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Phenotypic and genetic associations between reading comprehension, decoding skills, and ADHD dimensions: evidence from two population-based studies

Vickie Plourde,[1,2] Michel Boivin,[1,2,3] Nadine Forget-Dubois,[1,2] Mara Brendgen,[1,4,5] Frank Vitaro,[1,5,6] Cecilia Marino,[2,7,8] Richard T. Tremblay,[1,3,5,9] and Ginette Dionne[1,2]

[1]Research Unit on Children's Psychosocial Maladjustment, Quebec City; [2]Université Laval, Quebec City, Canada; [3]Institute of Genetic, Neurobiological, and Social Foundations of Child Development, Tomsk State University, Tomsk, Russia; [4]Université du Québec à Montréal, Montreal; [5]Sainte-Justine Hospital Research Center, Montreal; [6]Université de Montréal, Montreal; [7]Centre de Recherche de l'Institut Universitaire en Santé Mentale de Québec, Quebec City, Canada; [8]Scientific Institute Eugenio Medea, Bosisio Parini, Lecco, Italy; [9]School of Public Health and Population Sciences, University College Dublin, Dublin, Ireland

Background: The phenotypic and genetic associations between decoding skills and ADHD dimensions have been documented but less is known about the association with reading comprehension. The aim of the study is to document the phenotypic and genetic associations between reading comprehension and ADHD dimensions of inattention and hyperactivity/impulsivity in early schooling and compare them to those with decoding skills. **Methods:** Data were collected in two population-based samples of twins (Quebec Newborn Twin Study – QNTS) and singletons (Quebec Longitudinal Study of Child Development – QLSCD) totaling ≈ 2300 children. Reading was assessed with normed measures in second or third grade. Teachers assessed ADHD dimensions in kindergarten and first grade. **Results:** Both decoding and reading comprehension were correlated with ADHD dimensions in a similar way: associations with inattention remained after controlling for the other ADHD dimension, behavior disorder symptoms and nonverbal abilities, whereas associations with hyperactivity/impulsivity did not. Genetic modeling showed that decoding and comprehension largely shared the same genetic etiology at this age and that their associations with inattention were mostly explained by shared genetic influences. **Conclusion:** Both reading comprehension and decoding are uniquely associated with inattention through a shared genetic etiology.
Keywords: Reading, decoding, comprehension, inattention, hyperactivity/impulsivity, population-based studies.

Introduction

Dyslexia and attention-deficit/hyperactivity disorder (ADHD) are heritable and complex childhood disorders. Dyslexia is characterized by difficulties with accurate and/or fluent word reading that can be accompanied by poor spelling (American Psychiatric Association – APA, 2013) and impairment of reading comprehension (Snowling, 2013). Population prevalence ranges from 3% to 17.5% with generally more affected boys than girls (Rutter et al., 2004; Shaywitz & Shaywitz, 2003; Snowling, 2013). ADHD is characterized by clinical levels of inattention and/or hyperactivity/impulsivity symptoms. Population prevalence ranges from 5% to 12% also with more affected boys than girls (APA, 2013; Polanczyk, Silva de Lima, Lessa Horta, Biederman, & Rohde, 2007).

Both dyslexia and ADHD have been broadly studied and studies about their cooccurrence started in the 1990s, with statistics showing that approximately 15%–40% of children with one disorder fit criteria for the other (Gayán et al., 2005; Mayes, Calhoun, & Crowell, 2000; Willcutt & Pennington, 2000). One way the association between dyslexia and ADHD has been addressed is through a dimensional approach. Disorders are thus deemed to represent the end-tail of a continuum, with the whole range of reading abilities, inattention, and hyperactivity/impulsivity behaviors considered (Levy, Hay, McStephen, Wood, & Waldman, 1997; Polderman et al., 2007; Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992).

At the phenotypic level, such studies have focused on describing the association between direct measures or parent/teacher reports of reading and ADHD dimensions in population-based studies. Results have shown modest but consistent correlations between decoding skills or parent/teacher reports of reading and ADHD dimensions (ranging from −.10 to −.55) in the early school years, with stronger correlations for inattention than hyperactivity/impulsivity (Ebejer et al., 2010; Greven, Harlaar, Dale, & Plomin, 2011; Greven, Rijsdijk, Asherson, & Plomin, 2012; Paloyelis, Rijsdijk, Wood, Asherson, & Kuntsi, 2010; Rodriguez et al., 2007).

Two studies using a dimensional approach have looked at these associations using measures of reading comprehension (Greven et al., 2011; Pham, 2013). Greven et al. (2011) found modest correlations with reading comprehension and both

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inattention ($r = -.22$) and hyperactivity/impulsivity ($r = -.20$) in 12-year olds. Pham (2013) found similar results in 8–11 year olds for the association between reading comprehension and inattention but they found smaller nonsignificant associations between reading comprehension and hyperactivity.

With the exception of these latter studies, an important limitation of previous studies is the general omission of reading comprehension. Given that reading comprehension can be more cognitively demanding than decoding, it may generate a different pattern of associations with ADHD dimensions, especially in younger children still learning to read.

A second limit of previous studies is that they rarely control for the association between inattention and hyperactivity/impulsivity. As both dimensions are strongly correlated, either dimension could be associated with reading because of their shared variance. Similarly, other variables correlated with both reading and ADHD dimensions may explain part of their association. For example, Rabiner and Coie (2000) demonstrated that inattention, but not hyperactivity/impulsivity, predicted reading after controlling for prior reading ability, nonverbal abilities, and behavior problems, underlining the need to consider these variables.

An alternative way to address the association between reading and ADHD dimensions is to look for a shared etiology. Genetically informative designs, typically using a twin sample, give the possibility to unravel the genetic and environmental contributions to observed phenotypic correlations (Boivin et al., 2012).

Genetic studies of reading and ADHD dimensions have shown that they are all highly heritable in the early school years (reading: 67%–84%; inattention: 55%–79%; hyperactivity/impulsivity: 72%–88%) (Byrne et al., 2007, 2009; Larsson, Lichtenstein, & Larsson, 2006; McLoughlin, Ronald, Kuntsi, Asherson, & Plomin, 2007; Paloyelis et al., 2010). Byrne et al. (2007, 2009) have also shown that decoding skills and reading comprehension are similarly heritable in grades 1–2. Some studies have looked at the genetic and environmental etiology of the associations between reading and ADHD dimensions but only one of these used a reading comprehension measure and targeted the later primary school years with 12-year olds (Greven et al., 2011).

Genetic studies using teacher or parent reports of reading and ADHD (Greven et al., 2012; Paloyelis et al., 2010) found that associations were mostly due to shared genetic factors, more so between reading and inattention ($Rg = .42–.60$) than between reading and hyperactivity/impulsivity ($Rg = .05–.24$). Similar results were found when using direct measures of reading, mainly decoding (Ebejer et al., 2010; Greven et al., 2011). The only genetic study to include reading comprehension, focused on 12-year olds (Greven et al., 2011). It showed that the genetic correlations with inattention were similar across reading comprehension and decoding ($Rg = -.28$ and $Rg = -.26$, respectively) whereas the genetic correlations with hyperactivity/impulsivity were higher for comprehension than decoding ($Rg = -.18$; and $-.08$, respectively). These results have yet to be replicated in younger children. Moreover, as reading comprehension is neglected in clinical settings, studying the phenotypic and genetic correlations between reading comprehension and ADHD dimensions in younger readers may help clarify how much emphasis, in comparison to decoding skills, should be given to reading comprehension during assessments and interventions at this age.

The main objective is to assess the phenotypic associations and the genetic and environmental etiology between reading comprehension and ADHD dimensions in second and third grade readers, and to compare these associations with the associations between decoding skills and ADHD dimensions. Questions to be addressed are the following:

1. What are the unique contributions of inattention and hyperactivity/impulsivity to reading comprehension and decoding skills?
2. Are the genetic and environmental contributions to the significant associations between reading comprehension and ADHD dimensions similar to those between decoding and ADHD?

The first question was investigated in two population-based samples, a twin sample and a singleton sample, and the second question was addressed in the twin sample only.

Methods

Participants

Participants come from two longitudinal population-based studies: more than 660 families were initially enrolled in the Quebec Newborn Twin Study (QNTS: Boivin et al., 2012) and more than 2000 singletons in the Quebec Longitudinal Study of Child Development (QLSCD: Jetté & Des Groseilliers, 2000). Inclusion criteria at onset were the fluent use of French or English by the mother and no major medical complications at birth. Children were followed annually from birth on a range of individual, social, family, and school characteristics. Parents' consent was obtained before each data collection. Mean attrition between 5 months and 7 years was approximately 5% per year in the QNTS and 4.5% per year in the QLSCD. In the QNTS, zygosity was initially assessed via questionnaire (Goldsmith, 1991) and confirmed with DNA tests on a subsample ($n = 123$) of same-sex pairs showing a 96% correspondence (Forget-Dubois et al., 2003).

Data for this study were gathered when children were between the ages of 5 and 8 years. As the analyses use a Full Information Maximum Likelihood (FIML) approach, the number of children varies across measures. In the QNTS, a random subsample of French-speaking children completed the reading measures in second or in third grade ($n = 285$ in second grade and 240 in third grade) while all children in the QLSCD were in second grade.

Measures and procedure

Reading. In the QNTS, two computerized subtests of the Reading Skills Test (THAL: Pépin & Loranger, 1999) were administered to French-speaking children only. In the QLSCD,

two reading subtests of the Kaufman Assessment Battery for children (K-ABC: Kaufman & Kaufman, 1983) were administered to French- and English-speaking children. All scores were standardized based on the child's age.

Decoding. In the QNTS, the 'Phonetic decoding subtest' of the THAL was administered. A French phoneme was verbally identified in a stimulus-word shown on screen and verbal instructions were given to the child to identify if this phoneme appeared in a comparison-word (yes or no answer). The subtest includes 50 items and each item is rated as pass (1) or fail (0). The task was interrupted after the tenth item if the child failed five items or more. A time component bonus of 0–2 points per item was awarded when the response time was faster than the Z time scores of the normative sample. The test was standardized on a sample of 1418 French-speaking children and has good psychometric properties (internal consistency coefficient is .93). The norm mean for second graders is 37 (SD = 16) and 48 (SD = 12) for third graders.

In the QLSCD, the 'Reading decoding subtest' of the K-ABC was administered in which the child had to read aloud a series of words. The test includes 38 items rated as pass (1) or fail (0) and was interrupted after four consecutive errors. Start and end criteria were based on age. The test has good psychometric properties (internal consistency coefficient is .93). The norm mean is 100 (SD = 15).

Comprehension. In the QNTS, the 'Reading comprehension subtest' of the THAL was administered. The child had to silently read short texts with missing words and to choose the correct missing word from a two- or four-item forced-choice. This task includes two practice items followed by 40 items rated as pass (1) or fail (0) and was interrupted after three failed items or a response time larger than 30 s for two consecutive items. A time component bonus of 0–2 points per item was awarded when the response time was faster than the Z time scores of the norm sample. The test has good psychometric properties (internal consistency coefficient is .98). The norm mean for second graders is 31 (SD = 14) and 43 (SD = 12) for third graders.

In the QLSCD, the 'Reading understanding' subtest of the K-ABC was administered in which the child had to read a sentence, aloud, or silently, and act out the command (maximum of 20 items). The test includes 24 items rated as pass (1) or fail (0) and was interrupted after four consecutive failed items. The test has good psychometric properties (internal consistency coefficient is .95). The norm mean for second graders is 100 (SD = 15).

ADHD dimensions. In both samples, inattention and hyperactivity/impulsivity dimensions were rated with a questionnaire validated for its use with school-age children (Social Behavior Questionnaire – SBQ: Tremblay, Desmarais-Gervais, Gagnon, & Charlebois, 1987). Teachers rated the level of ADHD dimensions within the past 6 months, in kindergarten and first grade, on a three-point Likert scale: (0) never or not true, (1) sometimes or a little true, (2) often or very true with three items for inattention and five items for hyperactivity/impulsivity. Cronbach alphas in the QNTS and the QLSCD were, respectively, .89 and .86 in kindergarten and .90 and .91 in first grade for inattention and .90 and .88 in kindergarten and .89 and .88 in first grade for hyperactivity/impulsivity.

Behavior disorder symptoms. Behavior disorder symptoms were rated using four items of the SBQ. Cronbach alphas were .75 in the QNTS and .73 in the QLSCD. The scale was dichotomized as absence (0) or presence (1) of symptoms because of low occurrence.

Nonverbal abilities. Nonverbal abilities were assessed with the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence – Revised (WPPSI-R: Wechsler, 1989) in the QNTS and the Wechsler Intelligence Scale for Children – Third Edition (WISC-III; Wechsler, 1991) in the QLSCD. Raw scores were converted to standard scores based on test norms, with a mean of 10 and a standard deviation of 3. These subtests are known for their good internal consistency and test-retest reliability.

Statistical analysis

Descriptive statistics were computed with the Statistical Package for the Social Sciences (SPSS) and Wald Chi-Square Tests were performed with Mplus 5.21 (Muthén & Muthén, 2009) to test sex differences. Correlation coefficients were computed with Mplus 5.21. Fisher's r to z transformations were used to compare correlations for girls and boys. Standard multiple regressions, intraclass correlations, and multivariate genetic models were performed with Mplus 5.21. The MLR estimator, robust to the nonindependence of observations, was used in regression and multivariate genetic analysis. The FIML was the default estimator to allow the use of all available data with the inclusion of subjects with missing data. The likelihood-ratio chi-square tests, the Akaike's Information Criterion (AIC), the Bayesian Information Criterion (BIC), the comparative fit index (CFI) and the root mean square estimate of approximation (RMSEA) were used to quantify goodness of fit in the genetic analysis.

The basis of the twin method is to compare similarities between MZ twins, who share 100% of their genes, and DZ twins, who share 50% of their genes. In multivariate genetic analyses, both variances and covariances are decomposed into their additive genetic (A), shared environment (C), and nonshared environment (E) factors. Shared environment increases similarities between twins of the same family whereas nonshared environment decreases them. Univariate analyses can be performed to estimate in which proportion individual differences on a construct are influenced by genetic and environmental factors. Multivariate analyses additionally provide an estimation of the relative influence of genetic and environmental factors to the covariance between two constructs: Rg is the correlation between the genetic factors affecting two traits (Plomin, DeFries, McClearn, & McGuffin, 2008, p. 183).

Results

Descriptive statistics

Means and standard deviations are displayed in Table 1. The means and standard deviations for reading and nonverbal abilities are comparable to population norms in the QNTS and slightly above them in the QLSCD. Significant mean differences between girls and boys are apparent in both samples on inattention, hyperactivity/impulsivity and behavior disorder symptoms ($p < .05$) but not on reading and nonverbal abilities.

Correlations between reading and ADHD dimensions

Table 2 displays the correlations between the measures of interest. Reading abilities are moderately intercorrelated (.56 in the QNTS and .60 in the QLSCD), as are ADHD dimensions (.65 in the QNTS and .67 in the QLSCD). Both reading abilities are modestly and similarly correlated with ADHD

Table 1 Descriptive statistics for girls, boys and the total sample on decoding, reading comprehension, inattention, hyperactivity/impulsivity, nonverbal abilities, and behavior disorder in the QNTS and the QLSCD samples

	QNTS						QLSCD			
Variables	Age	Girls	Boys	Total	MZ	DZ	Age	Girls	Boys	Total
Decoding *M(SD) N*	8.37(.11)	35.38(16.95) 272	32.57(17.95) 244	34.05(17.49) 516	32.43(17.55) 218	35.24(17.35) 298	8.15(.26)	110.65(18.80) 766	108.93(20.98) 694	109.83(19.88) 1460
Comprehension	8.37(.11)	29.06(13.88) 275	28.62(14.80) 249	28.85(14.33) 524	27.49(14.25) 221	29.84(14.30) 303	8.15(.26)	108.85(23.56) 760	108.38(24.66) 690	108.63(24.09) 1450
Inattention K/1	6.57(.27)	.68(.58) 487	.97(.63) 475	.83(.62) 962	.77(.63) 398	.86(.61) 560	6.65(.26)	.58(.56) 760	.87(.62) 691	.72(.61) 1451
Hyperactivity K/1	6.57(.27)	.38(.45) 487	.67(.57) 475	.52(.53) 962	.45(.49) 398	.57(.55) 560	6.65(.26)	.28(.39) 759	.59(.54) 687	.43(.50) 1446
Nonverbal abilities	5.30(.26)	9.81(2.66) 473	10.21(2.96) 456	10.01(2.82) 929	10.21(2.76) 392	9.87(2.86) 531	6.15(.26)	12.69(3.19) 636	12.91(3.54) 564	12.79(3.36) 1200
Behavior disorder	7.09(.27)						7.15(.26)			
0 symptom		% 82.40	59.90	71.20	73.00	69.80		85.60	67.30	76.90
1 symptom or +		17.60	40.10	28.80	27.00	30.20		14.40	32.70	23.10
N		420	419	839	359	480		689	621	1310

K/1: combined kindergarten and first grade measures.

Table 2 Correlations (sig. 2-tailed) between reading abilities and ADHD dimensions. Pearson correlation coefficients are above the diagonal for the QNTS (N = 525–1,007) and are below the diagonal for the QLSCD (N = 691–765; and Total: N = 1,451–1,596)

Variables	1.	2.	3.	4.
1. Decoding		.56**	−.32**	−.18**
2. Comprehension	.60**		−.27**	−.11*
3. Inattention K/1	−.30**	−.31**		.65**
4. Hyperactivity K/1	−.23**	−.18**	.67**	

K/1: combined kindergarten and first grade measures. *p < .05; **p < .01.

dimensions, with the exception of reading comprehension and hyperactivity/impulsivity in the QNTS. Correlations are strongest overall between reading and inattention.

Separate correlations were computed for girls and boys, and compared with a formula developed to compare correlations across independent groups (Cohen, Cohen, West, & Aiken, 2003). In both samples, there were no significant differences between girls' and boys' correlations (results not shown).

What are the unique contributions of inattention and hyperactivity/impulsivity to reading abilities?

First, using age and sex regressed ADHD dimension scores, standard multiple regressions were computed in both samples to study the unique contributions of ADHD to decoding skills while controlling for the shared variance between inattention and hyperactivity/impulsivity, behavior disorder symptoms, and nonverbal skills (top portion of Table 3). Second, similar multiple regressions were computed with reading comprehension as the dependant variable (middle portion of Table 3). Results in both samples show that inattention and nonverbal abilities, but not hyperactivity/impulsivity, make significant unique contributions to both decoding and reading comprehension at this age. Notwithstanding, inattention is the best predictor of both decoding and reading comprehension in both samples.

Third, to determine if inattention has a unique contribution to reading comprehension above its contribution to decoding skills (the presumption here is that decoding is required to test comprehension), a last series of multiple regressions tested if inattention still predicts reading comprehension once decoding skills are taken into account (bottom portion of Table 3). In both samples, decoding was the best predictor of reading comprehension but inattention remained a significant unique predictor, showing that the association between reading comprehension and inattention is robust.

Additional models (not shown) were tested in the QNTS for reading scores without the time bonuses. Results were unchanged, indicating that

Table 3 Standard multiple regression models predicting decoding and comprehension, from ADHD dimensions, nonverbal abilities and behavior disorder symptoms

		QNTS		QLSCD	
Dependent variables	Predictors	B(*SE*)	*β*	B(*SE*)	*β*
1. Decoding	*N*	1,057		1,610	
	Inattention	−4.77 (1.14)**	−.25	−4.85 (.82)**	−.22
	Hyperactivity	.34 (1.21)	.02	−1.28 (.85)	−.06
	Behavior disorder	−2.96 (2.21)	−.08	−.17 (1.55)	−.00
	Nonverbal abilities	1.27 (.31)**	.20	.89 (.17)**	.15
2. Comprehension	*N*	1,057		1,610	
	Inattention	−4.32 (.92)**	−.27	−7.36 (.93)**	−.28
	Hyperactivity	1.46 (.97)	.09	.20 (.97)	.01
	Behavior disorder	−2.57 (1.77)	−.08	.78 (1.87)	.01
	Nonverbal abilities	1.07 (.25)**	.21	1.26 (.22)**	.18
3. Comprehension	*N*	1,057		1,610	
	Inattention	−2.35 (.86)**	−.15	−4.29 (.79)**	−.16
	Hyperactivity	1.29 (.82)	.08	1.05 (.83)	.04
	Behavior disorder	−1.31 (1.54)	−.04	.97 (1.52)	.02
	Nonverbal abilities	.54 (.20)**	.11	.71 (.18)**	.10
	Decoding	.41 (.03)**	.50	.66 (.03)**	.54

QNTS, Quebec Newborn Twin Study; QLSCD, Quebec Longitudinal Study of Child Development. **$p < .01$.

the association could not be attributed to the time component of the reading measure in this sample.

Are the genetic and environmental contributions to the significant associations between reading comprehension and ADHD dimensions similar to those between decoding and ADHD?

The genetic analyses were performed on reading comprehension, decoding, and age/sex regressed inattention only. Table 4 presents MZ and DZ intraclass correlations (ICCs). The ICCs show that MZ correlations were moderate to high while DZ correlations were more modest for all measures. The MZ-DZ differences were substantial, especially for reading comprehension, suggesting that genetic factors largely explain individual differences on all three measures.

The formal Correlated-Factors multivariate genetic model confirms this. Fit indices show the model offered a good fit to the data: χ^2 (33) = 31.97, p = .52; AIC = 5028.26, BIC = 5116.89, CFI = 1.00, RMSEA = .00. ACE estimates of variances for the three measures are reported in Table 4 and Figure 1A–C illustrates the full multivariate model. First, ACE parameters indicated that reading comprehension was the most heritable of the three measures with 68% of the variance on this measure explained by genetic factors, whereas the heritability was 48% for decoding and 42% for inattention symptoms. The genetic correlation between decoding and reading comprehension was high (.92), suggesting a high genetic overlap between these two reading abilities. The genetic correlations between decoding and inattention (Rg = −.77), and between reading comprehension and inattention (Rg = −.45) were also significant. These genetic correlations indicate that inattention and reading measures share some, but not all, of their genetic etiology. However, this shared genetic variance accounted for most of the observed modest phenotypic associations, as the shared and nonshared environmental correlations were nonsignificant.

An additional model (not shown) was tested in which sex, nonverbal abilities, and behavior disorder symptoms regressed reading abilities, and age, sex, nonverbal abilities, and behavior disorder symptoms regressed inattention were used. Parameter

Table 4 MZ and DZ intraclass correlations and number of participants, and estimates of heritability (A), shared environment (C), and nonshared environment (E) for decoding, reading comprehension, and inattention with 95% confidence intervals, from the multivariate model

	MZ		DZ				
	ICC	*n*	ICC	*n*	A	C	E
Decoding	.52	218	.32	298	.48 (.18, .78)	.07 (−.21, .36)	.45 (.36, .54)
Comprehension	.72	221	.32	303	.68 (.44, .92)	.03 (−.18, .25)	.29 (.20, .37)
Inattention	.58	398	.36	560	.42 (.18, .67)	.16 (−.05, .36)	.42 (.33, .51)

MZ, monozygotic twins; DZ, dizygotic twins; ICC, intraclass correlation; A, proportion of variance explained by additive genetic factors; C, proportion of variance explained by shared environmental factors; E, proportion of variance explained by unique environmental factors and error.

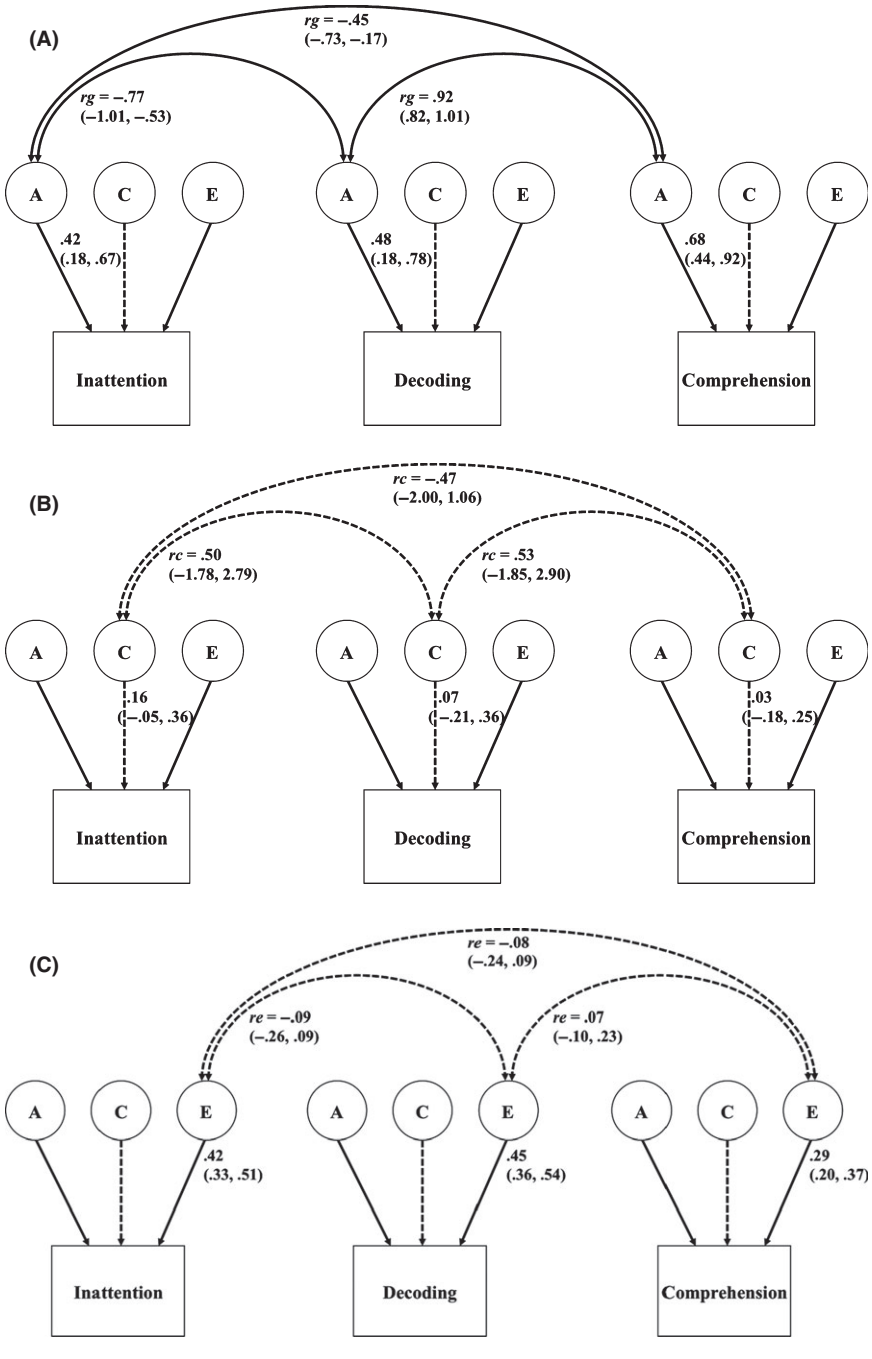

Figure 1 Correlated-Factors multivariate model showing the full model for the association between decoding and inattention, between reading comprehension and inattention, and between decoding, and reading comprehension. Standardized estimates with 95% confidence intervals. Curved double-headed arrows refer to A (section A), C (section B), and E (section C) correlations. Dotted double-headed arrow is nonsignificant correlations ($p > .05$)

estimates remained similar; therefore the simplest model is reported.

Discussion

The purpose of this study was to characterize the phenotypic associations, and genetic and environmental etiology of the associations between reading comprehension and ADHD dimensions in the early school years and compare them to results using decoding measures of reading. Results showed that inattention is the ADHD dimension uniquely associated with both reading comprehension and decoding, that inattention contributes uniquely to reading comprehension above and beyond decoding sills, and that the association between reading comprehension and inattention, like the one between decoding and inattention, is largely due to shared genes.

This is one of the first population-based study to include reading comprehension at these early stages of reading acquisition, to test the association between reading and ADHD dimensions while controlling for the shared variance between inattention

and hyperactivity, and to replicate results in two large-scale samples.

The case for including reading comprehension

In adults, Samuelsson, Lundberg, and Herkner (2004) have suggested that ADHD is more strongly associated with reading comprehension because it involves higher order cognitive skills. By contrast, reading comprehension is less studied than decoding skills in early readers. However, our results show that both comprehension and decoding are associated and that individual differences on both largely stem from the same genetic factors, replicating earlier results (Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006). They are also similarly associated with inattention and both share a substantial genetic etiology with inattention at this age. A tentative explanation of the similar association between both reading abilities and inattention could be that decoding skills are strongly implied in reading comprehension. Indeed, Keenan, Betjemann, and Olson (2008) have shown that reading comprehension measures similar to the one in this study (cloze-test format with short text passages) are more associated with decoding skills than other reading comprehension measures with longer text passages. Furthermore, decoding skills' prediction on reading comprehension was stronger in younger ($M \cong 9$ years old) than in older children ($M \cong 13$ years old).

However, our results show that a significant part of the association between inattention and comprehension cannot be attributed to decoding skills, suggesting that other mechanisms are possibly involved. This also suggests that children with inattention problems could have reading comprehension difficulties without decoding difficulties (commonly known as 'poor comprehenders'; Snowling, 2013). This result highlights the need to include reading comprehension as part of the standard assessment in early readers.

Modest but robust associations between reading and inattention: what do they mean?

As was the case in previous studies, reading abilities were only modestly correlated with ADHD dimensions. Thus, the modest associations in population-based studies between reading and inattention have been replicated across samples, age groups (6–12-years old), and a variety of reading and ADHD measures (Ebejer et al., 2010; Giannopulu, Escolano, Cusin, Citeau, & Dellatolas, 2008; Greven et al., 2011, 2012; Paloyelis et al., 2010; Pham, 2013; Rabiner & Coie, 2000; Rodriguez et al., 2007). The correlations in these population-based studies and cooccurrence rates (15%–40%) from a categorical perspective (Gayán et al., 2005; Mayes et al., 2000; Willcutt & Pennington, 2000) do converge. Although this means the majority of children with inattention problems do not have reading difficulties and vice-versa, those that do may constitute a specific phenotype with distinctive cognitive and genetic features that need to be understood.

In addition, the associations reported between reading and hyperactivity/impulsivity may have been misleading given that previous studies rarely considered the possibility that correlations between reading and hyperactivity/impulsivity arise because both ADHD dimensions are highly correlated ($rs > .60$). Indeed, some studies found no contribution of hyperactivity/impulsivity to reading after controlling for nonverbal abilities, gender, socioeconomic status, and other behavior difficulties (Giannopulu et al., 2008; Pham, 2013; Rabiner & Coie, 2000). Our study leads us to conclude that only inattention symptoms are uniquely associated with decoding and reading comprehension. This means that reading difficulties in hyperactive children possibly arise with underlying inattention symptoms and that inattentive children without hyperactivity/impulsivity possibly incur the same risk of reading difficulties as those with both sets of symptoms.

The genetic trail to understanding the associations between reading and inattention

An important question raised at this point may be why reading is specifically associated with inattention given that inattention does not appear to 'cause' reading difficulties. Ebejer et al. (2010) have shown that 'shared genes' is a better fitting model than a 'causal' genetic model for the association between inattention and decoding skills. Results indicate that a 'shared genes' model does provide an accurate explanation of the association between reading comprehension and inattention. One possible mechanism for these shared genes may be the genetic etiology of cognitive processes or neurological functioning underlying both phenotypes (Pennington, 2006). For instance, recent studies have identified naming and processing speed, also moderately heritable, as potential covariates of decoding skills and inattention (McGrath et al., 2011; Willcutt et al., 2010). However, to our knowledge, the specific covariates of reading comprehension and inattention symptoms have not been explored.

Another explanation for the shared genetic etiology between both reading skills and inattention could be pleiotropy – that is the effect of the same gene or group of genes on different phenotypes (Paloyelis et al., 2010). Accordingly, researchers have demonstrated that the ADRA2A gene (Stevenson et al., 2005), and loci at chromosomes 14q32, 13q32, 20q11 (Gayán et al., 2005), and 6p (Couto et al., 2009; Willcutt et al., 2002) could have such pleiotropic effects.

Both quantitative and molecular genetic studies will be crucial in understanding how inattention and reading skills are linked genetically. Limits of this study include the standard limitations of the

twin method (Plomin et al., 2008) and a possible underestimation of the associations between reading and ADHD dimensions as ADHD measures were averaged across kindergarten and first grade while reading was assessed at least a year later in second/third grade. Longitudinal studies are needed to understand how this association persists into adolescence and adulthood (Greven et al., 2012; Samuelsson et al., 2004). Finally, these results are relevant for parents, educators and clinical professionals. Environmental factors play a crucial role in the expression of genes and ensuing behaviors (Plomin et al., 2008). According to this study, inattention symptoms should be considered while doing reading assessments/interventions and these reading activities should focus on various reading abilities, including early reading comprehension.

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Correspondence

Ginette Dionne, École de psychologie, Université Laval, Pavillon Félix-Antoine-Savard, 2325 rue des Bibliothèques, Quebec City, QC G1V 0A6, Canada; Email: ginette.dionne@psy.ulaval.ca

Key points

- Reading and ADHD dimensions are consistently but modestly associated in the primary grades. Although both dimensions of ADHD show associations with reading, only inattention is uniquely associated with decoding and reading comprehension in 8-year olds.
- Reading comprehension is rarely assessed in studies of early readers but it appears to be uniquely associated with inattention even once decoding skills are considered, highlighting the need to review such practices.
- Shared genes account for the association between inattention and decoding, as for the association between inattention and reading comprehension.
- Quantitative and molecular genetic studies, as well as longitudinal studies, will be the key to understand the genetic underpinnings of these associations with correlated cognitive processes as well as their changes with age.

References

American Psychiatric Association (APA) (2013). *Diagnostic and statistical manual of mental disorders, Fifth Edition: DSM-IV-TR®*. Arlington, VA: American Psychiatric Publishing.

Boivin, M., Brendgen, M., Dionne, G., Dubois, L., Pérusse, D., Robaey, P., … & Vitaro, F. (2012). The Quebec newborn twin study into adolescence: 15 years later. *Twin Research and Human Genetics*, *16*, 64–69.

Byrne, B., Coventry, W.L., Olson, R.K., Samuelsson, S., Corley, R., Willcutt, E.G., … & DeFries, J.C. (2009). Genetic and environmental influences on aspects of literacy and language in early childhood: Continuity and change from preschool to Grade 2. *Journal of Neurolinguistics*, *22*, 219–236.

Byrne, B., Samuelsson, S., Wadsworth, S., Hulslander, J., Corley, R., DeFries, J., … & Olsen, R.K. (2007). Longitudinal twin study of early literacy development: Preschool through Grade 1. *Reading and Writing*, *20*, 77–102.

Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences*. Mahwah, NJ: Erlbaum.

Couto, J.M., Gomez, L., Wigg, K., Ickowicz, A., Pathare, T., Malone, M., … & Barr, C.L. (2009). Association of attention-deficit/hyperactivity disorder with a candidate region for reading disabilities on chromosome 6p. *Biological Psychiatry*, *66*, 368–375.

Ebejer, J.L., Coventry, W.L., Byrne, B., Willcutt, E.G., Olson, R.K., Corley, R., & Samuelsson, S. (2010). Genetic and environmental influences on inattention, hyperactivity-impulsivity, and reading: Kindergarten to grade 2. *Scientific Studies of Reading*, *14*, 293–316.

Forget-Dubois, N., Pérusse, D., Turecki, G., Girard, A., Billette, J.-M., Rouleau, G., … & Tremblay, R.E. (2003). Diagnosing zygosity in infant twins: Physical similarity, genotyping, and chorionicity. *Twin Research*, *6*, 479–485.

Gayan, J., Willcutt, E.G., Fisher, S.E., Francks, C., Cardon, L.R., Olson, R.K., … & DeFries, J.C. (2005). Bivariate linkage scan for reading disability and attention-deficit/hyperactivity disorder localizes pleiotropic loci. *Journal of Child Psychology and Psychiatry*, *46*, 1045–1056.

Giannopulu, I., Escolano, S., Cusin, F., Citeau, H., & Dellatolas, G. (2008). Teachers' reporting of behavioural problems and cognitive-academic performances in children aged 5–7 years. *British Journal of Educational Psychology*, *78*, 127–147.

Goldsmith, H.H. (1991). A zygosity questionnaire for young twins: A research note. *Behavior Genetics*, *21*, 257–269.

Greven, C.U., Harlaar, N., Dale, P., & Plomin, R. (2011). Genetic overlap between ADHD symptoms and reading is largely driven by inattentiveness rather than hyperactivity-impulsivity. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, *20*, 6–14.

Greven, C.U., Rijsdijk, F.V., Asherson, P., & Plomin, R. (2012). A longitudinal twin study on the association between ADHD symptoms and reading. *Journal of Child Psychology and Psychiatry*, *53*, 234–242.

Jetté, M., & Des Groseilliers, L. (2000). *Longitudinal study of child development in Québec (ELDEQ 1998–2002): Survey description and methodology (Volume 1, Number 1)*. Québec, Canada: Institut de la Statistique du Québec.

Kaufman, A.S., & Kaufman, N.L. (1983). *Kaufman assessment battery for children interpretive manual*. Circle Pines, Minn: American Guidance Service.

Keenan, J.M., Betjemann, R.S., & Olson, R.K. (2008). Reading comprehension tests vary in the skills they assess: Differential dependence on decoding and oral comprehension. *Scientific Studies of Reading*, *12*, 281–300.

Keenan, J.M., Betjemann, R.S., Wadsworth, S.J., DeFries, J.C., & Olson, R.K. (2006). Genetic and environmental influences on reading and listening comprehension. *Journal of Research in Reading*, *29*, 75–91.

Larsson, H., Lichtenstein, P., & Larsson, J.-O. (2006). Genetic contributions to the development of ADHD subtypes from childhood to adolescence. *Journal of the American Academy of Child and Adolescent Psychiatry*, *45*, 973–981.

Levy, F., Hay, D.A., McStephen, M., Wood, C., & Waldman, I. (1997). Attention-deficit hyperactivity disorder: A category or a continuum? Genetic analysis of a large-scale twin study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *36*, 737–744.

Mayes, S.D., Calhoun, S.L., & Crowell, E.W. (2000). Learning disabilities and ADHD: Overlapping spectrum disorders. *Journal of Learning Disabilities*, *33*, 417–424.

McGrath, L.M., Pennington, B.F., Shanahan, M.A., Santerre-Lemmon, L.E., Barnard, H.D., Willcutt, E.G., … & Olsen, R.K. (2011). A multiple deficit model of reading disability and attention-deficit/hyperactivity disorder: Searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry*, *52*, 547–557.

McLoughlin, G., Ronald, A., Kuntsi, J., Asherson, P., & Plomin, R. (2007). Genetic support for the dual nature of attention deficit hyperactivity disorder: Substantial genetic overlap between the inattentive and hyperactive–impulsive components. *Journal of Abnormal Child Psychology*, *35*, 999–1008.

Muthén, B.O., & Muthén, L.K. (2009). *Mplus (5.21) [Computer software]*. Los Angeles: Muthén & Muthén.

Paloyelis, Y., Rijsdijk, F., Wood, A., Asherson, P., & Kuntsi, J. (2010). The genetic association between ADHD symptoms and reading difficulties: The role of inattentiveness and IQ. *Journal of Abnormal Child Psychology*, *38*, 1083–1095.

Pennington, B.F. (2006). From single to multiple deficit models of developmental disorders. *Cognition*, *101*, 385–413.

Pépin, M., & Loranger, M. (1999). *Le Test d'habiletés en lecture (THAL): Guide d'utilisation (version 1.0)*. Québec, Canada: Réseau Psychotech.

Pham, A.V. (2013). Differentiating behavioral ratings of inattention, impulsivity, and hyperactivity in children: Effects on reading achievement. *Journal of Attention Disorders*, *00*, 1–10.

Plomin, R., DeFries, J.C., McClearn, G.E., & McGuffin, P. (2008). *Behavioral genetics* (4th edn). New York: Worth Publishers.

Polanczyk, G., Silva de Lima, M., Lessa Horta, B., Biederman, J., & Rohde, L.A. (2007). The worldwide prevalence of ADHD: A systematic review and metaregression analysis. *American Journal of Psychiatry*, *164*, 942–948.

Polderman, T.J.C., Derks, E.M., Hudziak, J.J., Verhulst, F.C., Posthuma, D., & Boomsma, D.I. (2007). Across the continuum of attention skills: A twin study of the SWAN ADHD Rating Scale. *Journal of Child Psychology and Psychiatry*, *48*, 1080–1087.

Rabiner, D., & Coie, J.D. (2000). Early attention problems and children's reading achievement: A longitudinal investigation. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 859–867.

Rodriguez, A., Järvelin, M.-R., Obel, C., Taanila, A., Miettunen, J., Moilanen, I., … & Olsen, J. (2007). Do inattention and hyperactivity symptoms equal scholastic impairment? Evidence from three European cohorts. *BMC Public Health*, *7*, 327.

Rutter, M., Caspi, A., Fergusson, D., Horwood, L.J., Goodman, R., Maughan, B., … & Carroll, J. (2004). Sex differences in developmental reading disability: New findings from 4 epidemiological studies. *The Journal of the American Medical Association*, *291*, 2007–2012.

Samuelsson, S., Lundberg, I., & Herkner, B. (2004). ADHD and reading disability in male adults: Is there a connection? *Journal of Learning Disabilities*, *37*, 155–168.

Shaywitz, S.E., Escobar, M.D., Shaywitz, B.A., Fletcher, J.M., & Makuch, R. (1992). Evidence that dyslexia may represent the lower tail of a normal distribution of reading ability. *The New England Journal of Medicine*, *326*, 145.

Shaywitz, S.E., & Shaywitz, B.A. (2003). Dyslexia (specific reading disability). *Pediatrics in Review*, *24*, 147–153.

Snowling, M.J. (2013). Early identification and interventions for dyslexia: A contemporary view. *Journal of Research in Special Educational Needs*, *13*, 7–14.

Stevenson, J., Langley, K., Pay, H., Payton, A., Worthington, J., Ollier, W., & Thapar, A. (2005). Attention deficit hyperactivity disorder with reading disabilities: Preliminary genetic findings on the involvement of the ADRA2A gene. *Journal of Child Psychology and Psychiatry*, *46*, 1081–1088.

Tremblay, R.E., Desmarais-Gervais, L., Gagnon, C., & Charlebois, P. (1987). The preschool behaviour questionnaire: Stability of its factor structure between cultures, sexes, ages and socioeconomic classes. *International Journal of Behavioral Development*, *10*, 467–484.

Wechsler, D. (1989). *Wechsler preschool and primary scale of intelligence-revised*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (1991). *Wechsler intelligence scale for children* (3rd edn). San Antonio, TX: Psychological Corporation.

Willcutt, E.G., Betjemann, R.S., McGrath, L.M., Chhabildas, N.A., Olson, R.K., DeFries, J.C., & Pennington, B.F. (2010). Etiology and neuropsychology of comorbidity between RD and ADHD: The case for multiple-deficit models. *Cortex*, *46*, 1345–1361.

Willcutt, E.G., & Pennington, B.F. (2000). Comorbidity of reading disability and attention-deficit/hyperactivity disorder: Differences by gender and subtype. *Journal of Learning Disabilities*, *33*, 179–191.

Willcutt, E.G., Pennington, B.F., Smith, S.D., Cardon, L.R., Gayan, J., Knopik, V.S., … & DeFries, J.C. (2002). Quantitative trait locus for reading disability on chromosome 6p is pleiotropic for attention-deficit/hyperactivity disorder. *American Journal of Medical Genetics*, *114*, 260–268.

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