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Genetic Influence on Literacy Constructs in Kindergarten and First Grade: Evidence from a Diverse Twin Sample

Jeanette Taylor and
Department of Psychology, Florida State University, 1107 W. Call St., Tallahassee, FL 32306-4301, USA

Christopher Schatschneider
Florida Center for Reading Research, Florida State University, Tallahassee, FL, USA.
Department of Psychology, Florida State University, 1107 W. Call St., Tallahassee, FL 32306-4301, USA

Jeanette Taylor: taylor@psy.fsu.edu

Abstract

Historically, twin research on reading has been conducted on older children and the generalizability of results across racial/ethnic/socioeconomic groups is unclear. To address these gaps, early literacy skills were examined among 1,401 twin pairs in kindergarten and 1,285 twin pairs in first grade (ages 5–7). A multi-group analysis was conducted separately for subsamples defined by neighborhood income while controlling for race/ethnicity within each grade. Substantial additive genetic and shared environmental effects were found for early literacy skills measured in kindergarten. In first grade, variance in early reading was associated with large additive genetic effects for middle and high neighborhood income twins, but shared environmental influence was substantial for low neighborhood income twins. Results suggest that the etiological architecture of some early literacy skills may differ across economic contexts.

Keywords

Early literacy skills; Reading; Phonological awareness; Genetic; Twins

Introduction

A recent theoretical paper by Kovas et al. (2007) reviews compelling evidence from the Twins' Early Development Study (TEDS) and other studies suggesting that learning disabilities and learning abilities are influenced by what they call "generalist genes," suggesting that examining the etiology of reading ability could inform our ultimate understanding of the causes of reading disability. Heritability for reading ability has been estimated to be as high as .81 (e.g., Byrne et al. 2007). Of course, the ability to read is not present at birth but rather develops in a cumulative manner typically beginning with a requisite mastery of early literacy skills including language comprehension, letter recognition, phonics, and decoding. Thus, early literacy skills are of particular importance in the development of reading ability, and variability in early literacy skills might have a somewhat different underlying etiological architecture than fully developed reading skills. However, much of the behavioral genetic literature on reading comes from twin samples of

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Correspondence to: Jeanette Taylor, `taylor@psy.fsu.edu`.

older children, adolescents, and adults. As such, the etiology of early literacy skills is not well understood.

Phonological awareness and decoding are central to the development of reading ability and indicators of these early literacy skills can be assessed in pre-readers. However, much of the twin research on these constructs is from older samples in which actual reading skills are already developed. For instance, Knopik et al. (2002) reported estimates of additive genetic influence on phonological decoding and phonemic awareness of .70 and .76, respectively, from data on 8- to 20-year-old twin pairs largely from middle class homes participating in the learning disability study at the Colorado Learning Disabilities Research Center (CLDRC). Using that same data set, Gayan and Olson (2003) reported similar magnitude estimates of additive genetic effects on those constructs, but they also found modest non-additive genetic effects for phonological decoding (.28) and phonemic awareness (.14). Byrne et al. (2002) provided one of the first insights into early phonological skills from a sample of 271 4–6-year-old same-sex twin pairs in pre-schools in Australia, Colorado, and Norway. They reported additive genetic estimates of around .50 for composite measures of phonological processing, suggesting that genetic influence on early phonological skills is substantial but smaller than what is found in older samples where more developed skills are being tapped. Petrill et al. (2006) also reported on a young multi-sample dataset from the Western Reserve Reading Project and the Northeast-Northwest Collaborative Adoption Projects (Deater-Deckard et al. 2003). In models based on 242 twin pairs (mean age 6.1) they reported moderate additive genetic estimates for phonological awareness (.48) and greater heritability for serial naming speed (.77), which some view as another phonological process (though there is some debate on this issue; see Wolf and Bowers 1999). In addition, the shared environment estimate was substantial for phonological awareness (.43) but negligible for serial naming (.01). Despite some difference in the magnitude of genetic effects for younger versus older samples, variance in phonological decoding and phonemic awareness is associated with genetic factors with estimates of shared environment showing more variability across studies.

Another important building block for reading ability is print knowledge, which is an umbrella term used to describe a host of skills from environmental print (e.g., identifying a stop sign) to letter names and sounds. Relatively little is known about the etiology of this early literacy skill because variability exists only among pre-readers—a developmental period that has not received wide attention in behavioral genetic research. Byrne et al. (2002) examined a number of print knowledge skills and found substantial influences of shared environment (ranging from .41 for environmental print knowledge to .60 for letter name knowledge). Heritability estimates for these tasks were modest and ranged from .02 for an assessment of print conventions to .24 for environmental print knowledge. Petrill et al. (2006) reported similar results for letter knowledge in their sample of 6-year-old twins, with letter name knowledge having heritability and shared environment estimates of .22 and .50, respectively. These studies suggest substantial shared environmental influence on print knowledge, but the results await replication with larger and more diverse samples.

The central skill in reading ability is, of course, word reading. Once a child gains an awareness of print, phonics, and the ability to decode phonemic sequences, then word reading can emerge. The heritability of word reading appears to be high. For instance, an estimate of .73 was obtained in a sample of 13-year-old twins with the remaining variance associated with non-shared environmental factors after controlling for IQ (Stevenson et al. 1987). Similarly, Reynolds et al. (1996) examined oral reading ability in 672 MZ and 647 DZ twin pairs aged 8–16 years participating in the Virginia Twin Study of Adolescent Behavioral Development and found that additive genetic factors accounted for 69% of the variance; however, shared environment accounted for only a modest (.13) proportion of

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variance. In an examination of adoptees and nonadoptees, Wadsworth et al. (2001) found moderate genetic effects on reading at ages 7 and 12 and larger effects at age 16. They also showed that a single set of genetic factors was associated with reading at each of those ages, suggesting that genetic influences on reading in childhood are still at work in adolescence. Finally, Bratko (1996) reported a genetic estimate of .52 for word fluency and a non-significant shared environment estimate of .14 from a small sample (160 pairs) of twins aged 15–19 years in Croatia. Thus, in samples of older children and adolescents in which reading ability is already (presumably) well established, variance in word reading and word fluency appears to be largely associated with genetic factors with little shared environmental influence. A recent study by Byrne et al. (2007) on their combined U.S.-Australian twin sample revealed similarly high estimates of genetic influence for word fluency (.81) and nonword fluency (.71) assessed at the end of first grade (around age 7). That result is consistent with findings from the TEDS study for similarly aged twins (Kovas et al. 2007). Thus, the literature suggests that once word reading comes online, the variability is associated mainly with differences in genetic factors, not shared environment.

Results from twin studies indicate that genetic influence on phonological skills and word reading is moderate to strong in magnitude. Early literacy skills (e.g., print awareness) that develop in advance of word reading appear to be influenced to a large extent by shared environment factors, but only a single study has examined preschool aged twins (Byrne et al. 2002). Shared environmental factors account for significant variance in print awareness, but it is smaller or nonexistent for other early literacy skills. Though the literature is consistent in its findings, it is also consistent in a potential confound: racial/ethnic/economic homogeneity of twin samples. Our understanding of the etiology of word reading and early literacy skills comes mainly from a few studies that appear to have similar demographics. The TEDS sample is representative of the population in the United Kingdom in terms of socioeconomic status and race/ethnicity but it is 92% White (Kovas et al. 2007); the CLDRC sample is from mostly middle class homes (Knopik et al. 2002; race/ethnicity not reported) in a state that is 90% White according to the U.S. Census Bureau; and Byrne et al. (2002, 2007) do not report the racial/ethnic composition or income distribution for their sample of U.S./Australian/Norwegian twins. Thus, it is not clear to what extent the findings in the literature are generalizable across race/ethnicity and across the range of economic environments.

Turkheimer et al. (2003) demonstrated that heritability of IQ varied as a function of socioeconomic status with greater shared environmental effects among poor children and greater additive genetic effects among children from affluent homes. Harden et al. (2007) replicated that finding when looking at school aptitude scores from the National Merit Scholarship Qualifying Test. However, van den Oord and Rowe (1997) failed to find lower heritability for school achievement measures, including reading, among children in lower socioeconomic environments. Similarly, Friend et al. (2009) failed to find higher heritability of high reading ability in twins of parents with high education levels (which can serve as a proxy for socioeconomic status). Though the evidence of a gene × socioeconomic environment (G × E) effect on cognitive abilities is not universal, it is consistent enough to suggest the possibility that the failure to find shared environmental influence on early literacy skills could be an artifact of the racial/ethnic/economic homogeneity of the twin samples that have been examined thus far.

The main goal of this report was to examine word reading and early literacy skills in a sample of 5–7-year-old twins, an age range that has received relatively little attention in twin research. Given the racial/ethnic/economic diversity of our sample, a secondary goal of the present study was to assess the generalizability of our findings and of prior findings on the genetic and environmental influence on early literacy skills by examining models in the

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entire sample of twins and also in subgroups based neighborhood income while controlling for race/ethnicity. The present report is among the first to come from an ongoing longitudinal project aimed at examining genetic and environmental influence on reading ability and disability from kindergarten through fifth grade. Though the ultimate goal of the project is to answer important multivariate and longitudinal questions, the present report focuses on univariate questions using data collected in kindergarten and first grade that will set the stage for future longitudinal analyses.

Based on prior findings in young twin samples, we expected to find substantial additive genetic influence on individual differences in early literacy skills. Based on the reports by Byrne et al. (2002) and Petrill et al. (2006), shared environmental influence was expected for measures of print awareness, particularly in the kindergarten sample. Based on the work by Turkheimer and his colleagues (Harden et al. 2007; Turkheimer et al. 2003), we expected to find greater magnitude effects for shared environment on individual differences in early reading measures in twins from low income neighborhoods as compared to twins from high income neighborhoods (for whom additive genetic factors were expected to show greater effects).

Methods

Participants

Twins included in this report are members of the Florida State Twin Registry (FSTR; Taylor et al. 2006) and were recruited as participants for the Florida Twin Project in Reading (FTP-R), a longitudinal study that is part of a Learning Disabilities Center at Florida State University and the Florida Center for Reading Research. In 2001, Congress passed the Elementary and Secondary Education Act, also known as the No Child Left Behind Act (NCLB). This act requires that states be accountable for student progress in all academic areas and insists that schools demonstrate how they are implementing research-based practices to improve student learning. Reading First, one of the most prominent programs under NCLB, is designed to help all students to become successful readers by providing funds to states that can be used to develop comprehensive reading instruction in kindergarten through third grade. Each state has a different method of meeting Reading First program requirements. In Florida, schools have to (1) employ one of five curricula deemed to have empirical support for its effectiveness, (2) participate in a sponsored professional development workshop each summer, and (3) conduct frequent within-year assessments of children’s progress in reading related skills from kindergarten through third grade. These progress monitoring assessments are to serve as the basis for instructional adaptation (Fuchs and Fuchs 2003) at both the classroom level and for particular student needs. These assessments are conducted three to four times a year by a trained Reading Coach, who is not the classroom teacher, and the data for each child is entered into a state-wide web-based system known as Florida’s Progress Monitoring and Reporting Network (PMRN). The PMRN is an incredibly rich source of data and it served both as the vehicle for twin ascertainment and as the source of achievement data.

Ascertainment of twins from the PMRN began with an identification of potential twin pairs and other multiples based on a match of children in the database on last name, birth date, and school. Parents of twins then had to be contacted by mail to confirm twin/multiple status, assess zygosity, and obtain consent to allow the use of the children’s PMRN data for twin analyses as part of the FTP-R. The parent mailing was either sent directly to parents (if contact information was obtained from the school district) and/or it was sent to schools to be carried home by one randomly selected member of the potential twin pair. The parent mailing contained a cover letter explaining the study and a reply card that contained five questions about similarity of the twins that have been used to assess zygosity in other twin studies and show an accuracy rate of over 95% when compared to DNA tests (Lykken et al. 1990). This procedure was approved by the Florida State University IRB as well as the IRBs of the 14 counties that were targeted first (representing northern, central, and southern parts of the state).

Of the 5,716 possible twin pairs/multiples in the first 14 counties targeted, a response was received from 43% of families. (Achievement scores from the PMRN could only be extracted on twin pairs whose parent had replied and consented to the use of the PMRN data for our twin study and, therefore, analyses comparing responders and non-responders were not possible. Similarly, address information was available only through a parent response in many cases and, therefore, analyses comparing responders and non-responders on neighborhood income using Census data were not possible.) Only 4% of responses indicated an ascertainment error (i.e., the children were not twins). Of those that did confirm twin/multiple status, 2,249 (95%) families agreed to participate in the FTP-R and become members of the twin registry (FSTR). Upon inclusion in the registry, twins within a pair were randomly designated as twin A or twin B. The present study examined early literacy skills and, therefore, focused only on twins with PMRN data from kindergarten (*M* age = 5.53; *SD* = .31) and/or first grade (*M* age = 6.61; *SD* = .43). Given the rarity of triplets and quadruplets and issues pertaining to non-independence of pairs that can result when they are included, each triplet set (*n* = 49) and quadruplet set (*n* = 1) was reduced to a single same-sex twin pair by removing the opposite-sex sibling or randomly selecting a same-sex member for removal. The kindergarten sample included 948 MZ pairs (490 female; 458 male) and 1,858 DZ pairs (464 female; 484 male; 910 OS). The first grade sample included 886 MZ pairs (450 female; 436 male) and 1,684 DZ pairs (454 female; 408 male; 822 OS). Note that the kindergarten and first grade samples were not independent with regard to twin membership.

The PMRN contains information on racial/ethnic group obtained from parents when they registered their children for school. Parents could identify the children into only one of six categories. The composition of the kindergarten/first grade sample was: 1.4%/.9% Asian/Pacific Islander, 21.9%/21.5% Black, 22.9%/23.2% Hispanic, .2%/.2% American Indian, 4.9%/4.8% Mixed, and 48.7%/49.4% White. Although this is certainly a common system for assessing race/ethnicity, it is not as comprehensive as a system in which race and ethnicity are assessed independently. Thus, parents of Hispanic children could opt to identify them by their race (Black, White, etc.) or by their ethnicity (Hispanic).

Measures

Initial sound fluency—This is a measure of phonological awareness that assesses a child’s ability to recognize and produce the initial sound in an orally presented word (Kaminski and Good 1996, 1998). The examiner presents four pictures to the child, names each picture, and then asks the child to identify (i.e., point to or say) the picture that begins with the sound produced orally by the examiner. For example, the examiner says, “This is sink, cat, gloves, and hat. Which picture begins with/s/?” Alternate-form reliability of the Initial Sound Fluency measure is .72 (Kaminski and Good 2003). This test was administered only in kindergarten.

Letter naming fluency—Letter Naming Fluency (Elliott et al. 2001; Speece and Case 2001) is a measure of print awareness that measures the number of correct letter sounds provided in 1 min. Lower case letters are randomly arranged on a standard size page (five rows and five columns) in 30 point, century Gothic font. Administration begins with three practice items and feedback. Students are required to give the sound of consonants (including either the hard or soft sound of “c” and “g”) and the short sound of vowels.

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Alternate-forms reliability (*r* = . 82–.93; Elliott et al. 2001; Speece and Case 2001) and predictive criterion-related validity with the Basic Reading Cluster score (WJ-R) is judged as adequate (*r* = . 58–.75; Elliott et al. 2001; Speece and Case 2001). The variable of interest is the number of sounds correctly produced in 1 min. This was measured only in kindergarten.

Phonemic segmentation fluency—This is also a measure of phonological awareness and it requires the child to segment the phonemes in an orally presented word containing three or four phonemes. Scoring also allows for partial credit. For example, a response to “sat” that reflected the onset and rime rather than three phonemes would earn a score of 2. The directions were modified slightly from Kaminski and Good (2003) to include additional practice items, picture cues, and more explicit feedback. Alternate-forms reliability (*r* = . 60–.90; Kaminski and Good 2003; Kaminski and Good 1996) and predictive and concurrent criterion-related validity with reading, spelling, and reading-related skills are adequate (*r* = . 54–.68; Kaminski and Good 1996; Kaminski and Good 2003). There are 20 alternate forms. The score reflects the number of correct segments produced in 1 min. This measure was given in kindergarten and first grade.

Oral reading fluency—This measure is a test of accuracy and fluency with connected text and assesses decoding of real words and was administered in first grade. The Oral Reading Fluency passages are calibrated for the goal level of reading for each grade level. Student performance is measured by having students read a passage aloud for 1 min. Words omitted, substituted, and hesitations of more than 3-s are scored as errors. Words self-corrected within 3-s are scored as accurate. The number of correct words per minute from the passage is the oral reading fluency rate. Speece and Case reported parallel forms reliability coefficient of .94 and predictive criterion-related validity coefficient of .78 (October–May) with the Basic Reading Skills Cluster score (WJ-R). These data correspond with other reports of strong technical adequacy of these measures (e.g., Deno 1985; Fuchs and Fuchs 1998; Marston 1989).

Neighborhood income group—Given that the primary measures for this study were obtained from the PMRN, a state-wide database of achievement measures, there was no contact with parents or twins beyond the brief mailing used to obtain consent and assess zygosity. Thus, an estimate of economic position of the family was made using 1999 U.S. Census Bureau data. Specifically, median family income for the zip code in which the twins currently reside was used as a proxy measure of the family’s socioeconomic status. In the kindergarten sample, the mean 1999 median family income was $46,001 (*SD* = $14,674; minimum = $17,906; maximum = $200,001). In the first grade sample, the mean 1999 median family income was $46,407 (*SD* = $15,197; minimum = $17,906; maximum = $121,466). Median family income was associated with race/ethnicity such that, in both the kindergarten and first grade samples, Black twins comprised a larger percentage of those with low neighborhood incomes (46%) compared to Hispanics (26%) or Whites (24%). Conversely, Whites comprised a larger percentage of those with middle (51%) and high (65%) neighborhood incomes than Hispanics (25 and 20%, respectively) or Blacks (17 and 7%, respectively). This confound was controlled for by adjusting median family income for race/ethnicity using the regression procedure outlined by McGue and Bouchard (1984). Income groups used in this report were formed by trichotomizing the race/ethnicity adjusted median family income variable from the Census data within each grade as follows: low income (bottom 25% of the distribution), middle income (26–74% of the distribution), and high income (uppermost 25% of the distribution).

Though other grouping cut points were certainly possible, the use of three groups provided a balance between the number of twin pairs at the upper and lower ends and a sufficient

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distinction between neighborhood income groups to be meaningful. For example, the low, middle, and high neighborhood income groups within the kindergarten sample all differed significantly from each other (p <.001) on average rent for vacant single family housing units in 1999 ($436 for the low zip group; $574 for the middle zip group; $732 for the high zip group), average median home value in 1999 ($83,796 for low zip group; $99,594 for middle zip group; $162,320 for high zip group), and percent of families receiving public assistance in 1999 (5.54% of low zip group; 3.06% of middle zip group; 1.71% of high zip group). The first grade sample showed the same significant (p <.001) differences between the low, middle, and high income groups and the means for the housing and public assistance variables were similar to those for the kindergarten sample.

Procedure

As noted above, children are tested at multiple time points across the school year and data from each testing is uploaded by the school/district into the state-wide PMRN database. This means that multiple samples of each measure might have been available for each twin in each grade. For this study, the *last* assessment point (end of school year) was used whenever possible (94% of kindergarten sample; 96% of first grade sample). If one or both members of a twin pair were missing data at the final assessment point, then the data from the latest assessment point in the school year available on both members of the pair was used (to ensure that one twin within a pair had not had more instruction prior to assessment). In addition, in cases where one or both members of a twin pair repeated kindergarten or first grade, scores from the *first* time through the grade were used to ensure that twins within a pair had a comparable amount of instruction prior to the assessment.

Analyses

All analyses were run separately on the kindergarten and first grade samples. Analyses began with descriptive statistics on each measure in the entire sample and an evaluation of the need to age- and/or sex-correct data. Descriptive statistics and twin correlations were calculated next for MZ and DZ twins in the entire sample and then for the three neighborhood income groups (low, middle, and high). A multi-group analysis was performed for the neighborhood income subgroups on each measure within each sample. Inspection of the twin correlations for each measure suggested that non-additive genetic factors were not likely a significant source of variance. Thus, each multi-group analysis began with a univariate model specified to decompose the total phenotypic variance (V_P) of a given measure into additive genetic effects (A), shared environmental effects (C), and non-shared environmental effects (E) by the following equation:

$$V_P = V_A + V_C + V_E \quad (1)$$

Models were fit to variance–covariance matrices, and the expected covariances were specified by the following equations:

$$\text{MZ covariance} = a^2 + c^2 \quad (2)$$

$$\text{DZ covariance} = .5a^2 + c^2 \quad (3)$$

All biometric models were estimated by maximum-likelihood using the Mx GUI software program (Neale et al. 1998). The chi-square (χ^2) goodness-of-fit statistic was used to assess the overall fit of each model. Reduced models were subsequently fit to the data and compared to the full model by means of chi-square difference tests. Reduced models that

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could be accepted over the full model were compared using Akaike's Information Criterion (AIC = $\chi^2 - 2df$; Akaike 1987) with the lowest AIC value indicating the best or most parsimonious model.

For all variables across both samples, the ACE univariate model provided the best fit across subgroups being examined in the multi-group analysis. As such, the ACE model was the base model for each multi-group analysis. The multi-group analysis for each variable began by fitting a fully unconstrained ACE model that allowed the estimate of variance associated with each parameter to vary across subgroups (e.g., low, middle, and high neighborhood income group). Next, a fully constrained model was fit in which the variance in each parameter is equated across subgroups to test for invariance in the estimates. The fully constrained model is the most parsimonious model available; if it fits and can be selected over the fully unconstrained model, then model-fitting stops. If the fully constrained model does not fit the data or provides a significant decrement in fit over the fully unconstrained model, then this indicates that there are significant differences across at least some subgroups in the model in the variance associated with one or more parameters. Model-fitting then continues by fitting reduced models in which variance in parameters are equated across subgroups or freed to vary (e.g., variance in A is equated across subgroups while variance in C and E are free to vary across subgroups).

Results

Distributions for early literacy measures were examined for deviations from normality and none required transformation prior to data analysis. Very modest but significant correlations were found between some measures and age and/or sex. Those variables were corrected for age and/or sex as needed using procedures outlined by McGue and Bouchard (1984). However, analyses on the untransformed data are reported because they produced results that were nearly identical to those from transformed variables. Given that the sample is racially/ethnically diverse, it was also possible that many of the twins were not proficient in English. Indeed, 78% of Hispanic twins and approximately 9% of White and Black twins in kindergarten or first grade were designated as limited in their English proficiency based on having been born in another country where English was not the native language and/or having a language other than English as the primary language spoken at home. To assess the possible effects of this, each achievement measure was adjusted for limited English proficiency status using the regression procedure outlined by McGue and Bouchard (1984). Correlations between the raw and the adjusted variables were near perfect and ranged from .98 for Initial Sound Fluency in kindergarten to .99 for Phonemic Segmentation Fluency in first grade, indicating that the raw and adjusted measures were essentially identical so we used the raw measures. Furthermore, the median family income variable adjusted for race/ethnicity was nearly perfectly correlated with the one adjusted for both race/ethnicity and limited English proficiency in both kindergarten ($r = .97$) and first grade ($r = .99$), suggesting that adjustment for race/ethnicity sufficiently controlled for limited English proficiency status as well.

Kindergarten sample

Table 1 presents means and standard deviations for the early literacy skills variables in kindergarten for the total sample and by income group. To examine the equal variances assumption that is made in twin research, MZ and DZ twins were compared for differences in means and variances for each measure in the total sample using a model-fitting approach. No significant sex effects were found for any of the kindergarten measures. However, a significant effect of twin order was found on the variances for Initial Sound Fluency. A re-ordering of the twins within pairs resolved the problem.

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Twin intraclass correlations are presented in Table 2 for each early literacy measure in the whole kindergarten sample and by gender and neighborhood income group. Correlations for the total sample were calculated for all available twins (regardless of whether neighborhood income data or race/ethnicity was available). In general, the twin correlations suggested that individual differences in early literacy skills in kindergarten were associated with genetic and shared environmental variance.

Table 3 presents a summary of the univariate and multi-group ACE model-fitting results for each measure in kindergarten for the total sample and for each neighborhood income group. For Letter Naming Fluency and Initial Sound Fluency, the univariate ACE models for the income group subsamples showed some variability in the estimates of each parameter. However, the multi-group analyses showed that these differences were not significant as the fully constrained model fit the data and could be selected over the fully unconstrained model for each variable. Results were consistent with the expectation of substantial shared environmental influence on early literacy skills in kindergarten. Phonemic Segmentation Fluency also showed variability in ACE parameter estimates in the univariate models, and the multi-group model showed that the magnitude of variance in A differs across income subgroups. As expected, shared environmental influence estimates were substantial for this early literacy skill in kindergarten. However, contrary to prediction, the highest estimate of shared environmental influence was for the high income subgroup and not the low income subgroup.

First grade sample

Table 4 presents means and standard deviations for the early literacy skills measures in first grade for the total sample and by neighborhood income group. As in the kindergarten sample, MZ and DZ twins were compared for differences in means and variances for each measure in the total sample using a model-fitting approach. There were no significant variance differences for Oral Reading Fluency, but there was a significant effect of zygosity on means such that MZ twins had a lower mean than DZ twins. The Phonemic Segmentation Fluency variable evidenced a significant sex effect on variances and covariances that suggested the likelihood of sex limitation effects. Unfortunately, the sample was not large enough to analyze the data separately by gender within the context of income groups. As such, only the twin correlations are provided for Phonemic Segmentation Fluency.

Twin intraclass correlations are presented in Table 5 for each early literacy measure in the whole first grade sample and by gender and neighborhood income group. Correlations for the total sample were calculated for all available twins (regardless of whether neighborhood income data or race/ethnicity was available). In general, the twin correlations suggested that individual differences in Oral Reading Fluency in first grade were associated with additive genetic factors, whereas, variability in Phonemic Segmentation Fluency appeared to be associated with shared environmental factors as well.

Table 6 presents a summary of the univariate and multi-group ACE model-fitting results for Oral Reading Fluency in first grade for the total sample and for each neighborhood income group. As predicted, the univariate ACE models suggested the variance in Oral Reading Fluency associated with additive genetic factors was lower for twins in low income neighborhoods than for twins in middle and high income areas. Also as expected, shared environmental variance was larger for the low income neighborhood group than for the other two groups. The multi-group analysis on the Oral Reading Fluency data confirmed this result as differences in variance in A and C were found across subgroups.

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Discussion

The primary goal of this report was to examine word reading and early literacy skills in a sample of 4–7-year-old twins, an age range that has received relatively less attention in genetically informative samples. A secondary goal was to assess the generalizability both of prior findings and of the findings in the present study on the genetic and environmental influence on early reading skills by examining models not just in the entire sample of twins but also in subgroups based on neighborhood economic position while controlling for race/ethnicity.

In kindergarten, individual differences in the early literacy skill of letter identification (Letter Naming Fluency) owed roughly equally to additive genetic, shared environmental and non-shared environmental factors. These results were not consistent with those of Byrne et al. (2002) or Petrill et al. (2006) as they had found larger estimates of shared environment in their young twin samples. The differences across these studies might very well owe to differences in measures of print knowledge. This conclusion is supported by the generalizability of our findings within our own sample. The results for Letter Naming Fluency noted above for the total sample held for all neighborhood income groups (in which race/ethnicity was controlled for), suggesting that the findings were generalizable across a diverse array of socioeconomic environments. This suggests that our findings for the particular measure of letter identification that we used were robust across the demographics of the Byrne et al. and Petrill et al. samples, so our findings might not be as comparable to theirs because of the difference in measures used.

In contrast to findings of substantial (around .70) additive genetic influence on phonemic awareness and decoding from older twin samples (Gayan and Olson 2003; Knopik et al. 2002), variability in early literacy skills related to phonological awareness as measured by Initial Sound Fluency and Phonemic Segmentation Fluency was associated with significant shared environmental variance in our total sample of kindergarten twins. Economic diversity was not associated with differences in genetic or environmental influence on the ability to recognize the sounds of the phonemes at the beginning of words (Initial Sound Fluency). However, the results suggested that environmental differences among twins in higher income areas accounted for the variability in early literacy skills related to phonemic segmentation. The examination of variance differences suggested the likelihood of sex limitation effects on Phonemic Segmentation Fluency in first grade. Although the sample was not adequately sized to examine both gender and income simultaneously, future directions with this diverse twin sample include the examination of etiological influences on growth in phonemic awareness measures like Phonemic Segmentation Fluency and further exploration of the gender effects suggested in this report.

The present study examined not just pre-reading skills but also early reading as measured by Oral Reading Fluency in first grade. Additive genetic factors accounted for nearly two-thirds of the variance in the whole sample, which was substantial but nonetheless lower than the estimates reported from other first grade twin samples (Byrne et al. 2007; Kovas et al. 2007). Results for the whole sample also suggested a significant influence of shared environment, which was not found in other similarly aged samples (Byrne et al. 2007). The difference between our results and those of other studies might lie, in part, in the differences in measures of oral reading. The Oral Reading Fluency measure used in this report might be more cognitively complex because it requires word reading within the context of a written passage. The other twin studies of first graders employed word list tests in which the students' task is to read individual words from lists without any context, and those tasks might be less cognitively complex. It is possible that the more complex reading task used in the present study tapped a wider range of cognitive processes (some of which have shared environmental influence). However, differences between the present results and prior studies can be more easily explained by differences in the relative influence of genes and environment across economic environments.

As expected, additive genetic and shared environmental parameters could not be equated across neighborhood income subgroups for Oral Reading Fluency. If our sample had been similar in its demographic make-up to the CLDRC sample, which is mostly middle class (Knopik et al. 2002), then our results would match fairly well to the existing literature in suggesting an effect of additive genetic factors of around 80% with little or no significant shared environmental effect on early reading ability (e.g., Byrne et al. 2007; Kovas et al. 2007). However, our data show that such a conclusion would not necessarily apply to twins from low income neighborhoods for who additive genetic factors account for only 42% of the variance in early reading ability.

Turkheimer and colleagues showed that the heritability of IQ (Turkheimer et al. 2003) and scholastic aptitude (Harden et al. 2007) was influenced more by shared environment than by genetic factors when examining children from poor families and, conversely, genetic factors showed stronger effects than shared environment in high income families. The present findings for early literacy skills measured in kindergarten were more in line with those from van den Oord and Rowe (1997). However, the results on actual reading in first grade were consistent with the findings on IQ/aptitude from Turkheimer and colleagues. The estimate of genetic influence in low income neighborhood twins was significantly lower than for middle and high income twins as indicated by non-overlapping confidence intervals on the estimates. Similarly, the shared environmental influence estimate was significantly higher for low income twins than for middle income twins. This effect was not accounted for by race/ethnicity as the income variable used to form the income groups was adjusted for race/ethnicity. Though we could not test this possibility, it might be that lower income neighborhoods have schools with less intense instruction for reading, which has been shown to increase estimates of shared environment (Samuelsson et al. 2008). Given our imperfect proxy measure of socioeconomic status, models explicitly testing for G × E were not conducted and the present results await replication once a more sensitive measure of family income can be obtained. Moreover, given that we did not directly test for G × E using biometrical models, the present data should be considered as providing a trend toward an interaction until additional testing can be done.

There were some notable strengths of the present study including the large sample of twins from diverse economic and racial/ethnic backgrounds. The use of standardized measures of achievement assessed in classrooms was another of the study’s strengths. The analytic strategy was aimed at assessing the generalizability of findings on the relative influence of genetic and environmental factors on individual differences in early literacy skills in an age group of twins that has not been widely studied. However, the results do need to be considered in light of the study’s limitations, the most prominent of which was the use of Census tract data as a proxy for socioeconomic position of the twins’ families. Certainly it would have been optimal to obtain assessments of family income and other indicators of socioeconomic status directly from the parents of the twins, but that was not possible. Also, while the reading measures examined have acceptable if not good psycho-metric properties, they represented only some of the measures that have been investigated in other twin research. As such, our data cannot address the issue of generalizability of behavioral genetic studies of other reading measures. Finally, gender is an important diversity variable that has received attention in twin studies of literacy skills (e.g., Reynolds et al. 1996). Evidence of sex limitation was found for one of the early literacy measures, Phonemic Segmentation Fluency, in first grade. We elected not to attempt to address sex limitation on top of income

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since the sample was large but not large enough to adequately split by gender within income group.

The development of reading ability progresses through the accumulation of various related skills. Some of those early literacy skills appear to be influenced heavily by the environment until the end of first grade, when children in the U.S. have had two formal years of schooling. The fact that some early literacy skills show differences in the relative influence of shared environmental and additive genetic factors across neighborhood socioeconomic position suggests that the etiology of these measures is not necessarily uniform for all contexts.

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Table 1

Means (and SDs) for early reading measures in kindergarten for the total sample and by neighborhood income group

Reading measure	Total	Low	Middle	High
Letter naming fluency	50.13 (19.24)	47.83 (19.02)	49.84 (19.33)	53.33 (18.95)
	N = 2,802	*N* = 654	*N* = 1,296	*N* = 654
Initial sound fluency	24.39 (13.64)	23.78 (13.39)	23.76 (13.41)	26.02 (14.21)
	N = 2,742	*N* = 644	*N* = 1,266	*N* = 636
Phonemic segmentation fluency	38.34 (17.95)	37.21 (18.48)	37.92 (18.32)	40.12 (16.50)
	N = 2,752	*N* = 646	*N* = 1,274	*N* = 640

Note: Ns are individuals. Total includes individuals with missing data for neighborhood income and/or race/ethnicity and, therefore, Ns for subgroups do not sum to the total N. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile

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Table 2

Intraclass correlations for early reading measures in kindergarten for the total sample and by gender and neighborhood income group

Reading measure	Total	Females	Males	OS	Low	Middle	High
Letter naming fluency							
MZ (N)	.68 (473)	.64 (245)	.71 (228)	–	.76 (113)	.69 (228)	.52 (106)
DZ (N)	.53 (928)	.59 (231)	.50 (242)	.50 (455)	.47 (214)	.54 (420)	.56 (221)
Initial sound fluency							
MZ (N)	.58 (460)	.56 (234)	.58 (226)	–	.56 (112)	.58 (222)	.60 (101)
DZ (N)	.42 (911)	.38 (224)	.48 (239)	.40 (448)	.38 (210)	.39 (411)	.49 (217)
Phonemic segmentation fluency							
MZ (N)	.65 (467)	.67 (242)	.62 (225)	–	.72 (110)	.64 (226)	.52 (105)
DZ (N)	.51 (909)	.61 (225)	.47 (236)	.48 (448)	.45 (213)	.55 (411)	.52 (215)

Note: Ns are pairs. Total includes individuals with missing data for gender, race/ethnicity and/or neighborhood income and, therefore, Ns for subgroups do not sum to the total N. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile

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Table 3

Summary of ACE models for early reading measures in kindergarten for the total sample and by neighborhood income group

Measure	Sample	Model	χ^2 (df)	*p*	AIC	A	C	E
Letter naming fluen.	Total	Univariate	1.59 (3)	.66	−4.42	.35 (.24–.46)	.34 (.25–.43)	.31 (.27–.35)
	Low	Univariate	2.60 (3)	.46	−3.40	.54 (.31–.78)	.21 (.00–.40)	.25 (.19–.33)
	Middle	Univariate	2.72 (3)	.44	−3.28	.37 (.21–.53)	.34 (.20–.47)	.29 (.23–.35)
	High	Univariate	6.06 (3)	.11	.06	.06 (.00–.33)	.51 (.30–.62)	.43 (.33–.53)
	Multi-group	Unconstrained	11.35 (9)	.25	−6.65			
	Multi-group	**Fully constrained**	**22.06 (15)**	**.11**	**−7.94**	**.34 (.22–.46)**	**.35 (.25–.44)**	**.31 (.27–.36)**
Initial sound fluen.	Total	Univariate	2.67 (3)	.45	−3.33	.37 (.22–.51)	.22 (.11–.33)	.41 (.35–.46)
	Low	Univariate	6.75 (3)	.08	.75	.39 (.07–.66)	.18 (.00–.42)	.43 (.33–.56)
	Middle	Univariate	3.27 (3)	.35	−2.73	.43 (.21–.64)	.16 (.00–.33)	.41 (.33–.49)
	High	Univariate	2.60 (3)	.46	−3.39	.24 (.00–.51)	.37 (.14–.57)	.39 (.29–.53)
	Multi-group	Unconstrained	12.62 (9)	.18	−5.38			
	Multi-group	**Fully constrained**	**17.13 (15)**	**.31**	**−12.87**	**.37 (.22–.51)**	**.22 (.10–.34)**	**.41 (.36–.47)**
Phonemic seg. fluen.	Total	Univariate	.68 (3)	.88	−5.33	.26 (.13–.38)	.38 (.28–.48)	.36 (.32–.41)
	Low	Univariate	4.60 (3)	.20	−1.40	.40 (.14–.66)	.28 (.04–.48)	.32 (.25–.42)
	Middle	Univariate	2.85 (3)	.42	−3.15	.25 (.06–.42)	.41 (.27–.55)	.34 (.28–.42)
	High	Univariate	.62 (3)	.89	−5.38	.01 (.00–.30)	.52 (.29–.60)	.47 (.36–.56)
	Multi-group	Unconstrained	8.06 (9)	.53	−9.94			
	Multi-group	Fully Constrained	20.65 (15)*	.15	−9.36			
	Multi-group	**Free A; equate C, E**	**9.84 (13)**	**.71**	**−16.16**			
	Low					**.29 (.15–.42)**	**.37 (.27–.47)**	**.34 (.28–.40)**
	Middle					**.26 (.13–.39)**	**.39 (.28–.49)**	**.35 (.30–.41)**
	High					**.09 (.00–.26)**	**.47 (.35–.58)**	**.43 (.36–.50)**

Note: Parameter estimates (and 95% CIs) are provided for the full ACE univariate models. For the multi-group model, parameter estimates are provided only for the best-fitting model, which is listed in *bold type*. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile. Letter naming fluen. = Letter naming fluency; Initial sound fluen. = Initial sound fluency; Phonemic seg. fluen. = Phonemic segmentation fluency

* $p = .05$ difference from unconstrained model

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Table 4

Means (and SDs) for early reading measures in first grade for the total sample and by neighborhood income group

Reading measure	Total	Low	Middle	High
oral reading fluency	63.88 (37.60)	57.54 (36.41)	63.60 (36.61)	71.28 (39.42)
	N = 2,562	*N* = 594	*N* = 1,193	*N* = 596
phonemic segmentation fluency	47.91 (14.05)	46.52 (15.02)	48.09 (13.64)	48.69 (14.30)
	N = 2,570	*N* = 598	*N* = 1,193	*N* = 600

Note: Ns are individuals. Total includes individuals with missing data for race/ethnicity and/or neighborhood income and, therefore, Ns for subgroups do not sum to the total N. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile

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Table 5

Intraclass correlations for early reading measures in first grade for the total sample and by gender and neighborhood income group

Reading measure	Total	Females	Males	OS	Low	Middle	High
Oral reading fluency							
MZ (N)	.82 (441)	.83 (225)	.82 (216)	–	.85 (95)	.82 (218)	.78 (101)
DZ (N)	.56 (839)	.53 (226)	.64 (203)	.48 (410)	.58 (201)	.48 (376)	.55 (195)
Phonemic segmentation fluency							
MZ (N)	.58 (443)	.53 (225)	.62 (218)	–	.69 (95)	.42 (219)	.66 (102)
DZ (N)	.39 (841)	.32 (227)	.42 (203)	.41 (411)	.39 (203)	.41 (375)	.39 (196)

Note: Ns are pairs. Total includes individuals with missing data for gender, race/ethnicity and/or neighborhood income and, therefore, Ns for subgroups do not sum to the total N. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile

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Table 6

Summary of ACE models for oral reading fluency in first grade for the total sample and by neighborhood income group

Measure	Sample	Model	χ^2 (df)	*p*	AIC	A	C	E
Oral reading fluen.	Total	Univariate	4.09 (3)	.25	−1.90	.62 (.53–.72)	.22 (.12–.30)	.16 (.14–.19)
	Low	Univariate	2.64 (3)	.45	−3.37	.47 (.28–.67)	.36 (.17–.52)	.17 (.13–.24)
	Middle	Univariate	3.21 (3)	.36	−2.79	.74 (.59–.86)	.10 (.00–.24)	.16 (.13–.19)
	High	Univariate	7.45 (3)	.06	1.45	.58 (.38–.79)	.24 (.04–.41)	.18 (.13–.25)
	Multi-group	Unconstrained	13.29 (9)	.15	−4.72			
	Multi-group	Fully Constrained	25.25 (15)	.05	−4.75			
	Multi-group	**Free A, C; Equate E**	**15.74 (11)**	**.15**	**−6.26**			
	Low					**.45 (.30–.64)**	**.37 (.18–.52)**	**.18 (.15–.22)**
	Middle					**.72 (.57–.85)**	**.11 (.00–.25)**	**.17 (.15–.20)**
	High					**.64 (.47–.84)**	**.21 (.01–.38)**	**.15 (.13–.18)**

Note: Parameter estimates (and 95% CIs) are provided for the full ACE univariate models. For the multi-group model, parameter estimates are provided only for the best-fitting model, which is listed in *bold type*. Low = zip codes with a median family income at or below the 25th percentile; middle = zip codes with a median family income between the 26th and 74th percentiles; high = zip codes with a median family income at or above the 75th percentile. Oral reading fluen. = Oral reading fluency