADHD subtypes did not; this was due, in part, to the arbitrary use of 6 (IN and/or HI) symptoms to delineate subtype membership. Moreover, studies of the academic and cognitive functioning, treatment outcomes, and etiologies of the DSM-IV ADHD subtypes did not provide strong support for their continued distinction (Willcutt et al., 2012).

The recently introduced DSM-5 diagnostic criteria continue to require that individuals exhibit 6 or more of IN and/or HI symptoms in order to qualify for a diagnosis of ADHD. However, individuals are now characterized as having ADHD with a predominantly inattentive, hyperactive-impulsive or combined *symptom presentation* (not 'subtypes'). This shift in language, from symptom subtype to presentation, is consistent with the proposal to use IN and HI symptom counts as "continuous modifiers" of a diagnosis of ADHD (Lahey & Willcutt, 2010; Willcutt et al., 2012). The underlying objective of these changes are to acknowledge the limits of characterizing individuals as having a particular subtype of ADHD (i.e., subtype instability, similar correlates and outcomes) while continuing to acknowledge the behavioral heterogeneity among children with a diagnosis of ADHD.

The prospect of reverting back to considering ADHD a single disorder without subtypes, which is reminiscent of DSM-IIIr, and using IN and HI symptoms as qualifiers to the diagnosis is interesting in light of recent efforts to re-examine the factor structure of ADHD symptoms. Spurred by the seminal work of Martel and colleagues (Martel, von Eye, & Nigg, 2010), a growing number of research groups have considered a bi-factor parameterization as an alternative to the simple one-, two, and three-factor models for ADHD symptoms. Although bi-factor models are not new (Holzinger & Swineford, 1937), their use in the social, clinical, and health sciences is (Reise, 2012). Bi-factor models are typically applied when researchers are interested in a common construct that consists of several highly related domains. When applied to ADHD, a bi-factor parameterization includes a general (overall) factor on which all symptoms load, as well as two (or three) specific factors on which the inattentive and hyperactive-impulsive (or inattentive, hyperactive, impulsive) symptoms also load. The canonical bi-factor model restricts the covariances between all of the latent factors to 0 (Chen, West, & Sousa, 2006). This makes the results more easily interpretable, as the total variation in each symptom (item) is completely decomposed into three mutually exclusive components—that attributable to the general factor (here ADHD), the specific factor (here IN or HI), and the residual term.

At least seven studies have fit bi-factor models to ADHD data (Gibbins, Toplak, Flora, Weiss, & Tannock, 2013; Martel, von Eye, & Nigg, 2012; Martel et al., 2010; Normand, Flora, Toplak, & Tannock, 2012; Toplak et al., 2009; Toplak et al., 2012; Ullebø, Breivik, Gillberg, Lundervold, & Posserud, 2012). In each case, the bi-factor model was deemed to provide the best (or equally good) fit to the data among all models considered—including traditional one-, two-, and three-factor CFA models with factor complexity of one (i.e., models in which ADHD items loaded on one and only one factor). Across studies, there was a tendency for the general factor to account for (1) more of the variation in HI symptoms than the HI-specific factor and (2) comparable amounts of the variation in IN symptoms relative to the IN-specific factor. The superiority of the bi-factor parameterization of ADHD symptoms also held across informants (parent vs. teacher report), instrument type (rating scale vs. diagnostic interview), ascertainment methods (clinical vs. community samples), and participant age (Martel et al., 2012; Normand et al., 2012; Toplak et al., 2012).

This emerging literature on the bi-factor model of ADHD symptoms is interesting in light of aforementioned proposal to abandon IN and HI subtypes of ADHD. The presence of a single dominant general factor is consistent with the prospect of defining ADHD as a single condition (no subtypes). Moreover, to the extent that the specific factors (IN, HI) account for additional systematic variation in child outcomes, above and beyond that attributable to the general factor, this would provide support for the use IN and HI scores as “continuous modifiers” of diagnosis (Lahey & Willcutt, 2010). However, to date, we are unaware of studies that have tested whether the specific IN and HI factors explain unique variation in clinically relevant outcomes beyond that attributable to the general ADHD factor. Although Martel and colleagues reported significant *bivariate* correlations between general (ADHD) and specific (IN, HI) factors with multiple indicators of psychopathology, cognitive functioning, personality traits, and genetic risk, they did not test whether general and specific factors uniquely predicted clinically relevant outcomes (Martel, Roberts, Gremillion, von Eye, & Nigg, 2011).

The current study had three objectives. First, we evaluated the fit of bi-factor and more traditional one-, two-, and three- factor CFA models for parent and teacher rated ADHD symptoms in a representative sample of 1st grade children. We focus on 1st grade because this was the first assessment in which participating children were in elementary school and for which parent and teacher ratings of ADHD symptoms were obtained at approximately the same time. This facilitated our use of multi-informant ratings of ADHD, which represents clinical best practice. Consistent with previous studies, we hypothesized that a bi-factor parameterization would provide an equally good fit to the observed ADHD symptom scores as any alternative parameterization and that the general factor would account for more of the observed variation in individual symptom scores than would either specific (IN, HI) factor.

Second, we tested the unique contributions of general (ADHD) and specific (IN, HI) latent factors as predictors of a wide range of clinically relevant school based outcomes including treatment utilization, teacher perceptions of a students need for treatment, academic functioning and motivation, as well as peer and teacher relationship quality. Although no previous study has done so, we reasoned that if the common factor accounted for a majority of the variation in ADHD symptoms, it would be a stronger predictor of these school-based outcomes than either specific (IN, HI) factor. To the extent that specific IN and HI latent factors explained unique variation in outcomes beyond that attributable to the general common factor, this would inform their use as continuous modifiers to a diagnosis.

Third, we tested how strongly general and specific *factor scores*, which were derived from a bi-factor model, were related to *observed scores* (i.e., IN, HI, total symptoms). In applied practice, clinicians have easy access to observed ADHD scores (e.g., symptom counts, mean scores) but not latent factor scores. Based on the results of Ullebø and colleagues (2012), we hypothesized that the general latent factor would not only explain most of the variation in the total observed ADHD symptom scores but that it would also explain more of the variation in the observed IN and HI symptom scores than would the IN and HI specific factors. To the extent that this was true, it would undermine the use of *observed* IN and HI symptom scores as "continuous modifiers" of clinical diagnosis because the *observed* IN and HI symptoms scores would not convey unique information beyond that attributable to overall ADHD risk, which is precisely their intended function in the Lahey and Willcutt (2010) proposal.

Method

Participants & Procedures

The Family Life Project (FLP) is an ongoing prospective longitudinal study of N=1292 families who live in two of the four major geographical areas of the United States with high poverty rates (Dill, 2001). Specifically, three counties in Eastern North Carolina (NC) and three counties in Central Pennsylvania (PA) were selected to be indicative of the Black South and Appalachia, respectively. Families who delivered a child in these six target counties between September 2003 and October 2004 were eligible for participation. A representative sample of 1292 children from these counties, with over-sampling of low-income families in both states and African American families in NC (child race and screens for household income level were obtained during hospital recruitment), was recruited. The sampling plan was designed to enhance the ability to study normative development among low-income and African American families in non-metropolitan communities, while facilitating our ability to make inferences back to the 6-county study area "as if" participants had been selected using simple random sampling (by incorporating stratification variables and probability weights into analysis). A full characterization of the sampling plan and study design of the FLP has been elaborated elsewhere (Vernon-Feagans, Cox, & Investigators, in press).

Families who were recruited into the study at the birth of their new child participated in a series of home visits when target children were 2, 6, 15, 24, 36, 48, 58 months old and most recently at 1st grade. School-based data were collected for children who were enrolled in preschool and for all children annually from kindergarten. The current study included children with parent- or teacher-rated ADHD behaviors at the 1st grade assessment (N = 1093; n=189 with parent ratings only, n=6 with teacher rating only, n = 898 with parent and teacher ratings), representing 85% of the total sample. Teacher ratings were collected in the Fall of the academic year, while parent ratings were obtained as part of home visits that occurred throughout the 1st grade year. Children were, on average, 7 years old at the time of ratings (i.e., child age at the time of teacher rating, M = 7.0, SD = 0.3 years; child age at the time of parent rating, M = 7.3, SD = 0.3). The overwhelming majority of parent ratings came from biological mothers (92%) and fathers (4%). For a minority of children, neither biological parent served in the role of primary caregiver, in which case ratings were collected from whoever served that role (for 2% this was maternal grandparents and for an additional 2% this was some other adult, including paternal grandparents, uncles, aunts, adoptive parents, etc.). Nevertheless, to facilitate communication, we use the general referent parent to describe adults who serve the role of primary caregiver. Families and children who were enrolled in the larger study but for who 1st grade assessments were not available (N = 199) did not differ from study participants (N = 1093) with respect to state of residence (42% vs. 40% residing in PA, $p = .63$), living in a household that was recruited into the low income stratum (74% vs. 78% poor, $p = .18$), primary caregiver educational status at study enrollment (80% vs. 80% with a high school degree/GED or beyond, $p = .93$), household structure (64% vs. 66% households with a spouse or partner, $p = .65$), or sex of the child (54% vs. 50% male, $p = .37$). However, children who did not participate in the 1st grade assessment were less likely to be African American (36% vs. 44%, $p = .05$).

Measures

Attention Deficit/Hyperactivity Disorder (ADHD) Symptom Ratings (Pelham, Evans, Gnagy, & Greenslade, 1992)—Parents and teachers independently completed the ADHD rating scale at the 1st grade visit. All 18 DSM-IV symptoms for ADHD were rated on a four point scale (0=not at all, 1=just a little, 2=pretty much, 3=very much). Following convention for the use of this instrument and others like it, items that were rated as either “pretty much” or “very much” were considered an approximation for symptom endorsement. We focus on dichotomous symptoms instead of Likert ratings because the former are often, but not necessarily, used for clinical decision making (clinicians are certainly able to rely on norm-referenced scores rather than symptom counts to make diagnostic decisions). Following research precedent (e.g., Bird, Gould, & Staghezza, 1992; Lahey et al., 1994; Piacentini, Cohen, & Cohen, 1992), individual symptoms were combined using the “or” rule (i.e., each symptom was deemed present if either parent or teacher endorsed it). Parent, teacher, and combined symptom counts had strong internal consistency (parent: IN $\alpha = .87$, HI $\alpha = .86$, total $\alpha = .92$; teacher: IN $\alpha = .92$, HI $\alpha = .91$, total $\alpha = .95$; combined: IN $\alpha = .91$, HI $\alpha = .89$, total $\alpha = .94$).

Treatment—Teachers were asked a series of questions about children's receipt of (and need for) medication and other school-based treatments. Specifically, teachers were asked whether a child had an individual education plan or IEP whether a child was taking any kind of medication for "ADHD, hyperactivity, trouble paying attention, or trouble controlling his or her temper", whether they believed that the child would benefit from this type of medication, whether the child received any other kind of special services because of "learning difficulties, emotional problems, or behavior problems", and whether they (the teacher) was considering referring the child for (additional) services (the specific type of which was not specified).

Teacher-Rated Academic Impairment—Teachers answered two questions regarding the child's relative standing in the class with respect to math and reading/literacy ability levels (these items were derived from the Head Start REDI Academic Performance Questions; http://headstartredi.ssri.psu.edu/). The specific questions stated "In terms of [reading and literacy /math] skills, would you say that this child is: near the very bottom of your class (0), in the bottom half of your class (1), in the solid middle of your class (2), in the top half of your class (3), or near the very top of your class (4)". We operationalized academic impairment by a rating that the child was "near the very bottom of the class" (i.e., ratings of 0 on the 0–4 scale). An additional question asked about the likelihood that the child would pass 1st grade. The specific question stated "Do you think this child will proceed to the next grade next year: highly unlikely (0), there are some serious concerns, probably not (1), there are some concerns but probably yes (2), definitively yes (3)". We operationalized risk for grade failure by ratings of 0 or 1.

Peer Relationship Ratings—Teachers rated four items on a 6-point Likert scale (0 = almost never, 1= rarely, 2= sometimes, 3= often, 4= very often, 5= almost always). These items were derived from the Excluded by Peers subscale of the Child Behavior Scale developed by Ladd and Profilet (1996). The items included "is liked by classmates", "is disliked by classmates", "is left out or ignored by classmates", and "is teased or picked on by classmates". We operationalized peer impairment by a combination of not being liked (i.e., ratings of "almost never" (0) or "rarely" (1) for "is liked by classmates") and being activity disliked (i.e., ratings of sometimes (2) or greater for "is disliked" or "is left out or ignored" or "is teased or picked on"). We also considered a dichotomous rating of whether the child had at least one friend ("Regardless of whether this child is popular or unpopular, does she or he have a special, close, 'best friend'?").

Student-Teacher Relationship Scale (STRS; Pianta, 2001)—The STRS Teachers completed the 8-item closeness and 7-item conflict scales of the STRS. These scales represent the teacher's impressions of his/her overall relationship quality with a student. Both the closeness and conflict scales exhibited good internal consistency, αs = .84 and .92, respectively.

Teacher Rating of Academic Achievement Motivation (TRAAM; Stinnett, Oehler-Stinnett, & Stout, 1991)—Teachers completed a 10-item subscale (factor 1) of the TRAMM that reflected the student's tendency to work to the best of his or her ability, to complete assignments without prompting, and to give good effort on school tasks. Items exhibited good internal consistency, α = .92.

Woodcock-Johnson III Tests of Achievement (WJ III; Woodcock, McGrew, & Mather, 2001)—The WJ III is a co-normed set of tests for measuring general scholastic aptitude, oral language, and academic achievement. The Letter Word Identification subtest was used as an indicator of early reading achievement, while the Applied Problems and Quantitative Concepts subtests were used as indicators of early math achievement. The validity and reliability of the WJ III tests of achievement have been established elsewhere (Woodcock et al., 2001).

Analytic strategy

The first objective of this study was to evaluate the fit of competing factor structures for ADHD symptoms. This was accomplished using confirmatory factor analyses (CFA). In order to accommodate dichotomous ADHD symptoms, CFA models used a robust weighted least square estimator (WLSMV). The WLSMV estimator has performed well in simulation studies (Flora & Curran, 2004). Models with a comparative fit index (CFI) >= .95 and a root mean squared error of approximation (RMSEA) index < .05 were indicative of good overall fit (Yu, 2003). The second objective of this study was to evaluate whether the general and/or specific latent factors from the bi-factor CFA model were jointly predictive of children's functional impairment. This was accomplished by estimating a series of structural equation models (SEM). Specifically, individual dichotomous and continuous outcomes were regressed onto the general (ADHD) and specific (IN, HI) latent variables factors using logit and identity link functions, respectively, using robust maximum likelihood estimation throughout. The third objective of this study was to test the association of the general and specific latent factor scores with the observed ADHD (IN, HI, total) scores. This was accomplished using linear regression models in which observed scores were regressed on (factor score estimates of) the general and specific factors from the bi-factor model. CFA and SEM models were estimated in version 7.1 of *Mplus* (Muthén & Muthén, 1998–2013). Regression models were estimated using version 9.3 of SAS® (PROC SURVEYREG). All statistical models took the complex sampling design (stratification and over-sampling of low income and, in NC, African American families) into account. Hence, results generalize to all children born in target counties and are not specific to low-income or African American children who were over-sampled here.

Results

A description of the sample is provided in Table 1. On average, children were 7 years old and evenly divided by gender (50% male). Consistent with the over-sampling of low-income families and the selection of low-wealth counties, the mean household income to needs ratio (INR) was 1.9 (inter-quartile range = 0.8 – 2.5). INR values of 2—twice the poverty line—are frequently characterized as the "working poor". Although a majority of households in this sample were poor, middle class families were also included in the sample (i.e., 10% of families had INR >= 4.0). Although nearly half of the children in the observed sample were identified as African American (44%), this was due to over-sampling, as the weighted proportion of African American children was closer to national norms (23%).

Behaviorally, children exhibited approximately 3 ADHD symptoms, per individual parent and teacher reports, and approximately 5 symptoms per combined parent and teacher reports. Most children were rated by teachers as having at least 1 friend (69%) and few children were rated as being not liked and actively disliked (3%). On average, teachers indicated that they had positive relationships with children (closeness M = 4.2, conflict M = 1.7). On average, children exhibited average levels of (pre)reading and math achievement (standard scores > 100). However, between 8 and 14% of children were identified as being at the bottom of their class in reading or math, respectively, and 10% were not expected to be promoted to 2nd grade by their primary teacher. With respect to treatment, 11% of children had an IEP, 9% were taking medication due to behavior problems, and 13% of children received some other forms of services for learning or behavior problems; moreover, teachers indicated that 19% of children would benefit from medication and that 13% of children would be referred for additional services.

Factor Structure of ADHD Symptomatology

The first research question addressed the factor structure of ADHD symptom data. We fit 1-, 2- (inattentive, hyperactive-impulsive), 3-factor (inattentive, hyperactive, impulsive), and bi-factor (general, inattentive, hyperactive-impulsive) models to parent, teacher, and combined ADHD symptoms. A synopsis of model fit is provided in Table 2. Three points were noteworthy. First, fit indices indicated that all four models provided excellent fit to the data, irrespective of informant (RMSEAs ranged from .04 –.07 and CFIs ranged from .98–1.0 for all models). Second, consistent with previous studies, the chi square test statistic was smallest for bi-factor models, though so were the degrees of freedom. Third, though not presented in Table 2, the estimated latent correlations between factors in the 2- and 3-factor models were very large. For example, in the 2-factor models, the inattentive and hyperactive-impulsive factors were correlated .98, .87, and .93 for parent, teacher, and combined informants, respectively (all *p*s < .001). Collectively, these results underscored the fact that global model fit, alone, was insufficient for determining which structure provided the best fit to the data—all models provided good overall fit and that sub-dimensions of ADHD were highly correlated.

We next investigated the parameter estimates from the bi-factor model. In order to best approximate good clinical practice (and to reduce the scope of Results), we focused exclusively on the factor loadings from the model that was based on combined informant reports of ADHD symptoms, though results were comparable for models that were based exclusively on parent or teacher symptom reports. Standardized factor loadings and item-level R^2 values were summarized in Table 3. Consistent with previous studies that fit bi-factor models, every ADHD symptom loaded more strongly on the general (the mean of standardized factor loadings for general factor was .84) than its specific (the mean of standardized factor loadings was .26 and .24 for inattentive and hyperactive-impulsive factors, respectively) factor. Together the general and specific factors explained an average of 79% of the observed variation in each individual symptom. Consistent with the pattern of standardized factor loadings, the majority (nearly 90%) of this variation was attributable to the general not specific factor. The specific factor never explained more of the variation in any symptom than did the general factor, and for most symptoms, the general factor explained at least 10 times more of the variation in a symptom than did the specific factor. There was also substantially more variability in the general versus the specific factors (φs = .83, .25, .10 for general, inattentive, and hyperactive-impulsive factors, respectively, all *p*s <= .001).

Criterion Validity of ADHD General and Specific Factors

Having established that the general factor explained more of the variation in individual symptoms and had greater variability than either of the specific factors, the next question was whether individual differences in specific factors explained unique variation in school based outcomes beyond that attributable to the general factor. To test this question, the bi-factor model that was based on combined reports was modified such that each school outcome was regressed on general and specific factors, continuing to restrict the factor covariances to 0. A synopsis of coefficients for all 15 outcomes is provided in Table 4.

Treatment—The general factor was significantly predictive of all 5 treatment related outcomes; every 1 standard deviation (SD) increase in general (overall) ADHD resulted in increased odds of receiving or needing treatment increased (odds ratios [ORs] = 2–17, see Table 4). The specific inattentive factor explained additional increased odds of either currently receiving (OR = 1.8) or being referred (OR = 5.5) for services related to learning, emotional, and behavioral problems. In contrast, the specific hyperactive-impulsive factor did not explain any unique variation in the receipt of or need for treatment.

Academic Functioning—The general factor was significantly predictive of all 6 academically related outcomes (including probability of grade promotion, teacher-rated and achievement testing for reading and math ability, and academic motivation). A 1 SD increase in general (overall) ADHD was associated with an increased odds of likely grade failure (OR = 2.7) and being at the bottom of the class in reading (OR = 2.9) and math (OR = 3.1) ability. Moreover, a 1 SD increase in the general factor was associated with a 1/3 of a SD decrease in reading and math achievement (βs = −.33 and −.34, *ps* < .001, respectively) and more than 1/2 of a SD decrease in academic motivation ($\beta = -.62$, $p < .001$). The specific inattentive factor explained additional variation in all 6 academic outcomes, with comparable (and somewhat larger) sized effects as those for the general factor. In contrast, the specific hyperactive-impulsive factor did not explain unique variation in any of the academically oriented outcomes.

Peer & Teacher Relationships—The general factor was significantly predictive of all 4 relational outcomes. A 1 SD increase in general (overall) ADHD was associated with an increased odds of peer impairment (not liked + actively disliked; OR = 3.0) and decreased odds of having at least one close friend (OR = 0.6). Moreover, a 1 SD increase in the general factor was associated with a 1/4 of a SD decrease in closeness ($\beta = -.27$, $p < .001$) with teachers and 1/2 of a SD increase in conflict with teachers ($\beta = .51$, $p < .001$). The specific inattentive factor only explained additional variation in teacher closeness ($\beta = -.24$, $p < .01$).

The specific hyperactive-impulsive factor explained additional variation in teacher conflict (β =.24, $p < .05$) and closeness (β =.20, $p < .05$)—though the latter effect was counter-intuitive (higher levels of hyperactive-impulsivity were associated with greater closeness).

Association between General and Specific Factors with Observed Symptom Scores

All of the foregoing results were based on latent variable representations of general (ADHD) and specific (inattentive, hyperactive-impulsive) factors. However, these estimates would rarely be available to clinicians, who would typically rely on mean rating scores (or symptom counts). A final question involved testing the association between general and specific factors to observed symptom scores. This was accomplished by obtaining factor score estimates for the general and specific factors from the bi-factor model and using these as predictors of mean ratings of total, IN, and HI scores (as above, based on combined parent and teacher ratings). We used mean ADHD scores in lieu of symptom counts because preliminary analyses, which are not presented, indicated that they had better distributional assumptions (i.e., mean Likert ratings were more normal than were symptom counts and retained more information on individual differences).

When considered alone, the general factor score explained 75% of the observed variation in observed inattention scores. With the addition of the two specific factors, the model R^2 improved to 80% ($\Delta R^2 = .05$, $F(2, 1088) = 145$, $p < .0001$). The general factor was a much stronger predictor of observed inattention scores than either specific factor ($\beta_{general} = .86$, $p < .0001$; $\beta_{inattentive} = .22$, $p < .0001$; $\beta_{hyperactive\text{-}impulsive} = -.02$, $p = .24$). A similar pattern of results was evident for observed hyperactive-impulsive scores. The general factor explained 73% of the observed variation in mean hyperactive-impulsive scores. With the addition of the two specific factors, the model R^2 improved to 79% ($\Delta R^2 = .06$, $F(2, 1088) = 150$, $p < .0001$). Once again, the general factor was a much stronger predictor than either specific factor ($\beta_{general} = .84$, $\beta_{inattentive} = -.09$, $\beta_{hyperactive\text{-}impulsive}$ =.11, all *p*s < .0001). Finally, when considered alone, the general factor score explained 81% of the observed variation in observed total ADHD score. With the addition of the two specific factors, the model R^2 improved to 82% ($\Delta R^2 = .01$, $F(2, 1088) = 22$, $p < .0001$). The general factor was a much stronger predictor than either specific factor ($\beta_{general} = .88$, $\beta_{inattentive} = .07$, $\beta_{hyperactive\text{-}impulsive} = .09$, all *p*s < .0001).

Discussion

Over the last three decades, the most prominent changes to the (DSM) diagnostic criteria for ADHD have involved the structure and organization inattentive, hyperactive, and impulsive behaviors and the corresponding implications it had for subtyping procedures (i.e., DSM III: ADD with and without hyperactivity; DSM III-r: ADHD with no consideration of subtypes; DSV-IV: inattentive, hyperactive-impulsive, and combined subtypes; DSM-5: ADHD with no consideration of subtypes but consideration of inattentive, hyperactive-impulsive and combined symptom presentations). Although there is a voluminous literature supporting the distinction between inattentive and hyperactive-impulsive behaviors (Willcutt et al., 2012), ADHD subtypes have not facilitated clinical (tailoring treatments to subtypes) or research (elucidating distinct etiological pathways) practice, in large part because of poor across-time stability of subtype membership. Lahey and Willcutt (2010) suggested that measures of inattention and hyperactivity-impulsivity may have value as continuous modifiers of an overall diagnosis of ADHD. The DSM-5 focus on symptom presentation versus symptom subtypes is consistent with this perspective. Here, we have noted a similarity between these changes to the diagnostic criteria for ADHD and a recent shift in the psychometric literature regarding the factor structure for ADHD symptomatology (i.e., emphasis on bi-factor models).

In this study, a bi-factor specification provided as good of a fit to the observed data as did more traditional 1-, 2-, and 3-factor models. Although global model fit was not informative about which structure provided the “best” fit to the data (because all models met or exceeded standard criteria for good fit), an inspection of the parameter estimates from the bi-factor model indicated that the vast majority of all of the observed variation in individual inattentive and hyperactive-impulsive symptoms was accounted for by a general factor. After that common source of variation was extracted, there remained variation that was uniquely related to hyperactive-impulsivity and inattention (each represented as specific factors). These results are consistent with a number of recent studies in the literature and suggest that although inattention and hyperactivity-impulsivity are dissociable factors, at the symptom level there is more shared than unique variance (Martel et al., 2010; Toplak et al., 2012).

The primary contribution of this study was to test whether general and specific factors were uniquely associated with multiple school based outcomes. The general factor, which represented the common, shared variation across IN and HI symptoms, was significantly related to all 15 outcomes. Consistent with decades of research, children with elevated levels of general (overall) ADHD were more likely to receive or need treatment, to do poorly academically, and to have worse relationships with teachers and peers. The specific inattentive factor, which represented variation that was uniquely shared among the IN symptoms (net of shared variation with HI symptoms), consistently explained unique variation in two indicators of treatment (receipt of and likely referral for services related to learning, emotional, and behavioral problems) and all 6 academic outcomes. These results are consistent with long-standing evidence regarding the role of inattentive symptoms as contributing to academic functioning (Frazier, Youngstrom, Glutting, & Watkins, 2007; Paloyelis, Rijsdijk, Wood, Asherson, & Kuntsi, 2010). These results also provide partial support for the idea that individual differences in inattentive items convey clinically meaningful information that is distinct from overall ADHD. In contrast, the specific hyperactive-impulsive factor, which represented variation that was uniquely shared among the HI symptoms (net of shared variation with IN symptoms), was only related to teacher relationship quality and in a relatively unimportant way (small effects, one in a counter-intuitive direction). These results do not provide support for the idea that individual differences in hyperactivity-impulsivity convey clinically meaningful information that is distinct from overall ADHD—at least not for the range of school based outcomes that were considered here.

The last question concerned how observed ADHD scores (total, IN, HI) were correlated with children’s standing on the general and specific latent variables. Results indicated that the general *latent* variable explained the vast majority of variation in the *observed* total, IN, and HI scores (R^2 = .73 – .81). Although the specific factors explained additional statistically significant variation in observed scores (ΔR^2 = .01 – .06), these increments were quite modest in magnitude and of questionable clinical utility (the statistical significance of ΔR^2 was certainly influenced by the large sample size). At the bivariate level, the general factor was strongly correlated (*r*s = .86 –.97, *p*s < .0001) with observed inattentive, hyperactive-impulsive and total scores, irrespective of whether these scores represented mean scores across Likert rating items or symptom counts. Taken together these results indicated that in clinical practice, the use of *total observed* ADHD scores will provide an excellent indicator of a child's overall level of ADHD (i.e., total ADHD observed scores correlated highly with a child's standing on the general factor from the bi-factor model). In contrast, the use of *observed* IN and/or HI scores will do a relatively poor job of representing their standing on the *specific latent factors* of IN or HI. This undermines the use of observed symptoms scores for purposes of continuous modifiers of diagnosis (including the use of IN and HI scores as implied by DSM-5). This is due to the fact that observed IN and HI scores are confounded by overall severity level. Our results imply that some post-processing of observed symptoms scores would be required before they can be used in the manner they were here (i.e., IN and HI scores would have to be purged of their common, shared variance with each other before they could provide information that was distinct from overall ADHD severity).

The results of this study do not support the notion that an exclusive focus on overall severity level of ADHD is the most parsimonious representation of the disorder. Although the general (overall ADHD) factor was clearly dominant in explaining both symptom-specific variation as well as the prediction of school based outcomes, the specific IN factor made unique contributions to the prediction of select school based outcomes above and beyond those attributable to the general factor. Moreover, for these outcomes, the specific IN factor exerted effects at least as large (and sometimes larger) as the general factor. Although the specific HI factor made negligible contributions to the outcomes considered here, this factor may prove useful for a different set of outcomes and/or at a different developmental period (e.g., risk for substance use in adolescence). An unresolved question in the field is whether continued efforts to distinguish youth on the basis of their IN and HI behaviors represents an optimal approach for future clinical and research practice. A variety of other subtyping approaches, including those that consider neurocognitive heterogeneity among ADHD youth, are actively being evaluated (e.g., Fair, Bathula, Nikolas, & Nigg, 2012). Given the number of neurocognitive constructs that have been implicated in ADHD (Clarke, Barry, McCarthy, Selikowitz, & Brown, 2002; Nigg, 2010; Sonuga-Barke, Bitsakou, & Thompson, 2010), it is likely that efforts to subtype ADHD youth along many of these dimensions will become more common. Future research would benefit from drawing explicit linkages between individual differences in the general ADHD and specific IN and HI factors that result from a bi-factor CFA model parameterization with neurocognitive constructs. For example, individual differences in the specific IN factor may be better approximated by measures of reaction time variability (Antonini, Narad, Langberg, & Epstein, 2013) or delay aversion (Paloyelis, Asherson, & Kuntsi, 2009). Clearly, all of these efforts are in accord with the larger imperative of subdividing ADHD youth in ways that facilitate individualized treatment efforts and/or elucidate multiple unique pathways into the disorder (Swanson et al., 2007).

This study is characterized by at least four weaknesses. First, all of the results were based on cross-sectional analysis of data collected when children were in 1st grade. Although previous studies have demonstrated that the bi-factor structure of ADHD symptoms provides an excellent (or at least as good as any alternative model) fit for participants of widely divergent ages (including adults), it is unclear whether the relative contributions of general versus specific factors in the prediction of child outcomes may vary across time. Second, despite the multiple benefits of relying on a large, unselected sample (e.g., avoidance of clinic referral bias), the vast majority of children in this study did not exhibit elevated levels of ADHD symptomatology. It is conceivable that specific IN and/or HI factors may have explained more or additional outcomes in samples that consist entirely of ADHD youth. Moreover, despite the explicit sampling frame, participants were recruited from non-metropolitan, low-wealth counties. It is unclear if a different set of results would have emerged in (sub)urban or high-wealth settings. Third, we were primarily interested in testing the relative contributions of general and specific factors as predictors of school based outcomes. These models did not consider numerous potential confounder variables (e.g., there are a variety of factors that influence which children are medicated that are unrelated to ADHD behaviors) and do no support causal inferences. Fourth, although it has become a common convention in research (and perhaps clinical) practice to combine parent and teacher reports of ADHD symptoms using the so called “or” rule, this is an overly simplistic approach that suffers from a variety of conceptual problems that are the focus of ongoing research (De Los Reyes & Kazdin, 2005; De Los Reyes, Thomas, Goodman, & Kundey, 2013).

In conclusion, the results of this study are in accord with recent studies that have emphasized the merits of a bi-factor parameterization of ADHD symptoms. The bi-factor model acknowledges IN and HI as dissociable symptom domains while demonstrating their substantial overlap. In this way, IN and HI symptoms exhibit both unity and diversity. While the overall level of general ADHD was consistently and strongly associated with a range of school based outcomes, the specific IN factor explained additional and unique variation in the academically oriented outcomes. The “spirit” of these conclusions is consistent with previous proposals, including recent changes in DSM-5, to use IN and HI scores as a means to characterize behavioral heterogeneity among children diagnosed with ADHD. However, in practice, the use of observed IN and HI scores will not serve their intended function because observed symptom scores confound overall severity level with characteristics specific to IN and HI. It remains to be determined whether the larger objective of using IN and HI symptom domains as a means to improve clinical decision making (e.g., tailoring treatments to symptom profiles) or research practice (e.g., to elucidate different etiological pathways into the disorder) is better achieved by subtyping efforts that also consider neurocognitive heterogeneity among ADHD youth.

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Table 1

Sample Description and Descriptive Statistics for Outcomes

			Unweighted		Weighted
	Informant	N	M	SD	M
Child age (years) at home visit	P	1093	7.3	0.3	7.3
Income to Needs Ratio	P	1093	1.9	1.7	2.3
Total ADHD Symptom Count	P	1086	3.2	4.5	3.1
Total ADHD Symptom Count	T	904	3.5	5.1	3.0
Total ADHD Symptom Count	P/T	1093	5.1	5.6	4.7
Teacher Relationship (closeness)	T	904	4.2	0.7	4.2
Teacher Relationship (conflict)	T	904	1.7	0.9	1.6
Academic Motivation	T	904	3.5	1.0	3.7
WJ: Applied Problems	C	1018	102.3	15.2	104.4
WJ: Letter-Word	C	1020	108.7	13.0	109.5
			%		%
Male	P	1093	50		51
African American	P	1093	44		23
Has IEP	T	903	11		11
Medicated for ADHD	T	904	9		9
Would benefit meds	T	903	19		17
Services for LEB	T	904	13		14
Will Refer for Services	T	904	13		11
Peer Relationship (disliked)	T	904	3		2
Peer Relationship (close friend)	T	904	69		70
Likely to Fail 1st grade	T	904	10		6
Low Reading Ability	T	904	14		13
Low Math Ability	T	904	8		7

Note: P = Parent, T = Teacher, P/T = Combined parent and teacher using "or" rule; C = Child (achievement testing); LEB = learning, emotional or behavioral problems.

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Table 2

Synopsis of Confirmatory Factor Models of ADHD Symptoms at 1st Grade per Parent, Teacher, and Combined (‘or’ rule) Reports.

Informant	**Factors**	χ^2	***df***	***CFI***	***RMSEA (90% CI)***
Parent (N = 1087)	1	375.1	135	0.99	0.04 (.04 – .05)
	2	372.8	134	0.99	0.04 (.04 – .05)
	3	359.3	132	0.99	0.04 (.04 – .05)
	Bi-factor	302.9	117	0.99	0.04 (.03 – .04)
Teacher (N = 904)	1	705.0	135	0.98	0.07 (.06 – .07)
	2	412.9	134	0.99	0.05 (.04 – .05)
	3	344.9	132	0.99	0.04 (.04 – .05)
	Bi-factor	252.0	117	1.00	0.04 (.03 – .04)
Combined (N = 1093)	1	566.8	135	0.99	0.05 (.05 – .06)
	2	455.8	134	0.99	0.05 (.04 – .05)
	3	415.2	132	0.99	0.04 (.04 – .05)
	Bi-factor	320.4	117	0.99	0.04 (.04 – .05)

Note: df = degrees of freedom; CFI = comparative fit index; RMSEA = Root mean squared error of approximation

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Table 3

Standardized Factor Loadings from Bi-factor Model (combined parent/teacher Ratings)

Symptom	*General*	*IN*	*HI*	*Total R^2*	*General R^2*	*IN/HI R^2*
1. Makes careless mistakes.	0.76	0.50	--	0.82	0.58	0.25
2. Fidgets, squirms in seat.	0.87	--	-0.04*	0.77	0.76	0.00
3. Difficulty sustaining attention	0.91	0.23	--	0.87	0.83	0.05
4. Leaves seat	0.89	--	0.13	0.82	0.79	0.02
5. Does not seem to listen	0.86	0.22	--	0.79	0.74	0.05
6. Runs about or climbs excessively	0.88	--	0.07*	0.79	0.77	0.00
7. Not follow through on instructions	0.88	0.24	--	0.82	0.77	0.06
8. Difficulty playing quietly	0.89	--	0.10*	0.79	0.79	0.01
9. Difficulty organizing tasks	0.86	0.30	--	0.84	0.74	0.09
10. Acts as if “driven by a motor”	0.76	--	0.23	0.63	0.58	0.05
11. Avoids tasks of sustained effort	0.80	0.37	--	0.78	0.64	0.14
12. Talks excessively	0.71	--	0.40	0.65	0.50	0.16
13. Loses things	0.78	0.08*	--	0.62	0.61	0.01
14. Blurts out answers	0.73	--	0.48	0.76	0.53	0.23
15. Easily distracted	0.93	0.16	--	0.90	0.86	0.03
16. Difficulty awaiting turn	0.90	--	0.28	0.88	0.81	0.08
17. Forgetful in daily activities	0.87	0.23	--	0.80	0.76	0.05
18. Interrupts or intrudes	0.76	--	0.48	0.81	0.58	0.23
Mean	0.84	0.26	0.24	0.79	0.70	0.08
Median	0.87	0.23	0.23	0.80	0.75	0.05

Note: N = 1093; IN = Inattentive; HI = Hyperactive-Impulsive;

*-indicates non-significant (p > .05) factor loadings

Table 4

Prediction of School-Based Outcomes from Bi-factor Latent Variables

	Independent (Latent) Variables			
	IN (Specific)	HI (Specific)	ADHD (General)	R^2
Dependent Variable	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	
Has IEP	1.5 (0.7–2.9)	0.5 (0.2–1.2)	**3.3 (2.0–5.3)***	.37
Medicated for ADHD	0.9 (0.5–1.7)	0.5 (0.2–1.1)	**5.8 (3.2–10.3)***	.52
Would Benefit Meds	1.1 (0.5–2.1)	0.6 (0.3–1.2)	**17.0 (7.8–37.4)***	.72
Services for LEB	**1.8 (1.2–2.8)**	0.7 (0.5–1.1)	**2.1 (1.6–2.8)***	.23
Refer for Services	**5.5 (1.8–16.4)**	1.3 (0.7–2.3)	**3.2 (2.0–5.1)***	.57
Peer (actively disliked)	2.1 (0.6–7.5)	5.6 (0.4–72.9)	**3.0 (1.7–5.1)***	.59
Peer (has close friend)	0.8 (0.5–1.1)	0.8 (0.5–1.1)	**0.6 (0.5–0.7)***	.11
Likely to Fail 1st grade	**3.8 (1.7–8.5)**	0.9 (0.5–1.5)	**2.7 (1.8–3.9)***	.45
Low Reading Ability	**5.3 (2.2–12.7)***	0.7 (0.5–1.1)	**2.9 (1.9–4.3)***	.55
Low Math Ability	**8.3 (1.4–47.7)***	0.9 (0.4–1.8)	**3.1 (1.6–5.7)***	.64
	β (95% CI)	β (95% CI)	β (95% CI)	R^2
STRS (closeness)	**−.24 (− .40–0.08)**	**.20 (.01–.38)***	**−.27 (−.35–.19)***	.17
STRS (conflict)	.13 (−.04–.31)	**.24 (.01–.47)***	**.51 (.43–.58)***	.33
Academic Motivation	**−.51 (−.62–.41)***	.08 (−.06–.21)	**−.62 (−.67–.56)***	.65
WJ Applied Problems	**−.26 (−.41–.10)**	.14 (−.02–.30)	**−.34 (−.41–.26)***	.20
WJ Letter-Word	**−.26 (−.41–.11)**	.13 (−.02–.27)	**−.33 (−.41–.25)***	.19

Notes: N = 1093;

* $p < .05$,

** $p < .01$,

*** $p < .001$; IN = Inattentive; HI = Hyperactive-impulsive; IEP = Individualized Educational Plan; On Meds = teacher report of whether the child is taking any medication for ADHD or related difficulties; Benefit Meds = teacher impression of whether the child would benefit from such medications; LEB = learning difficulties, emotional problems or behavior problems; R-Services = teacher intends to refer the child for services; STRS = Student teacher relationship scale; WJ = Woodcock Johnson