

Associations Between Reading Achievement and Independent Reading in Early Elementary School: A Genetically Informative Cross-Lagged Study

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This study used a cross-lagged twin design to examine reading achievement and independent reading from 10 to 11 years ($n = 436$ twin pairs). Reading achievement at age 10 significantly predicted independent reading at age 11. The alternative path, from independent reading at age 10 to reading achievement at age 11, was not significant. Individual differences in reading achievement and independent reading at both ages were primarily due to genetic influences. Furthermore, individual differences in independent reading at age 11 partly reflected genetic influences on reading achievement at age 10. These findings suggest that genetic influences that contribute to individual differences in children's reading abilities also influence the extent to which children actively seek out and create opportunities to read.

Outside of school, good readers in fifth grade may read as many words in 2 days as a poor reader does in an entire year (Gabrieli, 2009). Accordingly, the salutary effects of independent reading (or *print exposure*) for reading achievement are frequently emphasized, and there have been concerted efforts to develop positive reading habits among children. For example, initiatives that seek to encourage children to “read a million words” have been established in the United States and the United Kingdom. However, the National Reading Panel (National Institute of Child Health and Human Development, 2000) argued that, “. . . even though encouraging students to read more is intuitively appealing, there is still not sufficient evidence . . . to support the idea that such efforts reliably increase how much students read or that such pro-

grams result in improved reading skills” (p. 13). In the present study, we examine the evidence for the causality of independent reading for reading achievement using a genetically sensitive design.

Independent reading includes both behavioral and motivational components. The behavioral facet is typically conceptualized in terms of *quantity* or *frequency* of leisure-time reading, as assessed, for example, by questionnaires that ask about the frequency of book reading, or by checklist measures in which participants identify popular book titles or authors from a list interspersed with fake items to control for guessing (Acheson, Wells, & MacDonald, 2008). The motivational facet can be defined as *motivation to engage in reading*. It broadly encompasses individuals' beliefs about their competence as readers, their intrinsic and extrinsic motivation to read, and their purposes for engaging in reading (Baker & Wigfield, 1999). Both behavioral and motivational aspects of independent reading have been found to correlate with diverse

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aspects of reading. These include word recognition (Ecalte & Magnam, 2008; Harlaar, Dale, & Plomin, 2007; Leppänen, Aunola, & Nurmi, 2005), reading fluency (Martin-Chang & Gould, 2008; Quirk, Schwanenflugel, & Webb, 2009; Spear-Swerling, 2006), vocabulary (Cunningham & Stanovich, 1991; Martin-Chang & Gould, 2008), and reading comprehension (Cipielewski & Stanovich, 1992; Cunningham & Stanovich, 1997; Martin-Chang & Gould, 2008; Taboada, Tonks, Wigfield, & Guthrie, 2009). More broadly, independent reading has been linked to positive reading attitudes (Guthrie & Alvermann, 1999), greater self-confidence as a reader (Guthrie & Alvermann, 1999), and reading for pleasure in later life (Aarnoutse & van Leeuwe, 1998).

A Causal Effect of Independent Reading?

The conventional explanation for the association between reading achievement and independent reading is that extended reading practice facilitates reading development. It does so because independent reading provides opportunities to acquire new word meanings, develop high-quality lexical representations of words, and improve reading fluency, thereby freeing up mental resources for reading comprehension (Perfetti & Hart, 2002). Nonetheless, there is reason to be cautious. Most previous studies have examined reading achievement and independent reading concurrently. We cannot infer that independent reading leads to better reading from these studies because the causal arrow may point in the other direction: Better readers may simply choose to read more. According to Stanovich (1986), for example, poor readers are at greater risk for unrewarding early reading experiences that cause them to avoid opportunities for reading. This avoidance, in turn, constrains their reading development further. Conversely, children who make a good start in reading are likely to seek out opportunities to read, and these opportunities promote their reading development (Stanovich, 1986). As such, independent reading and reading achievement are bound in a reciprocal relation, where reading skill leads to more reading practice and independent reading subsequently strengthens reading skill. This hypothesis forms the cornerstone of the "Matthew effects" hypothesis, which states that better readers get even better over time, whereas poorer readers fall further behind their peers.

The difficulties of disentangling cause and effect in cross-sectional data can be circumvented by training studies that seek to determine whether increasing levels of independent reading result in

improvements in reading achievement, or vice versa. To date, the available evidence has been mixed. In a review of 14 training studies published between 1990 and 2000, the National Reading Panel (National Institute of Child Health and Human Development, 2000) found no evidence for a positive effect of programs that encourage large amounts of independent reading. However, these studies varied widely in their methodological quality and the reading outcome variables measured. Using a randomized case-control design, Reis and colleagues (Reis, Eckert, McCoach, Jacobs, & Coyne, 2008; Reis et al., 2007) reported positive effects on oral reading fluency among elementary school children ($n = 110$) who followed a program that sought to expose students to books in their areas of interest and provided daily supported independent reading of challenging self-selected books. This finding tentatively supports a causal role of independent reading in facilitating reading development. Another study, focused on children at risk for reading difficulties, failed to find support for the opposite question: Is children's tendency to read boosted by improving their reading skills? (Morgan, Fuchs, Compton, Cordray, & Fuchs, 2008). In this study ($n = 15$), increasing children's reading skills through tutoring did not lead to concomitant changes in their levels of independent reading or their motivation to read. This result suggests that reading achievement does not have on a causal effect on independent reading, although caution is necessary because the sample was small.

Longitudinal studies of the relation between reading practice and reading achievement have also been reported. Although longitudinal correlational studies cannot conclusively establish a causal link between two factors due to the much-cited third variable problem, they can provide information on temporal precedence, which is critical in determining the direction of influence (Bollen, 1989). Cunningham and Stanovich (1997) reported that first grade reading ability significantly predicted independent reading in Grade 11 independent of reading ability at Grade 11. However, independent reading was not assessed in first grade, leaving open the possibility that the effects of first grade reading on later independent reading partly reflected independent reading in the first grade year.

A stronger longitudinal design is the cross-lagged model, in which each variable in the model is regressed on all of the variables that precede it in time. To our knowledge, only two studies have used a cross-lagged design to examine the relation between reading achievement and independent

reading. Leppänen et al. (2005) examined three indicators of independent reading (book reading, magazine reading, and TV subtitle reading), and three indicators of reading achievement (word recognition, text comprehension, and sentence comprehension) in children assessed in first and second grades. Word recognition showed bidirectional associations with book reading and TV subtitle reading. Text and sentence comprehension, by contrast, showed unidirectional associations with reading practice: The more competent children were in sentence comprehension and text reading at the end of first grade, the more likely they were to read books, magazine, and TV subtitles in second grade; however, reading practice in first grade did not significantly predict sentence and text comprehension at second grade.

In a separate study, Quirk et al. (2009) examined the relations between reading fluency skill and two aspects of reading motivation, reading self-concept and goals for reading, over the course of the second grade year. Reading self-concept, but not children's goals for reading, was significantly related to reading fluency at each time of assessment. Moreover, support for bidirectional effects was found between reading fluency skill and reading self-concept. That is, children who started second grade with a higher fluency skill level tended to have higher reading self-concepts both in the middle and at the end of their second grade year, controlling for prior reading self-concept. In addition, children who had a relatively high reading self-concept at the beginning of their second grade year tended to develop their reading fluency skills across their second grade year more rapidly than those children who started the year with a lower reading self-concept, controlling for prior reading fluency skill level.

On balance, it can be said that training and longitudinal studies have yielded mixed findings regarding the relation between independent reading and reading achievement, with all possibilities supported: Reading achievement may precede independent reading (Cunningham & Stanovich, 1997; Leppänen et al., 2005), reading achievement does not precede independent reading (Morgan et al., 2008), independent reading may precede reading achievement (Reis et al., 2007; Reis et al., 2008), and there may be a bidirectional relation between at least some aspects of reading achievement and independent reading (Leppänen et al., 2005; Quirk et al., 2009). The diversity of findings may reflect a variety of factors, including differences in sample age and outcome measures. This suggests that further research is needed to clarify

the nature of the relation between reading achievement and independent reading.

Potential Genetic Confounds

Although training studies and longitudinal data permit some insight into the direction of effects between independent reading and reading achievement, a further methodological challenge remains. Specifically, environmental exposure is often subject to genetic "niche-picking," or gene-environment correlation (Plomin, DeFries, & Loehlin, 1977). These child effects arise when children actively select experiences based on their genetic predispositions (an *active gene-environment correlation*), or when children's genetically influenced characteristics evoke certain responses from others (an *evocative gene-environment correlation*). For example, a child with a high genetic proclivity for reading may seek out opportunities to read at home, and their parents may take him or her to the library on a regular basis. Conversely, a child at high genetic risk for reading difficulties may avoid reading and be less interested in library visits (Pennington et al., 2009).

To the extent that genetic factors influence the extent to which the child engages in independent reading, the association between reading achievement and independent reading may be due to genetic factors that influence the development of both, rather than a causal effect of one on the other. Consequently, it is important to determine whether, and to what extent, genetic child effects are important for independent reading. A better understanding of the etiological links between independent reading and reading achievement may help to inform expectations about prevention and intervention outcomes.

Twin studies provide a quasi-experimental tool for disentangling genetic and environmental influences that contribute to individual differences in a trait. Numerous twin studies have shown that individual differences in reading ability reflect both genetic and environmental influences (Byrne, Khlentzos, Olson, & Samuelsson, 2010; Olson, 2006). There is emerging evidence that this is also true for independent reading. For example, a U.S. study of twins aged 8–18 years reported that individual differences in independent reading were partly attributable to genetic factors, with a genetic effect size (heritability) of 52% (Olson & Byrne, 2005). A similar estimate (67%) was obtained in an Australian study of twins aged 11–29 years (Martin et al., 2009), and a lower but significant estimate

(10%) was obtained in a U.K. study of twins at age 10 (Harlaar et al., 2007).

Of the three twin studies that have examined the origins of independent reading, only Harlaar et al. (2007) also examined the links between independent reading and reading longitudinally. Word recognition skill at age 7 was a significant predictor of independent reading at age 10, and both significantly predicted word recognition at age 12. Most (80%) of the genetic variance in independent reading at age 10 reflected genetic influences on word recognition at age 7, consistent with the notion that children may seek out reading experiences consistent with their genetic proclivities for reading. After controlling for genetic and environmental influences on word recognition at age 7, there was also evidence that environmental influences on independent reading at age 10 influenced word recognition skills at age 12. Specifically, .09, or 9%, of the shared environmental variance—the variance due to family-wide environmental factors—in 12-year word decoding scores reflected shared environmental influences on 10-year independent reading.

These results suggest that there may be a positive feedback loop across development, wherein genetic effects on reading influence the extent to which children engage in reading, which in turn influences reading through environmental pathways. However, as in Cunningham and Stanovich (1997), early independent reading was not assessed, therefore precluding an analysis of the potential causal direction of effect between independent reading and literacy outcomes. In the present study, we used a cross-lagged twin design to clarify both the direction and the etiology of the association between reading achievement and independent reading over a 1-year period during the middle school years. Our analyses were driven by two sets of questions. First, does independent reading precede reading achievement, or does reading achievement precede independent reading? Second, what is the etiology of the relations between reading achievement and independent reading? We were particularly interested in determining whether the extent to which children read independently partly reflects their genetically influenced reading abilities, and whether reading achievement at age 11 partly reflects environmental influences on independent reading at age 10, thereby providing evidence of an environmental impact of independent reading on achievement. By identifying the degree to which there are genetic and environmental influences on one or both cross-lagged paths, we are able to make stronger inferences of causal as well as temporal

precedence of the effects of independent reading on reading achievement.

Method

Sample

The current study draws on the Western Reserve Reading Project (WRRP), an ongoing longitudinal twin study of reading and related cognitive skills. The total sample comprises 436 monozygotic (MZ) and same-sex dizygotic (DZ) twin pairs who were recruited through media advertisements, school nominations, Ohio State birth records, and Mothers of Twins clubs (Petrill, Deater-Deckard, Thompson, DeThorne, & Schatschneider, 2006). Twins have been assessed annually, beginning in kindergarten or first grade. The current analyses are based on 84 MZ and 107 DZ twin pairs who participated in assessments in the fifth and sixth waves of the study. Average age of assessment at Wave 5 (hereafter referred to as “age 10”) was 9.91 years ($SD = 0.83$); average age of assessment at Wave 6 (hereafter referred to as “age 11”) was 10.99 years ($SD = 0.84$).

Twin zygosity was determined using polymorphic DNA markers obtained from buccal swabs. For a handful of families who did not consent to DNA testing, twin zygosity was determined via a measure of twin physical similarity reported to be 95% accurate when compared to DNA analyses (Price et al., 2000). Although slightly positively skewed (skew = .049), parent education levels varied widely and were similar for fathers and mothers: 12% high school or less, 18% some college, 30% bachelor's degree, 24% some postgraduate education or degree, 5% not specified. The majority of twins were Caucasian (92%) and lived in two-parent households (6% single mothers).

Measures

At both waves of assessment, reading performance was assessed using the Word Identification and Passage Comprehension subtests from the Woodcock Reading Mastery Tests–Revised (WRMT–R; Woodcock, 1987). The Word Identification subtest involves reading a list of real words. For the Passage Comprehension subtest, the child reads a series of sentences or passages and provides a contextually appropriate word to fit in a blank. Children were individually assessed in their homes. To avoid biases that might occur if a single tester assessed both twins, members of each twin pair

were tested at the same time by different experimenters. Because Word Identification and Passage Comprehension scores were substantially correlated at both waves of assessment (.76 at age 10, .73 at age 11), we used a composite score for the purpose of the current analyses; this corresponds to the Woodcock-Johnson Total Reading-Short Scale cluster (Woodcock, 1987).

Independent reading was assessed at each test session by both the caregiver and the children themselves. The caregiver was asked to rate how often each twin read books at home for enjoyment. Responses were made on a 5-point scale (1 = *almost never*, 2 = *once a month*, 3 = *once a week*, 4 = *once a day*, 5 = *more than three times a day*). Twins completed the Motivation for Reading Questionnaire (MRQ; Wigfield, Guthrie, & McGough, 1996). The MRQ assesses 11 dimensions of reading motivation, grouped under three categories: *competence and efficacy beliefs*, *goals for reading*, and *social purposes of reading*. Responses were made on a 4-point scale (1 = *almost never*, 2 = *about once a month*, 3 = *about once a week*, 4 = *almost every day*). Twins filled out the questionnaires separately, in different rooms from each other.

For the purpose of the current study, we computed composite scores of independent reading by taking the mean of caregiver ratings and children's MRQ scores for *self-efficacy* and *challenge*. The self-efficacy and challenge scales fall under the *competence and efficacy beliefs* category of the MRQ. *Self-efficacy* assesses the belief that one can be successful at reading, whereas *challenge* assesses willingness to take on difficult reading material. Our composite scores of independent reading therefore reflect both children's reading behavior and their motivation to engage in independent reading. We specifically opted to look at competence and efficacy beliefs because these are thought to play a crucial role in an individual's decisions about which activities to do, how long to do them, and how much effort to put into them (Bandura, 1997). We did not include scales from the second and third categories of the MRQ, *goals for reading*, and *social purposes of reading*, because these mainly focus on school-based reading activities, rather than independent reading undertaken at home (Baker & Wigfield, 1999). Reliabilities for the self-efficacy and challenge scales were acceptable (.66-.74). Reliabilities for a third scale falling under the competence and efficacy beliefs category of the MRQ, *reading avoidance*, were lower (.55 at both ages). Thus, for the purpose of the current study, we focused only on the self-efficacy and challenge

scales. Both scales have previously been shown to correlate significantly with self-reported reading activity among fifth and sixth grade children (.43 for self-efficacy, .51 for challenge; Baker & Wigfield, 1999).

In the current study, the self-efficacy and challenge scales were moderately correlated ($r_s = .61$ at age 10 and $.67$ at age 11), and each showed low but significant correlations with caregiver ratings of independent reading (for self-efficacy: $r_s = .17$ and $.28$ at Times 1 and 2, respectively; for challenge: $r_s = .17$ and $.34$ at Times 1 and 2, respectively). Children's scores on the independent reading composite variable ranged from 1 to 5 and were normally distributed.

Analyses

We used structural equation modeling to examine the relative contributions of genetic and environmental effects to the longitudinal and cross-lagged relations between reading achievement and independent reading. Our analyses were based on the premise that genetic and environmental factors can be separated using MZ and DZ twins reared in the same family (Plomin, DeFries, McClearn, & McGuffin, 2008). Genetic relatedness differs by zygosity: MZ twins are genetically identical, whereas DZ twins share, on average, half of their segregating genes. As such, a genetic contribution to a trait is indicated when the similarity of MZ twins is greater than the similarity of DZ twins. This genetic contribution is assumed to reflect the effects of additive genetic influences (A): genes that together operate in an additive manner. If differences in a trait were completely governed by additive genetic effects, one would expect the DZ and MZ intraclass correlations to mirror the degree of genetic similarity across twin types, with coefficients of .50 and 1.00, respectively. A rough estimate of the proportion of variance due to additive genetic factors (heritability, or a^2) can be derived by doubling the difference between the MZ and DZ correlations, $a^2 = 2(r(\text{MZ}) - r(\text{DZ}))$.

Variance not attributable to genetic effects is divided into shared and nonshared environmental effects. Shared environmental effects (C) encompass any nongenetic factors that would be shared between twins. Such effects could include exposure to environmental toxins, birth trauma, or parent interaction style, but only to the extent that such factors are truly identical for both twins. Shared environmental effects are indicated to the extent that the resemblance between DZ twins is *greater*

than half the MZ correlation and can be estimated by the similarity between MZ twins that cannot be accounted for by genetic effects ($c^2 = MZr - a^2$). If the resemblance between DZ twins is less than half the MZ correlation this suggests that dominant genetic influences (D) may be operating: genetic effects that operate in a nonadditive manner. Finally, nonshared environmental influences (E) include nongenetic factors that differ between twins, such as specific injuries and illnesses, individual friendships, classroom assignments, and measurement error. The extent of nonshared environmental effects is estimated through the lack of similarity in MZ twins by subtracting the MZ intraclass correlation from 1.00. In quantitative genetic models, nonshared environmental influences also typically subsume the effects of measurement error, because such error will reduce twin similarity.

We examined the association between independent reading and reading achievement using a cross-lagged model for genetic data (Burt, McGue, Krueger, & Iacano, 2005). The Mx program (Neale, Boker, Xi, & Maes, 2006) was used for all analyses. Models were estimated from the raw data using full-information maximum likelihood. This method of estimation uses the raw data to generate covariance matrices of test scores for MZ and DZ twins (i.e., relating Twin 1's performance to Twin 2's performance in each zygosity group), and yields maximum-likelihood estimates for the effects of interest while taking missing data into account. For nested models, differences in model fit were examined using likelihood-ratio chi-square test. For nonnested models, differences in model fit was examined using the Akaike's information criterion (AIC; Akaike, 1987) and the sample-size adjusted Bayesian information criterion (BIC; Raftery, 1995). The

AIC and BIC are indices of relative fit, where smaller values indicate better model fit (i.e., the model that reproduces the observed variances and covariances with as few unknown estimated parameters as possible). We designated model parameters as significant if their 95% confidence intervals (CI) did not include zero.

Results

Means and standard deviations for the study variables (*W* scores on the Reading short form and composite scores for independent reading) are presented in Table 1. Most children's reading scores were within the average range for Grade 5 at age 10 (age equivalent = 10.5 years) and Grade 6 at age 11 (age equivalent = 11.2 years). Boys obtained higher reading achievement scores than girls at both waves of assessment. According to conventional interpretations of Cohen's *d* (Cohen, 1988), however, the effect size of the sex difference in reading achievement at both ages is very small. There was a medium-sized effect of sex on independent reading at both ages: Girls read more frequently and were more motivated to read compared to boys.

Phenotypic Associations

Phenotypic correlations among the measures are shown in Table 2. Independent reading and reading achievement were moderately correlated at both age 10 (.45) and age 11 (.51), and each showed significant 1-year stability (.90 for reading achievement, .56 for independent reading). Cross-trait, cross-time correlations were also significant:

Table 1
Means and Standard Deviations for Reading Achievement (Read) and Independent Reading (Print)

	Whole sample		Girls		Boys		Effect size of sex <i>d</i>
	<i>M</i> (<i>SD</i>)	<i>n</i>	<i>M</i> (<i>SD</i>)	<i>n</i>	<i>M</i> (<i>SD</i>)	<i>n</i>	
Read ₁	499.73 (15.31)	379	499.21 (16.15)	216	500.43 (14.12)	163	.12
Print ₁	3.08 (0.77)	355	3.21 (0.76)	199	2.91 (0.76)	156	.41
Read ₂	507.43 (13.17)	283	507.32 (14.05)	167	507.58 (11.85)	116	.17
Print ₂	3.17 (0.83)	238	3.29 (0.79)	145	2.99 (0.87)	93	.32

Note. Read₁, Print₁ = reading achievement and independent reading at age 10; Read₂, Print₂ = reading achievement and independent reading at age 11.

Table 2
Phenotypic Correlations Among Reading Achievement (Read) and Independent Reading (Print; With 95% Confidence Intervals in Parentheses)

	Print ₁	Read ₁	Print ₂
Read ₁	.45 (.35, .53)		
Print ₂	.56 (.45, .64)	.47 (.36, .56)	
Read ₂	.40 (.31, .48)	.90 (.88, .91)	.51 (.41, .59)

Note. Read₁, Print₁ = reading achievement and independent reading at age 10; Read₂, Print₂ = reading achievement and independent reading at age 11.

Independent reading at age 10 correlated .40 with reading achievement at age 11, whereas reading achievement at age 10 correlated .47 with independent reading at age 11.

Evidence for Bidirectional Links?

The first major goal of analysis was to determine whether there is evidence for bidirectional links between reading achievement and independent reading. The cross-trait, cross-time correlations suggest that this may be the case, but they do not control for the auto correlation of each variable. Thus, the next step of our analysis was to examine the associations between reading achievement and independent reading at ages 10 and 11 using a cross-lagged model, as shown in Figure 1.

Within the cross-lagged model, the cross-age associations function as partial regression coefficients. The critical coefficients are the cross-trait, cross-age regression paths (i.e., b_{21} , b_{12}). The path b_{21} represents the effect of independent reading at age 10 on reading achievement at age 11 independent of reading achievement at age 10. Conversely, the opposite cross-lagged path (b_{12}) represents the effect of reading achievement at age 10 on independent reading at age 11, controlling for the effects of independent reading at age 10. Thus, a comparison of these paths provides an indication of whether independent reading has temporal precedence over reading achievement, or whether the opposite is true. The cross-lagged model also provides estimates for the within-trait, cross-age regression coefficients (i.e., b_{11} , b_{22}), which index the stability of independent reading and reading achievement over time independent of the effects of the other trait.

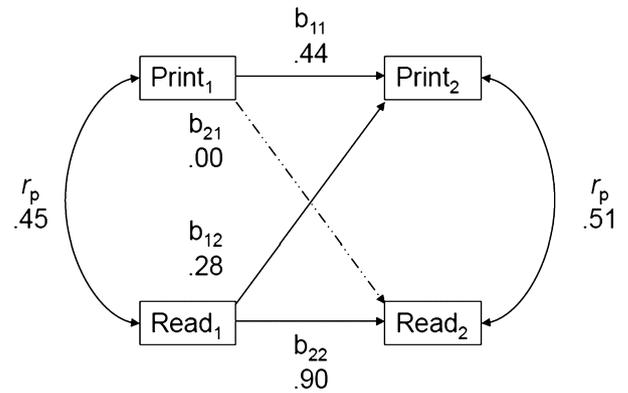


Figure 1. Path diagram of the cross-lagged model. Note. Independent reading (Print) and reading achievement (Read) are linked across time by partial regression coefficients representing cross-age stability in independent reading (b_{11}) and reading achievement (b_{22}), the cross-lagged effect of independent reading on reading achievement (b_{21}), and the cross-lagged effect of reading achievement on independent reading (b_{12}). Within-age correlations (r_p) between independent reading and reading achievement are also depicted. Dashed line indicates that the parameter estimate is not significantly different from zero.

The standardized partial regression coefficients from the cross-lagged model are shown in Figure 1. Estimates of variance can be obtained by squaring the partial regression coefficients of each path. Both stability path coefficients (b_{11} , b_{22}) were significant and substantial. Specifically, age 10 independent reading accounted for 19% (95% confidence intervals, CI: 9%–30%) of the variance in age 11 independent reading, and age 10 reading achievement accounted for 81% (CI: 76%–84%) of the variance in age 11 reading achievement. Additionally, reading achievement significantly predicted later independent reading. Specifically, age 10 reading achievement explained 8% (CI: 2%–15%) of the variance in age 11 independent reading, controlling for age 10 reading achievement. In contrast, age 10 independent reading did not have a significant effect on age 11 reading achievement, controlling for reading achievement at age 10 (0%, with CI: .00–.00).

We tested these paths more formally by comparing the fit of the full cross-lagged model with sub-models in which each of the four partial regression coefficients were constrained to zero. Neither of the stability coefficients could be removed from the model without a significant deterioration in model fit, as indicated by the likelihood-ratio tests (b_{11} : $\Delta\chi^2 = 41.27$; $df = 1$, $p < .01$; b_{22} : $\Delta\chi^2 = 1,053.14$; $df = 1$, $p < .01$, where the fit statistics for the full model are: $-2LL = 2,678.70$; $df = 1,212$). Removing the cross-lagged path linking age 10 reading achievement with age 11 independent reading also

resulted in a significant deterioration in model fit (b_{12} : $\Delta\chi^2 = 11.81$; $df = 1$, $p < .01$). However, the cross-lagged path linking age 10 independent reading with age 11 reading achievement could be eliminated without a significant reduction in model fit (b_{21} : $\Delta\chi^2 = 0.001$; $df = 1$, $p = .98$).

These findings confirm the pattern shown by the path coefficients, indicating that reading achievement significantly predicts later independent reading, but not vice versa. We note that this step informs the selection of subsequent analyses. Because age 10 independent reading did not significantly predict age 11 reading achievement, analyses to determine whether reading achievement at age 11 partly reflects environmental influences on independent reading at age 10 were not warranted.

Genetic and Environmental Contributions to the Variance in Independent Reading and Reading Achievement

We next estimated the extent to which genetic and environmental influences contribute to the variance within each measure. A first impression of the magnitude of these effects is provided by the comparison of MZ and DZ intraclass correlations, shown in the left-hand panel of Table 3. MZ correlations were uniformly higher than the DZ correlations. For reading achievement, the DZ correlations were approximately half the MZ correlations. This pattern provides evidence for genetic influences and negligible shared environmental influences. By contrast, the DZ correlations for independent reading were not significantly different from zero. This

Table 3
Intraclass Twin Correlations (ICC) and Variance Due to Genetic (A), and Nonshared Environmental (E) Factors (With 95% Confidence Intervals in Parentheses)

	MZ		DZ		Variance components	
	ICC	n	ICC	n	A	E
Print ₁	.59 (.42, .72)	73	.00 (.00, .17)	93	.62 (.45, .73)	.38 (.27, .55)
Read ₁	.88 (.81, .92)	81	.42 (.25, .57)	104	.90 (.85, .92)	.10 (.08, .15)
Print ₂	.61 (.40, .76)	48	.00 (.00, .21)	61	.55 (.36, .68)	.45 (.32, .64)
Read ₂	.77 (.65, .86)	61	.47 (.28, .62)	79	.75 (.69, .80)	.25 (.20, .31)

Note. n = number of pairs; MZ = monozygotic twins; DZ = dizygotic twins; Read₁, Print₁ = reading achievement and independent reading at age 10; Read₂, Print₂ = reading achievement and independent reading at age 11.

pattern is consistent with the possibility of dominant genetic effects, which would increase the genetic similarity of MZ twins over DZ twins.

Because the pattern of DZ correlations for independent reading suggest the possibility of genetic dominant effects, we compared the fit of a cross-lagged ADE model (which included additive genetic, dominant genetic, and nonshared environmental effects) with an ACE model (additive genetic, shared environmental, and nonshared environmental effects) and an AE model (additive genetic and nonshared environmental effects only). The AE model provided the best fit to the data, having lower AIC and BIC values (AIC = 82.42, BIC = -10.37) than both the ADE model (AIC = 86.45, BIC = -8.11) and the ACE model (AIC = 91.64, BIC = -5.51). This model, along with the standardized parameter estimates, is shown in Figure 2.

The right-hand panel of Table 3 shows the estimates of the genetic and environmental contributions to the variance within each trait from the AE model. Because the additive genetic and nonshared environmental effects are latent factors, they do not have a natural scale. Consequently, we fixed the total variance (i.e., the sum of A and E) within each measure to 1.00. At age 10, genetic factors accounted for 62% of the variance in independent reading and 90% of the variance in reading achievement. Nonshared environmental influences were also significant, accounting for 38% of the variance in independent reading and 10% of the variance in reading achievement. These estimates can also be obtained from Figure 2 by squaring the effects of genetic and nonshared environmental factors at age 10 to independent reading (i.e., a_1^2 and e_1^2) and to reading achievement (i.e., a_2^2 and e_2^2).

A similar etiological pattern emerged at age 11. Specifically, genetic factors accounted for 55% of the

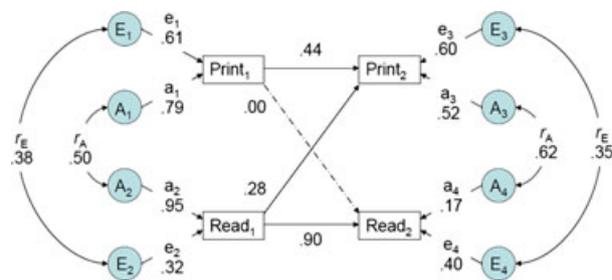


Figure 2. Standardized path estimates of the cross-lagged model with additive genetic (A) and nonshared environmental (E) contributions to independent reading (Print) and reading achievement (Read).

Note. Dashed line indicates that the parameter estimate is not significantly different from zero.

variance in independent reading and 75% of the variance in reading achievement. Nonshared environmental factors accounted for 45% of the variance in independent reading and 25% of the variance in reading achievement. These estimates can also be obtained from Figure 2 by summing the genetic and nonshared environmental variance specific to age 11 and genetic and nonshared environmental variance arising from age 10. For example, variance in independent reading at age 11 reflects the sum of: (a) the unique effects of genetic and nonshared environmental influences on independent reading at age 11 (i.e., $a_1^2 \times b_{11}^2$ and $e_1^2 \times b_{11}^2$), (b) the unique effects of genetic and nonshared environmental influences on age 10 reading achievement that influence age 11 independent reading (i.e., $a_2^2 \times b_{12}^2$ and $e_2^2 \times b_{12}^2$), (c) correlated genetic and nonshared environmental effects on reading achievement and independent reading at age 10 that influence age 11 independent reading (i.e., $2 \times [b_{11} \times a_1 \times r_A \times a_2 \times b_{12}]$ and $2 \times [b_{11} \times e_1 \times r_E \times e_2 \times b_{12}]$), and (d) specific genetic and nonshared environmental effects on age 11 independent reading (i.e., a_3^2 and e_3^2). Equivalent calculations can be used to derive the genetic and nonshared environmental contributions to reading achievement at age 11.

Within the cross-lagged model, the genetic and nonshared environmental factors on independent reading and reading achievement were correlated within each assessment wave. The within-wave, cross-measure genetic correlations (r_A) between independent reading and reading achievement were substantial: .50 (CI: .35–.62) at age 10 and .62 (CI: .46–.76) at age 11. The nonshared environmental correlations (r_E) were lower but significant: .38 (CI: .15–.57) at age 10 and .35 (CI: .14–.52) at age 11. We were also able to derive cross-wave, within-measure genetic and nonshared correlations from the model. Genetic influences on reading achievement correlated substantially ($r_A = .64$; CI: .49–.81) from ages 10 to 11, whereas genetic influences on independent reading correlated almost perfectly across this 1-year period ($r_A = .98$; CI: .95–1.00). That is, genetic influences were highly stable for both traits. The stability of nonshared environmental influences was lower but still significant, both for reading achievement ($r_E = .45$; CI: .33–.57) and independent reading ($r_E = .58$, CI: .50–.66).

Taken together, these findings indicate that variance in both independent reading and reading achievement is due primarily to genetic influences. Furthermore, approximately half of the genetic influences on independent reading and reading

achievement overlap within each wave. Nonshared environmental influences, which include measurement error, are also significant and show moderate overlap within each wave.

Etiology of the Relation Between Independent Reading and Reading Achievement

The second aim of the current study was to examine the etiology of the relations between reading achievement and independent reading. As a first step, we decomposed the significant phenotypic regression coefficients into genetic and nonshared environmental components. The results indicate that both stability coefficients are primarily influenced by genetic factors, with smaller but significant nonshared environmental influences. Specifically, genetic factors accounted for 67% (CI: 51%–77%) of the stability of independent reading and 90% (CI: 85%–92%) of the stability of reading achievement. Nonshared environmental factors accounted for the remaining stability: that is, 33% (CI: 27%–55%) for independent reading and 10% (CI: 8%–15%) for reading achievement. A similar pattern emerged for the significant cross-lagged path linking age 10 reading achievement with age 11 independent reading. Genetic factors accounted for 83% (CI: 67%–94%) of the effect of age 10 reading achievement on age 11 independent reading, whereas nonshared environmental factors accounted for 17% (CI: 6%–33%).

The evidence that both reading achievement and independent reading are genetically influenced, and that genetic factors contribute to the cross-lagged relation from age 10 reading achievement to age 11 independent reading, leads to a second and more central issue: To what extent do children's genetically influenced reading abilities influence the extent to which they subsequently read independently? This issue can be answered by looking more closely at the genetic effect on age 11 independent reading. As described earlier, the variance in age 11 independent reading can be broken down into four components: (a) genetic and nonshared environmental influences specific to reading achievement at age 10, (b) genetic and nonshared environmental influences specific to independent reading at age 10, (c) genetic and nonshared environmental influences common to independent reading and reading achievement at age 10, and (d) residual genetic and nonshared environmental influences at age 11, including measurement error. Estimates for each of these components are shown in Table 4. The proportion of the total genetic and

Table 4
Proportion of the Total Genetic (A) and Nonshared Environmental (E) Variation in Independent Reading at Age 11 (Print₂) (With 95% Confidence Intervals in Parentheses)

	A and E contribution to Print ₂ (with % of AE due to each effect)		Total % variance
	A	E	
Total variance	.55 (.36, .68)	.45 (.32, .64)	100
Proportion due to:			
Unique effects	.12 (.06, .19)	.07 (.03, .13)	19
Print ₁	22%	16%	
Unique effects	.07 (.02, .14)	.01 (.00, .02)	8
Read ₁	13%	2%	
Common effects	.09 (.05, .13)	.02 (.01, .04)	11
	16%	4%	
Specific effects	.27 (.09, .44)	.35 (.24, .53)	62
Print ₂	49%	78%	

Note. Total % of AE due to each effect is calculated by dividing the contribution of each effect by the total % due to AE. Total % variance is calculated by summing across each row.

environmental effects on age 11 independent reading due to each of the four components is also shown; accordingly, the percentages for each column sum to 100%.

As shown in Table 4, genetic influences accounted for 55% of the total variance in independent reading at age 11, of which .07, or 13%, reflected genetic influences unique to reading achievement at age 10 (calculation: $[\.95^2 \times \.28^2]/[\.55]$). Thus, genetic influences on reading achievement made a small but statistically significant impact on independent reading. The genetic variance in independent reading at age 11 was largely attributable to genetic influences *specific* to independent reading at that age (accounting for 49% of the genetic variance; calculation: $[\.27^2]/[\.55]$). There were smaller but significant effects of genetic influences specific to age 10 independent reading (accounting for .12, or 22%, of the genetic variance; calculation: $[\.79^2 \times \.44^2]/[\.55]$), and genetic influences common to independent reading and reading achievement (accounting for .09, or 16%, of the genetic variance; calculation: $2 \times [\.44 \times \.79 \times \.50 \times \.95 \times \.28]$).

We also examined the extent to which nonshared environmental influences on independent reading reflect earlier independent reading and reading achievement. Nonshared environmental factors accounted for 45% of the total variance in age 11 independent reading, and this was primarily attributable to nonshared environmental influences spe-

cific to age 11 independent reading. Specifically, nonshared environmental influences unique to age 10 independent reading accounted for .35, or 78%, of the nonshared environmental variance in age 11 independent reading (calculation: $[\.60^2]/[\.45]$). The remaining nonshared environmental variance in age 11 independent reading reflected nonshared environmental influences unique to age 10 independent reading (accounting for .07, or 16%, of the nonshared environmental variance; calculation: $[\.61^2 \times \.44^2]/[\.45]$) and nonshared environmental factors common to independent reading and reading achievement (accounting for .02, or 4%, of the shared environmental variance; calculation: $2 \times [\.44 \times \.61 \times \.38 \times \.32 \times \.28]$). Reading achievement at age 10 did not make a significant contribution to the nonshared environmental variance in age 11 independent reading.

Discussion

Educators want all children to read more, especially those with reading problems. But the evidence for this seemingly obvious causal direction is not clear-cut. The current study is the first to address the issue of the causality of independent reading for reading achievement using a genetically sensitive cross-lagged design. There were two key findings. First, reading achievement at age 10 predicted children's independent reading at age 11 above and beyond the effects of children's independent reading at age 10. By contrast, the cross-lagged relation between independent reading at age 10 and reading achievement at age 11 was not significant. Second, reading achievement partly influenced later independent reading via genetic mechanisms. We discuss these findings in turn.

Stability of Measures and Direction of Effects

We found that reading achievement at age 10 accounted for 8% of the variance in independent reading at age 11, over and above the effects of independent reading at age 10. The evidence for a predictive effect on early reading achievement on later independent reading mirrors previous findings (e.g., Cunningham & Stanovich, 1997; Lempinen et al., 2005; Quirk et al., 2009). By contrast, independent reading at age 10 did not predict reading achievement at age 11 after reading achievement at age 10 is taken into account. Thus, there was no evidence for significant bidirectional links between independent reading and reading

achievement. In interpreting these findings, we need to consider the stability of the variables across the 1-year span of the study. There was substantial cross-age stability for reading achievement: Age 10 reading achievement accounted for 81% of the variance in age 11 reading achievement, independent of the relation between reading achievement and independent reading at age 10. The extent to which children engaged in independent reading was also stable, although less so compared with reading achievement. Specifically, age 10 independent reading accounted for 19% of the variance in age 11 independent reading, over and above the relation between reading achievement and independent reading at age 10.

The stability of reading achievement is well known (e.g., Leppänen, Niemi, Aunola, & Nurmi, 2006; McCoach, O'Connell, Reis, & Levitt, 2006; Parrila, Aunola, Leskinen, Nurmi, & Kirby, 2005). For the current study, a key implication of this stability is that there is relatively less variance in reading achievement to be explained by other variables. Thus, the current results tell us that reading achievement, as assessed by the WRMT-R, is highly stable, and that the residual variance is due to factors other than independent reading, including error of measurement.

Etiology of the Relation Between Independent Reading and Reading Achievement

Our second aim was to clarify the etiology of the relation between reading achievement and independent reading. We found that individual differences in both reading achievement and independent reading were heritable and that approximately 50% of the genetic factors on these variables overlapped. This finding suggests that genes that contribute to reading in one context (as part of a formal psychometric assessment) probably contribute to reading in another (reading for pleasure). In addition, we found that individual differences in independent reading are heritable in part because they are a consequence of the child's earlier, genetically influenced reading skills. Specifically, 13% of the heritability of independent reading at age 11 reflected genetic influences on reading achievement at age 10. As described in the Introduction, this might arise through two processes: *active gene-environment correlations*, whereby the extent to which individuals seek out opportunities to read varies as a function of their genetically influenced reading skills, and *evocative gene-environment correlations*, whereby the

individual's genetically influenced reading skill influences the extent to which he or she receives opportunities and encouragement to read from others (e.g., parents and teachers). These processes, in isolation or combination, could contribute to the genetic links between early reading achievement and subsequent independent reading.

We were also interested in examining whether independent reading has a causal, environmentally mediated effect on reading achievement. Our results were negative in two respects. First, as described earlier, independent reading did not significantly predict reading achievement at age 11 controlling for reading achievement at age 10 at a phenotypic level. Second, environmental influences accounted for a relatively small proportion of the variance in independent reading. Moreover, the environmental effects were ascribed to the non-shared environmental component, which includes measurement error. The true nonshared environmental effect is likely to be smaller than the estimated effect because this component also included measurement error. Our results differ from Harlaar et al. (2007), who found evidence that shared environmental influences on independent reading at age 10 were significant and made a substantial contribution to the variance in word decoding at age 12, after controlling for early word decoding ability.

We did not find significant *shared* environmental effects for independent reading. The findings can be traced back to the DZ twin correlations, which were negligible for independent reading at both waves of assessment. This finding is puzzling because the simple genetic model predicts that DZ twin similarity should be at least half that of MZ twins. Very low or negligible DZ correlations imply that DZ twins are no more similar than two randomly paired children. This pattern can arise as a result of dominance, but our model fitting indicated that an ADE model did not fit the data as well as an AE model.

Another possible explanation for the negligible DZ correlations is that parent rating biases exaggerate the differences between DZ twins (contrast effects; Rietveld, Posthuma, Dolan, & Boomsma, 2003). In the case of DZ twins, it has been suggested that parents are keenly aware of the behavioral differences between their children and may use one sibling's behavior as an anchor for evaluating the behavior of other siblings (e.g., "she's always reading; her sister prefers to play tennis"). Parents of MZ twins, on the other hand, tend to highlight similarities among twins; an *assimilation*

effect (Plomin, Chipuer, & Loehlin, 1990). It is also possible that DZ twins themselves tend to highlight either real or perceived differences in reading motivation with their cotwin, when completing the MRQ (e.g., as a result of a desire to mitigate sibling competition). That is, if, in most cases, one twin regards his or her motivation to read as very different from his or her cotwin, then this may also partly account for the negligible DZ correlations. To explore these possibilities, we computed the twin correlations separately for parent ratings of independent reading and children's ratings on the MRQ. They were remarkably similar, both being close to zero for DZ twin resemblance. These findings suggest the possibility that the DZ correlations reflect real or perceived differences in the reading motivation of DZ twins, as rated both by caregivers and twins themselves. Arguably, however, this can only provide a partial explanation, as we might still expect a pattern of weak (but not zero) DZ correlations. The pattern of DZ correlations requires further investigation in larger twin samples and with other measures.

Limitations

Several limitations of the present study should be noted. The first concerns our measure of independent reading. The use of a composite measure can be considered a strength due to the increased reliability that can result from combining multiple measures. Nonetheless, there are limitations to using parent and child reports. In particular, respondents may tend to skew their responses toward socially desirable answers—overreporting reading frequency or motivation to read. Additionally, both parent and child reports may be subject to inaccurate or incomplete recall. Manipulation of the conditions under which self-reporting is conducted (e.g., asking for children's independent reading over a recent and specific time frame, such as the past week) may produce more accurate methods for measuring children's independent reading.

A second limitation is that our measure of independent reading may have omitted important, causally relevant components of independent reading. For example, we know nothing about the types of books the children were reading. Topping, Samuels, and Paul (2007) have suggested that independent reading may have a causal effect on reading development, but only if the types of texts are sufficiently challenging, being slightly above the reader's current independent reading

level. If the books that children read during their leisure time are mostly too easy, then their reading development is unlikely to benefit significantly. Conversely, if books are too hard (e.g., when children are still at the point of acquiring basic reading skills), then advances in reading skill are also likely to be slow. This scenario implies a causal effect that is contingent on the child's ability level and the difficulty level of the books they tend to read during their leisure time. Future work should use measures of independent reading that provide information on the nature as well as the frequency of children's independent reading.

A third limitation concerns the modeling approach that we used, which assumes, incorrectly, that all variables are measured without measurement error. To the extent that measurement error is present, relations will tend to be attenuated. Compounding this problem, if the reliability is not equivalent for both variables, the causal paths may be inaccurate estimates of the true relations. It is likely that the reliability of our independent reading measure was lower than that for reading achievement, and that this partly accounts for our finding that independent reading does not predict subsequent reading achievement. To reduce this problem, future studies should use latent variable models that attempt to estimate measurement error and remove it from the estimates of the relations between reading achievement and independent reading.

Finally, as noted already, the current study was limited to ages 10 and 11. It is possible that the relation between reading achievement and independent reading varies across time. For example, it has been found among high school students that poor comprehenders are just as likely as good comprehenders to say that they read frequently for pleasure, suggesting that other variables besides reading ability may become important in determining independent reading once some threshold level of reading skill has been reached (Spear-Swerling, Brucker, & Alfano, 2010; Strommen & Mates, 2004). Thus, the results apply only to individuals in late elementary school.

Implications and Directions for Future Research

At first blush, our findings may appear to present a disappointing picture to educators and families. Children who inherit genetic variations that favor reading development are more likely to engage in independent reading, which is also

substantially heritable. But, somewhat surprisingly, given these results, it seems that independent reading does not improve children's relative reading achievement. Instead, we found that individual differences in reading achievement are quite stable across the 1-year period examined in this study; that is, better readers at age 10 also tended to be better readers at age 11, regardless of how much independent reading they did. We would argue, however, that our findings do not diminish the importance of encouraging independent reading. As described in the Introduction, intervention studies have shown that increasing print exposure can lead to reading gains (e.g., Reis et al., 2007; Reis et al., 2008). If one considers that children have a range of potential reading trajectories, and that independent reading contributes to stronger reading development, then in the absence of any independent reading, reading skills are less likely to develop optimally. When children do engage in reading, they will tend to develop closer to their optimal trajectory.

What the current results do suggest is that promoting independent reading will not, on its own, improve reading achievement among all children. The evidence for a genetically mediated effect of reading achievement on independent reading is important, as it raises the possibility that the development of reading difficulties partly arises because the child's genetic predispositions influence the extent to which they are exposed to print. Consequently, interventions that seek to increase independent reading should consider genetic niche-picking influences. For example, if individuals seek out opportunities to read based partly on their genetically influenced reading skills (an *evocative gene-environment correlation*), increasing reading exposure alone may not be sufficient, particularly for children who are at genetic risk for reading difficulties. Instead, intervention efforts may require a two-pronged approach: tackling the symptoms of reading difficulties, which might otherwise lead to the avoidance of reading opportunities, and providing opportunities to increase children's levels of independent reading. An intriguing aspect of the findings is that some of the genes influencing independent reading were unrelated to reading skill. Speculatively, these genes may influence personality traits such as self-directedness, curiosity, and independence. Delineating achievement-independent genetic influences on independent reading, and how they interact with environmental factors, may provide further insights into how

we can improve interventions designed to increase levels of independent reading among school-age children.

Future research on the role of independent reading should consider more complex models between reading achievement and independent reading than we have done. For example, it is possible that independent reading directly influences some aspects of reading skill, but not others. As described in the Introduction, Leppänen et al. (2005) found that word recognition showed a bidirectional relation with book reading, whereas reading comprehension did not. Using a composite measure of reading, as we did, may have obfuscated evidence for direct associations between independent reading and reading skill. In addition, it is possible that the effects of independent reading are indirect, being mediated by vocabulary, background knowledge, or other factors. That is, independent reading may have a distal, rather than a proximal, causal influence on reading development. Finally, as noted earlier, our study only examined reading from ages 10 to 11; it is possible that independent reading may have stronger effects on reading achievement at earlier or later ages. These three scenarios are not mutually exclusive. For example, it may be the case that independent reading has a direct effect on word recognition in the early stage of learning because it facilitates the development of high-quality lexical representations of words. Later, as "reading for meaning" becomes more important, independent reading may promote the addition of new information to a reader's background knowledge (e.g., informational elements such as facts, events, or concepts, or new relations between elements that the reader already knew), and this background knowledge may mediate the effects of independent reading on subsequent reading gains. More fine-grained research, based on multiple time points, may help to resolve the causal paths linking independent reading and reading skills.

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