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Reading exposure: a (largely) environmental risk factor with environmentally-mediated effects on reading performance in the primary school years

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Background: It is widely believed that there are reciprocal links between reading achievement and reading exposure: children who read more do better at reading, and reading achievement itself promotes reading. We tested the hypotheses that these links arise because children's genetically influenced reading performance is correlated with their leisure-time reading exposure, and reading exposure, in turn, may have an environmentally mediated effect on later reading performance. **Method:** The sample consisted of 3039 twin pairs from the UK Twins Early Development Study (TEDS). Reading exposure was assessed at age 10 using the Author Recognition Test (ART). Reading performance was assessed at ages 7 and 12 using the Test of Word Reading Efficiency (TOWRE). **Results:** ART scores were moderately correlated with TOWRE scores at ages 7 and 12. Shared environmental variance in 7-year TOWRE performance accounted for most of the contribution made by 7-year TOWRE scores to the prediction of 10-year ART scores. Genetic influences on ART scores were modest, but this genetic variance almost completely reflected genetic variance in 7-year TOWRE scores. After controlling for genetic and environmental influences that overlapped between 7-year TOWRE and 10-year ART scores, there was evidence for a separate link between 10-year ART and 12-year TOWRE that was due to shared environmental influences. **Conclusions:** Genetic influences on early reading achievement contribute to later propensities to seek out reading experiences that might, in turn, reciprocally influence reading achievement through shared environmental paths. **Keywords:** Reading exposure, reading achievement, twins, genetics, environmental factors. **Abbreviations:** ART, Author Recognition Test; TOWRE, Test of Word Reading Efficiency; TEDS, Twins Early Development Study.

It is widely believed that in order to become a fluent and proficient reader, children need extended reading practice (Stanovich, 1986). Exposure to books and reading is a key part of educational curricula and remedial literacy programmes (e.g., the UK National Literacy Strategy), as well as wider social initiatives that try to instil interest and engagement in reading among children (e.g., *The Big Read*, British Broadcasting Corporation, 2003). The current study examined the relationship between reading achievement and reading exposure in the primary school years, using a genetically sensitive design.

The association between reading achievement and reading exposure has been scrutinised from several angles. One is that reading achievement encourages more reading. On this view, the development of fluent and efficient reading facilitates the accumulation of reading practice, whereas reading difficulties are more likely to result in unrewarding early reading experiences that lead to less involvement in reading-related activities (Stanovich, 1986). A complementary view is that greater reading experience facilitates the development of reading (Leppänen, Kaisa, & Nurmi, 2005). For example, a substantial amount of reading practice is required to develop automatised word-level skills, which in turn facilitate fluent and efficient reading. Longitudinal studies have demonstrated the importance of both directional links (e.g., Cipielewski & Stanovich, 1992; Cunningham & Stanovich, 1997; Oakhill & Cain, 2003; Organisation for Economic Co-operation and Development, 2003), with one study, using a cross-lagged design, suggesting that reading achievement has temporal precedence over reading exposure during the early school years (Leppänen et al., 2005). That is, children's reading skills contribute to their subsequent out-of-school reading habits, rather than vice versa.

One neglected factor in previous research is the potential contribution of genes and environmental factors to the links between reading achievement and reading exposure. There is robust evidence from both twin and adoption studies that individual differences in reading abilities are substantially heritable (Pennington & Olson, 2005). Less well known, but of special interest to this study, is that indices of reading experience are also partly due to genetic influences. For example, in the Colorado Learning Disabilities Research Center (CLDRC) sample of 8- to 18-year-old twins, reading exposure was assessed using a Title Recognition measure that required participants to identify popular book titles

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that were randomly interspersed with foils (made-up title names) (Olson & Byrne, 2005). The correlation between Title Recognition scores for monozygotic (MZ) twins ($r_{MZ} = .55$) was approximately double the correlation between scores for dizygotic (DZ) twins ($r_{DZ} = .24$). Because MZ twins are genetically identical, this finding implies that genetic influences contribute to individual differences in reading exposure, as assessed by Title Recognition, whereas shared environmental influences are minimal.

The evidence for genetic and environmental influences on reading exposure provides a window on the links between reading exposure and achievement. It is implausible that genes code for children's reports of their reading experience in any direct manner. However, it could be the case that genetic influences on individual differences in reading exposure reflect genetic influences on other aspects of development, including reading ability. For example, children who are at genetic risk for reading difficulties may be less likely to engage in reading outside school, creating an association between reading exposure and reading achievement at a phenotypic level.

Environmental factors may also contribute to the association between reading exposure and reading achievement. One scenario is that reading exposure and reading achievement reflect a common set of environmental risk factors. The extent to which a child reads is likely to depend, *inter alia*, on their access to reading materials, the extent to which these materials are developmentally appropriate, and attitudes towards reading in the home – factors that may also be correlated with reading achievement. Another possibility is that reading exposure has an environmentally mediated effect on reading achievement. That is, reading exposure influences reading performance independent of children's heritable characteristics, for reasons due to factors external to the child (e.g., family or school influences).

No published study, to our knowledge, has examined the relationship between reading exposure and reading achievement in a genetically informative design. The goals of the present study were two-fold. First, we examined the genetic and environmental influences contributing to the association between reading achievement assessed at age 7, and later reading exposure, assessed at age 10. We had no previous studies to guide us, but we hypothesised that the genetic influences on early reading also contributed to variance in later reading exposure. Second, we studied the genetic and environmental relationships between reading exposure at age 10 and later reading achievement at age 12. We were particularly interested in determining whether reading exposure predicts later reading achievement independent of the child's early reading achievement, and whether this link is environmental in nature. Evidence for an environmental link between reading experience and later reading achievement is consistent with an interpretation that environmental influences that contribute to variance in reading exposure partly explain later variance in reading achievement, independent of genotypic factors that influence reading.

Method

Sample

Analyses were based on 3039 twin pairs: 1116 MZ pairs (470 male, 646 female), 968 same-sex dizygotic DZ pairs (449 male, 519 female) and 955 opposite-sex DZ pairs. These twins were a subsample of the Twins Early Development Study (TEDS), a longitudinal study of twins ascertained from population records of live twin births in England and Wales (Oliver & Plomin, 2007). Zygosity was determined using polymorphic DNA markers (Freeman et al., 2003) or a parent-report measure of twin similarity (Price et al., 2000). Informed consent was obtained from all families at each wave of assessment.

Measures

Reading exposure. Reading exposure was assessed using an online adaptation of the Author Recognition Test (ART; Stanovich & West, 1989). Children were shown a series of names and asked to identify the names of people who wrote books for children by checking 'Yes' or 'No'. Instructions were presented in both text and audio forms. To circumvent the problem of respondents making socially desirable responses, we used the same method as Stanovich and West (1989) of mixing equal numbers of foils with real titles and authors. Respondents who are unfamiliar with the data would be expected to make more false positive responses.

In total, there were 21 'real' author names and 21 foils (listed in the Appendix). Real author names were taken from online lists of popular authors for children between 6 and 13 years. Foil names were taken at random from a register of children who were in the same class as the first author in the sixth grade. Scoring was determined by taking the proportion of author names checked and subtracting the proportion of foils checked. ART scores were normally distributed. Test–retest reliability of the ART across two weeks in a subsample of 37 twin pairs in TEDS was .96.

Reading ability. Reading ability was assessed by a telephone adaptation of the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) at ages 7 and 12. The TOWRE is a timed measure of fluency and accuracy in word reading, as assessed by reading aloud real words and pronounceable nonwords. Raw scores were summed and standardised on the basis of scores from the whole sample. TOWRE scores were normally distributed at both waves of assessment.

Mathematics. Mathematics was assessed at age 12 using a web-based adaptation of the National Foundation for Educational Research (NFER) Mathematics

Series (Clausen-May, Vappula, & Ruddock, 1999), a series of graded tests of numerical and non-numerical skills that tie in with the UK National Curriculum guidelines for mathematics (see Kovas, Haworth, Petrill, & Plomin, in press, for more details). Raw scores were summed and standardised on the basis of scores from the whole sample. Mathematics scores were normally distributed.

Analyses

Our analyses were based on standard quantitative genetic principles for twin data. The phenotypic (observed) variance within each variable and the covariance between variables can be attributed to additive genetic variance and environmental variance. Additive genetic (A) variance reflects variation in genotypes transmitted from parents to offspring. Environmental variance is divided into two parts: shared environmental variance (C), reflecting variation in non-genetic influences that affect all persons within a family to the same degree (e.g., family socioeconomic status (SES)), and nonshared environmental variance (E) (e.g., differential educational experiences), reflecting variation in environment influences that cause individual family members to differ from one another. These three variance sources can be separately estimated because shared environmental influences that contribute to familial resemblance are assumed to affect MZ and DZ twins equally, whereas resemblance due to genetic influences varies as a function of zygosity. That is, MZ twins are genetically identical; DZ twins share on average 50% of their segregating alleles (Plomin, DeFries, McClearn, & McGuffin, 2001).

Our analyses used a Cholesky decomposition framework. This approach may be regarded as factor model, in which each of the observed variables Pj, $j = 1\ldots m$ has a corresponding factor Fj. Each factor Fj may influence only variables Pj to Pm (Neale & Cardon, 1992). When genetically sensitive designs are used (as in the current study), it is possible not only to examine the phenotypic contribution of a predictor, but also the genetic and environmental contributions. In the current analyses, 7-year TOWRE, 10-year ART, and 12-year TOWRE were entered sequentially. Variance–covariance matrices derived from raw age- and sex-corrected (McGue & Bouchard, 1984) data were used in these analyses. We estimated model parameters and 95% confidence intervals (CI) in the computer program *Mx*(Neale, Boker, Xie, & Maes, 2002). Parameter estimates and confidence intervals were estimated by full-information maximum likelihood (FIML), which minimises bias resulting from missing data.

Results

Phenotypic links

At a phenotypic level, 10-year ART scores were moderately correlated with TOWRE scores at age 7 ($r_p = .40$; CI: .36–.45) and at age 12 ($r_p = .33$; CI: .28–.37). TOWRE scores showed strong stability from 7 to 12 years ($r_p = .67$; CI: .64–.69).

Twin correlations

Cross-twin, within-trait (intraclass) correlations provide a preliminary impression of the relative importance of genetic and environmental influences to the variance in a phenotype. For ART scores, the average MZ and DZ correlations were highly similar ($r_{MZ} = .58$, CI: .54–.62; $r_{DZ} = .53$, CI: .48–.57), indicating that that heritability of ART scores is relatively modest whereas shared environmental influences are substantial. The TOWRE at ages 7 and 12 showed a different pattern: MZ twins consistently resembled each other to a greater extent than DZ twins ($r_{MZ} = .75$ and .78 at ages 7 and 12; $r_{DZ} = .42$ and .43), providing evidence for genetic influences. Nevertheless, the DZ correlations were greater than half the MZ correlations. This pattern indicates that genetic influences do not account completely for twin similarity among DZ twins, and implies that twin resemblance (both in MZ and DZ pairs) must also partly reflect shared environmental influences. Further analyses comparing male and female twin correlations and same-sex DZ and opposite-sex DZ correlations provided no evidence for either qualitative or quantitative sex differences in the trends described above (details available from the corresponding author); therefore, all analyses were based on the full sample.

To what extent do individual differences in ART and TOWRE scores reflect genetic and environmental factors?

In a second stage of analysis, we examined the data using a genetic Cholesky decomposition model. In this model, shown in Figure 1 for one member of a twin pair, latent factors represent additive genetic (A), shared environmental (C), and nonshared environmental (E) influences on NC scores at age 7 and ART and Mathematics scores at age 10. The first set of latent factors, A_1, C_1, E_1, represent A, C and E effects that contribute to the total phenotypic variance in 7-year TOWRE scores, as well as A, C and E effects that contribute to the *shared* variance between 7-year TOWRE, 10-year ART, and 12-year TOWRE scores. The second set of latent factors, A_2, C_2, E_2, represent A, C and E effects that contribute to variance in 10-yr ART scores and the covariance between 10-yr ART scores and 12-yr TOWRE scores, independent of A, C, and E effects that influence 7-yr TOWRE scores. The third set of latent factors, A_3, C_3, E_3, represent residual A, C, and E effects on 12-year TOWRE scores. A similar trivariate model was used to examine the relationships between NC scores at age 7 and ART and Mathematics scores at age 10.

When the path coefficients in the Cholesky decomposition model are standardised, the proportion of the total phenotypic variance in each measure that is due to genetic influences can be estimated by summing the squared path coefficients from the latent genetic factors loading on that measure. Thus,

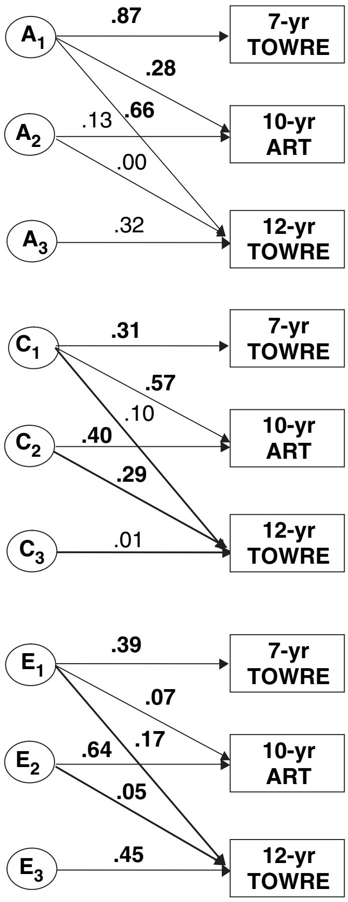

Figure 1 Standardised path coefficients (unsquared) from trivariate Cholesky decomposition of TOWRE scores at 7, ART scores at 9, and TOWRE scores at 12

for example, the heritability of ART scores is .10 (CI: .05–.19), which is the sum of the squared path coefficients for A_1 ($.28^2 = .08$) and A_2 ($.13^2 = .02$). Similar calculations can be used to estimate the proportion of phenotypic variance in each measure due to shared environmental influences and nonshared environmental influences; thus, .49 (CI: .42–.53) of the variance in ART scores is due to shared environmental influences, and .41 (CI: .38–.45) is due to nonshared environmental influences and measurement error. For TOWRE scores, there was evidence for substantial heritability at both age 7 (.75, CI: .68–.83) and at age 12 (.67, CI: .59–.72). Shared environmental influences were modest but significant (.10; CI: .05–.19 at age 7; .10, CI: .05–.17 at age 12), and nonshared environmental influences, including measurement error, were moderate (.15; .14–.17 at age 7; .24, CI: .22–.26 at age 12).

Does the variance in 10-year ART scores partly reflect genetic and environmental influences on 7-year TOWRE scores?

Our first aim was to examine the extent to which genetic and environmental influences contribute to the association between reading achievement at age 7 and reading exposure at age 10. The key data come from the loadings of 10-year ART scores on the first set of latent factors, A_1, C_1, E_1, which link 10-year ART scores to 7-year TOWRE scores. As shown in Figure 1, the path from genetic influences on 7-year TOWRE scores (A_1) to ART scores is significantly greater than zero (.28; CI: .22–.34), indicating that the heritability of ART scores partly reflects genetic effects that influence earlier reading achievement. Shared environmental influences affecting 7-year TOWRE scores also contribute to variance in 10-year ART scores (.57; CI: .41–.69). The covariation of nonshared environmental influences on 7-year TOWRE scores and 10-year ART scores is weaker but significantly greater than zero (.06; CI: .03–.11).

After accounting for variance shared with 7-year TOWRE scores, do genetic and environmental influences on 10-year ART scores contribute to variance in 12-year TOWRE scores?

Our second aim was to examine the genetic and environmental links between 10-year ART and 12-year TOWRE scores independent of their genetic and environmental links with 7-year TOWRE scores. Data on this issue are provided by the loadings of A_2, C_2, E_2 in Figure 2. The loadings of A_2 on 10-year ART (.13, CI: .00–.33) and 12-year TOWRE (.00, CI: .00–.52) scores are not significantly greater than zero, indicating that there are no significant genetic sources of variance on 10-year ART scores or the covariance between 10-year ART and 12-year TOWRE scores after the genetic overlap between these measures with 7-year TOWRE scores has been taken into account. In contrast, the second shared environmental factor (C_2) shows moderate and significant loadings on 10-year ART scores (.40, CI: .14–.54) and 12-year TOWRE scores (.29, CI: .13–.35). The second nonshared environmental factor loadings from E_2 has significant and moderate loadings on 10-year ART scores (.64, CI: .62–.66), but small and insignificant loadings on 12-year TOWRE scores (.05, CI: .00–.12).

These results can be re-expressed in terms of the proportion of variance shared between measures and specific to each measure. The squared path estimates are listed in Table 1. The first column indicates the total proportion of variance due to A, C or E, for each measure. The subsequent columns show, for each source of variance, how this variance is split into: (1) influences contributing to 7-year TOWRE assessments that also affect 10-year ART scores and 12-year TOWRE (A_1, C_1, E_1); (2) influences shared between 10-year ART and 12-year TOWRE scores independent of 7-year TOWRE scores (A_2, C_2, E_2); and (3) influences specific to 12-year TOWRE scores (A_3, C_3, E_3).

As shown in the top panel of Table 1, genetic influences that account for variance in 7-year TOWRE scores account for almost all of the genetic variance in 10-year ART scores and 12-year TOWRE

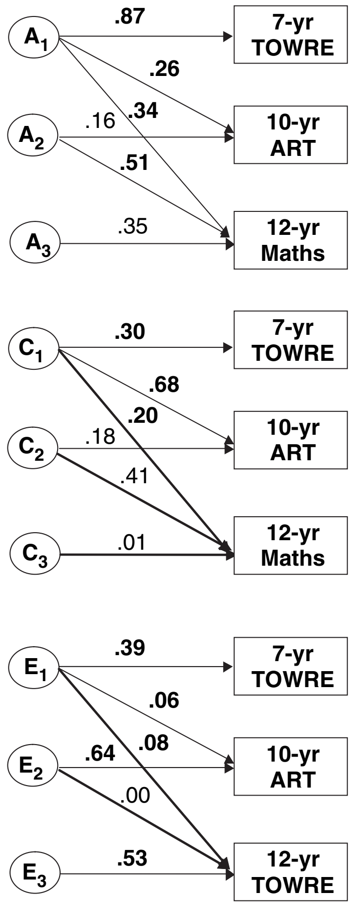

Figure 2 Standardised path coefficients (unsquared) from trivariate Cholesky decomposition of TOWRE scores at 7, ART scores at 9, and Mathematics scores at 12

scores. Specifically, genetic influences on 7-year TOWRE scores account for .08, or 80% of the total genetic variance in 10-year ART scores ($a^2 = .10$), and .44, or 66% of the total genetic variance in 12-yr TOWRE scores ($a^2 = .67$). Genetic variance in 10-year ART scores that is independent of genetic variance in 7-year TOWRE scores is not significantly greater than zero, and this source of variance does not contribute significantly to genetic variance in 12-year NC scores. Additionally, there is no evidence for a significant residual source of genetic variance on 12-year TOWRE, independent of genetic variance in 7-year TOWRE and 10-year ART scores.

Shared environmental influences (middle panel of Table 1) show a different picture. Of the shared environmental contribution to 10-year ART scores ($c^2 = .49$), .33, or 67%, reflects shared environmental influences that contribute to variance in 7-year TOWRE scores. In contrast, shared environmental influences on 7-year TOWRE scores only account for .01, or 10%, of the total shared environmental variance in 12-yr TOWRE scores ($c^2 = .10$). Although there is significant overlap between the shared environmental factors on 7-year TOWRE and 10-year ART scores, .16, or 33%, of the shared environmental variance in 10-year ART scores is independent of 7-year TOWRE, and this second source of shared environmental influence on 10-year ART scores contributes significantly to the variance in 12-year TOWRE scores. Specifically, .09, or 90%, of the shared environmental variance in 12-year TOWRE scores reflects shared environmental

Table 1 Squared path coefficients from trivariate Cholesky decomposition of 7-year TOWRE scores, 10-year ART scores and 12-year TOWRE scores (total % of variance explained by A, C, and E in first column; these can be calculated by summing the values in each row)

Additive genetic influences	a^2	A_1 Influences shared between all three measures	A_2 Influences independent of 7-year TOWRE	A_3 Influences independent of 7-year TOWRE and 10-year ART
7-yr TOWRE	.65 (.68–.80)	.75 (.68–.89)		
10-yr ART	.10 (.05–.19)	.08 (.05–.12)	.02 (.00–.10)	
12-yr TOWRE	.67 (.59–.72)	.44 (.37–.49)	.13 (.00–.29)	.10 (.00–.27)
Shared environmental influences	c^2	C_1 Influences shared between all three measures	C_2 Influences independent of 7-year TOWRE	C_3 Influences independent of 7-year TOWRE and 10-year ART
7-yr TOWRE	.09 (.05–.16)	.09 (.05–.16)		
10-yr ART	.49 (.42–.53)	.33 (.17–.48)	.16 (.03–.30)	
12-yr TOWRE	.10 (.05–.17)	.01 (.00–.06)	.09 (.01–.13)	.00 (.00–.10)
Nonshared environmental influences	e^2	E_1 Influences shared between all three measures	E_2 Influences independent of 7-year TOWRE	E_3 Influences independent of 7-year TOWRE and 10-year ART
7-yr TOWRE	.15 (.14–.17)	.15 (.14–.17)		
10-yr ART	.41 (.38–.45)	.00 (.00–.01)	.41 (.38–.44)	
12-yr TOWRE	.23 (.25–.29)	.03 (.02–.04)	.00 (.00–.01)	.221 (.19–.23)

influences on 10-year ART scores. There is no evidence for a significant residual source of shared environmental variance on 12-year TOWRE that is independent of shared environmental variance in 7-year TOWRE and 10-year ART scores.

Estimates for nonshared environmental influences, including measurement error, are given in the lower panel in Table 1. The results indicate that nonshared environmental influences are largely measure-specific.

In a final analysis, we examined the specificity of the genetic and environmental links between reading exposure and later reading achievement. This step may be revealing because neither genes nor environmental influences on reading and literacy experiences are likely to operate independently. Reading achievement at age 12 was substituted with our measure of mathematics ability at 12 years. Results from a Cholesky decomposition analysis of 7-year TOWRE, 10-year ART, and the 12-year measure of Mathematics are shown in Figure 2. The key features of this analysis are the genetic and environmental factor loadings on 12-year Mathematics. Similar to the findings for 12-year TOWRE scores (Figure 1), genetic and nonshared environmental influences on 7-year TOWRE scores make a significant contribution to the variance in 12-year Mathematics (.34; CI: .28–.39, and .08; CI: .05–.11, from E_1, respectively). There is also significant overlap between shared environmental influences on 7-year TOWRE and 12-year Mathematics (.20; CI: .06–.36). Independent of the genetic influences on 7-year TOWRE there is evidence for a second genetic factor that loads significantly on 12-year Mathematics but not 10-year ART. Conversely, independent of the shared environmental influences on 7-year TOWRE, there is evidence for a second shared environmental factor that loads significantly on 10-year ART but not 12-year Mathematics. Nonshared environmental influences independent of 7-year TOWRE are measure-specific.

Discussion

Anecdotal and empirical evidence suggest that reading exposure both predicts and is predicted by reading performance. This study extends previous work by bringing a genetic perspective to bear on the relationships between reading exposure and reading achievement.

Our first set of findings concerned the links between 7-year word recognition performance and 10-year reading exposure and links between 10-year reading exposure and 12-year word recognition performance. TOWRE scores at age 7 were moderately correlated ($r_p = .40$) with 10-year ART scores, indicating that better word recognition performance predicts greater exposure to books and reading in the elementary school years. We predicted that this relationship would be due to genetic influences, reasoning that children who are at genetic risk for reading difficulties may be less likely to engage in reading outside school. Our results partly confirmed this hypothesis. First, genetic influences accounted for approximately 10% of the variance in ART scores, suggesting that heritable characteristics of the child influence the child's reading exposure, and second, breaking down the heritability of ART scores into genetic influences shared with 7-year TOWRE and those specific to the ART shows that 80% of the heritability of the ART was attributable to genetic effects that also influence 7-year TOWRE. That is, genes affect reading exposure indirectly, via reading achievement.

The genetically mediated effects of 7-year TOWRE on 10-year ART may arise due to *active gene–environment processes*, whereby an individual's (genetically influenced) traits are associated with the environmental niches selected by the individual. For example, individuals who have difficulties in learning to read may read less compared to a child with a higher proportion of genes that positively influenced reading skill. In turn, their lack of exposure to reading materials may further interfere with their acquisition of reading skills. Another way in which genetic variation on earlier reading achievement may influence subsequent reading experience is through *evocative gene–environment processes*, referring to the tendency for individuals to evoke reinforcing reactions from others in response to the individual's genetic predispositions. For example, a child who enjoys and excels at reading may be more likely to receive books from parents and relatives. These transactional processes, in isolation or combination, could contribute to the genetic links between early reading achievement and subsequent reading exposure and reading achievement.

Notwithstanding this finding, it should be noted that the heritability of ART scores is modest and most of the variance in 10-year ART accounted for by 7-year TOWRE scores (.16) was due to shared environmental influences (.33, or 11%, of the variance in ART). That is, the extent to which children engage in reading largely reflects variation in the environments they experience, and at least some of this environmental variance reflects environmental influences on earlier word recognition. For example, children attending a poor or 'underperforming' school may be less likely to receive high-quality reading instruction and to receive fewer opportunities to engage in extended reading practice. That is, some pervasive risk factor or set of risk factors shapes both the child's reading performance and their subsequent reading experiences, independent of the child's genetic propensities. This finding is consistent with an emerging literature indicating that shared environmental influences are consequential for children's reading development (e.g., Petrill, Deater-Deckard, Schatschneider, & Davis, 2005; Petrill et al., 2006).

The finding that the heritability of 10-year ART is relatively modest is noteworthy in itself, as it implies that reading exposure at 10, as assessed by the ART, is primarily an environmental risk factor. Specifically, approximately 50% of the variation in ART scores was due to shared environmental factors, and a further 40% was due to nonshared environmental factors (and measurement error). In this regard, the results differ from the CLDRC sample (Olson & Byrne, 2005). The Title Recognition test used in the CLDRC was similar in format to the ART, but the twin correlations from the CLDRC suggest that approximately two-thirds of the variance in a Title Recognition test was due to additive genetic influences. Age differences may be one factor that contributed to the discrepancies in results between studies. The current study examined reading experience in participants at 10 years, with only minimal spread around this age. In contrast, the CLDRC sample ranged in age from 8 to 18 years. The finding that reading experience shows higher heritability in the older CLDRC sample is consistent with life-span theories which predict that individuals actively seek out experiences that are correlated with their genotypes, and that this propensity increases from early childhood through adulthood (Scarr & McCartney, 1983). For example, as children get older they are more likely to choose whether or not to borrow books from the library or to spend their pocket-money on books as compared with younger children, whose reading experience may be constrained more strongly by parental literacy practices and attitudes.

After taking into account the effects of genetic and environmental influences that were common to 7-year TOWRE performance and scores on the ART at age 10 and the TOWRE at age 12, there was evidence for a separate link between 10-year ART and 12-year TOWRE that was due to shared environmental influences. That is, independent of genetic and environmental influences on children's genetic propensities that contribute to individual differences in early word recognition performance, reading experience, as assessed by the ART, exerts an environmentally mediated effect on later word recognition performance. Furthermore, this shared environmental link was specific to the relationship between 10-year ART and 12-year TOWRE performance: there was no evidence for a similar shared environmental link between 10-year ART and 12-year Mathematics. This finding suggests that reading exposure partly contributes to children's reading development via environmentally mediated processes, and that this effect is specific to reading or word recognition, rather than to children's general academic development.

Limitations of our measures should be noted. The ART is a relatively indirect measure of reading exposure, and we cannot rule out that children were able to correctly identify some authors on the basis of their general world knowledge rather than through reading experience. Replication of the current findings using multiple measures of reading experience (e.g., questionnaires, self-report diaries), and for multiple aspects of reading (e.g., reading comprehension, spelling), is desirable.

Thinking about reading achievement and reading experience also raises a 'chicken-or-egg' question: does reading achievement initially foster greater reading experience (i.e., achievement → reading exposure) or does extended reading practice initially facilitate the development of reading skill (i.e., reading exposure → achievement)? As noted in the introduction, there is preliminary evidence that the predictive relationship between reading achievement and subsequent reading exposure in the early years of school is stronger than the predictive relationship between reading exposure and subsequent reading achievement (Leppänen et al., 2005). In this study, we did not have a measure of reading exposure at age 7. Had we done so, it would have been interesting to examine the cross-lag effects of reading exposure and reading achievement at age 7 on our 10- and 12-year measures in order to gain insight into the causal ordering of achievement and reading exposure in early reading development.

Notwithstanding these caveats, the current findings have theoretical and practical implications. Children with early reading difficulties and delays often have continued difficulties in reading, whereas children who do better in reading tend to maintain this advantage (Scarborough, 2001). Our findings suggest that this stability partly reflects genetic variation on early reading achievement that lead some children to read more and perform better, and others to be less likely to engage in out-of-school reading and perform less well. Additionally, our findings document that reading exposure has environmentally mediated effects on children's later reading performance beyond genetic transmission. From a practical standpoint, these findings suggest, first, that improving levels of early reading achievement may go some way towards fostering both engagement in reading and subsequent reading achievement, and, second, that fostering engagement in reading may weaken the cycle of poor reading achievement that can arise when children do not spend time reading.

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Appendix

Appendix: Author Recognition Test (ART)

Authors	Foils
Brian Jacques	Rosalind Miller
Michael Rosen	Barbara Braxton
Jacqueline Wilson	Marielle Van Veen
Anne Fine	Bob Ackers
Lemony Snicket	John Shelmadine
Anthony Horowitz	Tom Oxenbury
Robert Swindells	Kelly Mallows
J.K. Rowling	Faye Coomber
Raymond Briggs	Neil Smith
Terry Deary	P.E. Davies
Allan Ahlberg	Pamela Yeadon
Roald Dahl	Myra Kersner
Michael Morpurgo	Leighton Jell
Terry Pratchett	Michelle Barker
Philip Pullman	Jayne Chandler
Roger McGough	Helen Andrews
Lynne Reid Banks	Celia Eccleshare
C.S. Lewis	Stephanie Pursglove
Penelope Lively	Eric Lawson
Gillian Cross	C.I. James
Dick-King Smith	John Klosterman