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Expanding the environment: Gene × School-Level SES Interaction on Reading Comprehension

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Abstract

Background—Influential work has explored the role of family socioeconomic status (SES) as an environmental moderator of genetic and environmental influences on cognitive outcomes. This work has provided evidence that socioeconomic circumstances differentially impact the heritability of cognitive abilities, generally supporting the bioecological model in that genetic influences are greater at higher levels of family SES. The present work expanded consideration of the environment, using school-level SES as a moderator of reading comprehension.

Methods—The sample included 577 pairs of twins from the Florida Twin Project on Reading, Behavior and Environment. Reading comprehension was measured by the Florida Comprehensive Achievement Test (FCAT) Reading in third or fourth grade. School-level SES was measured by the mean Free and Reduced Lunch Status (FRLS) of the schoolmates of the twins.

Results—The best-fitting univariate G × E moderation model indicated greater genetic influences on reading comprehension when fewer schoolmates qualified for FRLS (i.e., "higher" school-level SES). There was also an indication of moderation of the shared environment; there were greater shared environmental influences on reading comprehension at higher school-level SES.

Conclusions—The results supported the bioecological model; greater genetic variance was found in school environments in which student populations experienced less poverty. In general, "higher" school-level SES allowed genetic and probably shared environmental variance to contribute as sources of individual differences in reading comprehension outcomes. Poverty suppresses these influences.

Keywords

Reading comprehension; G × E interaction; school-level SES; bioecological model

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The relation between socioeconomic status (SES) and cognitive ability and academic outcomes has been investigated for several decades (e.g. Coleman et al. 1966), finding negative correlations of cognitive and achievement outcomes with SES. Meta-analyses synthesizing the many studies indicate that the average correlational effect sizes between

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SES and cognitive/academic skills are around .30 (Sirin, 2005; White, 1982). While these studies have consistently found lower cognitive and academic achievement for more impoverished individuals, the focus has been limited to mean differences as a function of SES.

Fairly recently, influential work has begun exploring the role of family SES as an environmental moderator of genetic and environmental influences on general cognitive ability. This work has provided evidence that socioeconomic circumstances differentially impact the heritability of cognitive abilities. In a seminal article, Turkheimer and colleagues (2003) found a gene × environment (G × E) interaction in 7-year old children such that shared environmental influences not associated with those on SES were greater at lower levels of SES whereas genetic influences not associated with those on SES were greater at higher levels of SES. Subsequent studies have found similar patterns of results for cognitive outcomes at both earlier (2-years old; Tucker-Drob et al., 2011) and later stages of development (17-years old; Harden, Turkheimer, & Loehlin, 2007). Moderating effects of SES were also observed in a recent longitudinal study that measured cognitive ability multiple times from the ages of 2-14; however, a pattern of shared environment × SES rather than gene × SES was the most consistent moderating effect observed, with greater shared environmental effects in low SES environments (Hanscombe et al., 2012). That is, genetic influences unique to ability (i.e., not associated with those on SES) were not significantly different across levels of SES, but unique shared environmental did differ in magnitude across SES. In contrast, some studies have failed to find moderating effects on either genetic or shared environmental influences, although these have been in very young twins, suggesting possible changes with development (Tucker-Drob et al., 2011), and in international samples (e.g., van der Sluis et al., 2008).

Examination of such gene × SES interactions has also been extended beyond only general cognitive ability to important academic outcomes such as reading and math. Moderating effects have been observed as early as 4-years old for early math skills, with a trend of increasing variance towards higher SES, though not for prereading skills at this age (Rhemtulla & Tucker-Drob, 2012). Relatively consistently, moderation effects of some kind have been found for reading outcomes including first grade reading fluency (Taylor & Schatschneider, 2010), school-aged reading disability (Friend et al., 2008), high reading ability (Friend et al., 2009), and reading in older adults (Kremen et al., 2005). Thus, moderating effects on reading appear to emerge in the early elementary years and continue into older adulthood.

Overall, investigations of moderation of genetic and environmental influences on cognitive and academic outcomes have generally supported Bronfenbrenner and Ceci’s (1994) bioecological model in that genetic influences on outcomes, at least those not associated with those on SES, have generally been greater at higher levels of family SES. Under this model, actualization of genetic effects depends on environmental opportunity for expression. Individuals from more impoverished backgrounds have fewer environmental opportunities to actualize genetic potential and thus genetic potential for greater achievement is left unrealized. As such, under the bioecological model, along with lower mean levels of achievement, there will be less genetic variability at low levels of SES and greater genetic variability at higher SES. Though this pattern has been observed for the most part, some studies have been unable to detect any gene × SES interaction (e.g., Grant et al., 2010; van der Sluis et al., 2008) and others have found only shared environment × SES interactions (e.g., Hanscombe et al., 2012; Kremen et al., 2005). Interestingly, no known empirical reports indicate increased heritability at the low end of SES.

In general, family-level SES has been the only focus of gene × SES studies, but has been measured a few different ways. A handful of studies have utilized composites of SES (Hanscombe et al., 2012; Rhemtulla & Tucker-Drob, 2012; Tucker-Drob et al., 2011; Turkheimer et al., 2003); however, most studies have relied on single indicators. Parental education is the most widely used SES indicator in these studies (Friend et al., 2008; Friend et al., 2009; Grant et al., 2010; Harden, Turkheimer, & Loehlin, 2007; Kremen et al., 2005; van der Sluis et al., 2008), though family income (Hanscombe et al., 2012; Harden, Turkheimer, & Loehlin, 2007) and neighborhood income (Taylor & Schatschneider, 2010; van der Sluis et al., 2008) have also been used. To our knowledge, there has been no exploration of the effects of other levels of SES beyond family-related measures. Although the family is clearly an important aspect of a child's environment, school-level SES could conceivably be just as important for academic outcomes. This is especially the case for reading outcomes, as reading development is strongly associated with direct instruction (Foorman et al., 1998). Further, meta-analyses have shown that school-level SES is more highly correlated with academic outcomes than family-level SES (Sirin, 2005; White, 1982). This is likely due to the fact that school-level SES has an independent impact on achievement beyond that of family-level SES (Caldas & Bankston, 1997; Harris, 1995). It has been hypothesized that an individual's schoolmates form an important source of social capital which both directly (e.g., peer group influence) and indirectly (e.g., perceptions among educators of how students of different SES backgrounds are "supposed" to perform) affects student achievement outcomes (Caldas & Bankston, 1997).

In light of the goals of this special issue of the *Journal of Child Psychology and Psychiatry*, we present a novel operationalization of gene × SES interaction for reading comprehension, an important reading skill for school success that shows substantial genetic influence (Byrne et al., 2009; Harlaar et al., 2010; Harlaar et al., 2012). Specifically, the innovative aim of this study was to expand consideration of children's environment to incorporate school-level SES effects. Previously, all work has considered only the family environment, and for achievement outcomes the school environment is likely a key factor as well. Therefore, the moderating effects of school-level SES on genetic and environmental influences on reading comprehension achievement in the Florida Twin Project on Reading, Behavior, and Environment (Taylor et al., 2013) were explored using a univariate gene × environment interaction model (Purcell, 2002). Although the literature on gene × SES effects on reading achievement outcomes is mixed with regard to which sources of variance have been moderated by SES, we hypothesized a gene × SES moderation effect consistent with the bioecological model as other work examining general cognitive ability has suggested (e.g., Turkheimer et al., 2004).

Methods

Participants

The Florida Twin Project on Reading, Behavior, and Environment is an ongoing cross-sequential twin project in the state of Florida (Taylor & Schatschneider, 2010; Taylor et al., 2013). The project ascertains monitoring and achievement data for reading from the statewide educational database, Progress Monitoring and Reporting Network (PMRN), as well as additional data concerning twin behavior and environment via a questionnaire mailed directly to families beginning in 2010. For the current report, data were used from the 2007-2008 school year from 189 monozygotic (MZ; 97 female-female pairs, 92 male-male pairs) and 388 dizygotic (DZ; 91 female-female pairs, 100 male-male pairs, 197 opposite-sex pairs) twin pairs. Twins were in the third or fourth grade, and were approximately 8 years old (M = 8.18, SD = 1.33). According to parent report, 19% of the twins were African-American, 25% were Hispanic, 48% were Caucasian, and the remainder was mixed or other race/ethnicity. These percentages are very similar to those reported for the state of Florida by the U.S. Census Bureau.

Procedure and Measures

Zygosity of the twin pairs was determined via a parental five-item questionnaire on physical similarity (Lykken et al., 1990; Taylor et al., in press). Reading comprehension data was collected by trained administrators as part of statewide achievement testing required by normal school attendance, and test scores were uploaded into the PMRN via a web-based data collection system. PMRN data collection windows are determined by the Florida Department of Education and local school districts; for the present study all data were collected in March, 2008. Data from this school year only were used because the largest proportion of twins in the project were in the third or fourth grade, commonly considered key years in reading comprehension achievement (e.g., Chall, 1983). All parents of twins completed an informed consent form approved by the Florida State University Institute Review Board allowing their achievement and questionnaire to be used for this project.

Reading Comprehension

Reading comprehension was measured through the Florida Comprehensive Achievement Test (FCAT) Reading test. This group-administered criterion-referenced test is composed of six to eight reading passages with sets of 6 to 11 items of multiple choice, short answer or long answer response formats. Items are based on Sunshine State Standards benchmarks for reading, which incorporate four reading content clusters of: (1) words and phrases in context; (2) main idea, plot and purpose; (3) comparison and cause/effect; and (4) reference and research (Florida Department of Education, 2005). A Cronbach's alpha of .90 indicates the test has high reliability (Florida Department of Education, 2001). For this report, the IRT-based overall FCAT reading scale score was used.

School-Level SES

The PMRN houses data for all children enrolled in Florida public schools. Included in each child's PMRN record is Free and Reduced Lunch Status, which is a federally mandated National School Lunch Program providing eligible children free or reduced-price meals and free milk in school. For the 2007-2008 school year, children were eligible for reduced-price or free lunch if household income was less than $38,203 (for a family of four; Federal Register, 2007). Free and Reduced Lunch Status (FRLS) is a commonly used proxy for SES (Sirin, 2005). Using this data source, children in the same schools as twins enrolled in the project at the time of FCAT testing in the 2007-2008 school year were identified. All children in these schools who qualified for free or reduced-priced lunch were coded 1, and all children who did not qualify were coded 0. The mean per school of the twins' schoolmates free and reduced-price lunch status was then calculated as an indicator of School-Level SES. The total numbers of schoolmates who went into this calculation ranged from 71 to 1231 (M = 613, SD = 221). School-Level SES was moderately correlated with family-level SES (measured as the twins' FRLS), r=.56.

Analyses

Given that the school-level SES measure was continuous in nature and constant within twin pairs, the continuous univariate G × E model was used to estimate the moderating effects of school-level SES on reading comprehension (Purcell, 2002). This model allows for school-level SES to have a main effect on reading comprehension, as well as moderating effects on the additive genetic (inherited genetic influences; A), shared environmental (environmental influences which make siblings more similar; C) and nonshared environmental (environmental influences which make siblings unique; E) components of variance of reading comprehension (see Figure 1). Exploring Figure 1, β_M is the effect of school-level SES on the mean of reading comprehension. After variance common to school-level SES and reading comprehension is controlled, the variance of reading comprehension is decomposed into estimates of A, C, and E, each of which is expressed as a linear function of school-level SES. In Figure 1, the A pathway is estimated by the equation, $a + \beta_A$*SES, with a representing the constant additive genetic influence, and β_A representing the moderating effect of school-level SES on the additive genetic influence. This follows analogously for the C and E components.

Significance of moderation in the model was determined using two approaches. First, the significance of the moderation as a whole was tested by constraining all moderation pathways to zero and evaluating the reduction of model fit in relation to the full model which allowed moderation on A, C, and E components. As the constrained model is a nested model of the full moderation model, a significant chi-square difference from the full moderation model to the constrained model was indicative of significant moderation. Second, the significance of the individual moderation estimates of the A, C and/or E components in various combinations was tested as recommended by Purcell (2002) by constraining the appropriate parameters to zero and examining the models nested in the full moderation model. These comparisons were done using the chi-square difference test as well as the Akaike's Information Criterion (AIC; Akaike, 1987) as an index of goodness-of-fit and parsimony. Although it is common in the literature to provide 95% confidence intervals around parameter estimates to determine significance of moderation effects, recent work has indicated that this approach is inappropriate and inaccurate (Medland et al., 2009). Therefore, we present results from the model-fitting tests only.

A limitation of the univariate G × E model is its inability to estimate the extent to which gene-environment correlations are active in the relationship between the moderator and the outcome (Purcell, 2002; Plomin, DeFries & Loehlin, 1977). Such effects are certain to be present if the moderator is correlated with the outcome and the "environmental" moderator is genetically influenced. Considerable research has pointed to variance common to SES indicators and reading outcomes (Sirin, 2005) as well as genetic influences on indicators of SES (Vinkhuyzen et al., 2010; see also Plomin et al., 1994). Investigators can usually only control for these effects using the univariate G × E moderation model because the moderator is shared by twin pairs at the level of the family, and must do so by modeling the effect of the moderator on the mean of the outcome, and this study was no exception. Though it was not possible to model how genetic influences common to reading comprehension and SES might vary with level of SES, we did estimate the total reading comprehension variance caught up in this covariance and thus omitted from our variance decompositions. We did this by tabulating the total variance allocated to reading comprehension in the G × E model. This was the amount of reading comprehension variance throughout the sample that was not shared with school-level SES. The difference between this amount and 100% thus represented the proportion of reading comprehension variance that was common to SES and omitted from our variance decompositions.

The univariate G × E model was fit using full-information maximum-likelihood estimation in the OpenMx package (Boker et al., 2011) in R (www.R-project.org; Team RDC, 2011). OpenMx is able to account for missing data using FIML procedures for the outcome in the G × E model (i.e., reading comprehension), but not for the moderation variable of school-level SES, resulting in 48 pairs (8%) with missing moderation variables being dropped. Raw z-scored data corrected for age and age-squared were used. No mean or variance differences were found in reading comprehension between boys and girls in the sample, and sex was not found to be a significant predictor of reading comprehension. Furthermore, a multi-group sex-limitation model of FCAT scores testing sex effects was fit to the data and the variance across sex could be completely constrained, indicating that it was appropriate to combine male, female, and opposite-sex twins in the analyses (results available from first author upon request).

Results

Descriptive statistics are presented in Table 1, for reading comprehension separately by twin member as the pairs were not all complete but all data were used via FIML procedures. The correlation between reading comprehension and school-level SES was moderate, $r = -.37$, with the negative directionality indicating that the proportion of children in a school who qualified for FRLS, the lower the mean reading comprehension of the twins in the sample[1]. The intraclass correlations for reading comprehension were .83 for MZ twins, and .53 for DZ twins. They generated univariate proportions of variance for heritability of .67 (.95 confidence interval .52 to .83), shared environment of .17 (.95 confidence interval .02 to .18) and nonshared environment of .15 (.95 confidence interval .12 to .18).

Before examining the individual pathways of the G × E model, we tested for aggregate effects of SES on reading comprehension by constraining all parameters involving SES to 0. The chi-square difference test indicated a significant change in model fit ($\chi^2\Delta = 110.03$, $df\Delta = 4$, $p<.001$; see Table 2), and AIC increased from 474.83 to 576.85. This indicated that school-level SES had important effects on reading comprehension but did not specify the nature of these effects. The most likely effects were a direct main effect or some other kind of effect involving variance common to SES and reading comprehension, but our data did not allow us to distinguish among these possibilities. We thus next estimated the extent of the moderation effect on the mean but constrained all the moderating effects of school-level SES on variance in reading comprehension not shared with school-level SES. The chi-square test again indicated a significant but much smaller change in model fit ($\chi^2\Delta = 10.09$, $df\Delta = 3$, $p=.02$; see Table 2), and AIC increased from 474.83 to 478.91. Given this, we tested the individual moderation parameters through a series of submodels (Purcell, 2002). Three submodels resulted in non-significant changes in model fit from the full moderation model (see Table 2), and the lowest AIC suggested that the best-fitting submodel was the one with moderation on the A parameter alone (see Table 2).

After a best-fitting model is identified, subsequent results are commonly presented from this model. However, for these analyses we were not convinced that the small differences in AIC that were measured were evidence enough to ignore possible moderation of all sources of variance, especially moderation of shared environmental influences. Therefore, we present the parameter estimates from the full moderation model in Table 3 (the parameter estimates from the most parsimonious model of moderation of the A parameter only are also displayed for comparison). Figure 2 displays the full moderation model results graphically: there was somewhat greater genetic and shared environmental variance in reading comprehension not shared with SES when the twins' had fewer schoolmates qualifying for FRLS. The lines in Figure 2 represent the unstandardized estimates of genetic, shared environment and nonshared environmental variance for reading comprehension at the different levels of School-Level SES, so absolute trends are displayed (Purcell, 2002). Based on our technique described above, 7.5% of total reading comprehension variance was involved in gene-environment correlation with school-level SES, variance which we cannot show in Figure 2.

[1]Given the diversity of the present sample and the possible confounding of race/ethnicity by SES, we examined if the association between school-level SES and reading comprehension differed for the three race/ethnic groups in the sample with adequate data. Fisher r-to-z transformations suggested nonsignificant differences in the associations, which were $r = -.31$ (White, n=535), $r=-.16$ (Black, n=218) and $r=-.24$ (Hispanic, n=277).

Discussion

Well-cited work has highlighted the role of family socioeconomic status (SES) as an environmental moderator of variance in cognition (e.g., Turkheimer et al., 2003), although not all reports have indicated the same pattern of results (e.g., Hanscombe et al., 2012). Additional work has begun to examine the moderating effects of family SES on academic achievement outcomes such as reading (e.g., Friend et al., 2008, 2009), and in general the results support moderation effects but the directions and sources of variance moderated have not been consistent.

Given that reading outcomes are influenced by direct instruction (Foorman et al., 1998), it would seem that school-level moderators would also be important areas for study. Work examining school-level SES has suggested that there is a relation between the socioeconomic status of the pupils of a school and the academic achievement of individual students (Caldas & Bankston, 1997). Therefore, given the goal of this special issue of *JCPP* of considering different plausible environments for cognitive outcomes such as achievement, we explored the role of school-level SES as a moderator of genetic influences on reading comprehension. Previous work has indicated that the heritability of reading comprehension for children approximately 8-years-old in the US is moderate and significant (h^2=.58, Christopher et al., 2013; h^2 = .72, Logan et al., in press). Results from the present sample fell in this range (h^2=.67).

Using a novel approach, we capitalized on the PMRN data available in Florida to create a metric of school-level SES by calculating the mean FRLS of all children enrolled in the schools attended by twins in the Florida Twin Project on Reading, Behavior and Environment. Qualifying for the US Department of Agriculture's Free or Reduced Lunch plan is based on total household income, set by annual Federal income poverty guidelines and household size. Children who qualify for reduced meal plans have family incomes 185% or less of the poverty line, and children who qualify for free meal plans have family incomes of 130% or less of the poverty line. FRLS is a commonly used indicator of SES, with a meta-analysis suggesting a mean effect size of .33 for work exploring the relation between FRLS and academic achievement (Sirin, 2005). This suggests that smaller proportion of FRLS students (which is often described as having "higher SES") is associated with higher performance on achievement measures.

Results of the present study suggested significant moderation of variance in reading comprehension not shared with school-level SES in third and fourth grade. This moderation was shown for the additive genetic variance component and could not be ruled out for the shared environmental variance component, with increased variance in both found at higher levels of school-level SES. Importantly, given the potential for additional moderating effects on variance caught up in gene-environment correlation between reading comprehension and school-level SES, we were also able to quantify the total amount of variance in reading comprehension that might be involved at 7.5%. As the moderating effects we estimated involved about 40% of variance across the range of FRLS, it is very unlikely that they could be offset by counteracting moderation effects in this covariance. At the same time, by far the strongest effect in our model was the main effect of school-level SES on reading achievement, which was estimated at over a third of a standard deviation in reading achievement with every standard deviation increase in school-level SES. This effect would generally be assumed to apply uniformly to everyone across the range of school-level SES. That is, it would not be expected to affect variance. But we modeled the effect as we did because we did not have data to do otherwise, despite the distinct possibility that gene-environment correlation often accompanies gene-environment interaction (Johnson, 2007).

This is an area needing additional research attention in general, not simply for these phenotypes.

The genetic moderation result gives support to the bioecological model, which posits that genetic influences will be greater in more supportive environments (Bronfenbrenner & Ceci, 1994). Indeed, when school-level SES was low, genetic variance was constricted, and when school-level SES was high, the proportion of genetic variance was greater. Reading achievement is strongly associated with direct instruction which occurs in the formalized schooling environment (Foorman et al., 1998). In addition, achievement is higher in schools with higher SES levels (Caldas & Bankson, 1997). Given that children have many different potential reading trajectories (Raudenbush, 2005) and school SES is related to better reading outcomes, children in low SES schools may be less likely to achieve their reading achievement potential. To put it another way, poverty suppresses the expression of genetic potential for higher achievement. When school-level SES is high, children may be better able to achieve their potential and genetic influences are more likely to be a source of individual differences.

Although model fitting results did incrementally suggest that the best-fitting model included only genetic moderation of reading comprehension, we presented results of the full moderation model in an effort towards transparency. This model included moderation of the shared environmental component of variance on reading comprehension, with greater shared environmental influences with higher school-level SES. This may be considered contrary to the bioecological model (Bronfenbrenner & Ceci, 1994) when standardized (i.e., proportional) genetic and environmental results are considered because the moderating effect on shared environmental influences was greater than that on genetic influences, so that even as a proportion of variance, shared environmental influences were greater at higher school-level SES than at lower school-level SES. Although Bronfenbrenner and Ceci did not speak directly to changes in shared environmental influences across the distributions of environmental moderators, when greater genetic influences are expected in more supportive environments, lower environmental influences at the same level of the environmental moderator could be, and are often, expected in the literature (e.g., Friend et al., 2009) because proportional presentation is assumed.

The interpretation of the present shared environmental mediation result is the same in theme as for the genetic results discussed above, although some caution should be made in accepting the result due to the conflicting model-fit testing results. In the supportive environment of high school-level SES, reading trajectories are optimized and shared environmental effects contribute to individual differences in reading achievement. Although it is unknown what these shared environmental influences are, given the role of the direct instruction on reading outcomes, it could the case that the effects of the school instructional environment may foster greater reading achievement in high school-level SES schools. However, home environmental effects, such as the home literacy environment (e.g., Griffin & Morrison, 1997) are also likely to be sources of individual differences at higher levels of the moderator, especially given that school SES is not entirely devoid of family SES. Alternatively, it could be suggested that in low school-level SES environments, sources of shared environmental variance which could help children reach their reading potential (e.g., family efforts) may be undermined by the school-level SES environment.

Importantly school-level SES in the present sample appeared not to be simply a proxy for family-level SES. Twins' FRLS was only moderately correlated with school-level SES (r=.56). Additionally, multiple regression suggested that school-level SES accounted for additional variance above and beyond family-level SES when predicting reading comprehension (results available from first author). This would suggest that although family-level SES would seemingly be intricately related to school-level SES, school-level SES was an important predictor of reading comprehension outcomes independent of family influences. This is further supported by other work on this sample which indicated only moderation of the means of reading using the twins' FRLS as a family-level SES indicator (Soden-Hensler, 2012). We hypothesize that family-level SES may be playing a stronger role in gene-environment correlations in reading achievement than in moderation of variance in this sample, but due to present limitations in modeling, gene-environment correlations and moderation cannot be modeled together when a family constant variable such as SES is used. Future research could look at the relations between family-level SES and school-level SES on achievement outcomes, as they are undoubtedly associated. In all, this supports our main point of the importance of exploring different (i.e., not just the family) levels on the environment in gene × environment modeling.

There are limitations to this work. Although our sample was moderate in size compared to other published G × SES moderation studies (e.g., Turkheimer et al., 2003), published power analyses suggest that we had little statistical power. This likely contributed to our inability to determine the significance of moderation of the shared environment in the presence of a simultaneous moderation of the genetic effect (Hanscombe et al., 2012; Purcell, 2002). In light of the power limitation, we purposely chose to present all freely estimated parameters of the significant full moderation model. The results indicated that there was moderation of the components of variance on reading comprehension at different levels of school-level SES, but it was not clear if it occurred only for the genetic sources of variance, or for both genetic and shared environmental components. Moreover, we relied upon the usual assumptions of behavior genetic studies that twins are representative of the general population, that MZ and DZ twins receive equal environmental influences, that there was no assortative mating for reading achievement in our sample, and that genetic and environmental influences followed the patterns indicated by our model. Because these patterns can be very sensitive to environmental circumstances, it is very possible, even likely, that different patterns would be obtained in other places with different combinations of social conditions (e.g., school-system differences between countries; Samuelsson et al., 2008).

Behavioral genetic work has long pointed to the importance of both genetic and environmental sources of variance on reading comprehension outcomes. As a more recent step, gene × environment moderation analyses have indicated that the relations are more intricate than a simple univariate estimate would suggest. Given the phenotypic evidence of the importance of the school on achievement outcomes such as reading comprehension, we explored the importance of school-level SES as a moderating influence on the genetic and environmental reading comprehension. This novel work indicates the complexity of the role of the environment in achievement outcomes. Attending a school where more children of higher-income families also attend will not change that some children will do better on achievement tests than others, but instead it will allow for all children to achieve their optimal potential in reading comprehension.

Alternatively, it suggests that congregation of lower-SES families in schools may undermine reading achievement in even children with the most genetic potential and the most supportive home environments. Given the tendency for neighborhoods to be clustered by SES and for school assignment to be based on residence, this raises important policy considerations that should be addressed with additional research.

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Abbreviations

(FCAT)	Florida Comprehensive Achievement Test
(FRLS)	Free and Reduced Lunch Status
(SES)	socioeconomic status

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Key points

- Behavioral genetics has pointed to the important role of family SES as an environmental moderator on the genetic and environmental sources of variance in general cognitive ability not shared with SES, but results have been mixed for achievement outcomes.
- Phenotypic literature has pointed to the important role of the school, including school-level SES, on achievement outcomes, yet school-level SES has not previously been examined in gene × environment interaction models for these outcomes.
- This work proposed a novel way to operationalize the environment, combining the modeling approaches of behavioral genetics with the results of the education literature on sources of individual differences in reading achievement.
- Results indicated that school-level SES moderated reading comprehension outcomes, with trends towards great genetic and shared environmental variances at higher levels of SES

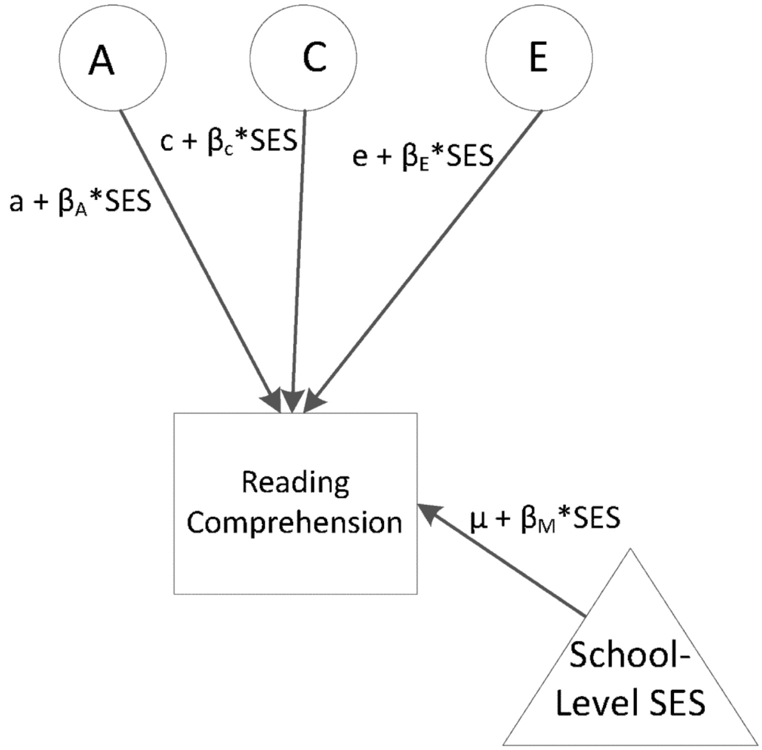

Figure 1.

The univariate G × E moderation model. Latent influences of genetic (A), shared environment (C), and nonshared environment (E) on variation in reading comprehension scores.

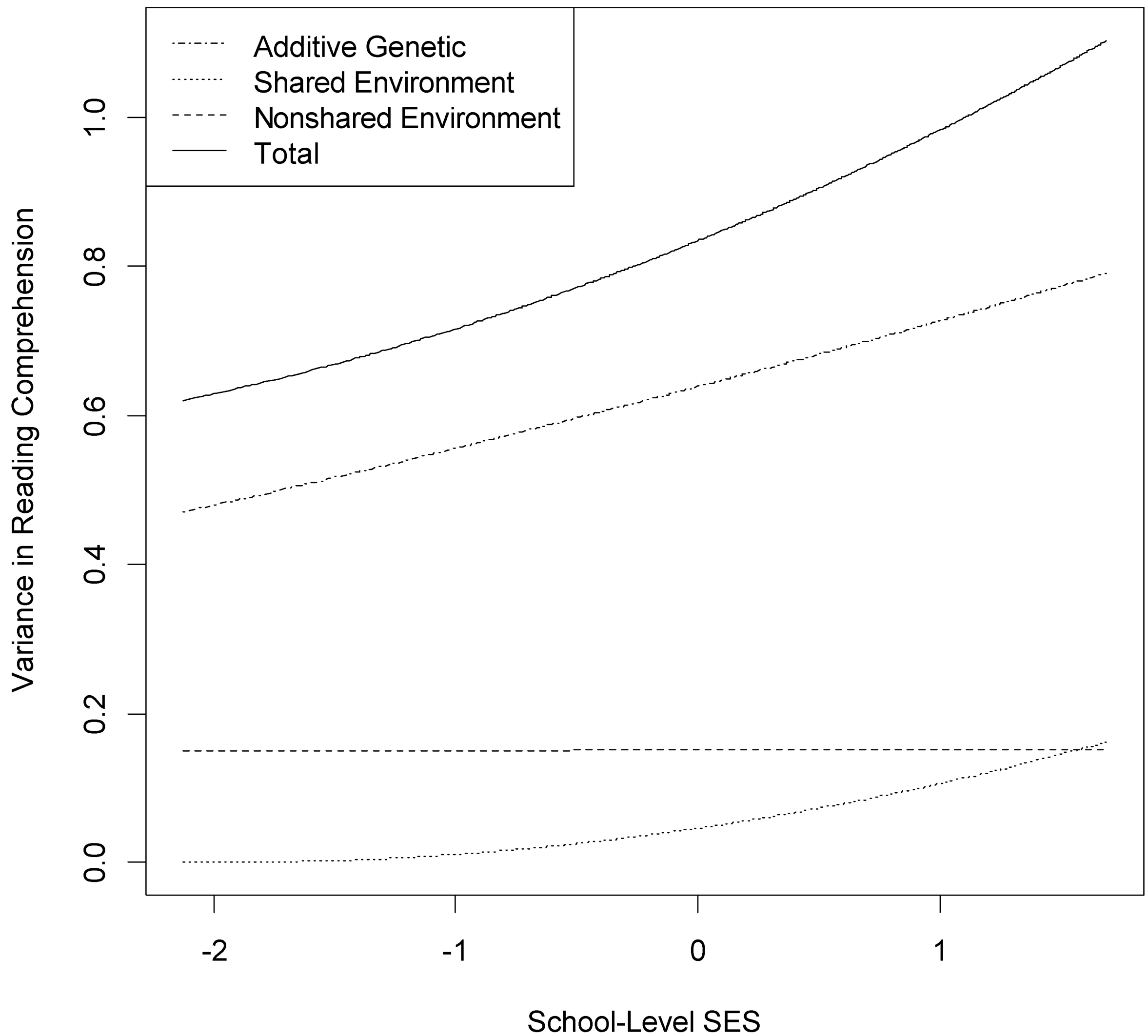

Figure 2.
Unstandardized genetic and environmental variance components in reading comprehension as a function of the school-level SES moderator (for all possible values of the moderator).

Table 1

Descriptive statistics for reading comprehension (FCAT) and school-level SES

Variable	Mean	SD	Min.	Max.	Skew	*n*
Reading comprehension twin 1	315.79	60.40	100	500	−.45	538
Reading comprehension twin 2	311.91	59.43	100	500	−.60	559
School-level SES	0.57	0.25	0.03	0.98	−.28	577

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Table 2

Model fit statistics of models testing for moderation on reading comprehension (FCAT) by school-level SES

Model	−2LL	df	AIC	$\chi^2 \Delta$	dfΔ	p-value
Full Model	2632.82	1079	474.83			
No Effect of SES	2742.85	1083	576.85	110.03	4	<.001
Means Effect Only	2642.91	1082	478.91	10.09	3	.02
Means Effect, Moderation of C and E	4198.29	1080	2038.29	1565.47	1	<.001
Means Effect, Moderation of A and E	4111.82	1080	1951.82	1478.99	1	<.001
Means Effect, Moderation of A and C	2632.83	1080	472.83	0	1	.99
Means Effect, Moderation of A	2633.67	1081	471.67	.84	2	.66
Means Effect, Moderation of C	2635.34	1081	473.34	2.51	2	.28
Means Effect, Moderation of E	2641.75	1081	479.75	8.92	2	.01

Note. Difference statistics were calculated from the Full Model as the base.

Table 3

Genetic and environmental parameter estimates and standard errors for reading comprehension (FCAT) moderated by school-level SES for the full moderation model, as well as the most parsimonious model of a Means Effect with Moderation of A

	Full Moderation Model		Means Effect, Moderation of A	
Parameter	**Estimate**	**S.E.**	**Estimate**	**S.E.**
a	0.80	0.04	.82	.05
c	0.21	0.13	.10	.35
e	−0.39	0.02	.39	.02
β_M	−0.35	0.03	−.36	.03
β_A	0.05	0.04	.08	.02
β_C	0.11	0.10	--	--
β_E	0.00	0.02	--	--

Note. a = additive genetic influence; c = shared environmental influence; e = nonshared environmental influences; β_M= Means effect; β_A = Moderation of additive genetic influence; β_C = Moderation of shared environmental influence; β_E = Moderation of nonshared environmental influence