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Rethinking Shared Environment as a Source of Variance Underlying Attention-Deficit/Hyperactivity Disorder Symptoms: Comment on Burt (2009)

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Abstract

Burt (2009) recently published a meta-analysis of twin studies on behaviors associated with childhood psychopathologies, concluding that the finding that traits associated with attention-deficit/hyperactivity disorder (ADHD) were the only behaviors that did not show a significant influence of shared environment (C) was surprising. We agree, highlighting four methodological issues that may account for this finding: (a) the use of nonlinear transformations to normalize skewed data; (b) low power to detect C and the subsequent presentation of reduced models; (c) the negative confounding of dominant genetic (D) and C influences in twin models with data exclusively from monozygotic and dizygotic twin pairs reared together; and (d) the correction used for contrast effects (a form of rater bias), which may lead to an overestimate of additive genetic (A) or D parameters at the expense of C. We offer suggestions for future research to address these issues, and we emphasize the need for additional research to examine possible shared environmental factors related to ADHD.

Keywords

ADHD; twin studies; heritability; objective data; meta-analysis

Highlighting the importance of accurately assessing etiological variance components underlying problem behaviors of childhood and adolescence, Burt (2009) conducted a meta-analysis into the additive genetic (A), dominant genetic (D), shared environmental (C), and child-specific environmental (E) influences underlying internalizing and externalizing behaviors associated with core childhood psychopathologies. The meta-analysis reported that, regardless of operationalization, a significant proportion of the variance (10%–30%) in conduct, oppositional defiant, internalizing and externalizing disorders, and anxiety/depression could be attributed to C (Burt, 2009), with the rest apportioned to influences of A and E. The only exception occurred with behaviors associated with attention-deficit/hyperactivity disorder (ADHD), for which only A, D, and E factors influenced the variation; the contribution of C was negligible. Burt (2009) concluded that there was “no convincing

explanation for this” (p. 625) and highlighted the potential role of methodological issues in influencing the conclusion.

We agree, and this article describes four methodological issues that may account for the finding of a lack of significant influence of C with respect to ADHD. As this null effect of C conflicts with research that argues for the causal role for C factors in at least some cases of ADHD (for example, prenatal risk factors such as maternal alcohol use and smoking; see Banerjee, Middleton, & Faraone, 2007, for a review), a resolution to this disparity is important for engendering a common, interdisciplinary approach to understanding the origins of ADHD. Data from twin studies over the past 10 years, a period during which increased sample sizes could address power issues, suggest that accounting for these methodological or statistical issues may result in the detection of significant influences of C. Indeed, the use of objective measures of ADHD symptoms, such as those from motion sensor data, offer promise in this respect (e.g., Wood, Rijdsdijk, Saudino, Asherson, & Kuntsi, 2008).

Given the methodological considerations raised by meta-analytic examination of structural equation models on twin data (outlined below), we conducted our own summary of twin studies including behavioral rating scale data on ADHD symptoms in school-age children (4–18 years) over the past 10 years that reported A, E, and C (or D) estimates and took average estimates for the parameters, unweighted for sample size. This exercise is intended to highlight alternative interpretations of the data, when not subject to the limitations of the classical twin method. The selection of relevant studies (summarized in Table 1) was the result of a PubMed search conducted with the terms “*heritability or twin study or genetics and ADHD or hyperactivity or impulsivity or inattention.*” Given power issues related to discriminating A, D, and C (Martin, Eaves, Kearsy, & Davies, 1978; Neale, Eaves, & Kendler, 1994; Posthuma & Boomsma, 2000; Rietveld, Posthuma, Dolan, & Boomsma, 2003), we included only studies with sample sizes of at least 300 twin pairs, and data were excluded if published twice (e.g., the same rating scale data on both a subsample and the full sample). Our final sample thus included 22 studies, which reported, in total, parameter estimates for 100 “subpopulations” (with such subpopulations indicating cases in which parameter estimates were reported separately for different groups, for example, separately for males and females or separately for different rating scales).

The average A estimate, from all analyses in all studies, was 59.5%. Thus, just about 60% of the variance was attributed to additive genetic effects. Slightly over one fifth (22%) of subpopulations reported D as a significant source of variance (as indicated by being included in the best fitting model or having a D parameter estimate where the lower bound of the 95% confidence interval did not overlap with 0). The average D estimate across results was 24.8%. Taking these parameters separately as an indication of overall heritability may be misleading, as some investigations reported only A, whereas others reported A and D combined, as contributing to the total heritability. It was therefore not possible to sum these two averages to ascertain the average estimate of total genetic variance. To estimate total “broad sense” heritability estimates underlying ADHD symptoms (i.e., A + D influences), we combined results that reported either A or D or A + D parameter estimates and averaged the total genetic variance underlying symptoms of ADHD across studies. The average broad-sense heritability was 61.8%.

C emerged as a significant source of variance underlying the behavioral symptoms of ADHD in 16% of subpopulations, with the average estimate for C equaling 27%. A further set of eight subpopulations reported a nonsignificant C component that was above 0, averaging 14.5%. Thus, across all of the investigations included in our analysis, the average amount of variance in ADHD symptoms attributable to C, across all subpopulations, stood at

22.4%. This result is at variance with Burt's conclusion that C does not significantly contribute to ADHD-related behaviors. We believe that this discrepancy is related to relevant methodological issues, which we discuss below.

Structural equation models specify the expected variances of—and covariances between—measured traits for a given model. How well a model fits is ascertained by the extent of discrepancy between the predicted model and the observed variance/covariance structure. One approach to model fitting is to adopt a principle of parsimony, whereby parameters are removed from models and the fit of reduced models is compared with that of full models, according to the chi-square distribution, with the difference in the number of parameters between the full and reduced models equaling the degrees of freedom of the test. (Neale, Boker, Xie, & Maes, 2006). When no significant reduction in fit occurs by dropping parameters, and reduced models are presented, the rest of the model estimates will change accordingly. Similarly, competing models that have the same number of parameters can be compared with indices such as Akaike's information criterion (AIC), where a model with a lower AIC better represents the data than does one with a higher AIC (Wagenmakers & Farrell, 2004). This latter method can be useful in choosing between, for example, (a) a model with A, C, and E influences underlying the trait and (b) a model with underlying A, D, and E influences.

In terms of the overall best fitting model, the most common model reported was a model with only A and E parameters. This pattern of findings indicated that a reduced model did not result in a significant drop in fit compared with the full model with three parameters. One interpretation, given such considerations as the sample size of the study and the ratio of monozygotic (MZ) to dizygotic (DZ) twin pairs, is that a parameter for C or D would not be necessary to explain the variance/covariance structure of the data at a statistically significant level (although one cannot automatically conclude in such a case that C or D is not operating to influence ADHD symptoms).

The same model, but with the inclusion of a sibling interaction parameter or parameters, was the second best fitting model. The next most common model included a C parameter (the ACE model), indicating that for these results, a model without C influences did not adequately explain the observed data. Models with dominance parameters (ADE or ADEs) were the least common models.

In evaluating results that report no role for C underlying ADHD traits, we highlight four key issues. First, the power to detect C may be low. When MZ correlations remain equivalent and DZ correlations rise, there is more power to reject the CE model than the AE model (Martin et al., 1978; Neale et al., 1994). That is, we have low power to detect C as significant, in comparison with A, which can lead to the conclusion that a model without C as a source of etiological influence is the most parsimonious description of the data. When parameters are presented from this reduced model, the other source of familial influences (A) is artificially inflated, soaking up the effects of C. Therefore, even if relatively small, C may play an important role yet be undetected in underpowered samples. In our analyses, in cases where the influence of C was nonsignificant, it still accounted for 2% to 40% of the variance in ADHD symptoms. Assuming that there are twice as many DZ twins as MZ twins in the sample, in order to have 80% power to detect a C parameter of 14% (the average estimate of nonsignificant C parameters) with a 60% heritability estimate, a sample size of 1,850 individuals is needed if the A estimate increases—and a sample of fully 1,678 individuals is needed if the E estimate increases (Rietveld, Posthuma, et al., 2003). The average sample size of those studies with a nonsignificant C parameter above 0 was 2,394 individuals. However, if we drop the estimated C to 10% (a smaller effect), a sample size of 2,589 individuals is required. Therefore, investigations that present parameter estimates

exclusively from a reduced (best fitting) model require careful interpretation, as they may disregard an important etiological role for C.

Second, D and C are confounded in the classical twin design, which may lead the role of C to be undetected. The general term D here refers to interactions between alleles on the same (dominance) or different (epistasis) genetic loci (Rijsdijk & Sham, 2002). As MZ twins are genetically identical, they correlate 1.00 for D within members of a twin pair. Because DZ twins correlate, on average, only .25 for these effects, D is therefore indicated by DZ twin correlations that are less than half the size of the MZ correlations. However, because C is correlated 1.00 between members of a twin pair in both MZ and DZ pairs, it is indicated by DZ correlations that are higher than half of the MZ correlations. With data exclusively from twins reared together, D and C cannot be estimated in the same model, as both scenarios cannot be observed at the same time (Neale et al., 1994). This situation, however, does not mean that the effects of D and C cannot coexist. Therefore, any twin study that detects D will automatically exclude C as a potential source of variance for computational (as opposed to theoretical or empirical) reasons.

Third, the role of contrast effects (s)—which mimic D and cannot be estimated at the same time as C because s and C have opposite effects on the MZ–DZ ratio of twin covariances—must be considered. Contrast effects arise as a form of rater bias when raters use the behavior of one twin as a benchmark against which to assess the behavior of another (Rietveld, Posthuma, et al., 2003). Models that include a sibling interaction parameter or parameters, in the case of ADHD-related behaviors, include an additional parameter to account for the effect that one twin's behavior (or the perception of such) has on that of the other. Where twins are erroneously judged to be less similar, this parameter is negative, in order to decrease twin covariance within members of a twin pair (Rietveld, Posthuma, et al., 2003). When this parameter is included in the variance of a trait, the negative sign of the path results in deflation of both MZ and DZ variances (Rietveld, Posthuma, et al., 2003). The differential amount of genetic sharing between MZ and DZ twins (100% in the case of MZ and 50%, on average, in the case of DZ), results in multiplication by 1 of the negative parameter in accounting for the variance of the trait in MZ twins but by .5 (its contribution to the variance of the trait in conjunction with A) and/or .25 (its contribution to the variance of the trait in conjunction with D) for DZ twins. This results in a higher negative value for MZ twins than for DZ twins, which lowers the variance more in the former case. Therefore, the variances of both types of twins are deflated, but the greatest effect is on MZ variances (Rietveld, Posthuma, et al., 2003). Covariances are also affected: As raters decrease the covariance between members of a twin pair, reporting behavior that is less similar or less correlated than the actual behavior of the contrast twin, DZ correlations sometimes become inappropriately low (Saudino, Cherny, & Plomin, 2000). Indeed, they are sometimes zero or even negative (Saudino et al., 2000). Thus, contrast effects mimic D in the pattern of twin correlations. In addition, however, they also significantly lower variance in MZ as compared with DZ twin pairs. If there is no power to detect sibling interaction (i.e., insufficient power to detect a significant difference in MZ and DZ variances), D will be indicated, and, as outlined above, C will not be estimated. This effect is often seen in parent ADHD ratings, and the common reliance on parents to report on (younger) children may be a contributing factor to the failure to detect C for this trait. This pattern is supported by the studies in Table 1 where teacher-only data are used, which we assume were not affected by contrast effects. Indeed, for teacher data, no study reported any influence of D.

Finally, the distributional property of the questionnaire used must be considered. The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997), the Child and Adolescent Psychiatric Assessment (CAPA; Angold & Fisher, 1999; Angold et al., 1995), the Child Behaviour Checklist (CBCL; Achenbach, 1991a), and the Conners' Parent Rating Scales

(CPRS; Conners, Sitarenios, Parker, & Epstein, 1998b) all ask the rater to judge the presence of symptoms and their severity. The Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale (SWAN; Swanson et al., 2005), in contrast, was designed to rate the presence of both symptoms and positive behaviors. The SWAN yields a more normal distribution in the general population, which does not require a linear transformation (Swanson et al., 2005). The use of transformations on skewed data may give rise to biased parameter estimates, including a reduction in C in one simulation study (Derks, Dolan, & Boomsma, 2004). For the SWAN, 50% of results report an ACE model to be that of best fit, in contrast to 0% of results from data obtained with the CAPA, the CBCL, or the SDQ. Furthermore, given issues surrounding the correction for contrast effects, the studies conducted with the SWAN did not report significant contrast effects, whereas for the other scales, the percentages of results reporting contrast effects were as follows: 100% for the CAPA and the SDQ, 25% for the CBCL, and 30% for the CPRS.

We also highlight the observation that research conducted with mechanical measures, such as actigraphs, provides an opportunity to gain measures free from rater bias. *Actigraphs* are motion sensor devices that measure activity level in an objective and quantifiable way. Although actigraphs measure only one aspect of ADHD symptoms (activity level), actigraph data show good discrimination between ADHD and comparison groups (Wood, Asherson, Rijdsdijk, & Kuntsi, 2009), indicating an activity level that is 25%–30% higher in children with ADHD as compared with control youths (Porrino et al., 1983). Motion sensor data often show a significant influence of environment. Indeed, two studies suggested that 11%–56% of the variance is accounted for by C influences (Saudino & Zapfe, 2008; Wood, Saudino, Rogers, Asherson, & Kuntsi, 2007), although the results did not always reach statistical significance. Notably, for mechanical measures of activity level, D is not indicated from twin correlations or model fit statistics (Saudino & Zapfe, 2008; Wood et al., 2007), which may indicate that D in the analysis of behavioral rating scale data is derived from a lack of power to detect contrast effects. Thus, we conclude that D in ADHD research should be interpreted with caution, given the issues outlined above and the conflicting results across different sources of information on ADHD behaviors.

In conclusion, a substantial portion of the variance in ADHD symptoms in the general population, and in the risk for a clinical diagnosis of ADHD, is undoubtedly due to genetic risk factors. However, despite the results of Burt's (2009) recent meta-analysis, the evidence is not conclusive regarding the absence of shared environmental factors for ADHD, particularly with respect to investigations that do have the power to detect contrast effects and thus conflate them with D. Although overall environmental variance in the etiology of ADHD is likely to be small, effects of individual environmental influences could be larger than the effects of individual genes, as well as more immediately useful for intervention treatments, highlighting the utility of future environmental research.

Thus, although twin literature has largely implicated the effect of nonshared environment for ADHD-related symptomatology, methodological considerations may call for a careful reinterpretation, given the evidence reviewed here. We recommend that future research (a) refine current twin models to more accurately account for rater biases, (b) investigate alternative forms of measurement of ADHD symptoms (including objective indicators), and (c) avoid dismissing the potential role of shared environment in accounting for individual differences.

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Table 1
Summary of Twin Studies on Symptoms of Attention-Deficit Hyperactivity Disorder Included in Analysis

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to			
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)
Nadder, Rutter, Silberg, Maes, & Eaves (2002)	Hyperactivity	CAPA interview	Mother	1,408	12–14	Male	AEs	71			29
	Inattention					Female	AEs	76			24
						Male	AEs	64			36
	Impulsivity					Female	AEs	66			34
						Male	AEs	81			19
	ADHD	Rutter B Scale and Conners' Scale	Teacher			Female	AEs	57			43
						Male	AE	56			44
	Hyperactivity	CAPA interview	Mother	1,019	14–15	Female	AE	57			43
						Male	AEs	56			44
	Inattention					Female	AEs	54			46
Larsson, Larsson, & Lichtenstein (2004)	Impulsivity					Male	AEs	54			46
						Female	AEs	47			53
	ADHD	Rutter B Scale and Conners' Scale	Teacher			Male	AEs	42			58
						Female	AEs	18			82
	ADHD symptoms	Binary scaled checklist based on DSM-IV criteria	Parent	1,106	8–9	Male	AE	48		40	52
						Female	AE	40			60
	Hyperactivity-impulsivity	MPNI Hyperactivity-Impulsivity scale	Teacher	1,636	11–12	Female	AE	68		12	19
						Male	AE	61 (34–70)		3 (0–26)	36 (30–44)
						Male	AE	74 (50–80)		2 (0–24)	24 (20–30)
						Male	ACE	49 (40–59)		3 (0–9) + 36 (27–44) ^b	12

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to			
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)
Kaprio, & Rose (2004)											
						Female	ACE	55 (45–66)		32 (20–42)	14 (12–16)
			Parent			Male	AE	78 (74–81)			22 (19–22)
						Female	AEs	81 (77–85)			19 (15–23)
Rietveld, Hudziak, Bartels, van Beijsterveldt, & Boomsma (2004)	Overactivity	CBCL	Mother	11,938 ^c	3	Male	ADEs	50	22		28
						Female	ADEs	41	33		26
	Attention problems	CBCL		10,657 ^c	7	Male	ADE	33	39		28
						Female	ADE	57	16		27
				6,192 ^c	10	Male	ADE	41	31		28
						Female	ADE	48	25		27
				3,124 ^c	12	Male	ADE	40	30		30
						Female	ADE	54	18		28
Kuntsi et al. (2004)	ADHD symptoms	Interview containing questions representing the DSM-IV ADHD symptom checklist and RCS	Sum of parent and teacher	1,116	5		AEs	72 (65–77)			28 (23–35)
Burt, Krueger, McGue, & Iacono (2001)	ADHD	DICA-R	Mother and self combination	753	10–12		ACE	57 (44–70)		11 (2–23)	32 (29–37)
Hay, Bennett, Levy, Sergeant, & Swanson (2007)	Inattention	SWAN	Parent	528	6–9		ACE	53	28		19

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to			
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)
Button, Thapar, & McGuffin (2005)	Hyperactivity-impulsivity						ACE	46		53	01
	Inattention	ATBRS					AE	90		0	10
	Hyperactivity-impulsivity					ACE	47			48	05
	Inattention	SWAN		488	12-20		AE	66		23	11
	Hyperactivity-impulsivity					ACE		31		66	3
	Inattention	ATBRS				AE		73		16	11
Dick, Viken, Kaprio, Pulkkinen, & Rose (2005)	Hyperactivity-impulsivity					ACE		76		18	06
	ADHD	DuPaul ADHD Rating Scale	Parent	1,896	5-18		ADEs	37 (17-57)	37 (17-58)		24 (21-26)
	ADHD	C-SSAGA-A	Self report	1,854 ^c	14		AE	52 (61-79)		18 (0-43)	31 (18-43)
Kuntsi, Rijdsdijk, Ronald, Asherson, & Plomin (2005)	ADHD symptoms	RRPSPC Hyperactivity subscale	Parent	3,451	2 3		AEs AEs	77 79			23 21
		SDQ Hyperactivity-Inattention subscale			4 7		AEs AEs	76 79			24 21
		CPRS-R DSM-IV ADHD Symptoms subscale			8	Male Female	ACE ACE	72 (66-78) 72 (66-78)		14 (7-19) 14 (7-19)	14 (13-16) 14 (13-16)
Polderman et al. (2007)	Attention problems	CBCL Attention Problems subscale	Mother	469	12		ADE	21	52		27
	Attention deficit	SWAN Attention Deficit subscale		560	12		AE	82			18
	Hyperactivity-impulsivity	SWAN Hyperactivity-Impulsivity subscale					AE	90			10

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to			
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)
Habersick et al. (2008)	DSM-IV ADHD symptoms: ADHD inattention	Childhood ADHD Symptoms Scale	Self retrospective report	3,896 ^c	22		AE	31 (23–40)			69 (61–77)
	DSM-IV ADHD symptoms: ADHD hyperactivity–impulsivity						AE	36 (27–43)			64 (57–73)
	DSM-IV ADHD symptoms: ADHD combined type						AE	37 (28–44)			63 (56–72)
Derks et al. (2008)	Attention problems	CBCL Attention Problems subscale	Mothers	10,018 ^c	7		ADE	41	36		23
					10		ADE	53	25		22
					12		ADE	68	07		25
	ADHD inattention	CPRS-R:S ADHD–Inattention subscale		4,887 ^c	12		ADE	79	05		16
McLoughlin, Ronald, Kuntsi, Asherson, & Plomin (2007)	ADHD	DISC		1,006 ^c	12		ADE	56	04		40
	Hyperactivity–impulsivity	CRPR-R DSM-IV Hyperactive–Impulsivity subscale	Parents	6,222	8		ACE ^d	79 (71–81)			21 (19–22)
	Inattentiveness	CPRS-R DSM-IV Inattentive subscale					ACE ^d	88 (87–89)			12 (11–12)
	Hyperactivity	SDQ Hyperactivity–Inattentive subscale	Parents	3,714	7	Male	AEs	77 (65–81)		00 (0–15)	23 (19–28)
Saudino, Ronald, & Plomin (2005)						Female	AEs	75 (60–79)		00 (0–19)	25 (20–30)
			Teachers (same)			Male	AE	74 (56–79)		02 (0–19)	24 (21–28)
						Female	AE	76 (70–80)		00 (0–15)	24 (20–28)

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to			
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)
Derks, Dolan, Hudziak, Neale, & Boomsma (2007)	Hyperactivity	CTRS-R-S Hyperactivity subscale	Teacher (different)	1,651 ^c	7	Male	AE	66 (49–72)		00 (0–15)	34 (28–42)
							AE	55 (33–62)		00 (0–18)	45 (38–54)
							AE	58			42
Derks, Hudziak, Van Beijsterveldt, Dolan, & Boomsma (2006)	Attention problems	CTRS-R-S ADHD Index	Teacher	2,259	7	Male	AE	61			39
							AE	55			45
							ADE	44	33		23
Ronald, Simonoff, Kuntsi, Asherson, & Plomin (2008)	ADHD behaviors	CBCL Attention Problems scale	Mother	2,057	8	Male	AEs	89 (87–90)			11 (10–13)
							AEs	80 (78–83)			20 (17–22)
							AE	67 (62–71)			33 (29–38)
Tuvblad, Zheng, Rane, & Baker (2009)	ADHD symptoms	SDQ Hyperactivity subscale	Teacher	2,720	9	Male	AE	59 (54–64)			41 (36–46)
							AE	61 (46–68)		0 (0–13)	39 (32–46)
							AE				
N. C. Martin, Piek, & Hay (2006)	ADHD symptoms	DISC-IV	Caregivers	605	9–10	Female	AE	88			11
							AE				
							AE				
N. C. Martin, Piek, & Hay (2006)	ADHD symptoms	ATBRS ADHD Impulsivity	Parents	1,288	5–16	Female	AE	85			14
							AE				
							ACE	76	13		11

Authors	Phenotype ^a	Measure	Informant	N	Age (years)	Group	Model	% of variance attributed to					
								Additive genetic (A)	Dominant genetic (D)	Shared environmental (C)	Child-specific environmental (E)		
Ehringer, Rhee, Young, Corley, & Hewitt (2006)	ADHD	SWAN ADHD Impulsivity	Self-report	1,162 + 426 siblings	12–19		AE	92			18		
		SWAN ADHD Hyperactivity–Impulsivity					AE	98			2		
		SWAN ADHD Combined Type					ACE	74		21	05		
		DISC-IV, Past Year					ACTE ^e	19 (0–37)		11 (0–29) ^e	70 (61–80)		
Rietveld, Hudziak, Bartels, van Beijsterveldt, & Boomsma (2003)	Overactive behavior	DISC-IV, Lifetime	Parents	3,671	3	MZ DZ	ACTE ^e	22 (0–39)		10 (0–27) ^e	68 (59–78)		
		CBCL Overactive Behavior subscale					ADEs	57	12		31		
							ADEs	59	13		28		
	Attention problems	CBCL Attention Problems subscale		3,373	7	MZ DZ Singletons	Singletons	61	13		26		
							MZ	44	27		29		
							DZ	44	28		28		
							Singletons	44	28		28		
							2,485	10	Male MZ	44	27		28
									Male DZ	44	27		28
									Male singletons	45	28		27
									Female MZ	62	11		27
							1,305	12	Female DZ	62	11		27
									Female singletons	62	11		27
									Male	36	33		31
									Female	68	5		28

Note. The best fitting model is presented in *italics* in the rightmost columns under “% of variance attributed to,” but where available, parameter estimates from full (nonreduced) models are presented in boldface. An “s” following the model indicates sibling interaction. CAPA = Child and Adolescent Psychiatric Assessment (Angold & Fisher, 1999; Angold, et al., 1995); MPNI = Peer Nomination

Inventory (Pulkkinen, Kaprio, & Rose, 1999); CBCL = Child Behavior Checklist (Achenbach, 1991a, 1992); RCS = Rutter Child Scales (Sclare, 1997); DICA-R = Diagnostic Interview for Children and Adolescents—Revised (Reich & Welner, 1988); SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal-Behavior Scale (Swanson, et al., 2005); ATBRS = Australian Twin Behaviour Rating Scale (Levy, Hay, McLaughlin, Wood, & Waldman, 1996); C-SSAGA-A = Child Semi-Structured Assessment for the Genetics of Alcoholism—Adolescent Version (Dick, Viken, Kaprio, Pulkkinen, & Rose, 2005); RRPSPC = Revised Rutter Parent Scale for Preschool Children (Hogg, Rutter, & Richman, 1997); SDQ = Strengths and Difficulties Questionnaire (Goodman, 1997); CPRS-R = Conners Parent Ratings Scale—Revised (Conners, Sitarenios, Parker, & Epstein, 1998a); DISC-IV = Diagnostic Interview Schedule for Children Version IV (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000); TRF = Teacher Report Form (Achenbach, 1991b). The Rutter B Scale is from Hogg et al. (1997) and Rutter (1967); the DuPaul ADHD Rating Scale is from DuPaul (1981); and the Childhood ADHD Symptoms Scale is from Barkley & Murphy (1998). MZ = monozygotic twins; DZ = dizygotic twins.

^aPhenotypes are listed as described by authors of the relevant studies.

^bC estimate decomposed into sex-specific influences and influences shared across the sexes.

^cNumber of individuals used, not twin pairs.

^dACE best-fitting model in the multivariate modeling, but parameter estimates only presented from reduced, best-fitting univariate model.

^eT in ACTE represents a parameter T, which is shared environmental influences influencing the etiology of ADHD symptoms in twins only (not siblings). C was estimated at 0 (0 – 14/15).