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Bifactor latent structure of ADHD/ODD symptoms: predictions of dual-pathway/trait-impulsivity etiological models of ADHD

G. Leonard Burns,[1] Marcela Alves de Moura,[2] Theodore P. Beauchaine,[3] and Keith McBurnett[4]

[1]Department of Psychology, Washington State University, Pullman, WA, USA; [2]Private Practice, Piracicaba, Brazil; [3]Department of Psychology, Ohio State University, Columbus, OH, USA; [4]Department of Psychiatry, University of California at San Francisco, San Francisco, CA, USA

Objective: To determine if ADHD/ODD symptoms are better represented by a bifactor model of disruptive behavior [general disruptive behavior factor along with specific inattention (IN), specific hyperactivity/impulsivity (HI), and specific oppositional defiant disorder (ODD) factors] than an ADHD-IN, ADHD-HI, and ODD three-factor model. **Method:** Mothers' and fathers' ratings of ADHD-IN, ADHD-HI, and ODD symptoms in a community sample of 4,658 children and adolescents (53% female) from Brazil, Thailand, and the US were used to evaluate the measurement models. **Results:** The bifactor model of disruptive behavior provided a better fit than the three factor model. The bifactor model also occurred with mothers' and fathers' ratings of male and female children and adolescents. **Conclusions:** Consistent with predictions derived from recently articulated dual-pathway and trait-impulsivity models of externalizing liability, and from behavioral genetics studies indicating near complete overlap in vulnerability to ADHD and ODD, ADHD and ODD symptoms arose from a single, general disruptive behavior factor, which accounted for all of the variance in HI subscale scores and over half of the variance IN and ODD subscales. Thus, IN, HI, and ODD subscale scores strongly reflect a general disruptive behavior factor – not the specific content of their respective constructs. **Keywords:** ADHD, oppositional defiant disorder, bifactor models, dual-pathway/trait-impulsivity theories.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) consists of inattention (IN) and hyperactivity/impulsivity (HI) symptoms (American Psychiatric Association, 2013). Traditionally, two-factor measurement models of ADHD-IN and ADHD-HI symptoms have been used to characterize these symptoms (Willcutt et al., 2012). Recent research, however, indicates that bifactor measurement models of ADHD provide better fit than two-factor models (Gibbins, Toplak, Flora, Weiss, & Tannock, 2012; Martel, von Eye, & Nigg, 2012; Normand, Flora, Toplak, & Tannock, 2012; Toplak et al., 2009, 2012; Ullebø, Breivik, Gillberg, Lundervold, & Posserud, 2012).

Bifactor models of ADHD include a general ADHD factor (on which all 18 ADHD symptoms load), a specific IN factor (on which the nine IN symptoms load), and a specific HI factor (on which the nine HI symptoms load). The general ADHD factor accounts for common variance in the 18 ADHD symptoms that is independent of the specific IN and specific HI factors, whereas the two specific factors account for variance in their respective symptom sets that is independent of the general ADHD factor. These general and specific factors must be orthogonal for empirical identification of the bifactor ADHD model (Chen, Hayes, Carver, Laurenceau, & Zhang, 2012). Figure 1A shows this model. As outlined below, bifactor latent structure is more consistent with current etiological models of ADHD, which identify common behavioral genetic and neural vulnerability to all externalizing symptoms (see e.g., Beauchaine & McNulty, 2013; Tuvblad, Zheng, Raine, & Baker, 2009).

Although bifactor measurement models have always yielded better global fit than ADHD-IN and ADHD-HI two-factor measurement models, no studies conducted to date have included ODD symptoms. Including ODD allows us to model a general disruptive behavior factor along with specific IN, HI, and ODD factors. The general disruptive behavior factor accounts for common variance in ADHD/ODD symptoms, with specific IN, HI, and ODD factors accounting for variance in their respective symptom sets, independent of variance accounted for by the general factor (see Figure 1B).

Both dual-pathway (Nigg, 2012, 2013) and trait-impulsivity (Beauchaine, Hinshaw, & Pang, 2010; Beauchaine & McNulty, 2013) etiological theories of ADHD make specific predictions about patterns of results that should emerge from bifactor models of disruptive behavior. These etiological theories predict bifactor latent structure for ADHD/ODD symptoms, along with differential predictions about general and specific factors. We first briefly describe these two etiological theories, then outline predictions each makes about bifactor measurement

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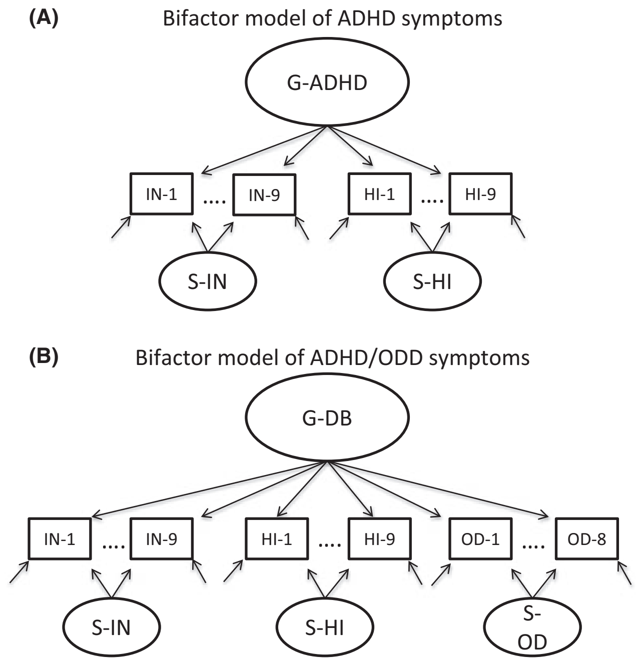

Figure 1 (A) Bifactor model of ADHD symptoms. (B) Bifactor model of ADHD/ODD symptoms. G = general; S = specific; IN = inattention; HI = hyperactivity/impulsivity; OD = oppositional defiant disorder; DB = disruptive behavior

models of disruptive behavior. Finally, we use mother and father ratings of ADHD/ODD symptoms in a community sample of children and adolescents from three countries to test these predictions.

Dual-pathway/trait-impulsivity etiological models of ADHD

Dual-pathway (e.g., Nigg, 2012, 2013, p. 398) and trait-impulsivity (e.g., Beauchaine & McNulty, 2013; Beauchaine et al., 2010) theories of ADHD assume that dysfunction in one neural system (low tonic and low phasic responding in the mesolimbic reward system, sometimes referred to as the "bottom-up" pathway; see Gatzke-Kopp et al., 2009) results in development of HI symptoms, with IN symptoms developing secondary to HI. This neurodevelopmental vulnerability increases a child's likelihood of developing ODD and later conduct disorder (CD) in contexts of potentiating environmental risk (e.g., coercive family processes, deviant peer group affiliations, and neighborhood violence). In contrast, dysfunction in frontal structures (i.e., the prefrontal cortex, anterior cingulate, etc., sometimes referred to as the 'top-down' pathway) results in direct development of IN (albeit through a different neural mechanism), much lower likelihood developing ODD and CD, and lower levels of trait-impulsivity (unless a child exhibits dysfunction in both pathways; see Beauchaine & McNulty, 2013).

Dual-pathway and trait-impulsivity theories offer several predictions regarding bifactor structure of ADHD/ODD. First, a general disruptive behavior factor should account for most of the reliable variance in total scores on the 26 symptoms of ADHD and ODD. This prediction follows directly from the assumption that dysfunction in the mesolimbic reward pathway plays an etiological role in development of all externalizing syndromes (Beauchaine & McNulty, 2013; Gatzke-Kopp et al., 2009). Importantly, such a finding would be consistent with well-replicated factor structure of externalizing behavior obtained in recent twin studies (e.g., Tuvblad et al., 2009). Second, as mesolimbic reward dysfunction is central to the development of HI symptoms, a specific HI factor should not explain much if any of the reliable variance in HI subscale scores, over-and-above variance accounted for the general disruptive behavior factor. Third, a specific IN factor should account for only some of the reliable variance in IN subscale scores given two neurological pathways to the development IN symptoms (i.e., secondary to HI symptoms given dysfunction in the bottom-up pathway vs. a primary result of dysfunction in the top-down pathway). Finally, a specific ODD factor should account for some variance in ODD subscale scores, as environmental conditions interact with bottom-up neurological dysfunction to potentiate development of ODD (Beauchaine & McNulty, 2013; Beauchaine et al., 2010). Substantiation of these four predictions would establish a more specific connection between contemporary etiological theories of ADHD and bifactor measurement models of disruptive behavior. Such results would also indicate that a bifactor latent structure better represents ADHD/ODD symptoms than the three-factor model.

Method

Participants and procedures

Participants were mothers ($n = 4{,}343$) and fathers ($n = 3{,}410$) of 4,658 children and adolescents from Brazil, the US, and Thailand (894 children from Brazil, 817 children from the US, 2,075 children from Thailand, and 872 adolescents from Thailand). Children were in Grades kindergarten through 6, and adolescents were in Grades 7 through 12. Mothers and fathers of Brazilian children were recruited from three elementary schools in Piracicaba, São Paulo, Brazil; US children from four elementary schools in Missoula, Montana and four elementary schools in Clarkston, Washington; Thai children from two elementary schools in Mahasarakham, northeastern Thailand; and Thai adolescents from 7th to 12th grade school in Mahasarakham. The average age of children and adolescents was 10.15 ($SD = 2.97$, range = 5–18) with 52.6% of the sample being female. With the approval of all schools and Washington State University's institutional review board, children and adolescents were given an envelope to take home to their parents containing a cover letter and behavior scales. Participation was voluntary and anonymous. The letter asked the parents to complete their ratings independently. Return rates were 49% for Brazilian children, 43% for US children, 71% for Thai children, and 85% for Thai adolescents. More detailed descriptions of the four samples appear in Burns et al., 2008; Burns, Desmul, Walsh, Silpakit, & Ussahawanitchakit, 2009).

Measure

The Child and Adolescent Disruptive Behavior Inventory (CADBI; Burns, Taylor, & Rusby, 2001) measures ADHD-IN, ADHD-HI, and ODD symptoms for the past month on an 8-point scale (0 times in the past month, 1–2 times in the past month, 3–4 times in the past month, 5–6 times in the past month, 1 time per day, 2–5 times per day, 6–9 times per day, 10 or more times per day). The CADBI also measures children's academic functioning (quality of homework, reading, arithmetic, and writing skills) and social impairment (quality of interactions with parents, other adults, peers, and siblings). Academic and social impairment items are rated on a 7-point scale [severe difficulty, moderate difficulty, slight difficulty, average performance (interactions) for grade level, slightly above average, moderately above average, and excellent performance (interactions)]. Academic and social impairment items are reversed keyed so higher scores represented higher levels of academic and social impairment. Earlier studies (Burns et al., 2008, 2009; Khadka & Burns, 2013) provide support for the reliability and validity of the scale's ADHD-IN, ADHD-HI, ODD, academic and social impairment scores.

Analytic strategy

Robust maximum likelihood estimation was used for analyses (MLR estimator, Mplus version 7.0, Muthén & Muthén, 1998–2012). Global model fit was evaluated with the Comparative Fit Index (CFI; ideal study criterion of ≥.95), root mean square error of approximation (RMSEA; ideal study criterion of ≤.05), standardized root mean square residual (SRMR; ideal study criterion ≤.05), Bayesian Information Criterion (BIC, model with the smallest BIC is preferred), and Akaike Information Criterion (AIC, model with the smallest AIC is preferred). The bifactor model of disruptive behavior was expected to fit better than three-factor (IN, HI, and ODD) and four-factor [IN, hyperactivity (HY), impulsivity (IM), and ODD] models.

Three procedures were used to evaluate predictions derived from the dual-pathway and trait-impulsivity etiological theories of ADHD. First, we determined the amount of common variance accounted for by the general and specific factors. Predictions associated with this analysis included: (a) the general factor would account for most of the common variance; (b) the specific HI factor would account for nearly no variance above the general factor; and (c) the specific IN and specific ODD factors would account for only some of the common variance, over-and-above the general disruptive behavior factor. Second, we calculated reliabilities (true score variance) for the total disruptive behavior scores and the IN, HI, and ODD subscales scales. Predictions associated with this analysis were (a) total disruptive behavior scores (sum of the 26 symptoms) would contain a substantial amount of true score variance; (b) the HI subscale scores would contain nearly no true score variance, over-and-above the general factor; and (c) the IN and ODD subscale scores would contain small amounts of true score variance, over-and-above the general factor. Finally, we determined if the pattern of loadings on general and specific factors was consistent with predictions from the etiological theories (i.e., substantial loading on the general factor, loadings close to zero on the specific HI factor, and modest loadings on the specific IN and ODD factors).

Results

Preliminary analyses

The one- (disruptive behavior), two- (ADHD and ODD), three- (IN, HI, and ODD), and four- (IN, HY, IM, and ODD) factor models, and the bifactor model of disruptive behavior were first evaluated in the four subsamples for mothers' and fathers' ratings. Each of ten analyses (five for mothers' ratings and five for fathers' ratings) yielded the same results as the total sample (i.e., bifactor model of disruptive behavior resulted in better global fit than the other models for each analysis). The bifactor model of disruptive behavior also showed good invariance of form across the four samples (mothers: χ^2 (1092) = 3230, CFI = .945, RMSEA = .042 (.041–.044), SRMR = .034; fathers: χ^2 (1092) = 2713, CFI = .945, RMSEA = .042 (.040–.044), SRMR = .043), and most like-item loadings were invariant across the four samples. Given that such similar results were obtained in each for the four samples, and that the bifactor model showed invariance of form across the four samples, all participants were included in a single sample to simplify presentation of results.

Model fit

Table 1 shows fit values for the five measurement models (one-, two-, three-, and four-factor models, and the bifactor model of disruptive behavior). Although the four-factor model provided a statistically better fit than the three-factor model for mothers' and fathers' ratings (both ps < .0001), correlations between the HY and IM factors were too high (>.90) to justify selection of the four-factor model relative to the three-factor model. In terms of

Table 1 Fit statistics for alternative models of ADHD and ODD symptoms

Model	Df	χ^2	CFI	RMSEA (90% CI)	SRMR	BIC	AIC
Mothers' Ratings (n = 4,343)							
1. One Factor	299	9466	.754	.084 (.083–.085)	.078	365584	365086
2. Two Factor	298	5517	.860	.064 (.062–.065)	.056	358277	357773
3. Three Factor	296	2636	.937	.043 (.041–.044)	.036	352987	352471
4. Four Factor	293	2424	.943	.041 (.039–.042)	.034	352618	352082
5. Bifactor DB	273	2106	**.951**	**.039** (.038–.041)	**.032**	**352116**	**351453**
Fathers' Ratings (n = 3,410)							
1. One Factor	299	7103	.749	.082 (.080–.083)	.080	267974	276495
2. Two Factor	298	4168	.857	.062 (.060–.063)	.059	271286	270801
3. Three Factor	296	1977	.938	.041 (.039–.043)	.037	267084	266587
4. Four Factor	293	1847	.943	.039 (.038–.041)	.035	266854	266339
5. Bifactor DB	273	1597	**.951**	**.038** (.036–.040)	**.030**	**266468**	**265831**

Bold entries indicate the best-fit value for each column. Models: (1) one factor = disruptive behavior factor; (2) two factor = ADHD and ODD factors; (3) three factor = IN, HI, and ODD factors; (4) four factor = IN, HY, IM, and ODD factors. ADHD = attention-deficit/hyperactivity disorder; DB = disruptive behavior; CFI = Comparative Fit Index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; BIC = Bayesian information criterion; AIC = Akaike Information criterion.

the first-order models, the three-factor model was the best choice with this result replicating many other studies (see Willcutt et al., 2012). The bifactor model of disruptive behavior, however, showed better global fit than all the first order models (e.g., smaller BIC and AIC values than the three- and four-factor models). The bifactor model of disruptive behavior also provided an excellent global fit in an absolute sense.

Given that the bifactor model of disruptive behavior was the best choice, we next tested whether predictions derived from the dual-pathway and trait-impulsivity etiological theories were consistent with specific parameters from the bifactor model. As described earlier, we examined common variance accounted for by the general and specific factors, reliabilities of total disruptive behavior scores and the IN, HI, and ODD subscales scores, and loadings for the symptoms to test these predictions.

Common variance explained by general and specific factors

Expected common variance (ECV) represents the percent of explained common variance that is attributable to the general and specific factors [i.e., "for each factor the ECV is the sum of the squared loadings for that factor divided by the sum of all squared factor loadings (the common variance) for the model", Brouwer, Meijer, & Zevalkink, 2013, p. 139]. Common variance accounted for by the general disruptive behavior factor was 71% for mothers and 69% for fathers, with the specific HI factor accounting for 4% (mothers) and 6% (fathers), the specific IN factor accounting for 14% (both mothers and fathers), and the specific ODD factor accounting for 11% (both mothers and fathers). Most of the common variance in symptoms was accounted for by the general disruptive behavior factor, with some attributable to the specific IN and ODD factors, yet almost none attributable to the specific HI factor. These results were consistent with predictions from the etiological theories (see above).

Reliability of the total and subscale scores in the bifactor model of disruptive behavior

Table 2 shows reliabilities for total disruptive behavior scores and the IN, HI, and ODD subscale scores. These values represented the amount of variance in each scale that was true score variance. The ω values for the IN, HI, and ODD subscales (.93, .91, and .91, respectively) represented the amount of variance in subscale scores accounted for by a blend of the general disruptive behavior factor and the relevant specific factor (Brunner, Nagy, & Wilhelm, 2012). The ω value for the total scale scores was .96. The ω values were conceptually similar to coefficient alpha (Reise, 2012).

The $\omega_{\text{hierarchical}}$ values indicated how much variance in scores was due to the general or specific factor. For the total scale scores, 85% of the variance was accounted for by the general disruptive behavior factor. The $\omega_{\text{hierarchical}}$ values for the IN, HI, and ODD subscales represented the amount of variance in the subscale scores accounted for by each specific factor, controlling for the general factor. For the HI subscale, only 4% of the variance in mothers' and 7% of the variance in fathers' scores was accounted for by the specific HI factor, whereas the general disruptive behavior factor accounted for 87% and 84% of the variance in the HI subscale scores for mothers' and fathers' ratings, respectively. For the IN subscale, the specific IN factor accounted for 36% of the variance, and the general disruptive behavior factor accounted for 57% of the variance in the scores. For the ODD subscale, the specific factor accounted for approximately 43%, and the general factor accounted for 48% of the variance. These results were consistent with the etiological models

Table 2 Reliabilities (standard errors) for total Disruptive Behavior Scale scores and ADHD-IN, ADHD-HI, and ODD subscale scores

Scales	ω Mothers	ω Fathers	$\omega_{hierarchical}$ Mothers	$\omega_{hierarchical}$ Fathers
Total sample				
IN subscale	.93 (.003)	.93 (.003)	.36 (.018)	.36 (.024)
HI subscale	.91 (.003)	.91 (.004)	.04 (.018)	.07 (.033)
ODD subscale	.91 (.003)	.91 (.004)	.43 (.019)	.42 (.024)
DB scale	.96 (.001)	.96 (.001)	.85 (.006)	.85 (.007)
Boys				
IN subscale	.93 (.004)	.93 (.004)	.38 (.028)	.37 (.034)
HI subscale	.91 (.004)	.91 (.005)	.05 (.033)	.10 (.047)
ODD subscale	.91 (.005)	.91 (.005)	.43 (.029)	.42 (.030)
DB scale	.96 (.002)	.96 (.002)	.85 (.008)	.84 (.010)
Girls				
IN subscale	.92 (.004)	.92 (.005)	.34 (.024)	.35 (.037)
HI subscale	.91 (.004)	.90 (.005)	.03 (.020)	.05 (.054)
ODD subscale	.91 (.004)	.91 (.005)	.43 (.025)	.42 (.039)
DB Scale	.96 (.002)	.96 (.002)	.86 (.007)	.85 (.010)
Children				
IN subscale	.94 (.003)	.93 (.004)	.34 (.064)	.34 (.032)
HI subscale	.92 (.004)	.91 (.004)	.11 (.087)	.16 (.036)
ODD subscale	.92 (.004)	.91 (.005)	.41 (.052)	.39 (.033)
DB scale	.97 (.002)	.96 (.002)	.85 (.008)	.84 (.009)
Adolescents				
IN subscale	.92 (.004)	.92 (.005)	.33 (.028)	.30 (.031)
HI subscale	.90 (.005)	.90 (.006)	.09 (.036)	.13 (.048)
ODD subscale	.91 (.004)	.92 (.005)	.37 (.029)	.38 (.036)
DB scale	.96 (.002)	.96 (.002)	.85 (.008)	.85 (.010)

ω represents the amount of variance in total scores on the relevant set of symptoms accounted for by a blend of the general and relevant specific factor. $\omega_{hierarchical}$ represents the amount of variance in total and subscale scores accounted for by the general or specific factor. IN = inattentive; HI = hyperactive/impulsive; ODD = oppositional defiant disorder; DB = disruptive behavior.

predictions about the amount of true score variance in the total and subscale scores.

Symptom-factor loadings for the bifactor model of disruptive behavior

Table 3 shows loadings for the bifactor model of disruptive behavior. Loadings on the general factor were significant and mostly substantial (range = .41−.77). The IN symptoms had significant and moderate loadings on the specific IN factor (range = .36−.57) with similar results for ODD symptoms on the specific ODD factor (range = .39−.60). However, seven of the nine HI symptoms did not have meaningful (>.30) loadings on the specific HI factor for mothers (range = −.10−.27) with six of these seven symptoms failing to have meaningful loadings for fathers as well (range = −.12−.23). These results were also consistent with predictions derived from the etiological theories.

Criterion validity of the factors in the bifactor model of disruptive behavior

Table 4 shows correlations between the general and specific factors from the bifactor model of disruptive behavior and the academic and social impairment factors. Given that the general and specific factors were orthogonal, correlations with the academic and social impairment factors represented independent relationships. Higher scores on the general disruptive behavior factor were associated with higher levels of academic and social impairment (*p*s < .001). Higher scores on the specific IN factor were also associated with higher scores on academic and social impairment (*p*s < .001), with the specific IN factor having a stronger correlation with academic impairment than the general disruptive behavior factor (*p*s < .05). The specific HI factor was not related meaningfully to the academic or social impairment factors (3 of the 4 correlations were approximately .00, and the 4th, although significant ($p < .05$), was only .09), and therefore did not exhibit incremental validity, over-and-above the general disruptive behavior factor. The specific ODD factor also did not show a significant relationship with the academic problems factor, and although its relationship with social impairment was significant (*p*s < .05), correlations were small and approximately half the magnitude of correlations between the general disruptive behavior factor and social impairment.

Fit of the bifactor model of disruptive behavior for boys and girls

The bifactor model of disruptive behavior provided a good fit for both sexes separately for mothers' and fathers' ratings (CFIs >.938 and RMSEAs <.04). The ω and $\omega_{hierarchical}$ values for total and subscale scores were also almost identical across sex (Table 2). Finally, measurement parameters (like-item loadings, intercepts, and residuals) were invariant across sex for the model (decrease in CFI ≥.01, increase in RMSEA ≥.015, or an increase in SRMR ≥.01 were used to indicate a failure of a set of constraints to hold, Chen, 2007). Table 5 shows these invariance results.

Fit of the bifactor model of disruptive behavior for children and adolescents

The bifactor model of disruptive behavior model also provided a good fit for both children (kindergarten to Grade 6) and adolescents (Grades 7–12) separately for mothers' and fathers' ratings (CFIs >.935 and RMSEA <.047). The ω and $\omega_{hierarchical}$ values for total scores and subscales were almost identical for children and adolescents (see Table 2). Given that adolescents were from Thailand, children were from Brazil, Thailand, and the US,

Table 3 Standardized loadings (standard errors) for the bifactor disruptive behavior model

	Mothers (n = 4,343)		Fathers (n = 3,410)	
IN symptoms	Specific IN	General DB	Specific IN	General DB
1. Close attention	.50 (.02)	.61 (.02)	.52 (.02)	.58 (.02)
2. Sustaining attention	.52 (.02)	.60 (.02)	.53 (.02)	.60 (.02)
3. Listen	.37 (.02)	.66 (.01)	.37 (.03)	.66 (.02)
4. Follow through	.53 (.02)	.59 (.02)	.51 (.03)	.61 (.02)
5. Organizational skills	.56 (.02)	.56 (.02)	.54 (.02)	.58 (.02)
6. Concentration	.57 (.02)	.59 (.02)	.57 (.02)	.61 (.02)
7. Loses things	.43 (.02)	.55 (.02)	.42 (.03)	.56 (.02)
8. Easily distracted	.43 (.02)	.64 (.01)	.46 (.02)	.61 (.02)
9. Forgetful	.36 (.02)	.57 (.02)	.37 (.03)	.57 (.02)
HI symptoms	Specific HI		Specific HI	
1. Fidgets/squirms	.27 (.05)	.65 (.02)	.37 (.04)	.62 (.03)
2. Leaves seat	.45 (.05)	.70 (.02)	.47 (.03)	.65 (.03)
3. Runs/climbs	.39 (.04)	.67 (.02)	.36 (.04)	.63 (.02)
4. Playing quietly	.15 (.04)	.71 (.01)	.16 (.05)	.67 (.02)
5. Talks excessively	.03 (.07)^{ns}	.73 (.01)	.19 (.09)	.70 (.02)
6. Driven/on the go	.15 (.06)	.72 (.02)	.23 (.08)	.67 (.03)
7. Blurts	−.05 (.05)^{ns}	.75 (.01)	.07 (.07)^{ns}	.73 (.02)
8. Awaiting turn	−.01 (.04)^{ns}	.65 (.02)	−.12 (.04)	.68 (.02)
9. Interrupts/intrudes	−.10 (.04)	.76 (.02)	−.07 (.07)^{ns}	.77 (.01)
ODD symptoms	Specific ODD		Specific ODD	
1. Argues	.51 (.02)	.56 (.02)	.53 (.02)	.56 (.02)
2. Loses temper	.56 (.02)	.56 (.02)	.58 (.02)	.55 (.02)
3. Refuses	.47 (.02)	.63 (.02)	.46 (.02)	.62 (.02)
4. Annoys	.46 (.02)	.59 (.02)	.45 (.02)	.61 (.02)
5. Blames	.55 (.02)	.52 (.02)	.52 (.03)	.54 (.02)
6. Gets annoyed	.56 (.02)	.52 (.02)	.53 (.02)	.53 (.02)
7. Resentful	.60 (.02)	.52 (.02)	.55 (.03)	.53 (.02)
8. Vindictive	.39 (.02)	.44 (.02)	.38 (.02)	.41 (.03)

IN = inattentive; HI = hyperactive/impulsive. ODD = oppositional defiant disorder; DB = disruptive behavior. All loadings were significant ($p < .05$) unless noted as nonsignificant (ns).

Table 4 Correlations (standard errors) of academic and social impairment factors with symptom factors from the bifactor model of disruptive behavior

	Academic Impairment		Social Impairment	
Factor	Mothers	Fathers	Mothers	Fathers
Specific IN	0.45 (.02)	0.42 (.02)	0.19 (.03)	0.22 (.03)
Specific HI	0.09 (.03)	0.00 (.03)^{ns}	0.02 (.03)^{ns}	0.01 (.05)^{ns}
Specific ODD	0.02 (.02)^{ns}	0.02 (.02)^{ns}	0.16 (.03)	0.15 (.03)
General DB	0.27 (.02)	0.27 (.02)	0.31 (.02)	0.31 (.03)

IN = inattention; HI = hyperactivity/impulsivity; ODD = oppositional defiant disorder; DB = disruptive behavior; DB = disruptive behavior. All correlations were significant ($p < .05$) unless noted as nonsignificant (ns).

Table 5 Invariance of measurement parameters of bifactor disruptive behavior model over sex

Model	df	χ^2	CFI	RMSEA (90% CI)	SRMR
Mothers' ratings of boys (n = 2,015) and girls (n = 2,292)					
1. Invariant form	546	2342	.951	.039 (.037–.041)	.033
2. Invariant loadings	594	2414	.951	.038 (.036–.039)	.036
3. Invariant intercepts	616	2529	.948	.038 (.036–.040)	.037
4. Invariant residuals	642	2633	.946	.038 (.036–.039)	.040
Fathers' ratings of boys (n = 1,629) and girls (n = 1,767)					
1. Invariant form	546	1907	.950	.038 (.036–.040)	.033
2. Invariant loadings	594	1926	.951	.036 (.035–.038)	.035
3. Invariant intercepts	616	2006	.949	.036 (.035–.038)	.035
4. Invariant residuals	642	2067	.947	.036 (.034–.038)	.038

CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual.

invariance analyses across age may not be meaningful (lack of invariance could be due to age and culture). The invariant form model, however, yielded a good fit for mothers' and fathers' ratings of children and adolescents' behavior (CFIs >.942 and RMSEAs <.044).

Discussion

Three aspects of these data – symptom factor loadings on the general and specific factors, common variance accounted for by the general and specific factors, and reliability values for total disruptive behavior scores and subscale scores for the bifactor model of disruptive behavior – were consistent with predictions derived from dual-pathway and trait-impulsivity etiological theories of ADHD and externalizing psychopathology more generally (e.g., that a general disruptive behavior factor should account for most of the true score variance in the ADHD/ODD symptoms, with the specific HI factor accounting for a trivial amount of variance in the HI symptoms and the specific IN and specific ODD factors accounting for a small amount of the variance in their respective symptoms). These findings were the same for mothers' and fathers' ratings across sex and different age groups.

In new edition of the diagnostic and statistical manual of mental disorders (APA, 2013), ADHD is in the general neurodevelopmental disorders category, whereas ODD is in the general disruptive, impulse-control, and conduct disorders category. Placement of ADHD in a different category than ODD and other externalizing conditions seems to imply different etiological processes. However, if ADHD and ODD (and other externalizing conditions) share a common etiology, as suggested by recent theoretical models (Beauchaine & McNulty, 2013; Beauchaine et al., 2010), accumulating behavioral genetics findings (e.g., Krueger et al., 2002; Tuvblad et al., 2009), and the outcome of our study, placing these disorders in the same general category more likely, in the words of Plato, 'carves nature at its joints'. Separating disorders across categories of the DSM encourages fractionated basic research and treatment-outcome development agendas, with potential adverse consequences in both domains (Beauchaine, Klein, Erickson, & Norris, 2013). Nevertheless, attention problems without HI may be associated with 'top-down' neural process, and therefore have a closer association with neurodevelopmental disorders than attention problems with HI.

Limitations

A major limitation of this study is that results are specific to a single scale and a 50% response rate for the Brazilian and US samples. It is important to test the bifactor model of disruptive behavior with other rating scales and diagnostic interviews. Longitudinal research is also needed to understand how the general and specific factors may vary over time, and if the specific IN factor continues to show a stronger correlation with academic impairment than general disruptive behavior. In addition, future studies should include CD and substance use symptoms to more thoroughly evaluate the merits of the bifactor model of disruptive behavior.

Conclusions

A general disruptive behavior factor accounted for most of the variance in ADHD/ODD symptoms. This factor also accounted for nearly all variance in HI subscale scores, and over half of the variance in IN and ODD subscale scores. These results imply that the IN, HI, and ODD subscale scores contain too little reliable variance to be viewed as specific measures of these constructs, independent of the general factor (i.e., the clinical interpretation of subscales scores must remember that most of the variance was accounted for by the general disruptive behavior factor).

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Correspondence

G. Leonard Burns, Department of Psychology, Washington State University, 233 Johnson Tower, Pullman, WA, 99164-4820, USA; Email: glburns@wsu.edu

Key points

- The best latent structure for the attention-deficit/hyperactivity disorder and oppositional defiant disorder symptoms remains under debate with most studies taking a description approach rather than attempting to connect measurement models of latent structure to theories of etiology.
- Consistent with predictions derived from recently articulated dual-pathway and trait-impulsivity theories of externalizing liability, and from behavioral genetics studies indicating near complete overlap in vulnerability to ADHD and ODD, ADHD and ODD symptoms arose from a single, general disruptive behavior factor, which accounted for all of the variance in HI subscale scores and over half of the variance IN and ODD subscales.
- These findings suggest that a closer connection between etiological models and measurement models of ADHD/ODD symptoms might lead to an improved understanding of these disorders.

Notes

1. A bifactor model of ADHD, with correlations among the general and specific factors will either fail to converge or yield inadmissible parameter values (Kenny & Milan, 2012, p. 160). Martel evaluated an empirically underidentified bifactor model of ADHD in two studies (Martel, Roberts, Gremillion, von Eye, & Nigg, 2011; Martel, von Eye, & Nigg, 2010), and an empirically underidentified bifactor model of disruptive behavior in one study (Martel, Gremillion, Roberts, von Eye, & Nigg, 2010). Inspection of parameters in the models suggests inappropriate values (e.g., a negative correlation [−.86] between general ADHD and group HI, a negative correlation [−.48] between general ADHD and group IN along with five of the nine group HI loadings above 1.50; see Martel et al., 2011; Figure 1). Such empirical underidentification renders interpretation difficult if not impossible.
2. The impulsivity factor included the talks excessively symptom to be consistent with Ullebø et al. (2012). The same results occurred with the use of only the three DSM-IV impulsivity symptoms.

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