Evidence for Common Etiological Influences on Early Literacy Skills in Kindergarten

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Abstract

Understanding how the etiology of print awareness and phonological awareness are related to the etiology of decoding can provide insights into the development of word reading. To address this issue, we examined the degree of overlap among etiological influences of pre-reading skills in 1,252 twin pairs in kindergarten. Genetic, shared environmental, and non-shared environmental factors were significant for all three literacy phenotypes. The majority of genetic and shared environmental influence on decoding was due to common factors that included print awareness and phonological awareness. Notably, only a single genetic factor contributed to all three literacy phenotypes but there was additional shared environmental influence common to phonological awareness and decoding. Findings suggest commonalities in the etiology of pre-reading literacy skills that could inform work on the development of reading skill.

Keywords

decoding; print awareness; phonological awareness; genetic; twins

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Much research has focused on identifying struggling readers as early as possible in order to provide intervention before students lag behind (Torgesen, 2004). Several reading-related skills have been identified that are highly predictive of later reading achievement including print awareness and phonological awareness (Adams, 1990; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). The National Early Literacy Panel (NELP) found that early alphabet knowledge and rapid automatized naming of letters/digits predicted decoding ($r = .50$ and $.40$, respectively) as well as reading comprehension ($r = .48$ and $.43$, respectively; Lonigan, Schatschneider, Westberg, & National Early Literacy Panel, 2008). Thus, gaining a better understanding of pre-reading skills and the sources of variation common to these skills and reading could provide opportunities to recognize and identify prereaders who may become struggling readers.

Among the more widely examined pre-reading skills is letter naming, a measure of print awareness, that is one of the single best predictors of future reading achievement (Adams, 1990; Scarborough, 1998; Snow, Burns, & Griffin, 1998). Given its high predictive ability, letter knowledge is frequently assessed in preschool and kindergarten. By the end of kindergarten, children should be able to recognize and name upper- and lowercase letters for most of the letters in the alphabet (Snow et al., 1998). Knowing the names of letters is a prerequisite to learning the correspondence of letters to sounds (Whitehurst & Lonigan, 1998), making letter naming a foundational skill for later literacy.

In addition to being able to discriminate units of print (such as letters) children must be able to discriminate units of language, including phonemes (Whitehurst & Lonigan, 1998). By the end of kindergarten, children should have at least some phonemic awareness, including that words can be segmented into smaller units of sound (Snow et al., 1998). The role of phonological awareness in learning to read has received a fair amount of attention and it is

now well established that phonological awareness has a causal influence on reading acquisition (Bradley & Bryant, 1983; Wagner & Torgesen, 1987; Wagner et al., 1997). Once a child has learned the alphabet and has developed phonological awareness, learning the alphabetic principle (the mapping of sounds to letters) enables him/her to decode words. Decoding of pseudowords is a direct measure of children's mastery of the alphabetic principle since there is no exposure to such words and they must be sounded out.

Though there has been considerable research on emergent literacy and early reading acquisition, the etiology of these skills is less understood. Much of the research on genetic and environmental influences on reading has relied on older samples (e.g., age 13, Stevenson, 1987) or samples including broad age ranges (e.g., age range 8–20, Light & DeFries, 1995; age range 6–12, Thompson, Detterman, & Plomin, 1991). More recently, studies involving younger samples have been conducted (e.g., Byrne et al., 2007; Harlaar, Spinath, Dale, & Plomin, 2005; Hohnen & Stevenson, 1999; Petrill, Deater-Deckard, Thompson, DeThorne, & Schatschneider, 2006; Taylor, Roehrig, Soden Hensler, Connor, & Schatschneider, 2010; Taylor & Schatschneider, 2010).

Print awareness, phonological awareness, and decoding have each been shown to be influenced by genetic and environmental factors in pre- and early readers. Measures of print awareness tend to be modestly affected by genetic factors (heritability estimates less than 30%) and more substantially influenced by environmental factors. For example, a composite measure of print knowledge in preschoolers in the International Longitudinal Twin Study (ILTS; Byrne et al., 2002) showed a shared environmental influence that was roughly twice the magnitude of the genetic influence. A similar outcome was found for letter identification in kindergarten and first grade twins (mean age 6.1) in the Western Reserve Reading Project (WRRP; Petrill et al., 2006). In a sample of kindergarteners in the Florida Twin Project on Reading (FTP-R), Taylor and Schatschneider (2010) found that letter naming fluency had approximately equivalent influences of genetic, shared environmental, and non-shared environmental influences.

In contrast, moderately high heritability estimates (50–65%) have been found for phonological awareness across various studies of first and second grade children (Byrne et al., 2002; Hohnen & Stevenson, 1999) and for a latent phonological awareness factor in kindergarten (Byrne et al., 2005). Shared environmental influences on phonological awareness in these studies were moderately low but nonetheless larger than the estimate of non-shared environment. The WRRP sample showed similar estimates of genetic and shared environmental influences (.48 and .43, respectively; Petrill et al., 2006) as did the FTP-R although with estimates of genetic and shared environment both in the 20–40% range (Taylor & Schatschneider, 2010).

The genetic effects on decoding pseudowords and words are substantial in early readers as compared to environmental effects. High heritabilities were found in a sample of 7-year olds participating in the Twins Early Development Study (TEDS; Kovas, Haworth, Dale, & Plomin, 2007) on both nonword reading (.67) and word reading (.69), whereas shared environmental influences were minimal (.15 and .13, respectively). In the WRRP sample, about half of the variability in decoding pseudowords (.49) was due to genetic factors, with a moderate effect of shared environment (.31; Petrill et al., 2006). In contrast, genetic effects on reading words (.68) were substantial whereas shared environment was much less so (.22). Hohnen and Stevenson (1999) reported heritabilities of .60 and .59 on a literacy composite for 6 and 7-year old children, respectively. Conversely, shared environmental influences were more modest (.36 and .32, respectively). A latent factor of reading that included both words and nonwords was highly heritable (.70) with only modest shared environment effects (.22) in the ILTS kindergarten sample (Byrne et al., 2005).

While the univariate results speak to the relative impact of genetic and environmental factors on each of these skills, a multivariate approach is required to establish the degree of overlap in these etiological factors among the skills. Hohnen and Stevenson (1999) examined the link between phonological awareness and literacy in 6 and 7-year-old children and found common genetic influences on both phonological awareness and literacy; however, when performance IQ and general verbal ability were controlled, no independent genetic variance was observed between the two skills. This was not true for environmental influences: additional covariance between phonological awareness and literacy was environmentally mediated. This suggests that genetic and environmental influences for literacy and phonological awareness overlap in beginning readers and that environmental factors may be particularly important in the covariance of these skills. In a more developmental approach, Byrne and colleagues (2005) investigated print knowledge and phonological awareness in preschool and their relationship with kindergarten reading, finding that most of the variability in these skills was accounted for by common genetic and environmental influences, though some of the genetic variance in phonological awareness and reading was independent.

Understanding how the etiology of print awareness and phonological awareness are related to the etiology of decoding can provide insights into the development of word reading. The phenotypic literature on the acquisition of these skills is well-established and the behavioral genetic research indicates that the traits are influenced by both genes and environment and, furthermore, that there is some degree of overlap in genetic and environmental factors among these skills from preschool to kindergarten. However, it is not clear whether the same genetic and environmental factors are acting on these skills during the phase when students initially read. The current study filled this gap in the literature by investigating common versus distinct genetic and environmental influences on measures of print awareness, phonological awareness, and decoding ability in kindergarten.

Method

Participants

The Florida Twin Project on Reading (FTP-R) is a longitudinal study that is part of a Learning Disabilities Center at Florida State University and the Florida Center for Reading Research. Twins were ascertained from the Progress Monitoring and Reporting Network (PMRN), a state-wide database of achievement measures administered three or four times per school year. Potential twin pairs were identified in the PMRN based on a match of children with the same last name, birth date, and school. Parents of potential twins were contacted by mail to assess zygosity and obtain consent to allow the use of the children's PMRN data for twin analyses. Zygosity was assessed using five questions about similarity of the twins that have been used in other twin studies and show an accuracy rate of over 95% when compared to DNA tests (Lykken, Bouchard, McGue, & Tellegen, 1990). This procedure was approved by the Florida State University IRB as well as the IRBs of the various counties in Florida from which twins have been ascertained thus far (representing northern, central, and southern parts of the state).

At the time of this report, 5,716 possible twin pairs/multiples had been identified in 14 Florida counties and a response was received from 43% of families. Data from the PMRN were only available for twins whose parent replied and consented and, therefore, analyses comparing responders and non-responders were not possible. Only 4% of responses indicated an ascertainment error (i.e., the children were not twins). The present study examined early literacy skills measured in kindergarten. From the initial sample of 2,620 individual twins with data on at least one of the study measures in kindergarten, a total of 1,252 pairs with complete data on all measures were available for analysis (116 twins from

the initial sample were excluded due to missing data on one or two measures). The present sample included 427 monozygotic (MZ) pairs (197 male; 230 female) and 825 dizygotic (DZ) pairs (209 male; 210 female; 406 opposite-sex). Some of this sample was included in a previous report examining effects of socioeconomic status on these same measures (Taylor and Schatschneider, 2010).

The mean age of the sample at the beginning of kindergarten was 5.56 ($SD = 0.40$). Parents reported on the racial/ethnic status of the twins when they registered them for school and this information is contained in the PMRN. Parents could identify the children into only one of six categories and the percent of each category represented in the present sample was as follows: 1.5% Asian/Pacific Islander, 20.8% Black, 23.4% Hispanic, 0.2% American Indian, 5.1% Mixed, and 48.5% White. The rest (0.5%) had missing data.

Measures

Letter Naming Fluency (LNF)—Letter Naming Fluency (Elliott, Lee, & Tollefson, 2001; Ritchey, 2002; Speece & Case, 2001) is a measure of print awareness that measures the number of correct letter names provided in one minute. Upper and 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. Reported alternate-forms reliability ($r =$. 82–.93; Elliott et al., 2001; Speece & 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 & Case, 2001).

Phoneme Segmentation Fluency (PSF)—In this measure of phonological awareness, a child is presented orally with a word containing three or four phonemes and asked to produce the individual phonemes. A child is given one point for each correctly produced phoneme. The directions are modified slightly from Kaminski and Good (2003) to include additional practice items, picture cues, and more explicit feedback (Ritchey, 2002). Reported alternate-forms reliability ($r =$ .60 to .90; Kaminski & Good, 1996, 2003; Ritchey, 2002) and predictive and concurrent criterion-related validity with reading, spelling, and reading-related skills are adequate ($r =$.54 to .68; Kaminski & Good, 1996; 2003; Ritchey, 2002). There are 20 alternate forms. The score is the number of correct phonemes produced in one minute.

Nonsense Word Fluency (NWF)—This is a measure of print awareness that requires the child to read vowel-consonant and consonant-vowel-consonant, single syllable pseudowords all of which have the short vowel sound. After a practice trial, the examiner instructs the child to read the "make believe" words as quickly and accurately as possible. If the child does not respond within 3 seconds, the examiner prompts with "next?" The stimuli are presented in 10 rows of five words each. Reported alternate-forms reliability is strong (r =. 83 to .94; Kaminski & Good, 2003; Speece, Mills, Ritchey, & Hillman, 2003) and predictive and concurrent criterion-related validity coefficients with reading ($r =$. 36 to .91; Kaminski & Good, 2003; Speece et al., 2003) are adequate to strong. There are 20 alternate forms. The original scoring guidelines give credit for correctly producing individual phonemes or for producing the pseudoword as a blended unit. Thus, if the nonsense word is "vab," 3 points are awarded if the child says "/v/ /a/ /b/" or "vab." Partial credit is awarded when only some phonemes are produced. The NWF score is the total number of letter-sounds correctly produced in one minute.

Procedure

All measures were administered in students' schools by district-employed testers who were trained using a state-approved training procedure. The state-wide PMRN database includes

information from multiple assessments within the school year. For this study, the *last* assessment point (end of school year) was used. The scores from the first time through kindergarten were used in cases where one or both members of the twin pair repeated the grade.

Analyses

Descriptive statistics and phenotypic (Pearson) correlations among all measures were calculated for the entire sample and by zygosity. Intraclass correlations were also calculated by zygosity. Genetic influence is inferred when the magnitude of the MZ twin intraclass correlation exceeds that of the DZ twin correlation. Correlations of similar magnitude across zygosity are indicative of shared environmental influence. As an initial step in evaluating genetic and environmental influence on the covariation of the literacy measures, cross-twin cross-trait correlations were calculated in which a trait score from one twin (e.g., letter naming fluency) was correlated with a different trait score from the co-twin (e.g., phoneme segmentation fluency). If the MZ cross-twin cross-trait correlation is greater in magnitude than the corresponding DZ twin correlation, then genetic influence on the covariation between the two traits is inferred.

The intraclass correlations indicated that non-additive genetic factors (evidenced by an MZ twin correlation that is more than twice the magnitude of the DZ twin correlation) were not influencing any measure and, therefore, those effects were not estimated in the biometrical models. Thus, the total phenotypic variance (V_P) in each decoding-related measure was decomposed into additive genetic effects (A), shared environmental effects (C), and non-shared environmental effects (E) by the following equation:

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

The expected covariances among twins were specified as follows:

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

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

In order to examine the extent to which genetic and environmental influences contribute to variability in each measure and to their covariation, a multivariate Cholesky decomposition model was utilized. Based on theories of the development of reading skill, the Cholesky model was specified with Letter Naming Fluency as the first phenotype followed by Phoneme Segmentation Fluency and then Nonsense Word Fluency. A Cholesky decomposition is akin to a factor analysis in which etiological influences (A, C, and E) are represented as latent factors onto which the observed variables can load. Variance in each observed variable can load onto one or more latent factors. For each source of etiological influence, the maximum number of factors equals the number of observed variables. Covariance paths in the model (e.g., a_{21}, c_{32}, etc.) allow for an assessment of common sources of etiological influence on different phenotypes.

Models were fit to raw data using full information maximum-likelihood in the Mx GUI software program (Neale, Xie, Boker, & Maes, 2003). The fit of a model is indicated by the -2LL estimate. Reduced models were fit by setting one or more parameters to zero. In this way, the significance of a covariance path could be tested. Reduced models were then compared to the full model using a -2LL difference test in which the difference in likelihood estimate values was tested for significance using the difference in df between the full and

reduced models as the df for the test, which is distributed as a chi-square. A non-significant -2LL difference test indicated that the reduced model could be accepted over the full model. Reduced models that could be accepted over the full model were compared to each other using Akaike's Information Criterion (AIC = χ^2 - 2df; Akaike, 1987) with the lowest AIC indicating the best-fitting model.

Finally, the multivariate Cholesky model provided an estimate of the genetic correlation (r_{axy}, the association of genetic factors contributing to pairs of measures) and environmental correlations (r_{cxy}, the association of shared environmental factors contributing to pairs of measures; r_{exy}, the association of unique environmental factors contributing to pairs of measures).

Results

Analyses were prefaced by an examination of the distribution of each variable for normality and none required transformation. Means and standard deviations for the literacy measures are presented in Table 1 for the whole sample and by zygosity. An important assumption in twin research is that MZ twins are more alike than DZ twins because of their greater genetic rather than environmental similarity. If MZ twins receive more similar treatment in their environment than DZ twins and that greater similarity has an effect on the phenotype of interest, then the MZ twin variance for that phenotype would be smaller than the DZ twin variance. None of the measures showed a significant variance difference. Table 1 presents the results of the tests for mean differences by zygosity. Means were evaluated with an alpha corrected for the number of tests ($p = .016$), and though effect sizes for all three literacy skills were small ($d = .09 - .10$), nonsense word fluency showed a significant difference by zygosity. The phenotypic (Pearson) correlations in the whole sample were as follows: letter naming fluency-phoneme segmentation fluency, $r = .45$; letter naming fluency-nonsense word fluency, $r = .69$; phoneme segmentation fluency-nonsense word fluency, $r = .48$. As expected, the different early literacy measures were significantly ($p < .001$) correlated with one another.

Twin intraclass correlations by zygosity and by gender within zygosity are presented in the upper part of Table 2. The pattern of correlations was similar for males and females, but the opposite-sex DZ correlations did not approximate the geometric mean of the same-sex DZ correlations for any variable suggesting the possibility of sex limitation or sex differences in the magnitude (scalar) or type (nonscalar) of etiological influence. To investigate sex differences, multigroup multivariate Cholesky models were fit to the data to assess scalar and nonscalar effects following suggestions by Neal, Røysamb, and Jacobson (2006). In brief, a model was fit in which genetic and environmental correlations were constrained across sex to test scalar sex limitation. That model fit better than the one in which correlations were not constrained. Next, four models were fit that tested for genetic or shared environmental nonscalar effects on either males or females. The best fitting of those four models was the one with nonscalar genetic effects for males. That model was then compared to the model with no scalar sex limitation (genetic and environmental correlations constrained across sex) and the latter provided a non-significant difference in fit, indicating that the nonscalar sex effect for males was not significant. Finally, a model in which estimates of A, C, and E were constrained across sex was fit to the data and it provided a non-significant difference in fit over the model with no scalar sex limitation, indicating that there was no scalar or nonscalar sex limitation and that model-fitting could continue on combined data. Table 2 also provides the cross-twin cross-trait correlations and the phenotypic correlations. The pattern of intraclass and cross-twin cross-trait correlations were consistent with the expectation in suggesting the influence of both genetic and shared environmental influences on each measure and on their bivariate associations.

As foreshadowed by the pattern of intraclass correlations, the ACE model was the best-fitting base model as reduced models (e.g., AE) provided a significant decrement in fit. Next, covariance paths were tested in a series of reduced models. First, all covariance paths for a given source of variance (A, C, or E) were dropped. If that reduced model could not be accepted over the full ACE model, then the parameter estimates from the full model were used to identify specific paths to be tested for significance. The multivariate Cholesky model-fitting results are presented in Table 3. Reduced models in which all covariance paths associated with a particular source of variance were dropped provided a significantly worse fit than the full model. The reduced models that provided a non-significant change in fit over the full model were compared using the AIC fit statistic and the best-fitting model was the one in which the a_{32} and c_{33} paths were dropped. The best-fitting model is presented in Figure 1. As indicated in Figure 1, the first additive genetic factor (A_1) accounted for variance in each of the three early literacy skills and that was the only additive genetic factor common to the second and third phenotypes in the model. Shared environmental variance in the three early literacy skills was accounted for by just two factors. Non-shared environmental variance was accounted for by three factors with the covariance paths yielding significant parameters that were nonetheless small in magnitude.

The Cholesky model produces univariate estimates of A, C, and E for each phenotype and, as expected, significant estimates of both A and C were found for each literacy skill. Univariate estimates of each source of variance can be derived from Figure 1 by squaring path estimates pointing to the phenotype from respective etiological factors. As illustrated in Figure 1, the first observed variable in a Cholesky decomposition can have loadings on just the initial factor for each source of variance. Thus, the univariate estimates of genetic, shared environmental, and non-shared environmental variance [and 95% CI] for letter naming fluency are derived by squaring the A_1, C_1, and E_1 paths: $a^2 = .40$ [.26 – .53], $c^2 = .26$ [.15 – .36], and $e^2 = .34$ [.30 – .39], respectively.

The amount of variance associated with A, C, and E for the other phenotypes in the model in Figure 1 can be further decomposed into that which is attributable to a factor that is common to other phenotypes and that which is unique to the phenotype. The additive genetic variance in phoneme segmentation fluency is the sum of squared paths from factors A_1 and A_2, or .28 [.14 – .43]. Most of the genetic variance in phoneme segmentation fluency (78%: $.47^2/[.25^2 + .47^2]$) was unique to that decoding-related skill and the remainder (22%) was associated with the A_1 factor common to all of the decoding-related skills. The estimate of shared environment effect on phoneme segmentation fluency was $c^2 = .30$ [.19 – .42], and just over half (57%) of that was common to letter naming fluency and nonsense word fluency. In contrast, nearly all (95%) of non-shared environmental variance ($e^2 = .41$ [.36 – .46]) for phoneme segmentation fluency was unique to just that skill. For the third variable in the model, nonsense word fluency, the majority (75%) of the additive genetic variance ($a^2 = .52$ [.41 – .62]) was attributable to the A_1 factor common to all of the decoding-related skills and the remainder was unique to nonsense word fluency. There was no genetic factor common to just phoneme segmentation and nonsense word fluency. All of the shared environmental variance for nonsense word fluency ($c^2 = .19$ [.10 – .28]) was common to the other reading skills and the bulk of that (77%) was common to both of the other phenotypes and the remainder was common to just phoneme segmentation fluency. The reverse was true for non-shared environmental variance ($e^2 = .29$ [.25 – .33]) for which 85% was unique to only that phenotype.

Finally, the correlations among the genetic factors, the shared environmental factors, and the non-shared environmental factors associated with the phenotypic variables in the model were computed. There was a moderate correlation between the genetic factors that contribute to variability in letter naming fluency and phoneme segmentation fluency skills

(r_{axy} = .47). Similarly, the genetic correlation between phoneme segmentation fluency and nonsense word fluency was also moderate (r_{axy} = .41), indicating common genetic influences as well as specificity. The genetic correlation between letter naming and nonsense word fluency was much stronger (r_{axy} = .87), suggesting that the genetic factors that contribute to variability in nonsense word fluency are largely the same as those that contribute to variability in letter naming fluency. The shared environmental correlations were uniformly high among the factors contributing to variability in decoding-related skills (r_{cxy} = .76, .87, and .98, for letter naming fluency-phoneme segmentation fluency, letter naming fluency-nonsense word fluency, and phoneme segmentation fluency-nonsense word fluency, respectively). Based on the high genetic and shared environmental correlations found between some factors, additional reduced Cholesky models were fit testing the significance of the a_{33} and c_{32} paths but none of the reduced models could be selected over the best-fitting model shown in Figure 1, indicating that the A_2, A_3 and C_2 factors could not be dropped from the model. The non-shared environmental correlations were uniformly small in magnitude (r_{exy} = .22, .34, and .26, for letter naming fluency-phoneme segmentation fluency, letter naming fluency-nonsense word fluency, and phoneme segmentation fluency-nonsense word fluency, respectively), indicating that largely different sets of non-shared environmental factors contributed to variability in the three early literacy skills.

Discussion

It is well established that print awareness and phonological awareness in early readers are predictive of future reading achievement. Genetically sensitive studies are beginning to indicate the extent to which these early reading-related skills are due to genetic and environmental factors. However, the extent to which the genetic and environmental factors that influence each of these skills is common or unique is less well known. The aim of the current study was to investigate the overlap of etiological influences on measures of print awareness, phonological awareness, and decoding in beginning readers.

The present findings showed that the bulk of genetic and environmental influences on decoding are common to print awareness and phonological awareness. About half of the variability in decoding in kindergarteners was due to genetic factors and the vast majority (75%) of those genetic influences were common to print awareness and phonological awareness. Similarly, 77% of the shared environmental influence on decoding was common to print awareness and phonological awareness. That is, the same factors that are acting on the pre-reading skills print awareness and phonological awareness are also acting on decoding. For phonological awareness this overlap was substantial for shared environment but only moderate for genetic influences. In contrast, for print awareness this overlap was substantial for both shared environment and genetic influences. Interestingly, interventions targeting phonological awareness have succeeded in improving reading achievement (e.g., Blachman, Tangel, Ball, Black, & McGraw, 1999; Mathes et al., 2005), whereas interventions that focus primarily on letter knowledge (the print awareness measure in the current study) have had non-significant or only modest effects on subsequent reading (Piasta & Wagner, 2010). This suggests that the reasons that phonological awareness interventions succeed could be due to overlap of common environmental factors impacting phonological awareness and reading more so than overlap of genetic factors. The lack of significant effects for interventions focused on letter knowledge despite substantial overlap of both shared environmental and genetic factors might be because letter knowledge seems to tap a process that is influenced by genetic factors that continue to have an effect on later decoding and this process may not be adequately affected by current interventions.

The environmental link between phonological awareness and reading observed in the current study was also seen in another study of early readers. After controlling for performance IQ and general verbal ability, Hohnen and Stevenson (1999) found that there was no additional genetic influence common to phonological awareness and a composite of literacy skills, but there was additional common environmental influence. In the current study, there was also no common genetic influence between just phonological awareness and decoding; all of the shared genetic influence between the two skills was via a genetic factor which also included print awareness. Also similar to Hohnen and Stevenson, current findings showed significant (though relatively small) additional common environmental influences on phonological awareness and decoding beyond that shared with print awareness. This further supports the idea that environmental factors may be of particular importance in the observed covariance of these two skills. As discussed above, the modest genetic correlation coupled with higher environmental correlations (especially for shared environment) offers further support that this may be the case.

The pattern of results from the Cholesky decomposition in the current report and those from two studies with ILTS twins (Byrne et al., 2005, 2006) show both similarities and differences. Similar to the present study, Byrne and colleagues found that beyond the genetic factor that included print awareness, phonological awareness, and reading, there was no additional significant shared genetic influence between phonological awareness and reading. Although phonological awareness and reading are known to be developmentally intertwined constructs, converging evidence suggests that they are nonetheless influenced to a degree by independent genetic influences. While the genetic architecture across the literacy skills examined was similar in the current study and in the ILTS studies (Byrne et al., 2005, 2006), there were differences in the magnitude of the overall effects. We found that about one quarter of the total genetic influence on phonological awareness was common to print awareness and reading, whereas Byrne et al. (2005, 2006) found that about half of the genetic influence on phonological awareness was common to print awareness and reading. Thus, we provide independent evidence that converges on the finding that there appears to be a single genetic factor that contributes to both pre-reading skills (print awareness and phonological awareness) and decoding with additional contributions from skill-specific factors on the more complex skills.

Our results are also consistent with the prior investigations (Byrne et al., 2005, 2006) in showing that decoding in kindergarten is not influenced by a unique shared environmental factor. However, we found two shared environmental factors: one common to all of the early literacy skills and one common to just the higher level skills of phoneme segmentation and decoding. Byrne et al. (2005, 2006) found just a single shared environmental factor common to all three reading related skills. This difference may be due to the disparate timing of data collection for the phonological awareness and reading measures. In the current study, both phonological awareness and decoding were taught in the same educational environments to kindergarteners and, therefore, the measures of these skills were concurrently collected. In the Byrne et al. (2005, 2006) studies, the phonological awareness measures were administered during preschool and the reading measures were administered during kindergarten. There is also quite a lot of environmental variability in the FTP-R twin sample as participants come from a wide range of SES backgrounds. Further, the sample is drawn from Florida where early education experience varies widely with some children participating in the state-funded Voluntary Pre-Kindergarten program and others not (the PMRN data set does not provide information on this and so participation in pre-K cannot be estimated in the present sample). The large environmental variability in the current sample may explain the greater proportion of variability due to environmental factors and potentially the additional shared environmental factor that was found.

The results of the current study should be considered in light of potential limitations. Though the PMRN affords the advantage of data collection from a large and diverse sample, it is limited in that only state-prescribed measures and very restricted environmental variables are available. At the time of data collection for this report, no environmental variables such as preschool attendance prior to kindergarten, quality of current literacy instruction, home literacy environment, or parental education were available. As such, it was not possible to test the influence of potential sources of environmental influence. With regard to the literacy measures investigated, we found somewhat higher non-shared environmental estimates than other studies (e.g., Byrne et al., 2005, 2006) that may be due to larger measurement error. If that is the case then the higher variability in non-shared environment would not fully reflect true non-shared environmental influences (to the extent that it includes measurement error) and would serve to reduce the true variability that could be captured in genetic and shared environmental estimates. Another limitation was that there are other early literacy skills that were not examined. Finally, a measure of general intelligence was not available for the present sample and it could be that some of the etiological factors that were identified are related primarily to overall intellectual ability. Prior research suggests that this is probably more of an issue with regard to the genetic factor contributing to early literacy skills rather than the environmental factors (Hohnen & Stevenson, 1999). Nonetheless, additional studies are needed to examine how the etiological factors associated with general intellectual functioning interface with the etiological factors associated with literacy skills.

Despite these limitations, the results of the present study provide independent converging evidence of great overlap in genetic and environmental influences on early literacy skills. Future studies can build on this growing knowledge base and investigate whether the observed trends of common etiological influences continue or whether new genetic and environmental influences come online as reading skills develop in later grades.

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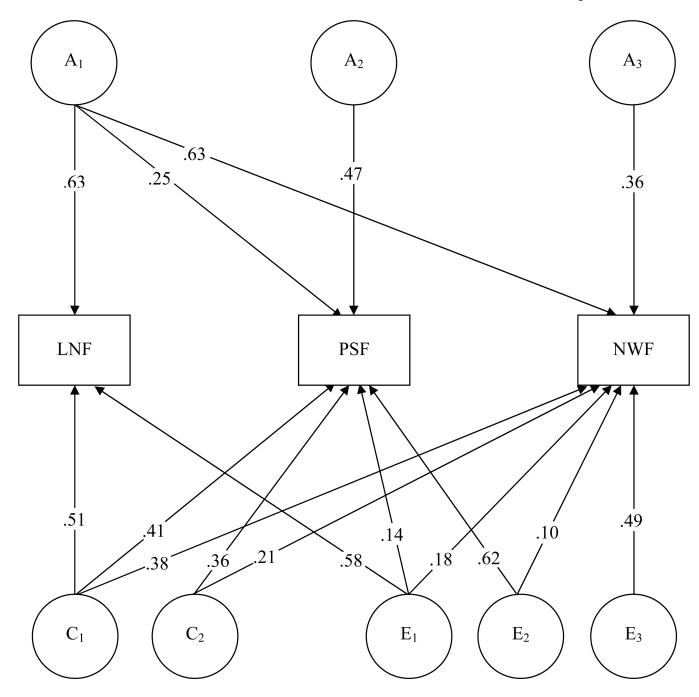
Figure 1.
Best-fitting multivariate Cholesky decomposition model for decoding-related skills. A = additive genetic effects; C = shared environmental effects; E = non-shared environmental effects.

Table 1

Means (and Standard Deviations) for Decoding-related Measures for the Total Sample and by Zygosity

	Total Sample N=2,504	MZ N=854	DZ N=1,650	MZ vs. DZ t (2,502)
Letter Naming Fluency	52.39 (17.92)	51.28 (17.53)	52.97 (18.09)	−2.24
Phoneme Segmentation Fluency	40.07 (17.03)	38.97 (17.47)	40.64 (16.78)	−2.33
Nonsense Word Fluency	43.93 (24.91)	42.23 (23.95)	44.81 (25.35)	−2.46[*]

Note: Ns are for individuals. Independent samples *t*-tests are reported for the comparison between MZ and DZ twins. Variances did not differ significantly between MZ and DZ twins for any measure.

[*] *p* = .014.

Table 2

Correlations for Decoding-related Measures by Gender and Zygosity

	MZ N=427	MZ Male N=197	MZ Female N=230	DZ N=825	DZ Male N=209	DZ Female N=210	DZ OS N=406
Intraclass Correlation							
Letter Naming Fluency	.64	.67	.61	.47	.47	.53	.43
Phoneme Segmentation Fluency	.61	.58	.63	.45	.47	.53	.39
Nonsense Word Fluency	.69	.72	.66	.46	.52	.48	.41
Cross-twin Cross-trait Correlation							
Letter Naming-Phoneme Segmentation	.36	.38	.35	.29	.26	.39	.26
Letter Naming-Nonsense Word	.57	.59	.54	.40	.41	.44	.36
Phoneme Segmentation -Nonsense Word	.43	.45	.41	.30	.28	.42	.25
Phenotypic Correlation							
Letter Naming-Phoneme Segmentation	.43	.43	.44	.46	.49	.48	.44
Letter Naming-Nonsense Word	.68	.69	.67	.70	.72	.71	.68
Phoneme Segmentation -Nonsense Word	.53	.55	.51	.46	.50	.47	.42

Note: Ns are pairs. OS = opposite-sex.

Table 3

Multivariate Cholesky Model-fitting Results

Model	-2LL	df	AIC	$-2LL_\Delta$
ACE	17995.84	7488	3019.84	—
Drop all A covariance paths	18050.21	7491	3068.21	54.37 (3)[*]
Drop only a_{32} path	17996.03	7489	3018.03	0.19 (1)
Drop all C covariance paths	18026.58	7491	3044.58	30.74 (3)[*]
Drop only c_{33} path	17995.94	7489	3017.94	0.10 (1)
Drop all E covariance paths	18100.67	7491	3118.67	104.83 (3)[*]
Drop only e_{32} path	18015.22	7489	3037.22	19.38 (1)[*]
Drop only a_{32}, c_{33}, and e_{32} paths	18021.85	7491	3039.85	26.01 (3)[*]
Drop only a_{32} and c_{33} paths	**17996.31**	**7490**	**3016.31**	**0.47 (2)**

Note: The best-fitting model is presented in bold type. A = additive genetic effects; C = shared environmental effects; E = non-shared environmental effects; AIC = Akaike Information Criterion; $-2LL_\Delta$ = difference in -2LL estimate between the ACE model and the reduced model.

[*] $p < .05$.