The hierarchical factor model of ADHD: Invariant across age and national groupings?

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Abstract

Objective: To examine the factor structure of Attention-Deficit/Hyperactivity Disorder (ADHD) in a clinical sample of 1373 children and adolescents with ADHD and their 1772 unselected siblings recruited from different countries across a large age range. Hierarchical and correlated factor analytic models were compared separately in the ADHD and sibling samples, across three different instruments and across parent and teacher informants. Specific consideration was given to factorial invariance analyses across different ages and different countries in the ADHD sample. **Method**: A sample of children and adolescents between 5 and 17 years of age with ADHD and their unselected siblings was assessed. Participants were recruited from seven European countries and Israel. ADHD symptom data came from a clinical interview with parents (PACS) and questionnaires from parents and teachers (Conners Parent and Teacher). **Results**: A hierarchical general factor model with two specific factors best represented the structure of ADHD in both the ADHD and unselected sibling groups, and across informants and instruments. The model was robust and invariant with regard to age differences in the ADHD sample. The model was not strongly invariant across different national groups in the ADHD sample, likely reflecting severity differences across the different centers and not any substantial difference in the clinical presentation of ADHD. **Conclusions:** The results replicate previous studies of a model with a unitary ADHD component and separable specific traits of inattention and hyperactivity/impulsivity. The unique contribution of this study was finding support for this model across a large developmental and multinational/multicultural sample and its invariance across ages.

Keywords: ADHD, hierarchical models, bifactor model, factorial invariance

Attention-Deficit/Hyperactivity Disorder (ADHD) is characterized by problems with attention, impulsivity, and hyperactivity. The diagnosis derives from 18 symptoms indexing these behavioral domains [American Psychiatric Association (APA), DSM-IV-TR, 2000]. There is substantial continuity in maintaining a diagnosis of ADHD from childhood to adolescence (Faraone, Biederman, & Mick, 2006); however the phenotypic expression is highly variable within the diagnosed group and across time (Barkley, 2006; Nigg, 2006). Current diagnostic formulations distinguish between symptoms of inattention and those of hyperactivity-impulsivity. Three ADHD subtypes are recognized in the DSM-IV: the predominantly inattentive type, the predominantly hyperactive-impulsive type, and the combined type (where patients meet criteria on both the inattention and the hyperactive/impulsivity domains). This formulation is currently under review as part of the deliberation of the DSM-5 panel. Indeed, this current characterization remains controversial (Barkley, 2001; Diamond, 2005; Hinshaw, 2001; Lahey, 2001; Milich, Balentine, & Lynam, 2001).

Here we focus on factor models of co-occurrence among ADHD symptoms. Two major types of factor models, correlated factor models and hierarchical models, have been used to examine coherence and distinctness among ADHD symptom domains. Hierarchical models provide a way to simultaneously conceptualize both the coherence and separability of symptoms from separate domains. These models include a single general factor accounting for covariation among all symptoms along with separate, specific factors of inattention, hyperactivity, and impulsivity that vary orthogonally from the general factor. These models are also termed as bifactor models in the statistical literature. Hierarchical models are different from correlated factor models that only have factors for the symptom domains of inattention and hyperactivity and/or impulsivity (see Figure 1). Several studies have shown hierarchical models with a general factor as having a better fit than correlated models for reported symptoms of ADHD (e.g., Dumenci, McConaghy, & Achenbach, 2004; Gibbins et al., in press; Martel, Von Eye, & Nigg, 2010; Toplak et al., 2009). These papers span clinical and community samples, and child, adolescent, and adult samples with ADHD. A one-factor model has also been considered, but thus far it has no empirical support (Dumenci et al., 2004).

Hierarchical models explicitly acknow-ledge the common covariation among all ADHD symptoms, which is consistent with the conceptualization of ADHD as a single disorder. There are several lines of evidence suggesting that there is substantial commonality between the domains of inattention and hyperactivity-impulsivity. Inattentive symptoms tend to be more highly correlated with hyperactivity and impulsivity than with other domains of psychopathology (Adams, Kelley, & McCarthy, 1997; Conners, 2008; Strickland et al., 2011), with the exception of oppositional defiant disorder in some studies (Lahey et al., 2008). Current models of ADHD also highlight how the symptom domains of inattention, hyperactivity, and impulsivity likely interact to give rise to the heterogeneous expression of ADHD (Nigg & Casey, 2005; Sagvolden, Johansen, Aase, & Russell, 2005; Sonuga-Barke, 2005; Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008). To replicate and extend these findings, the current study examined different factor models in a large sample of ADHD patients recruited from a broad age range and from diverse national groupings. We were thus able to test whether a hierarchical model held for the whole sample and whether it also was invariant across different age groups and nationalities.

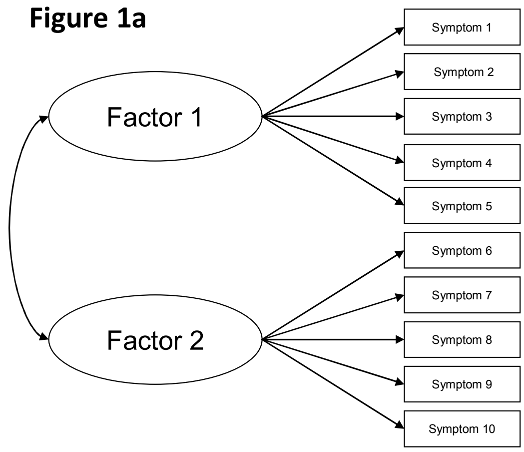
A developmental perspective is important to integrate into models of individual ADHD symptoms, such that a single set of factors could parsimoniously explain the changes that occur over development. Age differences in scores from ADHD measures may reflect true differences in the constructs being measured or may simply reflect measure-ment differences due to age. Therefore, establishing measurement invariance across age groups is important. The behavioral presentation of ADHD changes considerably from childhood to adolescence. For instance, the expression of hyperactivity seems to decrease from childhood to adolescence and inattention commonly appears later in development than hyperactivity and impulsivity (Biederman et al., 2000; Hart et al., 1995; Larsson et al., 2006; Nigg, 2006). This developmental change introduces complex issues with respect to diagnosis. Subtypes have been used to characterize these different symptom presentations, and the instability of ADHD subtypes in developmental samples has also been well demonstrated (Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Todd et al., 2008). Some of this instability of subtypes may be attributable to measurement variability (Lahey et al., 2005; Valo & Tannock, 2010); however some of this variability would be expected from a developmental perspect-ive, which would presume that children's symptom presentations change over the course of development. What is needed is a coherent model that can represent these shifts and changes in symptoms.

In addition to the question of developmental change and continuity in ADHD symptoms, the current sample also had the unique characteristic of having recruited participants from seven European countries and Israel by 12 different research centers. Most studies examining cross-national samples have been concerned with whether there are comparable rates of prevalence across different countries (Faraone, Sergeant, Gillberg, & Biederman, 2003; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007) rather than consistency in symptom patterns across countries. In addition to testing the five different factor models in the full sample, invariance analyses were also conducted to examine consistency of the best overall model across countries.

Thus, in the current study we first estimated five different factor models to determine which model best accounted for ADHD symptoms pooling all ages and locations using a sample of children and adolescents with ADHD and their siblings. The five factor structures included: a) a one-factor model of inattention/ hyperactivity / impulsivity; b) a non-hierarchical two-factor model with correlated inattention and hyperactivity/impulsivity factors (the correlated 2-factor model); c) a non-hierarchical three-factor model with correlated inattention, hyperactivity, and impulsivity factors (the correlated 3-factor model); d) a hierarchical model of a general ADHD factor with two specific factors of inattention and hyperactivity/impulsivity (the hierarchical 2-factor model); and e) a hierarchical model of a general ADHD factor with three specific factors of inattention, hyperactivity, and impulsivity (the hierarchical 3-factor model).

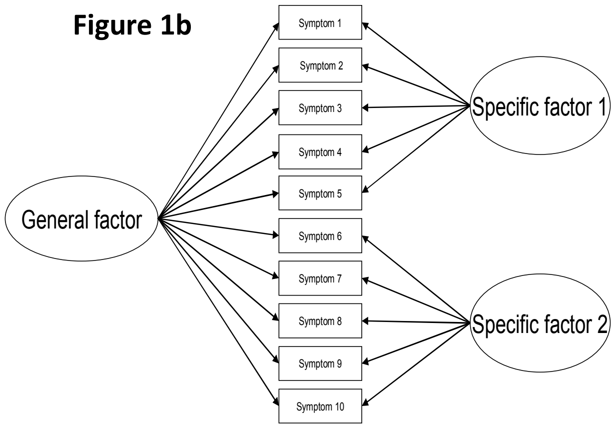
Based on previous research, we expected that a hierarchical model with a general ADHD factor would provide the best fit to observed ADHD symptoms in both the ADHD and sibling samples and across instruments and informants. We then examined whether these modeled relationships among symptoms are equiv-alent across different groups by formally assessing *measurement invariance* in the ADHD group. Group differences in observed scores on measurement instruments can be attributed to true differences on the constructs being measured only if measurement invariance or equivalence holds across groups (e.g., Widaman & Reise, 1997). Based on the best fitting model, we conducted invariance analyses to determine whether the measurement parameters relating the constructs implied by the model to the observed symptoms are equivalent across age groups and locations in the ADHD group.

Figure 1a



Generic example of a correlated two-factor model for 10 observed symptoms

Figure 1b



Generic example of a hierarchical model with a general and two specific factors for same 10 observed symptoms.

Method

Participants and Procedure. Participants included 1373 ADHD proband children (87% males; aged 5 to 17 years, Mean age = 10.95, SD = 2.78) and their 1772 unselected siblings (50.2% male; Mean age= 10.87, SD=3.36), with reports from parents and teachers. Participants were recruited if they were diagnosed or suspected to meet criteria for ADHD combined subtype, as defined by the DSM-IV-TR (2000). Most of the ADHD proband children met criteria for ADHD combined subtype (n = 1217; 88.6%). A smaller proportion met criteria for the hyperactive/impulsive subtype (n = 27; 2.0%) or the inattentive subtype (n = 53; 3.9%), and 76 children did not meet criteria for ADHD (5.5%). The unselected siblings contained children and adolescents with ADHD symptoms on the whole continuum. The PACS interview was administered for the siblings only in cases of suspected ADHD, and the Conners Parent and Teacher forms were administered for all of the siblings included in this study. The data were obtained from the International Multicentre ADHD Genetics (IMAGE) project which includes a total of eight countries, specifically 7 European countries (Belgium, England, Germany, Ireland, Spain, Switzerland, and The Netherlands) and Israel. This research meets ethical guidelines and adherence to the legal requirements of each study country. This project involved the collection of behavioral data from 1400 proband-sibling pairs and molecular genetic data on the children and their parents. Full details on this sample are reported in Müller et al. (2011a; 2011b).

Measures

Parental Account of Childhood Symptoms (PACS). An adapted version of the PACS interview was used in the IMAGE study (see Chen et al., 2008; Müller et al., 2011a). The ADHD section of the PACS was included in this study, assessing for inattentive behavior (9 symptoms), hyperactive behavior (6 symptoms), and impulsive behavior (3 symptoms). In this interview, parents were asked to rate the frequency or severity of behaviors in pre-specified contexts (when child was unmedicated), which were then mapped onto a scale with specific categories for each question. Parents were asked to rate their child's behaviour not in terms of deviance from normality, but rather by describing the behaviour according to its frequency or severity. The ADHD-section of the PACS, which was used to confirm the ADHD diagnosis, covered ADHD-related behaviour in different situations (such as watching TV and doing homework). A specific age-adjusted algorithm combined and weighed the rated behaviour across situations ultimately leading to a dichotomous score for the presence or absence of the corresponding ADHD DSM-IV symptom.

Conners Parent and Teacher Ratings. The Conners rating scales (CPRS/CTRS-R:L; Conners, 1997) were completed by parents and teachers. Each scale contained a set of 18 questions covering the DSM-IV ADHD symptoms. Each item had a 4-point response scale.

Statistical Approach. The entire ADHD sample was used for confirmatory factor analysis (CFA) to assess the best fitting model among hypothetical candidates. Because the PACS symptoms have a dichotomous response scale and the Conners rating scale items have a four-point response scale, all models were fitted to the matrix of polychoric correlations among symptoms to account for their categorical nature using a "robust" weighted least-squares estimator (see Flora & Curran, 2004), implemented as the mean- and variance-adjusted weighted least squares (WLSMV) estimator in Mplus (version 5.2; Muthén & Muthén, 2002). Model fit was evaluated using the root mean square error of approximation (RMSEA), comparative-fit index (CFI), and Tucker-Lewis index (TLI) with good model fit indicated by RMSEA values of 0.08 or lower along with CFI and TLI values of 0.95 or higher.

Invariance analyses were conducted comparing three different age groups (9 years and under, 10-12 years, and 13 years and older) in the current sample to determine whether the measurement properties of the instruments are equivalent across age with respect to the ADHD constructs. Invariance analyses were also conducted with different locations according to the following groupings based on language: Belgium and The Netherlands (n = 439), United Kingdom and Ireland (n = 431), Germany and Switzerland (n = 205), and Israel (n = 249). Spain was not included in the invariance analyses due to small sample size (n = 77). Sample sizes and means on the instruments for the ADHD group and the unselected siblings group are shown in Tables 1 and 2. These indices are reported by each age group and location for the ADHD group.

To test factorial invariance across age and location in the ADHD group, we followed procedures outlined by Widaman and Reise (1997) using a series of nested multiple-group CFA models. Although nested model comparisons often rely on χ^2 difference tests, recent methodological research suggests that examining alternative fit indices is preferable because the χ^2 statistic is overly sensitive to sample size and ignores model parsimony. Thus, in the current analyses two models were considered to have equivalent fit if the decrease in CFI (ΔCFI) was .01 or less and if the increase in RMSEA (ΔRMSEA) was not greater than .01 (Chen, 2007, Cheung & Rensvold, 2002).

To establish configural invariance in the ADHD group, we examined the fit of a two-group model in which the basic model specification was identical across groups, but all parameters were free to vary across groups (except those needed for overall model identification; see Millsap & Yun-Tein, 2004). Next, to test weak invariance, the fit of the initial configural invariance model was compared to that of a model with all factor loadings constrained equal across groups. If weak invariance held, we then tested strong invariance by comparing the fit of the weak invariance model to that of a model with all factor loading and all symptom threshold parameters constrained to equality across groups. However, because PACS items are dichotomous, model identification requires equal thresholds across groups (Millsap & Yun-Tein, 2004); thus, a weak invariance model with constrained loadings and freed thresholds is not estimable, while the PACS configural invariance model has freed loadings and constrained thresholds.

Table 1. *Sample Characteristics*

	Total ADHD Sample	Ages ≤ 9 y (ADHD)	Ages 10-12 (ADHD)	Ages ≥ 13 (ADHD)	Unselected Siblings
M age (SD)	10.95 (2.78)	7.83 (1.12)	10.98 (.82)	14.31 (1.30)	10.87 (3.336)
			Mean # PACS parent reported symptoms (SD)		
N	1373	450	512	411	401
Total ADHD	13.73 (3.04)	13.63 (2.97)	13.90 (3.04)	13.62 (3.12)	10.78 (4.58)
Inattention	6.81 (1.65)	6.62 (1.65)	6.90 (1.64)	6.93 (1.65)	5.62 (2.45)
Hyperactivity & Impulsivity	6.91 (2.00)	7.02 (1.91)	7.01 (1.97)	6.69 (2.11)	5.15 (2.87)
			Mean rating on Conners Parent (SD)		
N	1340	441	500	398	1770
Total ADHD	37.11 (9.26)	37.58 (9.18)	37.12 (8.78)	36.55 (9.92)	16.63 (23.71)
Inattention	19.47 (5.11)	18.99 (5.04)	19.52 (4.91)	19.94 (5.40)	9.43 (15.47)
Hyperactivity & Impulsivity	17.64 (5.62)	18.58 (5.40)	17.60 (5.38)	16.65 (5.98)	7.21 (13.70)
			Mean rating on Conners Teacher (SD)		
N	1269	425	476	358	1679
Total ADHD	30.50 (11.33)	33.35 (10.80)	30.16 (11.04)	27.52 (11.53)	19.40 (46.00)
Inattention	16.37 (6.07)	17.17 (6.00)	16.30 (5.90)	15.57 (6.26)	11.15 (28.07)
Hyperactivity & Impulsivity	14.08 (6.86)	16.10 (6.47)	13.81 (6.76)	12.01 (6.79)	8.14 (24.55)

Results

The correlations between age and total scores for all 18 ADHD symptoms in the ADHD group were non-significant for the PACS interview and Conners Parent scale and significant for the Conners Teacher scale (r = -.23, p < .001). Age was not significantly correlated with inattention or hyperactivity/impulsivity ratings for all three instruments. Overall, correlations between age and ADHD symptoms were very small or non-significant.

Table 2. *Sample Characteristics of ADHD Sample by Country Groupings*

	Ireland and United Kingdom	Belgium and The Netherlands	Germany and Switzerland	Israel
M age (SD)	11.68 (2.86)	11.11 (2.72)	10.30 (2.32)	10.41 (2.81)
	Mean Number of PACS parent reported symptoms (SD)			
N	427	439	205	235
Total ADHD	14.18 (3.07)	14.10 (2.64)	14.01 (3.10)	12.66 (3.15)
Inattention	7.02 (1.68)	6.88 (1.65)	6.94 (1.51)	6.51 (1.59)
Hyperactivity & Impulsivity	7.16 (1.97)	7.22 (1.64)	7.07 (2.06)	6.17 (2.22)
	Mean Ratings on Conners Parent (SD)			
N	386	417	194	224
Total ADHD	40.62 (9.22)	36.31 (8.47)	34.95 (9.40)	33.33 (9.34)
Inattention	21.34 (4.96)	18.91 (4.85)	18.57 (5.21)	17.60 (5.18)
Hyperactivity & Impulsivity	19.36 (5.69)	17.36 (5.15)	16.33 (5.74)	15.71 (5.84)
	Mean Ratings on Conners Teacher (SD)			
N	354	402	188	201
Total ADHD	27.34 (12.83)	29.32 (10.12)	32.70 (10.82)	32.86 (9.89)
Inattention	15.12 (6.86)	15.41 (5.55)	17.78 (5.68)	17.72 (5.49)
Hyperactivity & Impulsivity	12.21 (7.50)	13.92 (6.13)	14.91 (7.00)	14.96 (6.45)

CFA Model Selection

The 18 ADHD symptoms from the PACS parent interview and Conners Parent and Teacher scales were fitted to separate CFA models for each of these three instruments. The model fit statistics for the total ADHD sample are presented in Table 3. Across all three instruments, the hierarchical models had RMSEA values below .07 and demonstrated a better fit than the correlated models across both instruments and informants (although for the PACS, CFI and TLI did not meet conventional criteria for good fit). Within each instrument and informant, the hierarchical 2-factor and 3-factor models had very similar model fit. We focus our remaining results on the hierarchical model with two specific factors because it is more parsimonious than the model with three specific factors.

Across all three instruments, all symptoms had significant, positive loadings on the general ADHD factor (all *ps* < 0.05; see Table 4 for standardized factor loading estimates and R^2 values), with the exception of the “Does not seem to listen” symptom from the PACS interview. With the Conners Parent and Conners Teacher instruments, most inattention items were slightly more strongly related to their specific factor than the general factor, whereas this pattern was more mixed for the PACS inattention symptoms. For all three instruments, the hyperactivity/impulsivity symptoms were all more strongly related to the general factor than to their specific factor (except the "Blurts out answers" PACS symptom).

Table 3. *Fit of ADHD Symptom CFA Models by Instrument for ADHD Sample*

Model	df	χ^2	CFI	TLI	RMSEA	RMSEA 90% CI
Parent PACS (N = 1374)						
One-factor model	135	1050.41	.790	.761	.070	.066 - .074
Correlated 2-factor	134	786.54	.850	.829	.060	.056 - .064
Correlated 3-factor	132	752.65	.857	.835	.059	.054 - .063
Hierarchical 2-factor	**117**	**426.54**	**.929**	**.907**	**.044**	**.039 - .048**
Hierarchical 3-factor	**117**	**417.11**	**.931**	**.910**	**.043**	**.039 - .048**
Parent Conners (N = 1388)						
One-factor model	135	2862.17	.798	.771	.121	.117 - .125
Correlated 2-factor	134	1375.37	.908	.895	.082	.078 - .086
Correlated 3-factor	132	1350.76	.910	.895	.082	.078 - .086
Hierarchical 2-factor[1]	**117**	**709.24**	**.956**	**.943**	**.060**	**.056 - .065**
Teacher Conners (N = 1350)						
One-factor model	135	4324.05	.810	.785	.152	.148 - .156
Correlated 2-factor	134	2197.52	.906	.893	.107	.103 - .111
Correlated 3-factor	132	2076.51	.912	.898	.105	.101 - .109
Hierarchical 2-factor	**117**	**828.58**	**.968**	**.958**	**.067**	**.063 - .072**
Hierarchical 3-factor	**117**	**867.45**	**.966**	**.955**	**.069**	**.065 - .073**

Note. df = degrees of freedom; χ^2 = chi-square fit statistic; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation. [1]Fit statistics are not reported for the hierarchical 3-factor model for the Parent Conners instrument because the estimator did not converge to a proper solution.

Overall, these findings confirm that a single, dominant general factor underlies all 18 DSM-IV ADHD symptoms along with separate specific factors accounting for residual covariation among symptoms from the same domain (i.e., inattention and hyperactivity/impulsivity). A larger proportion of the variance in hyperactive/impulsive symptoms was consistently associated with the general factor, whereas a larger proportion of the

Table 4. *Completely Standardized Factor Loadings for Hierarchical 2-Factor Model Fitted for Parent PACS Interview, Parent Conners (CP), and Teacher Conners (CT) Across Full ADHD Sample*

ADHD Symptom	Factor									R^2		
	General			Specific Ina			Specific Hyp/Imp					
	PACS	CP	CT	PACS	CP	CT	PACS	CP	CT	PACS	CP	CT
1. Fails to give attention & makes careless mistakes.	.357	.399	.359	.628	.551	.555				.522	.464	.438
2. Difficulty sustaining attention.	.589	.451	.526	*-.019*	.434.	.538				.347	.392	.567
3. Does not seem to listen.	*.021*	.581	.513	.249	.299	.382				.062	.427	.410
4. Does not follow through on instructions.	.320	.399	.371	.259	.639	.597				.169	.567	.494
5. Difficulty organizing tasks.	.279	.348	.364	.511	.628	.700				.338	.516	.622
6. Avoids tasks that require sustained mental effort.	.304	.343	.386	.324	.612	.529				.197	.492	.429
7. Loses things.	.322	.325	.370	.729	.545	.520				.635	.402	.407
8. Easily distracted.	.358	.601	.712	.442	.330	.312				.323	.470	.605
9. Often forgetful.	.269	.375	.160	.698	.583	.557				.559	.481	.336
10. Often fidgets.	.751	.594	.710				.131	.164	*-.084*	.581	.380	.511
11. Leaves seat in class.	.727	.578	.752				*-.075*	.187	-.163	.534	.369	.592
12. Runs about or climbs excessively	.729	.686	.765				*-.012*	.454	-.209	.531	.676	.628
13. Difficulty playing quietly.	.655	.623	.547				.416	*.038*	.123	.602	.389	.314
14. Always "on the go."	.902	.632	.737				-.202	.301	*-.033*	.854	.490	.545
15. Often talks excessively.	.506	.535	.640				.200	-.138	.265	.296	.305	.480
16. Blurts out answers.	.525	.649	.642				.639	-.235	.399	.684	.477	.572
17. Difficulty waiting in lines.	.318	.715	.727				.214	*-.009*	.350	.147	.512	.652
18. Often interrupts.	.585	.725	.691				*.109*	-.229	.347	.354	.578	.599

Note. All factor loadings are significant ($p < .05$) except those in italics the variance in inattentive symptoms was consistently associated with the inattention specific factor. For the PACS, the general factor explains only 11.69% of total variance for the inattention symptoms, while the inattention specific factor explains 23.38% of total inattention symptom variance. But, the general factor explains 42.68% of total variance for the hyperactivity/impulsivity symptoms, while the hyperactivity specific factor explains only 8.25% of total hyperactivity/impulsivity symptom variance. For the Conners parent report, the general factor accounts for 18.95% of inattention symptom variance and specific factor accounts for 27.83%. The general factor accounts for 40.99% of hyperactive/ impulsive symptom variance and the specific factor accounts for only 5.41% of variance in these symptoms. For the Conners teacher report, the general factor accounts for 19.53% of inattention symptom variance and the specific factor accounts for 28.31%. The general factor accounts for 48.06% of hyperactive/ impulsive symptom variance and the specific factor accounts for only 6.29% of variance in these symptoms.

The 5 models were also estimated in the sample of unselected siblings. For each of these instruments, the hierarchical 2-factor and 3-factor models had better fit than any of the non-hierarchical models. In fact, the hierarchical 2-factor and 3-factor models had the same values for the model fit indices (PACS: CFI=.96, TLI=.95, RMSEA=.06; Conners Parent: CFI=.99, TLI=.99, RMSEA =.07; Conners Teacher: CFI=.99, TLI=.99, RMSEA=.06).

Measurement Invariance across Age and Location in the ADHD group

We examined factorial invariance by age for the hierarchical two-factor model separately for the three instruments, each time assessing invariance for the age 9 and under group compared to the age 10 to 12 group, and then comparing the age 10 to 12 group to the age 13 and older group. Strong factorial invariance holds across age groups for all three instruments in the ADHD group. Thus, the measurement properties of the PACS and Conners questionnaires are equivalent across age with respect to relating the ADHD constructs implied by the hierarchical factor models to the 18 observed symptoms. The results of the invariance analyses are presented in supplemental tables available online.

Next, we examined factorial invariance by location for the hierarchical two-factor model separately for the three instruments in the ADHD group. We estimated a series of two-group models, making all possible pair-wise comparisons between the four country groupings (i.e., 1. Ireland / UK, 2. The Netherlands / Belgium, 3. Germany/ Switzerland, and 4. Israel). For the PACS interview, strong invariance held between Holland/Belgium and each of the other locations. However, strong invariance was rejected across Ireland/UK versus both Germany/Switzerland and Israel and across Germany/Switzerland versus Israel. Therefore, while the hierarchical two-factor model fits the PACS data well across all locations (i.e., configural invariance), there is some variation in the factor loadings for this model as a function of location.

For the Conners Parent Scale, strong invariance held across all location comparisons with the exception of Ireland/UK versus Holland/Belgium and Ireland/UK versus Israel, for which weak invariance held but strong invariance was rejected. Similarly, for the Conners Teacher Scale, strong invariance held across all location comparisons with the exception of Ireland/UK versus Holland/Belgium and Holland/Belgium versus Israel, for which weak invariance held but strong invariance was rejected. Therefore, for both the Conners Parent and Conners Teacher scales, factor loadings for the hierarchical model are equivalent across all locations, but there is some variation in the individual symptom thresholds (i.e., rates of symptom endorsement for a given level of the unobserved constructs) across location.

Discussion

The present study compared five factor models to determine the best representation of the relationships among the ADHD symptoms from the dimensions of inattention and hyperactivity-impulsivity using a sample of 1373 children referred for ADHD and 1772 unselected siblings. Across all three instruments and across parent and teacher informants, the hierarchical, general factor model with two or three specific factors had a better fit than the single factor or correlated factor models. Invariance analyses indicated strong invariance across age but strong invariance was not obtained consistently across locations in the ADHD group.

The current findings replicate previous research that has shown the hierarchical or bifactor model to be a better fitting model than correlated factor models of ADHD symptoms (Dumenci et al., 2004; Gibbins et al., in press; Martel et al., 2010; Toplak et al., 2009). Importantly, the replication in the current study was obtained in the ADHD sample, as well as in the unselected siblings. The hierarchical models with two and three specific factors both fit the data well, but the model with two specific factors was interpreted as was the more parsimonious model. The pattern of loadings suggests that the hyperactive-impulsive symptoms were more strongly and consistently related to the general factor than were the inattentive symptoms. Inattentive symptoms also significantly loaded onto the general factor, but with more inconsistency in the strength of their relationships to both general and specific factors. The hyperactive-impulsive symptoms may have been reported with consistently more variability than inattention symptoms, reflecting the predominance of these symptoms in childhood. This hierarchical model accounted for 35% to 48% of the total variance in reported symptoms of inattention and 46% to 54% for symptoms of hyperactivity-impulsivity (depending on the instrument). The finding of the common and separate variance among the symptom domains of ADHD is reflected in the findings from quantitative genetic studies (Greven, Rijsdijk, & Plomin, 2011; McLoughlin, Ronald, Kuntsi, Asherson, & Plomin, 2007). Using population twins samples, these studies consistently found that the symptom domains of ADHD are influenced by partially overlapping sets of genes, with genetic influences that are shared between the two domains, in addition to domain-specific genetic influences.

The fact that strong invariance was obtained across three different age groups in the ADHD sample suggests that the general factor model is robust and equivalent across age with respect to the ADHD latent constructs generated from the 18 symptoms. This finding underscores the importance of continuities of relationships among ADHD symptoms across development. An integral and possibly interactive relationship between inattentive and hyperactive/impulsive symptoms has been demonstrated longitudinally in children and in quantitative genetic studies of ADHD. Ratings of hyperactivity-impulsivity in childhood have been shown to predict inattentiveness in early adolescence, but the reverse was not found (Greven, Asherson, Rijsdijk, & Plomin, 2011). These authors suggested that hyperactivity-impulsivity may exacerbate inattentive symptoms over time, although the mechanisms involved remain unclear and could involve behavioral, cognitive, or neurobiological pathways. In another longitudinal study examining trajectories of ADHD symptoms, hyperactivity-impulsivity symptoms decreased over time, whereas inattention symptoms increased over time (Larsson, Dilshad, Lichtenstein, & Barker, 2011). These results were interpreted as potentially explaining the developmental trajectories from hyperactive-impulsive to combined subtype in early to middle childhood and from the combined to inattentive subtype during the later transition to adolescence and young adulthood (Biederman et al., 2000; Hart et al., 1995).

In general, twin studies have shown that genetic influences on composite measures of ADHD are largely stable (Kuntsi, Rijsdijk, Ronald, Asherson, & Plomin, 2005; Larsson, Larsson, & Lichtenstein, 2004; Price, Simonoff, Asherson, Curran, Kuntsi, Waldman, et al., 2005), although there are new genetic influences acting on ADHD at different ages. The developmental relationship between inattention and hyperactivity-impulsivity is also influenced by shared genetic influences, with both new and stable genetic effects at different developmental stages (Larsson et al., 2006; Nadder, Rutter, Silberg, Maes, & Eaves, 2002; Greven et al., 2011). Moreover, during adolescent development, more than half of the genetic influences acting on the two symptoms domains were novel effects (Greven et al., 2011), which might be related to the developmental changes seen in the balance between inattentive and hyperactive-impulsive symptoms.

From a developmental perspective, it is also important to explain how inattention and hyperactivity-impulsivity are related to cognitive performance and behavioral phenotypes, although no consistent picture has emerged yet. Inattention has been reported to be strongly associated with executive function difficulties (Chhabildas, Pennington, & Willcutt, 2001; Nigg et al., 2005), whereas delay discounting has been associated with hyperactive-impulsive symptoms (Scheres, Lee, & Sumiya, 2008), though not consistently (Paloyelis, Asherson, Mehta, Faraone, & Kuntsi, 2010). Both of these general domains uniquely predicted ADHD symptoms in child samples (Campbell & von Stauffenberg, 2009; Sonuga-Barke, Dalen, & Remington, 2003). That these two domains have been implicated in ADHD has been a key component in dual-pathway concept-ualizations of ADHD, in which executive and motivational pathways are not regarded as competing theories, rather that deficits in both processes are thought to give rise to the manifestation of ADHD (Sonuga-Barke, 2002; 2003; 2005). Understanding the overlap and separability between these pathways will be critical for explaining the heterogeneity observed in ADHD. Halperin and Schulz (2006; Halperin, Trampush, Miller, Marks, & Newcorn, 2008) have used a developmental perspective to explain symptom change in ADHD as reflecting the degree to which prefrontally mediated executive functions develop and can compensate for stable subcortical deficits. Such developmental theories will play an important role in explaining the common and separable variance between inattention and hyperactivity-impulsivity in ADHD.

Strong invariance, however, did not hold consistently across all of the locations in the ADHD group. Notably, the same instruments were used in all locations, with proper training to establish reliable administration (Müller et al., 2011a). Thus, these differences are less likely to be attributable to differences in administration, but may be attributable to the rates of symptom endorsement in some locations. This is consistent with Müller et al.'s (2011a) report on symptom patterns in the IMAGE dataset, where the mean number of symptoms reported differed significantly across several countries. That was also the case in the present study, as participants in Israel had the lowest number of symptoms reported on the PACS ($p < .0001$), participants in Ireland and the United Kingdom had the highest ADHD ratings on the parent Conners ($p < .0001$) and lowest rating (with Belgium and The Netherlands) on the teacher Conners ($p < .0001$). This pattern likely explains why strong invariance was not obtained in the current study across locations. Therefore, the site differences likely reflect severity differences across the clinical ascertainment centers, and not any substantial difference in the clinical presentation of ADHD.

Clinically, the current study also suggests that the current DSM-IV conceptualization for diagnosing ADHD may not be the optimal set of constructs. The current findings support a unitary construct of ADHD, with additional covariation of symptoms manifest in the separate orthogonal factors of inattention and hyperactivity-impulsivity. A focus on specific symptoms or symptom domains may be too narrow in understanding the full clinical presentation of ADHD. A hierarchical factor model accommodates clinical presentations of predominantly inattentive symptoms and acknowledges the presence of levels of hyperactivity-impulsivity that may contribute to the presenting problems. The implications of this model suggest that all 18 symptoms should be rated together to derive a single overall score, with consideration to both inattention and hyperactivity/impulsivity as additional dimensional factors. These scores should all be taken into account in the assessment and treatment of ADHD. This model is therefore different from that implied by the current DSM-IV, as the diagnosis of inattentive and hyperactive/impulsive subtypes tend to disregard the contribution of the other symptom domain. Hierarchical factor models therefore may lend themselves to more dimensional approaches for modeling symptom domains, as opposed to categorical boundaries. Similar implications follow for other diagnostic classifications, such as the ICD-10 (WHO, 2007).

Limitations of the current study were the oversampling of children and adolescents with primarily combined type symptoms in the ADHD sample and the cross-sectional design. However, the hierarchical factor model has been shown to have a good fit in samples with a more substantial representation of youth with primarily inattentive symptoms (Toplak et al., 2009). Nonetheless, it is important to examine this model further in youth with purely inattentive symptoms. Criterion validation studies are also needed to determine whether the separate latent constructs are differentially associated with other variables, such as other forms of psychopathology (in particular, oppositional defiant disorder, Lahey et al., 2008) and executive functions or cognitive processes.

Conclusion

The current study demonstrated that the hierarchical factor model had a better fit compared to a single factor or correlated factor models of ADHD symptoms in a large-scale sample of children and adolescents with ADHD and separately among their siblings. The unique aspects of this sample were the inclusion of multiple countries that represent a diverse set of cultures. The hierarchical factor model, which formally acknowledges the common covariance among the inattention and hyperactive-impulsive symptoms, had the best fit across all age groups and across all locations. These findings were replicated across three different instruments (including a clinical interview and questionnaires) and across parent and teacher informants. The invariance analyses showed strong measurement invariance across age, but not across locations. This model highlights the importance of the common variance of individual symptoms from these separate domains across instruments, informants, and different ages throughout childhood in a large and diverse sample of children with ADHD and their unselected siblings.

Key points:

1. The current study replicated a hierarchical model with a general ADHD factor and two specific factors of inattention and hyperactivity in a large sample of children and adolescents with ADHD, and separately in their unselected siblings.

2. This replication extends previous work as consideration was given to different periods of child and adolescent development and different ethic/cultural groups. Strong measurement invariance was obtained holding by age.

3. A major implication of the general factor is that in addition to deriving a total score across all inattention and hyperactivity/impulsivity symptoms, these symptom domains should also be examined dimensionally and taken into account in the assessment and treatment planning of ADHD. This measurement should be taken even when these levels do not meet the current clinical threshold of six symptoms in each domain, as indicated in the current DSM-IV.

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Supplemental Tables

A1. *Results of Factorial Invariance Testing by Age for Hierarchical 2-Factor Model in ADHD Sample*

Factorial invariance model:	Configural		Weak invariance				Strong invariance			
	CFI	RMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA
PACS Interview										
Age 9 and under vs. age 10-12	.924	.048	--	--	--	--	.938	-.014	.046	.002
Age 10-12 vs. age 13 and older	.916	.053	--	--	--	--	.940	-.024	.049	.005
Parent report										
Age 9 and under vs. age 10-12	.913	.063	.947	-.034	.060	.003	.947	.000	.061	-.001
Age 10-12 vs. age 13 and older	.914	.071	.948	-.034	.053	.018	.957	-.009	.050	.003
Teacher report										
Age 9 and under vs. age 10-12	.927	.072	.967	-.050	.058	.014	.974	-.007	.053	.005
Age 10-12 vs. age 13 and older	.935	.073	.971	-.036	.062	.011	.975	-.004	.057	.005

A2. *Results of Factorial Invariance Testing for Hierarchical 2-Factor Model by Location for PACS Interview in ADHD Sample*

Factorial invariance model:	Configural		Strong invariance			
	CFI	RMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA
Ireland & UK vs. Holland & Belgium	.906	.048	.887	.019	.050	-.002
Ireland & UK vs. Germany & Switzerland	.941	.051	**.902**	**.039**	**.069**	**-.018**
Ireland & UK vs. Israel	.929	.048	**.913**	**.016**	**.058**	**-.010**
Holland & Belgium vs. Germany & Switzerland	.865	.070	.876	-.011	.054	.016
Holland & Belgium vs. Israel[a]	.814	.072	.832	-.018	.072	.000
Germany & Switzerland vs. Israel	.932	.050	**.910**	**.022**	**.064**	**-.014**

Note. Results in bold correspond to comparisons for which strong invariance does *not* hold. [a]To obtain a properly converged solution for the configural invariance model for this comparison, it was necessary to constrain the inattention specific factor loadings equal across group.

A3. *Results of Factorial Invariance Testing for Hierarchical 2-Factor Model by Location for Conners Parent Scale in ADHD Sample*

Factorial invariance model:	Configural		Weak invariance				Strong invariance			
	CFI	RMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA
Ireland & UK vs. Holland & Belgium	.912	.068	.927	-.015	.069	-.001	**.905**	**.022**	**.079**	**-.010**
Ireland & UK vs. Germany & Switzerland	.929	.071	.955	-.026	.062	.009	.947	.008	.067	-.005
Ireland & UK vs. Israel	.921	.069	.938	-.017	.067	.002	**.923**	**.015**	**.075**	**-.008**
Holland & Belgium vs. Germany & Switzerland	.916	.072	.937	-.021	.067	.005	.940	-.003	.067	.000
Holland & Belgium vs. Israel[a]	.910	.069	.923	-.013	.069	.000	.917	.006	.073	-.004
Germany & Switzerland vs. Israel[b]	.924	.075	.919	.005	.081	-.006	.923	-.004	.079	.002

Note. [a] To obtain convergence for the strong invariance model for this comparison, it was necessary to allow the thresholds for symptom 14 to freely vary across groups (except the first threshold, which must be constrained for identification). [b]To obtain convergence for the strong invariance model for this comparison, it was necessary to allow the thresholds for symptom 16 to freely vary across groups (except the first threshold, which must be constrained for identification).

A4. *Results of Factorial Invariance Testing for Hierarchical 2-Factor Model by Location for Conners Teacher Scale in ADHD Sample*

Factorial invariance model:	Configural		Weak invariance				Strong invariance			
	CFI	RMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA	CFI	ΔCFI	RMSEA	ΔRMSEA
Ireland & UK vs. Holland & Belgium	.948	.073	.971	-.023	.067	.006	**.948**	**.023**	**.090**	**-.023**
Ireland & UK vs. Germany & Switzerland	.955	.079	.975	-.020	.075	.004	.971	.004	.078	-.003
Ireland & UK vs. Israel	.953	.083	.963	-.010	.085	-.002	.957	.006	.089	-.004
Holland & Belgium vs. Germany & Switzerland	.934	.075	.963	-.029	.068	.007	.962	.001	.068	.000
Holland & Belgium vs. Israel	.929	.079	.953	-.024	.073	.006	**.941**	**.012**	**.080**	**.007**
Germany & Switzerland vs. Israel	.928	.091	.951	-.023	.085	.006	.949	.002	.085	.000