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Learning to Write Letters: Examination of Student and Letter Factors

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Abstract

Learning to write the letters of the alphabet is an important part of learning how to write conventionally. In this study, we investigated critical factors in the development of letter-writing skills using exploratory item response models to simultaneously account for variance in responses due to differences between students and between letters. Letter-writing skills were assessed in 415 preschool children aged 3 to 5 years. At the student level, we examined the contribution of letter-name knowledge, letter-sound knowledge, and phonological awareness to letter-writing skills. At the letter level, we examined seven intrinsic and extrinsic factors in understanding how preschool children learn to write alphabet letters: first letter of name, letters in name, letter order, textual frequency, number of strokes, symmetry, and letter type. Results indicated that variation in letter-writing skills was accounted for more by differences between students rather than by differences between letters, with most of the variability accounted for by letter-name knowledge and age. Although significant, the contribution of letter-sound knowledge and phonological awareness was relatively small. Student-level mechanisms underlying the acquisition of letter-writing skills are similar to the mechanisms underlying the learning of letter sounds. However, letter characteristics, which appear to play a major role in the learning of letter names and letter sounds, did not appear to influence learning how to write letters in a substantial way. The exception was if the letter was in the child's name.

Learning to Write Letters: Examination of Student and Letter Factors

Competency in writing (and reading) is a necessary ingredient for children's academic success (e.g., Graham & Perin, 2007). Conventional writing first begins with children learning to write the letters of the alphabet. The importance of letter-writing skills is supported by empirical evidence indicating that the ability to write letters is an excellent predictor of early spelling, a word-level writing skill (Puranik, Lonigan, & Kim, 2011). Furthermore, substantial evidence indicates that letter-writing fluency (i.e., writing letters of the alphabet under timed conditions) is an excellent predictor of written compositional quality and quantity in kindergarten and elementary school children (e.g., Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Jones & Christensen, 1999; Puranik & Al Otaiba, 2012). Thus, learning to write letters constitutes an important early skill in the process of learning to write conventionally.

Despite the importance of letter-writing skills, less is known about the factors that contribute to the acquisition of letter-writing skills than is known about the development of letter names and letter sounds. An increased understanding of the factors that contribute to letter-writing skills could have important implications not only for improving basic developmental theories about writing but also for improving educational practices. In this study, we investigated the contribution of letter-name and letter-sound knowledge and phonological awareness (PA)—established predictors of children’s reading skills—to children’s letter-writing acquisition. In addition to the student characteristics of letter knowledge and PA, research indicates that letter characteristics such as letter type (whether a letter is a consonant–vowel [CV] or vowel–consonant [VC] letter) also influences the development of letter-name and letter-sound knowledge (Justice, Pence, Bowles, & Wiggins, 2006; Kim, Petscher, Foorman, & Zhou, 2010; Treiman & Kessler, 2003). These letter characteristics also are likely to influence the development of letter writing. Hence, this study examined the contribution of both student-level factors and letter characteristics to the acquisition of letter writing in preschool children. We addressed this question using exploratory item response modeling that allowed for the correct partitioning of variation among student factors and letter characteristics.

Student and letter factors

Student-level factors—A large body of research now exists demonstrating the important role of letter knowledge in the acquisition of literacy skills (e.g., Bond & Dykstra, 1967; McBride-Chang, 1999; Share, Jorm, Maclean, & Matthews, 1984; Stevenson & Newman, 1986). Knowledge of letter names measured in preschool is one of the best concurrent and longitudinal predictors of learning to read in an alphabetic writing system (e.g., Lonigan, Schatschneider, & Westberg, 2008; see also Foulin, 2005, for a review). Research indicates that children learn a letter sound more easily when they know the name of the letter than when they do not know the name of the letter (Ehri, 1987; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). In addition to the facilitating letter-sound knowledge, some evidence indicates that knowledge of letter names facilitates early spelling (Treiman & Rodriguez, 1999). Letter names appear to provide a link between letters and print and help children to understand that the words they see on a page or spellings are not arbitrary strings of letters. In this study, we asked whether knowledge of letter names facilitated letter writing similar to its role in facilitating letter-sound knowledge and spelling. Letter writing represents a child’s attempt to retrieve the graphic shapes and names of letters, and as such it should be facilitated by letter-name and/or letter-sound knowledge. Studies examining emergent literacy skills in young children have indicated strong correlations between letter-name and letter-writing skills ($r_s = .80-.83$; Molfese, Beswick, Molnar, & Jacobi-Vessels, 2006; Worden & Boettcher, 1990) and between letter-sound and letter-writing skills ($r = .83$; Worden & Boettcher, 1990).

Phonological awareness, which represents sensitivity to and ability to manipulate sound units in words, is related to letter-name and letter-sound knowledge (Burgess & Lonigan, 1998; Mann & Foy, 2003; McBride-Chang, 1999; Share, 2004) and is a very strong predictor of learning to read in an alphabetic language (Lonigan, Burgess, & Anthony, 2000; Wagner & Torgesen, 1987; Wagner, Torgesen, & Rashotte, 1994). Relations between PA and

alphabet knowledge are relatively robust. PA continues to be a unique predictor of letter-name and letter-sound knowledge even after accounting for variance at the child level and controlling for environmental factors (Burgess & Lonigan, 1998; Lonigan et al., 2000; Torppa, Poikkeus, Laakso, & Eklund, 2006). Furthermore, studies indicate that the relationship between letter-name and letter-sound knowledge and PA may be reciprocal (e.g., Burgess & Lonigan, 1998; Foy & Mann, 2006; Wagner et al., 1994). Children use their PA abilities to extract the letter sound from its name (Foy & Mann, 2006; Share, 2004), and PA has a greater facilitative effect on learning a letter sound when the letter name is known compared with when the letter name is unknown (Kim et al., 2010). In addition to facilitating reading skills, research indicates that both alphabet knowledge and PA also support word spelling, an early writing task (Puranik et al., 2011). Thus, letter names, letter sounds, and PA were included as student-level predictors because these skills may also play an important role in the development of children's letter-writing skills.

Finally, because preschoolers in this study ranged in age from 3 to 5 years, it was essential to include age as a student level factor. Accounting for children's age was important for two reasons. First, given that writing requires some degree of fine motor control, younger children may have more difficulty with letter writing than older children even when other factors related to letter writing are equal. Previous studies have indicated differences in letter writing based on age (e.g., Puranik & Lonigan, 2011). Second, we expected that letter-name knowledge would be a significant contributor to letter-writing skill; however, letter name knowledge of 3-year-olds would be different from that of 5-year-olds.

Letter-level factors—Although researchers have tended to focus on variations in skills at the student level as contributors to early reading skills, findings of more recent research highlight the need to also account for variation at the letter level (e.g., Evans, Bell, Shaw, Moretti, & Page, 2006; Justice et al., 2006; Kim & Petscher, 2011; Kim et al., 2010; Phillips, Piasta, Anthony, Lonigan, & Francis, 2012; Treiman, Levin, & Kessler, 2010). These letter-level factors could be intrinsic; that is, they are part of the essential nature of the letters themselves and might help to describe inter-letter differences. Alternatively, letter-level factors could be extrinsic; that is, they result from social/environmental influences of learning such as influences at home and school as well as print exposure (e.g., Justice et al., 2006). We examined the influence of four extrinsic factors previously shown to influence the learning of letter names, letter sounds, and letter writing (i.e., first letter of a child's name, later letters in a child's name, textual frequency, and letter order) and three intrinsic factors (i.e., letter type such as CV or VC letter, number of strokes in a letter, and letter symmetry).

Letters in children's names: Evidence indicates that children learn the names of the letters contained in their own names before other letters. This influence is likely because children are exposed repeatedly to their names at home and at school compared with other words (e.g., Bloodgood, 1999; Treiman & Broderick, 1998). Children also demonstrate an own-name advantage when learning to write, and substantial evidence indicates that it is the first word a child learns to write (Bloodgood, 1999; Both-de Vries & Bus, 2010; Puranik & Lonigan, 2011, 2012; Treiman & Broderick, 1998). Although children's names are the first words they learn to write, this bias is most profound for the initial letter of their names.

Justice and colleagues (2006) reported that children were 11 times more likely to know the first letter of their names compared with other letters in their names. The primary reason for this finding is that it is the first letter they see and it is frequently capitalized, which improves saliency (Treiman & Kessler, 2003).

Whereas the influence of the first letter in a child's name is the strongest, Justice and colleagues (2006) reported that children were 1.5 times more likely to know the other letters in their names compared with letters not in their names. Research examining writing in preschool children indicates that children tend to use the letters contained in their names more often than other letters when spelling words (e.g., Both-de Vries & Bus, 2010).

Textual frequency: Another factor that is likely to influence the acquisition of alphabet knowledge is textual frequency. Frequency appears to be an important factor in spoken word learning (Goodman, Dale, & Li, 2008; Hoff & Naigles, 2002; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Naigles & Hoff-Ginsberg, 1998; Rice, Oetting, Marquis, Bode, & Pae, 1994). Unlike the literature on oral language, however, the influence of textual frequency of letters on written language is mixed. Treiman, Kessler, and Pollo (2006), who examined factors affecting the learning of letter names in U.S. and Brazilian preschool children (mean age of 4 years 9 months), reported two findings suggesting that textual frequency may influence the learning of letter names. First, children in both countries made more errors on letters that occur less frequently in print in their respective languages compared with letters that occur more frequently. Second, differences in letter frequencies between English and Portuguese resulted in different patterns of performance of children in the two countries. In another study, when Pollo, Kessler, and Treiman (2009) compared the spellings of the same group of children, they found that early spellings were not random; the letters children used in their early spellings also reflected the relative frequencies of the letters found in the language to which the children were exposed. Portuguese-speaking children used more vowels in their early spellings compared with their English-speaking peers. Pollo and colleagues concluded that this was a reflection of the fact that vowels are more prevalent in Portuguese words than in English words. Puranik, Petscher, and Lonigan (2013), who examined letter writing in preschool children, reported that 5 of the 10 letters that children found easiest to write (A, B, T, I, and P) had high textual frequencies; however, they also reported that the remaining 5 of the 10 letters that were easiest for children to write (O, L, X, H, and E) were not among the most frequently occurring uppercase letters in English. In this study, we attempted to clarify the role of textual frequency in the development of letter-writing skills.

Letter type: In English, letters are generally iconic, meaning that a letter name generally includes the sound that the letter represents (Treiman & Kessler, 2003). Studies have shown that children tend to use the iconic properties of letter names to acquire letter-sound knowledge. For example, preschool and kindergarten children learn the sounds of the letters contained in their names in the salient initial position of the letter (i.e., CV letters such as t and b) before letters that have their sounds at the end of their names (i.e., VC letters such as m and s) or letters that do not contain the sounds in their names (i.e., no-sound letters [NSLs] such as h and y) and vowels (a, e, i, o, and u; Foy & Mann, 2006; Kim et al., 2010;

McBride-Chang, 1999; Treiman & Kessler, 2003; Treiman, Tincoff, & Richmond-Welty, 1997; Treiman et al., 1998). Whereas letter type might not directly affect learning to write a letter like it does learning letter sounds, it may affect letter writing indirectly. For example, children are more likely to learn to write a letter if they have a name/label for it. Thus if the letter name for a CV letter is learned before a VC letter or a vowel, this might influence which letters children learn to write first.

Number of strokes: Letters differ in the number and combination of individual strokes. Although previous research on examination of number of strokes in children learning the Latin alphabet has been mixed (e.g., Treiman & Kessler, 2011), stroke features may affect the number and combination of muscles, mostly of the wrist and fingers that must be employed and controlled during writing (Hulstijn & van Galen, 1983; van Mier & Hulstijn, 1993). In contrast, research with Chinese children indicates that visual complexity affects the performance of their writing; that is, children produce more characters that contain few strokes than characters that contain many strokes (Yin & Treiman, 2013). Thus, the number of strokes in a letter could be a potential factor that might affect letter-writing skills, especially when children are first learning to write.

Letter symmetry: Finally, letters differ based on symmetry. Symmetry or correspondence in shape, and relative position of parts on opposite sides of a dividing line or median plane, could influence letter writing. Children learning the Latin alphabet perform better on writing and copying tasks with symmetrical letter forms such as the letter H compared with asymmetrical letter forms such as the letter J (Treiman & Kessler, 2011). Similar findings have been noted for Chinese children (Chan & Louie, 1992; Yin & Treiman, 2013).

The current study

In this study, we examined the influence of student- and letter-level factors on preschool children's letter-writing abilities. It is important to note that some of the specific letter-level factors tested in the current study are not necessarily new (i.e., some have been tested in prior work); however, the current study is the first to test several letter-level factors simultaneously. In addition, it is the first study to simultaneously examine the influence of student- and letter-level factors on the development of preschool children's letter-writing skills. We hypothesized that letter name would be a significant student-level factor and, consistent with previous research, we expected letter writing skills to vary by age groups. Therefore, our analysis included examining letter-writing skills at different age groups. The four questions addressed in this study were as follows:

1. How much of the variance in letter-writing skills is accounted for by student- and letter-level-factors?
2. What are the probabilities of writing a given letter correctly as a function of student- and letter-level factors at different ages?
3. What are the probabilities of writing each individual letter correctly at different ages?

4. What are the probabilities of writing each individual letter correctly at different ages conditional on letter-name knowledge?

METHOD

Participants

Participants in this study were 415 preschool children between 3 and 5 years of age ($M = 52.53$ months, $SD = 8.99$). These children were part of two larger studies examining emergent writing skills in preschool children. They were recruited from 59 public and private preschool centers that were selected to represent children from a wide range of socioeconomic status (SES) backgrounds. Among the sample, 59 children came from high-SES centers (<25% of students receive subsidies), 192 children came from mid- to high-SES centers (25–49% of students receive subsidies), 93 children came from low- to mid-SES centers (50–75% of students receive subsidies), and 70 children came from lowSES centers (>75% of students receive subsidies). One child was home-schooled. Participants in Sample 1 were recruited from a mid-size city in western Pennsylvania (in the eastern United States), and participants in Sample 2 were recruited from mid-size cities in western Pennsylvania and north-central Florida (in the southeastern United States). The SES and age distribution across Samples 1 and 2 were comparable. English was the primary language spoken in the home for all children, and these children had no known developmental disorders per teacher reports. Parental consent was obtained for each participating child. The sample was composed of 148 3-year olds, 134 4-year-olds, and 133 5-year-olds. Demographic information about the participants across both samples is provided in Table 1.

Procedure

As part of the two larger studies, data on various literacy measures were collected; however, only data pertinent to this study are reported here. Children were tested individually at their preschool centers by trained research assistants. These assessments were generally conducted in a quiet room and completed in two or three sessions that lasted approximately 20 to 40 min each, depending on each child's attention skills. The assessment team was made up of graduate and undergraduate students and field staff who completed a training program prior to administering the test battery. The staff and students were given multiple opportunities to practice. Each assessor was observed at least once (and more times if needed) by a senior project member to ensure fidelity of test administration.

Measures

Letter writing—To assess letter-writing skills, children were asked to write each of 26 uppercase letters of the alphabet in a fixed random order. The examiner said the name of the letter, and children were asked to write the letter. Children were not provided with any feedback even if they wrote the letter incorrectly, and they were not given directions regarding writing uppercase or lowercase letters; however, as expected for this age group, children mostly wrote uppercase letters. The only feedback children received was for on-task behaviors. Children's responses were scored dichotomously as correct or incorrect. To account for age and developmental level, children were not penalized for poor penmanship

or letter reversals. The maximum score was 26. Internal consistency reliability for the letter-writing task was .98.

Letter names—For this task, children were shown a card with an uppercase letter printed on it and were asked to name the letter. All 26 letters were presented to the children in a fixed random (non-alphabetic) order. The maximum score was 26. Internal consistency reliability for the letter-naming task was .97.

Letter sounds—Children were shown individual uppercase letters in a random non-alphabetic order and were asked to say the letters' sounds. The examiner provided feedback if children provided the letter name instead of the letter sound for the first two stimuli by saying, "That's the name of the letter; now tell me the sound that letter makes." The maximum score was 26. Internal consistency reliability for the letter-sound task was .96.

Phonological awareness—PA was assessed using the Phonological Awareness subtest of the Test of Preschool Early Literacy (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007) as it is designed for use with 3- to 5-year-olds. This subtest (alphas = .86–.88) consists of 27 items that assess skills across the developmental continuum of PA. The subtest has good psychometric properties for 3- to 5-year-olds and substantial evidence of validity (e.g., concurrent validity coefficients of .59–.77 with other measures of vocabulary, PA, and alphabet knowledge; Lonigan et al., 2007).

Data coding

To examine the influence of extrinsic and intrinsic letter-level factors, for each child the data were coded to indicate whether a letter was the first letter in the child's name and whether the letters were the later letters in the child's name. The later letters were all of the letters in a child's name except the first letter. To code for textual frequency, each letter was assigned a number from 1 to 26 based on Jones and Mewhort's (2004) report regarding frequency of occurrence of uppercase letters in print. As noted by other researchers, no such counts are available for children's literature (Treiman & Kessler, 2011). To account for letter order, letters A through L were coded as early and letters M through Z were coded as late. To account for letter type, letters were coded as CV letters (B, C, D, G, J, K, P, and T), VC letters (F, L, M, N, R, and S), NSLs (Q, H, X, Y, and W), and vowels (A, E, I, O, and U). The letters A, H, I, M, O, T, V, W, and X were coded as symmetrical, whereas the remaining letters were coded as asymmetrical. Finally, letters were coded for the number of strokes (e.g., C and O = 1, D, L = 2, B and F = 3, M and W = 4). Coding and data entry were completed by two research assistants to reduce errors.

Data analysis

A series of explanatory item response models (EIRMs; De Boeck & Wilson, 2004) were used to address the research questions. The data were structured to model variances in letter-writing scores relative to predictors of individual differences among students (i.e., letter-name and letter-sound knowledge and PA) as well as individual differences among letters (i.e., CV letters, VC letters, NSLs, and vowels). A hallmark of EIRMs is that the person and item variances can be treated as fixed or random, depending on the nature of the research

question. In the current design, the EIRM uses a model known as a doubly explanatory model (i.e., explaining both person and item variance; De Boeck & Wilson, 2004), whereby the goal is to identify which predictors act as important explanatory variables in understanding individual differences across the clustering units of students and letters.

The general form of the latent regression linear logistic trait model (LR–LLTM) can be seen in the Appendix A, where Y_{pi} is the response of person p to item i , π_{pi} is the probability that $Y_{pi} = 1$, and η_{pi} is the expected value of the underlying continuous distribution via the logit link. The portions to the right of η_{pi} in the diagram represent the linear prediction of Y_{pi} , whereby $\beta_1, \dots, \beta_K$ are the fixed item predictors, $\vartheta_1, \dots, \vartheta_J$ are the fixed person predictors, β_0 is the item intercept, and θ_p is the random intercept. Such models have gained increased use in literacy research (e.g., Gilbert, Compton, & Kearns, 2011; Kim & Petscher, 2011; Kim et al., 2010) and may be characterized as generalized linear mixed models (De Boeck & Wilson, 2004).

To answer Research Question 1, which estimated how much of the variance in letter-writing skills was due to student- and letter-level differences, an unconditional LR–LLTM (hereafter referred to as Model 1) was used. Without the inclusion of any predictors, the unconditional LR–LLTM estimates the mean log odds of any student correctly writing any letter (i.e., the fixed effects) as well as the amount of variance in letter-writing skills due to differences between students and differences between letters (i.e., the random effects). To facilitate a user-friendly interpretation of the mean coefficients, the log odds were converted to a predicted probability for any coefficient that was statistically significant. Model 2 included a dummy-coded student covariate of whether the student correctly knew the name of the letter. Similarly, Models 3 to 5 evaluated the extent to which student- and letter-level predictors explained individual differences at each respective level. Model 3 extended Model 2 with the inclusion of a dummy-coded covariate of whether the student correctly knew the sound of the letter as well as the interaction between letter-name and letter-sound knowledge, and Model 4 added a grand-mean-centered variable for PA. Lastly, Model 5 added the following predictors of letter variance: (a) a dummy code indicating whether the letter was the first letter in the student's name, (b) a dummy code indicating whether the letter was later in the student's name, (c) a grand-mean-centered measure of textual frequency, (d) a dummy code to indicate letter order, (e) dummy-coded variables to indicate letter type (CV, VC, NSL, or vowel), (f) a dummy code to indicate whether the letter was symmetrical or asymmetrical, and (g) a dummy code to indicate the number of strokes in a letter. Because Model 5 included $k - 1$ letter features of CV letters, VC letters, NSLs, and vowels, CV letters were chosen as the referent. Subsequently, the coefficients for VC letters, NSLs, and vowels tested whether the value was significantly different from CV letters; thus, it was necessary to estimate specific contrasts among the other three letter features to test whether VC letters, NSLs, and vowels were statistically distinguished from each other.

As mentioned previously, because our participants ranged in age from 3 to 5 years, it was hypothesized that differential variability would exist in the letter-writing random effect between the younger and older students. In addition, because younger children were less likely to know letter names, it was hypothesized that letter-name knowledge might account for greater between-letter variances in younger children when compared with older children.

Traditional mixed effects models include age as either a continuous or categorical covariate in the model to serve as a main effect to test for age effects as well as to serve as a moderator. In the current analysis, which was concerned with both fixed and random effects, including age as a covariate would not allow estimating the importance of letter- and student-level variables relative to the random effects for each of the age groups. Subsequently, prior to testing the unconditional model, a preliminary model was fit to test whether a heterogeneous variance–covariance structure existed across the age groups. A significant chi-square for this test provides evidence of a different variance–covariance structure by age group, thereby suggesting that individual group models could be estimated to allow for the unique contribution of independent variables to be reflected within each grade level. Finally, because we expected letter-name knowledge to contribute significantly to letter-writing skills, we used the random effects estimated in Model 2 to examine the contribution of knowledge of letter names. By using the random effects estimated in this conditional model, it was possible to estimate the probabilities of correct letter writing when the student knew the name of the letter or when the student did not know the name of the letter. At each phase of modeling, pseudo- R^2 coefficients were computed to estimate how much of the variance in the student and letter random effects was explained by the selected covariates for the respective model types.

RESULTS

Descriptive data

Descriptive data for the measures for each age group are presented in Table 1. The average score on the letter-writing task was 10.46 ($SD = 9.94$), with older preschoolers showing better performance compared with younger preschoolers. Large standard deviations for the letter-writing task relative to their respective means were noted for both 3- and 4-year-olds, which may be indicative of floor effects. The distribution of scores was examined at each age level; results indicated that 47% of 3-year-olds obtained a total letter writing score of 0, compared with 19% of 4-year-olds and 0% of 5-year-olds. For 5-year-olds, 22% of students obtained total letter writing scores of 26. As expected, on average children performed better on the letter-naming task than they did on the letter-writing task. The average score for the letter-naming task was 16.15 ($SD = 9.97$), with 16% of 3-year-olds obtaining a score of 0, compared with 4% of 4-year-olds and 0% of 5-year-olds. The mean for the letter sound task was 8.46 ($SD = 8.61$), with 52% of 3-year-olds obtaining a score of 0, compared with 28% of 4-year-olds and 4% of 5-year-olds.

Research Question 1: How much of the variance in letter-writing skills is accounted for by student- and letter-level factors?

Prior to testing for differences in letter-writing skills, we estimated whether the variances due to letters and students varied by age. A chi-square test suggested that the variances in letter writing due to student and letters varied across ages, -2 residual log likelihood = 61,037, $\chi^2(5) = 71.52$, $p < .001$; subsequently, Models 1 to 5 were uniquely estimated for each age group. The random effects for between-student and between-letter differences across the five models for each age group are reported in Table 2. The 95% confidence intervals for the Wald test of variances in each of the models across grade levels did not include 0, indicating

that the variance components were statistically significant for both students and letters. Across the three age groups, the decomposition of variances demonstrated that most of the variance in responses was due to student-level differences (i.e., Model 1 in Table 2). The intraclass correlations computed from these coefficients indicated that 81% of the variance in letter writing for 3-year-olds [i.e., $4.58/(4.58 + 1.09)$], 91% for 4-year-olds, and 82% for 5-year-olds were due to differences between students. In addition, the variances in letter-writing scores due to letter-level differences were 19% for 3-year-olds [i.e., $1.09/(1.09 + 4.58)$], 10% for 4-year-olds, and 18% for 5-year-olds.

The next step involved modeling the specific student- and letter-level predictors across the remaining models (i.e., Models 2–5 in Table 2) for each of the individual age groups. For the model involving 3-year-olds, the inclusion of letter-name and letter-sound knowledge and PA, as well as the letter characteristics, resulted in student variance decreasing from 4.58 in Model 1 to 3.38 in Model 5 (i.e., $\text{pseudo-}R^2 = .26$). The letter variance decreased slightly from 1.09 in Model 1 to 0.93 in Model 5, which translated into a $\text{pseudo-}R^2$ of .14. Student-level variances for the models with 4- and 5-year-olds demonstrated decreases similar to those for 3-year-olds, with 39% variance explained for 4-year-olds when comparing the student variances between Models 1 and 5 and a 45% reduction in variance between Models 1 and 5 for 5-year-olds. The letter variance for 4-year-olds decreased from 0.77 to 0.74 between Models 1 and 5 ($\text{pseudo-}R^2 = .04$), and a larger reduction occurred for 5-year-olds from 0.80 to 0.60 ($\text{pseudo-}R^2 = .25$).

Research Question 2: What are the probabilities of writing a given letter correctly as a function of student- and letter-level factors at different ages?

As it pertains to the impact of the student- and letter-level predictors, the associated fixed effects for these models are reported in Tables 3–5 for 3-, 4-, and 5-year-olds, respectively. For the following discussion, we limit our substantive presentation to the results from Model 5 (Table 2) because this represented the final step in model building and, thus, the most comprehensive picture of the item (letter) and person (student) relationships to item responses. The average log odds for correctly writing a letter for the referent group for 3-year-olds was 4.44 (see Table 3) and, when converted to a predicted probability (i.e., 0.01), indicated that children had a 1% chance of correctly writing a letter when controlling for the other predictors in the model. Letter name was significantly associated with letter writing. When children knew the name of the letter they were asked to write, the log odds of correctly writing the letter increased by 1.84 units, $t(3594) = 7.29$, $p < .001$; however, the practical implication of this result was that a child's predicted probability of correct letter writing conditional on letter-name knowledge increased marginally from 1% to 7%.

Of the seven letter-level predictors in Model 5, two demonstrated significant effects. When the letter written was the first letter in the child's name, there was a significantly higher probability of writing it correctly, predicted probability = .03, $t(2744) = 3.14$, $p < .001$; however, as noted with the letter-name knowledge variable, an individual's probability of correctly writing the letter when it was the first letter in the name was 4%. In addition, students had a higher probability of correctly writing vowels, predicted probability = .04, $t(3594) = 2.05$, $p < .001$, compared with CV letters.

Different associations among the student and letter covariates with letter writing were observed for 4-year-olds. Letter-name knowledge, letter-sound knowledge, and PA were significantly related to the outcome (see Table 4). The average log odds for the referent in this age group for correctly writing a letter was -2.64 , which translated into a predicted probability of .07. When the student knew the name of the letter, the likelihood of writing it correctly increased from 7% to 33%, $t(2271) = 7.50$, $p < .001$, controlling for the other components in the model. Similarly, knowledge of the letter sound led to an increase in the probability of correctly writing the letter, predicted probability = .10, $t(2271) = 2.17$, $p < .05$. The impact of PA ability was marginal, whereby a unit increase in PA did not change the predicted probability of correct letter writing even though a significant log odds difference was estimated. Three of the seven letter-level predictors demonstrated significant associations with the outcome. When the presented letter was a vowel, children's log odds of correct letter writing increased by 1.29 units, $t(2271) = 2.45$, $p < .05$, moving their predicted probability from 7% to 21%. Similar to results for 3-year-olds, when the letter written was also the first letter in the child's name, a significantly higher probability was estimated, predicted probability = .30, $t(2271) = 4.71$, $p < .001$, translating into a probability increase from 7% to 30%, and when the letter appeared later in the child's name, a significant effect was observed, predicted probability = .12, $t(2271) = 2.89$, $p < .01$, translating into a probability increase from 7% to 12%.

For the referent 5-year-olds (see Table 5), the average log odds for correct letter writing was 0.02 but was not significantly different from 0; thus, the estimated predicted probability for the referent was .50. Letter-name and letter-sound knowledge and PA were significantly associated with the outcome. Knowledge of the letter name resulted in a 1.48 increase in the log odds and increased the probability of writing correctly from .50 to .82, $t(2645) = 7.64$, $p < .001$. Thus, the likelihood of writing a letter correctly when the child knew the name of the letter increased from 50% to 82%. Similarly, letter-sound knowledge was related to correct writing, $t(2645) = 2.67$, $p < .01$, resulting in an increase in the probability of correct writing from 50% to 60%. PA was marginally related to letter writing, whereby an increase in overall PA resulted in only a 0.04 log odds change in letter writing, $t(2645) = 4.97$, $p < .001$ (i.e., the likelihood of writing a letter correctly increased by 2%). No significant differences were observed among the CV letters, VC letters, NSLs, and vowels ($p > .05$); however, when the letter written was the first letter in the child's name, the log odds increased by 1.55, translating into a probability increase from 50% to 83%, $t(2645) = 4.01$, $p < .001$. In addition, when the letter to be written appeared later in the student's name, the log odds of correctly writing the letter increased by 0.36, predicted probability = .59, $t(2645) = 1.97$, $p < .05$.

Two important findings from the random and fixed effect results from this set of models (Tables 3–5) need to be highlighted. First, most of the variance in item responses was due to differences between students, with approximately one third of that variance being explained by their letter-name knowledge, letter-sound knowledge, and PA. Second, of the seven letter-level predictors, only one predictor was consistently associated with letter writing (i.e., when the letter was the first letter of the student's name) when controlling for the other model covariates. Moreover, the combination of letter-level predictors did little in explaining individual differences between letters in the 3- and 4-year-old groups.

Research Question 3: What are the probabilities of writing each individual letter correctly at different ages?

As part of Models 1 and 2 for each age group, the random effects for each of these two models were extracted in order to calculate the probability of correct letter writing for each age group as well as the extent to which the probabilities differed in magnitude when accounting for whether the student correctly knew the letter name. Model logits and associated probabilities for correct letter writing in the full sample and individual age groups are reported in Table 6. To correctly estimate the probability of a correct response, the opposite of the model coefficient (i.e., logit^{-1}) was calculated. That is, whereas the estimated logit for the letter A for the full sample was -0.09 , the opposite of this value (0.09) allowed for the correct probability calculation (i.e., .48). Probabilities in Table 6 reveal a range of difficulty for the full sample, with the letter O having the highest likelihood of being written correctly (predicted probability = .89) and the letter K having the lowest probability of being written correctly (predicted probability = .10).

The age-adjusted probabilities indicate that average 3-year-olds had a low probability of correctly writing any of the letters. Only two letters (L and O) had calculated probabilities greater than .10 for 3-year-olds, whereas the probabilities of writing the remaining 24 letters were less than .05. The estimates for 4-year-olds were higher, with probabilities ranging from .11 (i.e., G) to .88 (i.e., O). Despite this wide range, only three letters had a probability of being written correctly that was greater than .50 (i.e., A, L, and O). The 5-year-olds had a much higher probability of correctly writing each letter than did the 3- and 4-year-olds, with estimates ranging from .63 (i.e., Z) to .99 (i.e., O).

Research Question 4: What are the probabilities of writing each individual letter correctly at different ages conditional on letter-name knowledge?

The predicted probabilities of correctly writing a letter for each of the three age groups conditional on whether the student knew the name of the letter ($LN = 1$) or did not know the name of the letter ($LN = 0$) are reported in Table 7. The impact of letter-name knowledge was most readily observed for 3-year-olds, especially when viewing the letters A, I, L, and O. The predicted probability for correctly writing the letter A increased from 3% to 16% when 3-year-olds knew the name of the letter, an increase of 13%. Similarly, a 13% increase occurred for I, a 29% increase occurred for L, and a 42% increase occurred for O when 3-year-olds knew the letter names. Large differences were also observed for 4-year-olds, most notably for L (40% increase), A and X (38% increase), H (36% increase), I (34% increase), and O (31% increase) when they knew the names of the letters. Fully 22 of the 26 letters had increases of 20% or more in the predicted probability for 4-year-olds when the name of the letter was known. The greatest calculated differences for 5-year-olds were for the letters Z and Q (36% increase), J, K, and U (35% increase), and G (34% increase). For 5-year-olds, 23 letters had increases of 20% or more in their probability of correct letter writing conditional on name knowledge.

DISCUSSION

In this study, we examined factors that could potentially contribute to children's developing ability to write letters, a precursor skill to more complex aspects of writing. The results of this study revealed that the primary contributors to children's letter-writing skills were age and letter-name knowledge. The proportion of variance in letter writing that was accounted for by student-level factors ranged from 81% to 91%, whereas the proportion of the variance in letter writing that was accounted for by differences in letter characteristics ranged from 10% to 19%. The influences of both student factors and letter characteristics were larger for older children than they were for younger children.

Contribution of student-level factors

As with other language skills, letter writing follows a developmental trend, evident from the descriptive data and confirmed by the LR–LLTM, indicating that a significant proportion of the variance at the student level was explained by age. In addition to age, children's knowledge of letter names significantly predicted their ability to write letters. Previous studies examining the relationship between letter naming and letter writing in young children have reported strong correlations between these two skills (e.g., $rs = .80-.83$; Molfese et al., 2006; Worden & Boettcher, 1990). This study adds to the understanding of the impact of letter-name knowledge on letter-writing skills by examining the specific relation between knowing a letter's name and being able to write the letter. The results revealed a significant and strong effect of letter-name knowledge for 4- and 5-year-olds. The probability of knowing how to write a letter increased, on average, from 5% to 25% for 4-year-olds and from 44% to 78% for 5-year-olds when students knew a letter's name. Letter-name knowledge had little to no effect on 3-year-olds' letter-writing abilities, perhaps because of low letter-name knowledge and limited letter-writing abilities.

For 4- and 5-year-olds, letter-sound knowledge and PA skills also contributed to letter-writing abilities. Notably, however, the degree of variation in letter-writing ability explained by letter-sound knowledge and PA was substantially less than the degree of variability explained by letter-name knowledge. In studies where the influence of PA on letter-sound knowledge has been examined, it has typically been found that PA has a larger role. The difference in the influence of PA, however, is likely due to the fact that both letter-sound knowledge and PA skills are associated with an underlying sensitivity to sounds in words. Writing letters, at least at the decontextualized level (i.e., not in the context of words), does not appear to require sensitivity to sounds in words.

Although the results of this study indicate a substantial influence of knowledge of letter names on children's ability to write letters, these results do not indicate the direction of the effect. In these data, children's letter-naming scores were higher than their letter-writing scores, suggesting that letter-name knowledge precedes letter-writing ability. It may be that children learn letter names before they learn to write letters; however, this developmental sequence is not indicative of a causal relation. Letter shapes are arbitrary (i.e., the shape of the letter has no direct connection to its name or sound) and, as such, have no meaning for children. It seems unlikely that children would randomly learn to write a letter if they do not have a name for it. It seems more likely that knowing the name of a letter is motivating for

children to learn how to write the letter. The linkage in this study between knowing the name of a specific letter and being able to write that letter supports this possibility.

Whereas it seems likely that children learn to write a letter after they know its name, an alternative scenario could be that after children learn the names of and write a few letters, letter writing could boost children's knowledge of letter names; that is, the relationship between the two may be bidirectional. Diamond, Gerde, and Powell (2008) examined growth in Head Start children's name writing and letter knowledge at three time points and found that children whose name writing was more sophisticated (i.e., contained more letters) knew more letter names. Although they reported bidirectional influences of writing on growth of letter names and of letter names on growth of writing competence, Diamond and colleagues' results must be interpreted cautiously because the researchers specifically examined the relationship between name writing (which contains a restricted set of letters) and letter-name knowledge; moreover, this bidirectional relationship was present only for the more advanced writers and not the less advanced writers. Additional research is needed to establish directional and causal relations between letter-name knowledge and letter-writing skills.

The results of this study are consistent with results from two previous studies: one that reported on an item response theory (IRT) analysis of preschool children's letter-name knowledge (Phillips et al., 2012) and one that reported on an IRT analysis of preschool children's letter-writing skills (Puranik et al., 2013). The findings of these two studies indicated a large overlap between the 10 letters that children were most likely to be able to name and the 10 letters that children were most likely to be able to write (i.e., O, B, A, X, P, E, T, and H) as well as between the 10 letters that children had the most difficulty with naming and the 10 letters that children had the most difficulty with writing (i.e., V, U, Q, N, J, G, Z, and Y). Our finding regarding the significant contribution of letter name knowledge to letter writing not only is consistent with the results of these two studies but also provides an excellent means for bridging the findings from these two reported studies, adding to our current knowledge concerning the important role of letter-name knowledge in children learning to write letters of the alphabet.

Contribution of letter factors

Across all three age groups, only a small proportion of differences between letters could be attributed to differences between letters. Although the proportional increase of variance explained by letter differences was greater for 5-year-olds compared with 3-year-olds, it represented a small proportion of the overall variance in letter writing. Even for 5-year-olds, although 25% of the letter variance was explained, it represents a small proportion of the overall variance in letter-writing ability given that the baseline variance due to letter differences was 18%. This finding indicates that a different mechanism underlies the learning of letter sounds and learning to write letters.

The only letter-level characteristic that was consistently associated with letter writing was whether the letter was the first letter of the child's name. The important role of the first letter is consistent with findings from previous research on letter-name knowledge and on the development of letter-writing skills. Justice and colleagues (2006) reported that children

were 11 times more likely to know a letter name if it was the first letter of their names. Research examining children's letter-writing skills have indicated that children are more likely to know how to write the first letter of their names compared with other letters (e.g., Bloodgood, 1999; Both-de Vries & Bus, 2010; Puranik & Lonigan, 2011, 2012). For 4- and 5-year-olds, the letters in their names also were associated with correct letter writing.

Apart from the effect of the letters of a child's name, however, no other letter feature examined in this study (i.e., letter type, letter order, textual frequency, number of strokes, or symmetry) made a substantial and consistent contribution to letter writing. These results contrast somewhat with studies of children's knowledge of letter names and letter sounds indicating that the type of letter (CV letter, VC letter, NSL, or vowel) provides important cues and might facilitate the acquisition of letter names and associated letter sounds. Unlike letter sounds, where it appears that letter names provide important cues to facilitate learning (e.g., Ehri, 1987; Treiman et al., 1997), letter names do not provide cues regarding the shape or form of the letter. Letter order also has been shown to have a moderate impact on learning of letter names (i.e., letters appearing earlier in the alphabet sequence have a small advantage compared with letters appearing later in the alphabet sequence; Justice et al., 2006; McBride-Chang, 1999); however, letter order was not associated with the ability to write a letter in this study.

Our finding that textual frequency did not contribute substantially to learning of letter writing is contrary to findings of Pollo and colleagues (2009), who reported that children's early spellings reflect the textual frequencies of the language to which they are exposed, and Treiman et al. (2006), who reported that textual frequency was one of the factors affecting the learning of letter names. One reason for the differences in the results of this study and those of Pollo and colleagues (2009) could be the task itself—letter writing versus spelling. Perhaps the words chosen for the spelling task, and hence the letters that children were required to write, reflected the textual frequencies of a language. No such bias was inherent in our task. In addition, because children were required to spell words, it is possible that they used only the letters they knew how to write, whereas in this study, children were required to write all 26 letters. Importantly, unlike Pollo and colleagues' study, we not only examined variances at the student and letter levels but also examined the contribution of several letter characteristics implicated in previous research simultaneously using newer and more sophisticated statistical techniques, which may account for the differences in study results. In Treiman et al. (2006) study, letter names was the outcome variable. It appears that textual frequencies affect learning of letter names but not letter writing.

Finally, our result that the number of segments/strokes did not affect letter writing is in line with previous research. Treiman and Kessler (2011) examined data from four previous studies examining letter writing in young English-speaking children from preschool to first grade and found no clear evidence to support the fact that the number of strokes in a letter affected letter writing. In contrast, the number of strokes appears to be an important factor in learning Chinese characters (Yin & Treiman, 2013). A simple and straightforward explanation is that there is very little variability in the number of strokes used to write Latin letters (ranging from one to four), whereas Chinese characters are much more complex.

Limitations and conclusions

This study is the largest and most diverse evaluation of preschool-age children's letter-writing skills to date; however, it is not without limitations. We did not examine the impact of classroom instruction on children's letter writing. Teachers reported using one of several comprehensive curricula to teach reading; however, none of the teachers reported using a comprehensive curriculum to teach writing or following a specific scope and sequence to teach letter writing. Although preschool children are not provided with explicit writing instruction, some teachers do provide informal writing instruction that includes teaching children to write their names and explore writing. Thus, it is possible that results might differ for children who attend preschool programs where some writing instruction is provided compared with preschool programs where no writing instruction is provided. Although it is likely that classroom instruction may explain some of the variance at both the student and letter levels, it is important to note that we recruited children from 59 different preschool settings in two different geographical locations. Moreover, our preschools included a good mix of both public and private pre-kindergarten (pre-K) centers.

Second, although letter-name knowledge accounted for a significant proportion of the variance at the student level (31% for 4-year-olds and 23% for 5-year-olds), a substantial amount of variance remained unexplained. These results indicate the need to explore and include other student-level factors in future studies. Future studies should investigate other student factors such as cognitive and oral language skills and knowledge of print concepts that might be significant contributors. Assessing fine motor skills could also help to explain some of the variance at the student level and should be examined in future research. Another factor we did not examine was the overall quality of the home environment, including home literacy practices that could also likely account for some of the student-level differences noted.

Turning to variation at the letter level, although we included a comprehensive set of factors, we were able to account for a very small proportion of the variance. The result regarding the small contribution of letter-level factors was surprising due to the lack of explanatory power. Perhaps it was because letter writing was assessed only at one time point. Given the ages of participants in this study, the stability of performance might be questionable, especially for the youngest children. Assessing letter writing over several time points during the year, or better yet longitudinally as children progress through kindergarten when letter-writing skills are perhaps more stable, might be a better indicator of the development of letter-writing skills. Another limitation of this study was that letters were dictated to all children in the same random order and could have resulted in some order effects. Varying letter order in the letter writing task might mitigate order effects.

Despite the above-mentioned limitations, the contributions of this study are substantial, especially because little is known about what factors influence how children learn to write letters of the alphabet. The results of this study suggest that the student-level mechanisms underlying the acquisition of letter-writing skills are similar to the mechanisms underlying the learning of letter sounds (e.g., Kim et al., 2010, in kindergarten children). However, in contrast to results of studies of children's letter-name and letter-sound knowledge, only a small proportion of the variance in letter-writing skills could be attributed to differences

between letters, although the letter characteristics examined in this study were based on research on studies examining letter names, letter sounds, and letter writing.

In conclusion, our results regarding the probabilities of letter writing at different ages could be used when assessing letter writing in preschool children, especially when assessing school readiness skills. They could be used to design alternate forms to measure growth in letter-writing skills throughout the school year. The findings of this study showing that student factors, more than letter factors, contribute to letter-writing skills also have important implications for instruction. The findings that letter-name knowledge contributed substantially to letter-writing skills, coupled with the results of Phillips and colleagues (2012) and Puranik and colleagues (2013), suggest that it might be beneficial to introduce the same letters for teaching letter names and for letter writing. Such instructional decisions can be made only after several questions are first addressed experimentally. For example, a well-designed experimental study would reveal whether teaching how to write letters when students knew the letter names compared with when students did not know the letter names resulted in better letter-writing skills. We hope that the findings of the current study are used to inform instruction of letter-writing skills congruent to more recent studies that have begun to explore the increased utility of combining letter-name and letter-sound instruction (e.g., Piasta & Wagner, 2010).

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Appendix

Explanatory item response models for latent regression linear logistic test model

Table 1

Demographic and descriptive statistics for 3-year-olds ($n = 148$), 4-year-olds ($n = 134$), and 5-year-olds ($n = 133$).

Demographic information	Full sample		3-year-olds		4-year-olds		5-year-olds	
	Mean (<i>SD</i>)		Mean (<i>SD</i>)		Mean (<i>SD</i>)		Mean (<i>SD</i>)	
Age (months)	52.53 (8.99)		42.49 (2.93)		53.19 (3.49)		63.04 (2.63)	
Gender	Female	53.0%	21.0%		15.2%		16.9%	
	Male	47.0%	14.7%		17.1%		15.2%	
Ethnicity	Asian	3.4%	1.0%		1.7%		0.7%	
	Black	28.9%	12.5%		11.1%		5.3%	
	Hispanic	1.9%	0.7%		0.5%		0.7%	
	Other	2.9%	1.4%		0.5%		1.2%	
	White	62.7%	20.0%		18.6%		24.1%	
Measure	Mean (<i>SD</i>)	Range	Mean (<i>SD</i>)	Range	Mean (<i>SD</i>)	Range	Mean (<i>SD</i>)	Range
Letter writing	10.46 (9.94)	0–26	2.77 (5.09)	0–26	10.28 (9.36)	0–26	19.20 (7.02)	2–26
Letter naming	16.15 (9.97)	0–26	9.9 (9.56)	0–26	16.63 (9.44)	0–26	22.63 (5.81)	2–26
Letter sounds	8.46 (8.61)	0–26	3.70 (6.18)	0–26	7.46 (7.73)	0–26	14.76 (7.95)	0–26
Phonological awareness ^a	92.37 (16.59)	54–140	90.01 (14.66)	63–140	91.63 (15.39)	55–126	95.47 (18.97)	54–124

^aStandard scores from Phonological Awareness subtest of Test of Preschool Early Literacy (TOPEL), mean = 100, SD = 15

Table 2

Estimated variance components from the latent regression linear logistic trait model.

Group (years)	Model	Source of variance	Variance component	SD	Wald 95% confidence interval		
					Lower	Upper	
Age 3	Model 1	Student	4.58	0.71	3.46	6.35	
		Letter	1.09	0.35	0.63	2.31	
	Model 2	Student	3.21	0.53	2.38	4.58	
		Letter	0.98	0.32	0.56	2.11	
	Model 3	Student	3.10	0.53	2.28	4.45	
		Letter	0.97	0.32	0.56	2.10	
	Model 4	Student	2.78	0.57	1.93	4.34	
		Letter	1.22	0.42	0.68	2.78	
	Model 5	Student	3.38	0.57	2.48	4.85	
		Letter	0.93	0.37	0.49	2.42	
Age 4	Model 1	Student	7.33	1.09	5.59	10.03	
		Letter	0.77	0.24	0.45	1.59	
	Model 2	Student	5.08	0.80	3.81	7.10	
		Letter	0.61	0.20	0.35	1.29	
	Model 3	Student	4.64	0.76	3.45	6.59	
		Letter	0.63	0.20	0.36	1.34	
	Model 4	Student	3.99	0.78	2.81	6.11	
		Letter	0.80	0.27	0.45	1.77	
	Model 5	Student	4.50	0.88	3.17	6.89	
		Letter	0.74	0.29	0.38	1.99	
Age 5	Model 1	Student	3.66	0.55	2.78	5.05	
		Letter	0.80	0.26	0.47	1.69	
	Model 2	Student	2.83	0.45	2.12	3.97	
		Letter	0.63	0.21	0.36	1.36	
	Model 3	Student	2.35	0.39	1.74	3.36	
		Letter	0.63	0.21	0.36	1.35	
	Model 4	Student	1.87	0.36	1.33	2.83	

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Group (years)	Model	Source of variance	Variance component	SD	Wald 95% confidence interval	
					Lower	Upper
Model 5		Letter	0.66	0.22	0.38	1.43
		Student	2.02	0.38	1.44	3.05
		Letter	0.60	0.24	0.32	1.58

Table 3

Fixed effects for latent regression linear logistic trait model: 3-year-olds.

Model	Coefficient	Estimate	SE	df	t value	p value
Model 1	Intercept	-3.58	0.30	25	-12.10	<.001
Model 2	Intercept	-4.41	0.31	25	-14.41	<.001
	LN	1.86	0.23	3674	8.20	<.001
Model 3	Intercept	-4.51	0.31	25	-14.34	<.001
	LN	1.94	0.25	3596	7.83	<.001
	LS	0.95	0.52	3596	1.82	.069
	LN * LS	-0.60	0.54	3596	-1.10	.270
Model 4	Intercept	-4.81	0.36	25	-13.21	<.001
	LN	1.89	0.30	2746	6.31	<.001
	LS	1.83	0.76	2746	2.39	.017
	LN * LS	-1.61	0.79	2746	-2.04	.042
	PA	0.02	0.01	2746	1.59	.112
Model 5	Intercept	-4.44	0.81	18	-5.46	<.001
	LN	1.84	0.25	3594	7.29	<.001
	LS	0.90	0.52	3594	1.72	.085
	LN * LS	-0.56	0.54	3594	-1.03	.304
	VC	0.44	0.58	3594	0.76	.450
	NSL	0.27	0.69	3594	0.39	.695
	Vowel	1.18	0.58	3594	2.05	.041
	Symmetry	0.11	0.51	3594	0.22	.829
	Stroke	-0.31	0.25	3594	-1.24	.213
	FLN	1.34	0.31	3594	4.34	<.001
	LIN	0.29	0.21	3594	1.35	.176
	TXTRQ	-0.03	0.03	3594	-0.82	.410
	LO	0.15	0.46	3594	0.32	.750

Note. LN, letter naming; LS, letter sounds; PA, phonological awareness; VC, vowel-consonant letter; NSL, no-sound letter; Stroke, number of strokes; FLN, first letter in student's name; LIN, later letters in student's name; TXTRQ, textual frequency; LO, letter order; pp, predicted probability.

Table 4

Fixed effects for latent regression linear logistic trait model: 4-year-olds.

Model	Coefficient	Estimate	SE	df	t value	p value	pp
Model 1	Intercept	−0.91	0.30	25	−3.02	.006	.29
Model 2	Intercept	−2.06	0.29	25	−7.09	<.001	.11
	LN	1.68	0.17	3310	9.66	<.001	.41
Model 3	Intercept	−2.25	0.30	25	−7.52	<.001	.10
	LN	1.78	0.20	3197	9.07	<.001	.38
	LS	0.83	0.42	3197	2.00	.046	.20
	LN * LS	−0.52	0.43	3197	−1.21	.228	–
Model 4	Intercept	−2.57	0.36	25	−7.07	<.001	.07
	LN	2.11	0.27	2272	7.89	<.001	.39
	LS	0.83	0.71	2272	1.16	.246	–
	LN * LS	−0.45	0.73	2272	−0.61	.540	–
	PA	0.09	0.02	2272	5.78	<.001	.08
Model 5	Intercept	−2.64	0.77	18	−3.42	.003	.07
	LN	1.92	0.26	2271	7.50	<.001	.33
	LS	0.44	0.20	2271	2.17	.030	.10
	LN * LS	0.10	0.02	2271	5.85	<.001	.07
	VC	0.45	0.53	2271	0.84	.399	–
	NSL	1.13	0.61	2271	1.84	.065	–
	Vowel	1.29	0.53	2271	2.45	.014	.21
	Symmetry	−0.23	0.46	2271	−0.50	.620	–
	Stroke	−0.23	0.23	2271	−1.00	.318	–
	FLN	1.79	0.38	2271	4.71	<.001	.30
	LIN	0.65	0.22	2271	2.89	.004	.12
	TXTRQ	−0.03	0.03	2271	−0.90	.369	–
	LO	0.18	0.41	2271	0.43	.665	–

Note. LN, letter naming; LS, letter sounds; PA, phonological awareness; VC, vowel–consonant letter; NSL, no-sound letter; Stroke, number of strokes; FLN, first letter in student's name; LIN, later letters in student's name; TXTRQ, textual frequency; LO, letter order; pp, predicted probability.

Table 5

Fixed effects for latent regression linear logistic trait model: 5-year-olds.

Model	Coefficient	Estimate	SE	df	t value	p value	pp
Model 1	Intercept	1.69	0.25	25	6.76	<.001	.84
Model 2	Intercept	0.35	0.27	25	1.28	.212	–
	LN	1.48	0.17	3299	8.53	<.001	.86
Model 3	Intercept	–0.13	0.28	25	–0.48	.638	–
	LN	1.66	0.20	3272	8.28	<.001	.82
	LS	1.26	0.36	3272	3.50	.001	.75
	LN * LS	–0.78	0.37	3272	–2.11	.035	.88
Model 4	Intercept	–0.35	0.29	25	–1.18	.250	–
	LN	1.76	0.22	2646	8.06	<.001	.80
	LS	1.08	0.41	2646	2.62	.009	.67
	LN * LS	–0.75	0.42	2646	–1.77	.077	–
	PA	0.04	0.01	2646	4.95	<.001	.42
Model 5	Intercept	0.02	0.67	18	0.04	.972	–
	LN	1.48	0.19	2645	7.64	<.001	.82
	LS	0.39	0.15	2645	2.67	.008	.60
	LN * LS	0.04	0.01	2645	4.97	<.001	.52
	VC	0.16	0.47	2645	0.35	.726	–
	NSL	0.91	0.54	2645	1.69	.092	–
	Vowel	0.80	0.47	2645	1.70	.090	–
	Symmetry	–0.04	0.41	2645	–0.09	.927	–
	Stroke	–0.26	0.20	2645	–1.30	.192	–
	FLN	1.55	0.39	2645	4.01	<.001	.83
	LIN	0.36	0.18	2645	1.97	.049	.59
	TXTRQ	–0.04	0.03	2645	–1.71	.087	–
	LO	0.13	0.37	2645	0.34	.731	–

Note. LN, letter naming; LS, letter sounds; PA, phonological awareness; VC, vowel–consonant letter; NSL, no-sound letter; Stroke, number of strokes; FLN, first letter in student's name; LIN, later letters in student's name; TXTRQ, textual frequency; LO, letter order; pp, predicted probability.

Table 6

Full sample and age-based letter logits and calculated probabilities of correct letter writing.

Letter	Full sample		Age 3 years		Age 4 years		Age 5 years	
	$-\beta_i$	$p(1 \theta = 0)$	logit	$p(1 \theta = 0)$	logit	$p(1 \theta = 0)$	logit	$p(1 \theta = 0)$
A	-0.09	.48	3.02	.05	-0.13	.53	-2.69	.94
B	-0.28	.43	3.25	.04	0.07	.48	-2.53	.93
C	-0.81	.31	3.62	.03	1.22	.23	-2.53	.93
D	-0.89	.29	2.92	.05	1.36	.21	-2.01	.88
E	-0.68	.34	3.37	.03	0.61	.35	-2.08	.89
F	-1.15	.24	3.9	.02	0.88	.29	-1.43	.81
G	-1.93	.13	4.55	.01	2.06	.11	-0.91	.71
H	-0.6	.35	3.37	.03	0.27	.43	-1.94	.87
I	-0.52	.37	3.37	.03	0.54	.37	-2.54	.92
J	-2.09	.11	4.74	.01	1.92	.13	-0.53	.63
K	-2.14	.10	6.71	<.01	1.84	.14	-0.69	.67
L	0.36	.59	1.79	.14	-0.53	.63	-2.45	.92
M	-0.76	.32	3.25	.04	0.54	.37	-1.74	.85
N	-1.41	.20	4.05	.02	1.42	.19	-1.37	.80
O	2.14	.89	0.22	.45	-2.01	.88	-4.78	.99
P	-0.73	.33	3.76	.02	0.74	.32	-2.29	.91
Q	-1.85	.14	4.2	.02	1.7	.15	-0.69	.67
R	-1.49	.18	4.95	.01	1.29	.22	-1.37	.80
S	-1.23	.23	4.2	.02	1.29	.22	-1.74	.85
T	-0.47	.39	2.92	.05	0.54	.37	-2.29	.91
U	-1.67	.16	3.62	.03	1.49	.18	-0.69	.67
V	-1.8	.14	4.37	.01	1.7	.15	-0.85	.70
W	-1.33	.21	4.2	.02	1.29	.22	-1.49	.82
X	-0.23	.44	4.74	.01	0.07	.48	-3.74	.98
Y	-1.51	.18	4.37	.01	1.29	.22	-1.13	.76
Z	-1.93	.13	4.55	.01	1.56	.17	-0.53	.63

Probabilities of correct letter responses conditional on age and whether child knew letter name (LN = 1) or did not know letter name (LN = 0).

Table 7

Letter	Age 3 years		Age 4 years		Age 5 years	
	LN = 0	LN = 1	LN = 0	LN = 1	LN = 0	LN = 1
A	.03	.16	.20	.58	.72	.92
B	.02	.11	.18	.53	.70	.91
C	.02	.10	.08	.31	.71	.91
D	.03	.18	.08	.32	.64	.89
E	.02	.12	.14	.46	.67	.90
F	.01	.08	.11	.41	.53	.83
G	.01	.05	.05	.21	.42	.76
H	.02	.12	.18	.54	.61	.87
I	.03	.16	.17	.51	.76	.93
J	.01	.05	.05	.23	.33	.68
K	.00	.02	.05	.23	.35	.70
L	.09	.38	.31	.71	.71	.91
M	.03	.15	.16	.50	.60	.87
N	.02	.10	.08	.31	.51	.82
O	.22	.64	.56	.87	.91	.98
P	.02	.09	.13	.45	.69	.91
Q	.01	.07	.06	.25	.36	.72
R	.01	.04	.08	.31	.49	.81
S	.01	.07	.08	.33	.58	.86
T	.03	.18	.14	.46	.68	.90
U	.02	.11	.07	.29	.36	.71
V	.01	.08	.07	.30	.46	.79
W	.01	.06	.08	.33	.53	.83
X	.01	.04	.20	.58	.84	.96
Y	.01	.07	.08	.33	.46	.79
Z	.01	.05	.06	.27	.31	.67