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Genetic and environmental influences on early literacy skills across school grade contexts

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Abstract

Recent research suggests that the etiology of reading achievement can differ across environmental contexts. In the US, schools are commonly assigned grades (e.g., “A,” “B”) often interpreted to indicate school quality. This study explored differences in the etiology of early literacy skills for students based on these school grades. Participants included twins drawn from the Florida Twin Project on Reading ($n=1313$ pairs) aged 4 to 10 years during the 2006–2007 school year. Early literacy skills were assessed with DIBELS subtests: Oral Reading Fluency (ORF), Nonsense Word Fluency (NWF), Initial Sound Fluency (ISF), Letter Naming Fluency (LNF), and Phoneme Segmentation Fluency (PSF). School grade data was retrieved from the Florida Department of Education. Multi-group analyses were conducted separately for subsamples defined by “A” or “non-A” schools, controlling for school-level socioeconomic status. Results indicated significant etiological differences on pre-reading skills (ISF, LNF, and PSF), but not word-level reading skills (ORF and NWF). There was a consistent trend of greater environmental influences on pre-reading skills in non-A schools, arguably representing “poorer” environmental contexts than the A-schools. Importantly, this is the case outside of resources linked with school-level SES, indicating that something about the direct environment on pre-reading skills in the non-A-school context is more variable than for A-schools.

Keywords

early literacy; school quality; twins; nature; nurture

Early literacy skills encompass both pre-reading skills, such as print knowledge and phonemic awareness, as well as word-level reading skills. Word-level reading skills involve the fluency and accuracy of reading connected text as well as understanding the properties of letters and how they fit together to make words (Dodd & Gillon, 2001). Both pre-reading and word-level reading skills set the foundation for reading and writing development, as well as academic performance throughout the school-years (Whitehurst & Lonigan, 2001; Lonigan et al., 2013). Research shows that individuals with poor reading foundations and deficits in skills like phonological processes tend to have a difficult time with reading related

activities when compared to peers, and are unlikely to ever catch up (Whitehurst & Lonigan, 2001; Wagner et al., 1997; Francis et al., 1996). Moreover, children with poor reading foundations are at a higher risk for being identified as in need of special education and they are less likely to engage in reading activities when compared to more skillful peers (Whitehurst & Lonigan, 2001). Children with poor reading skills are also less likely to be exposed to content knowledge and vocabulary than are more skillful readers (Cunningham & Stanovich, 1997). Given the foundational role of early literacy skills, it is important to gain a better understanding of the factors that contribute to these skills.

Using genetically sensitive designs, the role of genetic and environmental influences on early literacy skills has been well established, although results vary across studies and measures (Samuelsson et al., 2007). Looking first at pre-reading skills, in a study combining twin and adoption samples from the US, moderate and significant heritability was indicated for letter knowledge (heritability, $h^2=.35$), and the heritability was also moderate and significant for phonological awareness ($h^2=.52$; Petrill et al., 2006). In a different sample of US twins, a high estimate of heritability for phonemic awareness was reported ($h^2=.76$; Knopik et al., 2002). A moderate estimate heritability was indicated again for phonological awareness in samples across the US, Scandinavia, and Australia ($h^2=.61$; Byrne et al., 2005; $h^2=.61$ Samuelsson et al., 2005), as well as in a sample of English twins ($h^2=.38$; Kovas et al., 2005). Finally, in a recent study of twins using a racially and economically diverse US sample, researchers found significant genetic and environmental influences on pre-reading skills of letter naming fluency (LNF) ($h^2=.34$), initial sound fluency (ISF) ($h^2=.37$), and phonemic segmentation fluency (PSF) ($h^2=.29$ for low income, $h^2=.26$ for middle income, and $h^2=.09$ for high income participants; Taylor & Schatschneider, 2010).

More recently, twin studies have begun to examine the roles of specific environmental influences moderating the extent to which genetic and environmental influences impact individual differences in early literacy skills, moving beyond simple univariate estimates of heritability. Many of these studies utilize various aspects of social constructivist theories, like Bronfenbrenner's ecological model (1979) which emphasizes the role of the environment (particularly home and community) on human development. There is a long history of investigating the role of the environment phenotypically on achievement and literacy, examining elements such as: maternal literacy practices, socioeconomic status (SES), home literacy environment, family beliefs and values about education, home language environment, and more (Edwards 2014; Pfof, Hattie, Dorfler, & Artelt, 2014; Malin, Cabrera, & Rowe, 2014; Campbell et al., 2003; Hart & Risley, 1992; Whitehurst & Lonigan, 1998; Phillips, 2005). Mirroring this phenotypic literature, various environmental factors have been analyzed as potential moderators of genetic and environmental influences on achievement outcomes as well. Family-level SES was one of the first and most widely studied environmental contexts to be reviewed as a moderator of genetic and environmental influences on cognitive outcomes. Turkheimer et al. (2003) conducted one of the first studies that found a gene x environment (family-level SES) interaction on IQ. These results indicated a greater influence of shared environmental factors on IQ for children from poorer homes, and greater influences of genetic factors on IQ for children from wealthier homes. Results similar to this have been produced in other studies as well. For instance, Tucker-Drob et al. (2011) found the same gene-by-SES interaction among 2-year-olds on mental

ability. Beyond family-level SES, Hart et al. (2013) found a relationship between school-level SES and reading comprehension. In the Hart study, however, the impact of school-level SES acted to moderate the genetic and environmental factors influencing reading comprehension in such a way that there were greater genetic influences on reading comprehension for children in lower school-level SES contexts, and greater shared environmental influences when school-level SES was higher. Teacher quality has also been explored as an environmental context that moderates the genetic and environmental variance in reading achievement, with results indicating that higher teacher quality is associated with more genetic variance in reading achievement (Taylor et al., 2010). Furthermore, Taylor and Schatschneider (2010) examined kindergarten and first grade twin pairs and found that neighborhood-SES influenced the proportion of genetic and environmental influences on early literacy skills in first grade twin pairs. In the first grade sample, variance in early literacy skills was associated with additive genetic effects for middle-SES and high-SES twins, while shared environmental influences were substantial for low-SES twins (Taylor & Schatschneider, 2010).

While previous work has established the role of the environment as a moderator of genetic and environmental influences on reading outcomes, the environment itself has only been partially defined. The family-level environment is critical for reading skills and has been granted much focus; however, the school environment is of particular importance as well. Currently, the school environment hasn't been thoroughly examined, especially beyond SES-related factors.

An indicator of the overall school environment is reflected by school grade, which is thought to be a proxy for broader school aspects such as school resources (Heyneman & Loxley, 1983), teacher and staff years' of experience (Card & Krueger, 1990), grade repetition and dropout rates (Lee & Barro, 2001), teacher preparedness and training (Card & Krueger, 1990; Mihaly et al., 2012), school safety (Cohen et al., 2009), student learning growth (Lee & Barro, 2001; Goldhaber, Liddle, & Theobald, 2013), and student test performance (Lee & Barro, 2001; Goldhaber, Liddle, & Theobald, 2013; Gibbons & Silva, 2011). In the US, it has become common to quantify "school quality" by assigning schools a letter "grade," (e.g., "A," "B"), which is typically operationalized by student standardized test performance, student gains throughout the school year, and graduation rates (Bennett, 2013). This grade is publicly available and often used by parents in deciding what schools to send their children to, influencing housing markets and neighborhood demographics (Friesen et al., 2012; Glynn & Waldeck, 2013). The calculation of these school grades are typically based on arbitrary cut off values of an underlying continuous metric, to where the difference between a school receiving a grade of 'A' and another school receiving a 'B' could be a one point difference in score. However, to the public and to administrators, an 'A' graded school is assumed to be qualitatively better quality than a 'B' school, and so on. Most schools are graded based on the overall percentage of the school's students scoring below, at, or above state-grade-level standards, while ignoring factors influencing the achievement gap (Glynn & Waldeck, 2013). The achievement gap is a well-documented phenomenon indicating that on average, wealthier students perform better than poorer students academically, and also, Asian and White students tend to perform better than Black and Hispanic students (Glynn & Waldeck, 2013). This means that schools with better performing students on state testing,

and therefore “better quality” schools as indicated by school grades, are more likely to be located in wealthier, less diverse communities. Given this greater environmental stability for schools with higher grades, it can be hypothesized that there may be a moderation of the etiology of reading skills based on the school’s grade.

With the literature establishing environmental contexts such as SES, teacher quality, and classroom quality as essential to literacy outcomes, a logical next step would be exploring the role of school grade, an indicator of “school quality,” on early literacy skills. The specific research question here was if there are differences in the etiology of early literacy skills for students in schools assigned different grades. It was hypothesized that school quality (school grade being a proxy) would follow a bioecological framework: as the quality of the school increased the genetic influences on early literacy would increase, whereas a decrease in school quality was expected to be associated with greater environmental influences on early literacy skills. Importantly, this hypothesis was considered while controlling for school-level SES, which has previously been indicated to be a source of etiological moderation in this sample (Hart et al., 2013).

Methods

Participants

Participants for this study were drawn from the Florida Twin Project on Reading (Taylor, Hart, Mikolajewski, Schatschneider, 2012). The Florida Twin Project on Reading is an ongoing cohort-sequential twin project that collects monitoring and achievement data on reading in the state of Florida from the Progress Monitoring and Reporting Network (PMRN), a statewide educational database. Participants included 1313 twin pairs from kindergarten through grade 3 (ages 4.88 – 10.70¹; M age = 7.26; SD = 0.95), specifically 442 monozygotic (MZ) twin pairs (227 female-female pairs, 215 male-male pairs) and 871 dizygotic (DZ) twin pairs (221 female-female twin pairs, 219 male-male twin pairs, and 431 opposite-sex pairs). Sample size reflects all participants with available data. The sample’s racial/ethnic makeup included 1% Asian, 22% Black, 24% Hispanic, less than 1% Native American/Pacific Islander, 4% Mixed, 48% White, and 1% “Other”. The percentages reported are similar to values reported by the U.S. Census Bureau for the state of Florida (<http://quickfacts.census.gov/qfd/states/12000.html>).

Procedures and Measures

To identify the zygosity of the twin pairs, parents filled out a five-item questionnaire during intake into the larger project that measured the physical similarities of the twins (Lykken, Bouchard, McGue, & Tellegen, 1990). Reading data from the Dynamic Indicators of Basic Early Literacy Skills (DIBELS) measure were obtained from the PMRN for the 2006–2007 school year. This time point was chosen simply because it represented the school year with the greatest sample size available. The DIBELS assessment is comprised of five brief measures relating to early literacy skills: Initial Sound Fluency (ISF), Letter Naming Fluency (LNF), Phonemic Segmentation Fluency (PSF), and word-level skills of Oral

¹There were three participants total that were over the age of 10.

Reading Fluency (ORF) and Nonsense Word Fluency (NWF). DIBLES data were collected by trained administrators in elementary schools at multiple time points throughout the school year and data were entered into the PMRN database. Data from the spring collection period were used for this study, except for ISF which was from the winter collection period as it is not collected in spring. School grades for the 2006–2007 school year were ascertained from the Florida Department of Education (<http://schoolgrades.fldoe.org/>). The parents of all of the twin participants completed informed consents approved by the Florida State University IRB allowing for the usage of achievement and questionnaire data to be used in the present study.

Initial Sound Fluency (ISF)—ISF measures phonological awareness and the ability to recognize and produce the initial sound in an orally presented word (Kaminski & Good, 1996). The student must identify the answer by pointing to the picture that corresponds to the same sound that is presented orally by an administrator. For example, the administrator points to four pictures saying “This is a sink, cat, gloves, and hat. What picture begins with /s/” (Goffreda & DiPerna, 2010). This test is administered in the beginning, middle, and end of preschool as well as the beginning and the middle of kindergarten. The score for this measure is equal to the number of correct initial sounds recited per minute (Goffreda & DiPerna, 2010). Alternate forms reliability for this test is .72 (Kaminski & Good 2002).

Letter Naming Fluency (LNF)—LNF measures knowledge of alphabetic letters by assessing the number of correct letter sounds provided in one minute (Elliott et al., 2001; Speece & Case, 2001). For this test, lower case letters are randomly arranged on a page (five rows and five columns). The test starts with three practice items and feedback. The student must orally give the hard or soft sound of each consonant and the short sound of each vowel (Elliott et al., 2001; Speece & Case, 2001). This measure is given in the beginning, middle, and end of kindergarten as well as in the beginning of first grade. Alternate forms reliability is between .82–.93 (Elliott et al., 2001).

Phonemic Segmentation Fluency (PSF)—PSF measures phonological awareness. The student must segment an orally presented monosyllabic word into the appropriate amount of phonemes. For example, a student would identify the word “bat” as having three phonemes (/b/ /a/ /t/). The total score for PSF is the total number of correct phonemes identified within one minute. Directions for this test were modified from Kaminski and Good (2002) to include additional practice items, picture cues, and more explicit feedback. This measure is given in the middle and end of kindergarten as well as the beginning, middle, and end of first grade. The alternate forms reliability is .60–.90 (Kaminski & Good, 2002; Kaminski & Good, 1996).

Oral Reading Fluency (ORF)—ORF tests the decoding of real words by measuring accuracy and fluency while reading connected text. This test is given starting in the middle of first grade through the third grade and is calibrated for each goal reading level for each grade level. Students read a passage aloud for 1 min, with the total number of words read correctly used as the final score. Omitting or substituting words and/or hesitating for more than three seconds are scored as errors. If the student self-corrected within 3 seconds the

errors were scored. Parallel forms reliability has been previously reported as high as .94 (Speece & Case, 2001).

Nonsense Word Fluency (NWF)—NWF measures a student's understanding of alphabetic principle and phonological recoding (Goffreda & DiPerna, 2010). A student must read a list of phonetically correct non-words (e.g., og, cav, lig), as either letter sounds or sound out the entire word. The final score is the total correct number of sounds produced in one minute. This test is administered in the middle and end of kindergarten through the beginning of second grade. The alternate forms reliability ranges from .58–.92 (McMaster et al., 2005; and Jordan et al., 2006).

School grade—For the 2006–2007 school year there were eight factors taken into account by the Florida Department of Education in calculating school grades: student achievement level scores on the Florida comprehensive achievement test (FCAT) reading achievement, FCAT mathematics achievement, FCAT science achievement, FCAT writing achievement, learning gains in reading, learning gains in math, the lowest performing students making reading gains, and the lowest performing students making math gains (Blomberg, 2007). A point system is used in which a school receives one point for each percentage of students who scored at or above state standards for each of the eight factors. That is one point for each percentage of students scoring at or above FCAT Achievement level 3 for FCAT reading, math, and science, at or above 3.5 for writing, as well as one point for each percentage of students who made learning gains over the school year in reading and math, and finally one point for each percentage of the lowest performing students making gains in reading and math (Blomberg, 2007). Schools that received 525 points and above were graded as “A” schools, schools receiving 495–524 points were “B” schools, 435–494 were “C” schools, 395–434 were “D” schools and schools receiving less than 395 points were “F” schools (Blomberg, 2007). In addition to the point system, schools were also evaluated on two more conditions: the percentage of students tested and the adequate progress of the lowest performing students in reading and math. If schools received enough points to earn a grade of “A,” at least 95% of their students had to have been tested for the school to formally receive the score of “A”. For each of the other letter grades at least 90% of students had to have been tested. For the progress of the lowest performing students, if a school earned an “A” it had to show adequate progress of the lowest quartile of students in both reading and math for the current year of grading. If the school earned a “B” or a “C” it had to show progress of the lowest quartile in both reading and math for either the current year of grading, or the previous year (Blomberg, 2007). If the schools did not meet these criteria, the resulting grade based on the point system would be lowered one letter grade.

Analysis

First, due to there being low sample sizes in some of the grade categories, a data reduction procedure was explored in an attempt to collapse categories that were not statistically different in order to increase sample size for each. This was done by examining group differences on NWF across school grades, explored using ANOVA in SAS 9.4. NWF was selected as it represented the early literacy measure with most of the sample available for

analysis. From this ANOVA, it was determined that separating school grade as “A” versus “non-A” subgroups was appropriate.

As a first step in the genetically-sensitive modeling, twin intraclass correlations, MZ twins versus DZ twins, were conducted for each early literacy measure by school grade subgroup. This allowed an initial description of the genetic and/or environmental influences on each early literacy measure. Following these intraclass correlations, multi-group analyses using structural equation modeling were then performed across school grade subgroups (A versus non-A schools) for each early literacy measure, resulting in five separate analyses. For each measure, univariate additive genetic (inherited genetic influences; A), shared environmental (environmental influences that serve to make siblings more similar; C) and nonshared environmental (environmental influences that make siblings less similar, plus error; E) components of variance were estimated by school grade subgroup. A fully varying model (the unconstrained model), where A, C, and E estimates were allowed to vary by school grade subgroup was then subsequently compared to a model where the A, C, and E estimates were invariant (the constrained model), or not allowed to vary across school grade subgroups. If a chi-square difference test between these two models was non-significant, the constrained model was accepted and model testing stopped there. If a chi-square difference test indicated that there was a significant reduction in model fit after constraining across subgroups, it was determined that there were school grade subgroup differences in A, C, and/or E components of variance. From there, in an effort to determine the most parsimonious model, sub-models representing various combinations of A, C, and/or E estimates were set to be invariant across subgroups (e.g., A allowed to vary across subgroups, C, and E set to be invariant) and subsequently tested against the unconstrained model. The final model was chosen based on the sub-model that was not significantly different from the unconstrained model, based on chi-square difference testing, that also had the lowest Akaike’s information Criterion (AIC; Akaike, 1987). If all sub-models showed significant changes in chi-square model fit from the unconstrained model, the unconstrained model was maintained as the final model.

All structural equation modeling were conducted using raw data with age, age squared, gender, and, importantly, school-level socioeconomic status (i.e., percentage of school’s students receiving free and reduced lunch services in the school during the 2006–2007 school year; $M = 54.31\%$, $SD = 25.09\%$, range = 1.91%–98.30%) regressed out. Additional analyses were conducted without controlling for school-level SES (maintaining the other control variables), and are presented in supplementary tables. The structural equation modeling was conducted using Mx (Neale et al., 2003) with maximum likelihood estimation.

Results

Descriptive statistics for the early literacy measures are presented in Table 1 for the total sample as well as by school subgroup. The results from the ANOVA indicated significant differences in NWF scores between school types $F(4,2632) = 8.33$, $p < 0.001$. Post hoc Bonferroni tests indicated significant differences when A schools ($M = 72.39$, $SD = 41.01$) were compared to B schools ($M = 63.82$, $SD = 37.14$), to C schools ($M = 63.74$, $SD = 37.76$),

and to D schools ($M= 57.75$, $SD= 46.25$), but not F schools ($M= 59.71$, $SD= 38.78$). As noted previously, the decision to split the sample into “A” and “non-A” schools was supported by the data; specifically the ANOVA results indicated significant differences when A-graded schools were compared to all other school types other than “F” scores, which had low available sample size. There were no other significant differences between the school types. Table 1 also presents *t*-test results comparing the means between “A” schools and “non-A” schools for each early literacy measure. The results indicate significantly higher mean values for all early literacy measures in schools that were graded “A” when compared to schools that were graded “non-A” (i.e., “B” through “F”).

Pearson correlations for school-SES, school grade and the early literacy measures are presented in Table 2. Coefficients for all residualized data while controlling for school-SES are presented in the lower triangle of the table. All correlations were significant at $p<0.01$ or $p<0.001$, aside from the correlations between school-SES with ISF, LNF, PSF, ORF, and NWF, as well as ORF with ISF and LNF. No values were given for the correlations between ORF and ISF and ORF and LNF because the administration of these pre-reading measures (ISF and LNF), given only in kindergarten, does not overlap with the word level reading skill (ORF) given only after kindergarten. Coefficients for all residualized data without controlling for school-SES are presented in the upper triangle of the correlation table. Aside from the correlations between ORF with ISF, and ORF with LNF, all correlations where school-SES was not controlled were significant at $p<0.01$, or $p<0.001$. School-SES was negatively correlated with all other measures, such that literacy scores were lower in schools with a higher percentage of children receiving free or reduced lunch. School grade was positively correlated with all early literacy measures for the data not controlling for school-SES.

Twin intraclass correlations are presented in Table 3 for each early literacy measure. For the total sample, the MZ correlation coefficients were greater in magnitude than DZ correlation coefficients, indicating genetic influences. Additionally, the MZ twin correlations were no more than twice as large as DZ twin correlations, indicating shared environmental influences. Finally, MZ twin correlations were less than one, indicating nonshared environmental influences. When examining the intraclass correlations by school subgroup, differential etiology across the school subgroups was indicated.

A summary of the multigroup model-fitting results for each early literacy measure for “A” schools and “non-A” schools is presented in Table 4, and the subsequent genetic (A), shared (C), and nonshared (E) environmental components of variance for each early literacy measure are presented in Table 5. Overall, the model fitting results indicated significant etiological differences on the pre-reading skills (ISF, LNF, and PSF), but not for the word-level reading skills of ORF and NWF, when “A” schools were compared to “non-A” schools. Model fitting results indicated that the constrained model did not fit the data well for ISF, LNF, and PSF, suggesting that there were significant differences in the ACE parameters for these pre-reading skills between the subgroups (Table 5). The univariate results for ISF indicated greater genetic influence on ISF for “A” schools versus greater shared and nonshared environmental influences for “non-A” schools (Table 5). For LNF, shared environmental influences were higher in non A-schools than in A-schools (Table 5).

Univariate results for PSF indicated higher shared and nonshared environmental influences for “non-A” schools versus “A” schools (Table 5).

Multigroup analyses indicated that for the word-level reading skills of ORF and NWF, the constrained model fit the data best, and therefore there were no significant differences in the ACE components between “A” schools and “non-A” schools (Table 4). Both ORF and PSF indicated significant and moderate additive genetic, shared environmental, and nonshared environmental influences (Table 5).

Supplementary Table 1 also provides model-fitting results for analyses conducted on data without controlling for school-level SES. The same trend was seen in the results controlling for school-SES. Model-fitting indicated significant differences between “A” and “non-A” schools for pre-reading skills, but not word-level reading skills (see supplementary Table 1). Univariate estimates for these analyses are presented in supplementary Table 2.

Discussion

The purpose of this study was to assess the presence of etiological differences on early literacy skills across school quality contexts, as measured by school grade. We hypothesized that better school grades would be associated with greater genetic influences on early literacy, while poorer graded schools would be associated with increased environmental influences on early literacy. School grade was chosen here as an environmental measure of interest because it informs many of the decisions that parents, teachers, administrators, and the general public make in regards to housing and school choice, as well as resources provided to the school.

In general, the pattern of results indicated that there were greater shared environmental influences on pre-reading skills in the “non-A” school subgroup, and greater additive genetic influences on these same measures for the “A” school subgroup, supporting our hypothesis. These significant differences between “A” and “non-A” schools are maintained despite overlap in the confidence intervals of the different groups (e.g., LNF and PSF) as means can still be significantly different even in the case of overlapping confidence intervals (Cumming & Finch, 2005; Austin & Hux, 2002). These results are consistent with the bioecological model (Bronfenbrenner & Ceci, 1994), which has been supported by other works exploring the impact of family-level SES (Harden et al., 2007) and classroom quality (Taylor et al., 2009). Additionally, a similar pattern of results was reported from this same dataset using similar DIBELS scales measured at different school years, concentrating on the role of neighborhood-level SES (Taylor & Schatschneider, 2010). However, that study did not find significant etiological differences in pre-reading skills LNF or ISF due to neighborhood-level SES (Taylor & Schatschneider, 2010). From these results, if we endorse the idea that an “A” graded school represents a better quality school, then better quality schools were associated with greater genetic influences on pre-reading skills, whereas, shared environmental influences accounted for more variance in poorer quality schools. It is important to note that these results were not due to school-level SES factors, as those effects had already been partialled out. It is, however, difficult to discuss aspects of quality without taking into account SES factors. Moreover, the analyses conducted in this study examined

the etiology of early literacy in the presence and absence of school-level SES. The results for both groups of analyses follow the same trends, however the differences in magnitude between A graded schools and non-A schools are greater when SES is taken into account (Supplementary Table 2). This suggests that school-level SES is largely driving the etiological differences we see, while school grade is accounting for a smaller, but still significant, portion of these differences.

Curiously, the same trend supporting the bioecological model was not observed for word-level reading skills in the present study. It is not known why there was no moderation for word-level reading skill, versus pre-reading skill, but the consistency of the results by type of early literacy measure is compelling. As there is typically thought to be a developmental pattern where pre-reading skills precede reading skills, perhaps the moderation of school grade is best seen in these more basic skills. Interestingly, Taylor and Schatschneider (2010) were able to find etiological differences in ORF in relation to neighborhood-level SES in a sample drawn from the same broader population (although they did not test NWF). It should be noted that the analyses conducted by Taylor and Schatschneider (2010) were different compared to the present analyses. Primarily, we would not necessarily expect that neighborhood-level SES would act exactly as school-grade would, in terms of environmental influences on early literacy skills. Neighborhood-level SES taps the socioeconomic state of the families living in the communities surveyed, which may reflect the education levels of the families as well as employment rates and crime rates in the neighborhoods. School grade, on the other hand, reflects the academic performance of the students. The two variables are measuring different constructs. These differences between the two environmental contexts likely contributed to the differences across the studies. Additionally, there were sample differences between the two studies. Taylor and Schatschneider (2010) chose to focus on kindergarten and first grade children collapsed over multiple school years, whereas, for the present study, kindergarten through third grade twin pairs were assessed in one school year. Moreover, the mean age for the two studies were different, with a mean age of 5.53 for the kindergarten sample and 6.61 for the first grade sample in the Taylor and Schatschneider (2010) study, and a mean age of 7.26 for the present study. In addition to these age and grade differences, the overall sample size for the Taylor and Schatschneider study was much larger, yet more narrow in scope (age/grade) than the present study. It is not known if one or all of these differences, or others not stated here, contribute to the group differences on the word-level reading measures. What is important is that for the total sample in the Taylor and Schatschneider study, we see the same trend in the variance accounted for by genetic and environmental influences as we see in the present study, this study however did not pick up on group differences. Also, what is remarkable is that etiological differences were consistently found for pre-reading measures due to environmental influences distal to the child's reading environment for both studies.

There are many potential sources of this environmental variability for lower-graded schools, namely at the neighborhood, school, and home environment levels. The school environment is often times reflective of the surrounding community and neighborhood environment. Better performing schools tend to be located in and help shape more affluent neighborhoods; neighborhoods that are in close proximity to employment opportunities, shopping, and recreational conveniences (Kane et al., 2006), allowing for more stable and enriched

environments surrounding the schools. Communities are often segregated along economical and racial lines (Kane et al., 2006), meaning that better performing schools are typically less diverse, racially and economically, also resulting in less environmental variability. Turning towards the school, based on yearly progress reports and school report cards, school grades tend to be consistent and stable over the years, especially for schools that are more highly graded, which may mean that the level of instruction given to students over the years is also consistent. School districts often use a merit pay system, where teachers in schools graded more highly are rewarded (Dee & Keys, 2004). This payment system works to attract better quality teachers to better performing schools, and these teachers may be more likely provide explicit, consistent, and stable lessons to students. On the other side, poorer quality schools are more likely to see frequent teacher turn over, and more likely to hire new teachers or poorer overall teachers, all resulting in more variable instructional environments (Lankford et al., 2002). Finally, the home environments of students attending better performing schools are more likely to be stable, which may also help to explain the greater genetic influence on pre-reading skills for students attending “A” schools. Research has shown that the home environment can be predictive of academic achievement in students, with a more stable home predicting higher achievement (Todd & Wolpin, 2007).

There are a few limitations that should be mentioned in regard to the school grade measure. First, there was an unequal distribution of students between the initial “A” through “F” graded schools that necessitated a dichotomization of the school grade variable. Ideally, each grade level would be explored using continuous data modeling techniques. Also, school grade is an omnibus indicator of school quality that attempts to synthesize a complex environment into a single value much the way a student’s grade is an omnibus indicator of the amount of learning he/she achieved in a subject. At the school level, the grade provides a measure of accountability for principals and teachers, which some have described as noisy and disconnected from what it is intended to measure (Figlio & Lucas, 2004). Another limitation is the inability to model and account for the gene-environment correlation, in that student’s genetic influences related to reading may also be correlated with the quality of the schools. All students at a given school share the same school grade, and in order to properly assess this phenomenon it would be necessary for school grade or school quality to be measured at the individual level. The measure of school quality potentially picks up on genetic characteristics of the parents or students, as school choice is not random; however, the group-level measurement of this variable prevents our exploration of these characteristics.

The results of this study suggest that environments in lower graded, and by proxy “lower quality,” schools appear to be more variable, leading to environmental factors accounting for the majority of variance in pre-reading skills. An important implication of these results is that minority and low-SES students may be disproportionately affected by school quality due to the large proportion of these groups in lower performing schools. These groups may, in turn, be significantly more impacted by the more variable environment when learning early reading skills as opposed to students in higher graded schools, thereby contributing to the achievement gap between minorities and non-minorities.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Research Highlights

- This study demonstrates the role of school grade (e.g., “A”), an omnibus index of school quality assigned by state governments, as a moderator of the genetic and environmental influences on children’s early literacy skills
- A large and representative twin sample was used to show that school grade moderates the genetic and environmental influences on pre-reading skills, outside of the influences of socioeconomic status (SES)
- There was a consistent trend of greater environmental influences on pre-reading skills in non-A schools, arguably representing “poorer” environmental contexts than the A-schools
- Minority and low-SES students may be disproportionately affected by school grade due to the large populations of these groups in lower performing schools. These groups may, in turn, be significantly more impacted by the more variable environment when learning early reading skills as opposed to students in higher graded schools, thereby contributing to the achievement gap

Table 1

Descriptive statistics for early literacy measures by school subgroup

Measure	School	Mean	SD	n	skew	kurtosis	min	max	t-value (df)	p-value
ISF ¹	Total	24.41	14.39	922	1.38	4.02	0.00	120.00	-2.26 (920)	0.02
	A	25.16	14.35	619	1.47	4.70	0.00	120.00		
	B	25.89	15.26	115	0.94	1.86	0.00	84.00		
	C	21.49	12.59	136	1.42	4.83	0.00	82.00		
	D	19.91	15.28	34	1.73	3.80	0.00	69.00		
	F	19.78	17.06	18	1.55	3.12	0.00	69.00		
LNF ²	Non-A	22.88	14.37	303	1.23	2.76	0.00	84.00		
	Total	51.91	18.56	942	-0.03	0.21	0.00	110.00	-2.41 (555.25)	0.02
	A	52.96	17.81	633	0.05	0.26	2.00	110.00		
	B	52.53	20.05	117	0.15	-0.54	13.00	98.00		
	C	49.20	19.81	137	-0.45	0.29	0.00	99.00		
	D	41.84	18.89	37	0.94	2.07	6.00	103.00		
PSF ³	F	52.11	17.86	18	-1.34	3.33	0.00	80.00		
	Non-A	49.75	19.87	309	-0.09	0.02	0.00	103.00		
	Total	43.39	16.32	1866	-0.55	0.27	0.00	89.00	-4.03 (1092)	<0.001
	A	44.53	15.18	1234	-0.60	0.58	0.00	89.00		
	B	43.68	16.73	254	-0.61	0.15	0.00	75.00		
	C	41.13	18.62	303	-0.26	-0.24	0.00	88.00		
ORF ⁴	D	29.57	18.29	51	0.05	-0.97	0.00	66.00		
	F	39.04	17.88	24	-0.76	0.55	0.00	72.00		
	Non-A	41.14	18.16	632	-0.39	-0.23	0.00	88.00		
	Total	87.33	44.32	2182	0.23	-0.49	0.00	227.00	-10.53 (2108)	<0.001
	A	94.04	44.15	1464	0.08	-0.57	0.00	218.00		
	B	75.53	43.61	273	0.61	0.14	0.00	216.00		
NWF ⁵	C	71.23	38.51	379	0.35	-0.31	0.00	195.00		
	D	76.14	47.33	43	0.84	1.13	0.00	227.00		
	F	86.17	49.32	23	0.68	-0.12	14.00	190.00		
	Non-A	73.64	41.46	718	0.55	0.15	0.00	227.00		
	Total	69.24	40.34	2637	0.75	0.00	0.00	231.00	-5.74 (1912.8)	<0.001
	A	72.39	41.01	1743	0.62	-0.40	0.00	222.00		
	B	63.82	37.14	340	1.06	1.58	0.00	228.00		
	C	63.74	37.76	446	0.93	0.77	0.00	231.00		
	D	57.75	46.25	73	1.48	2.11	0.00	223.00		
	F	59.71	38.78	35	0.83	-0.08	0.00	145.00		
	Non-A	63.12	38.30	894	1.02	1.17	0.00	231.00		

Note: Total indicates all schools combined. The t-values result from comparing "non-A" schools to "A" schools, and the p-value is the significance test for the t-test. Analyses were conducted on raw data. The sample size reflects individuals.

¹ DIBELS Initial Sound Fluency (ISF).

² DIBELS Letter Naming Fluency (LNF).

³ DIBELS Phoneme segmentation fluency (PSF).

⁴ DIBELS Oral Reading Fluency (ORF).
⁵ DIBELS Nonsense Word Fluency (NWF).

Table 2

Pearson correlations for SES, school grade, and environmental measures.

	School-SES	School Grade	ISF	LNF	PSF	ORF	NWF
School-SES	1 n=3141	-0.56** n=3133	-0.22** n=910	-0.18** n=926	-0.16** n=1834	-0.24** n=2128	-0.13** n=2582
School Grade	-0.56** n=3133	1 n=3133	0.08* n=908	0.08** n=924	0.11** n=1828	0.22** n=2122	0.13** n=2574
ISF	0.00 n=910	-0.04 n=908	1 n=945	0.40** n=932	0.33** n=932	- n=0	0.36** n=932
LNF	0.00 n=926	-0.02 n=924	0.36** n=903	1 n=955	0.50** n=955	- n=0	0.65** n=955
PSF	0.00 n=1834	0.02 n=1828	0.28** n=903	0.48** n=926	1 n=1887	0.20** n=932	0.40** n=1887
ORF	0.00 n=2128	0.09** n=2122	- n=0	- n=0	0.19** n=908	1 n=2189	0.76** n=1705
NWF	0.00 n=2582	0.06* n=2574	0.32** n=903	0.63** n=926	0.38** n=1834	0.76** n=1656	1 n=2660

Note. School grade is coded as A = 1 and not A = 0. SES is the percent of students who receive free or reduced priced lunch. Correlations done using raw data, residualized for age, age squared, and gender only are above the diagonal. Correlations done using final data used in subsequent models, raw data that has been standardized by residualizing for age, age squared, gender and school-SES, are below the diagonal.

*
p<0.01,

**
p<0.001. The sample size reflects individuals.

Table 3

Twin intraclass correlations for early literacy measures by zygosity for the whole sample and by school subgroup

Measure	Total	A-Schools	Non-A Schools
Initial Sound Fluency			
MZ (<i>n</i>)	.39 (310)	.46 (186)	.30 (124)
DZ (<i>n</i>)	.31 (574)	.29 (407)	.40 (165)
Letter Naming Fluency			
MZ (<i>n</i>)	.56 (322)	.47 (192)	.65 (130)
DZ (<i>n</i>)	.45 (581)	.37 (416)	.64 (163)
Phoneme Segmentation Fluency			
MZ (<i>n</i>)	.51 (618)	.53 (392)	.48 (224)
DZ (<i>n</i>)	.35 (1183)	.32 (800)	.40 (379)
Oral Reading Fluency			
MZ (<i>n</i>)	.83 (696)	.83 (482)	.84 (212)
DZ (<i>n</i>)	.58 (1401)	.57 (927)	.60 (470)
Nonsense Word Fluency			
MZ (<i>n</i>)	.65 (862)	.68 (554)	.58 (306)
DZ (<i>n</i>)	.52 (1679)	.54 (1120)	.46 (553)

Note. All correlations were significant at $p < 0.001$. Analyses were conducted on standardized data, controlling for age, age squared, gender, and school-SES. The sample size reflects individuals.

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Note. $-2LL = \text{negative } 2 \log \text{ likelihood}$. The best fitting models are bolded. Analyses were conducted on standardized data, controlling for age, age squared, gender, and school-SES.

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Table 5

Additive genetic, shared environmental and nonshared environmental variance components with 95% confidence intervals (in parentheses)

Measure	School Subgroup	Additive Genetics	Shared Environment	Nonshared Environment
Initial Sound Fluency	A-Schools	0.58 (0.25–0.69)	0.00 (0.00–0.00)	0.42 (0.31–0.58)
	Non-A-Schools	0.00 (0.00–0.00)	0.35 (0.06–0.48)	0.65 (0.52–0.81)
Letter Naming Fluency	A-Schools	0.20 (0.00–0.47)	0.30 (0.09–0.5)	0.50 (0.39–0.62)
	Non-A-Schools	0.15 (0.00–0.36)	0.48 (0.28–0.64)	0.37 (0.28–0.48)
Phoneme Segmentation Fluency	A-Schools	0.50 (0.28–0.65)	0.07 (0.00–0.23)	0.43 (0.35–0.53)
	Non-A-Schools	0.36 (0.20–0.50)	0.18 (0.03–0.33)	0.46 (0.37–0.56)
Oral Reading Fluency	A-Schools	0.49 (0.39–0.59)	0.34 (0.25–0.43)	0.17 (0.15–0.20)
	Non-A-Schools	0.49 (0.39–0.59)	0.34 (0.25–0.43)	0.17 (0.15–0.20)
Nonsense Word Fluency	A-Schools	0.32 (0.19–0.45)	0.35 (0.25–0.45)	0.33 (0.29–0.38)
	Non-A-Schools	0.32 (0.19–0.45)	0.35 (0.25–0.45)	0.33 (0.29–0.38)

Note. Significance is indicated by bold type, as determined by confidence intervals not bounding zero. Analyses for these results were conducted on standardized data, controlling for age, age squared, gender, and school-SES.