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The Contributions of Phonological Awareness and Letter-Name Knowledge to Letter-Sound Acquisition—A Cross-Classified Multilevel Model Approach

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In the present study, we investigated critical factors in letter-sound acquisition (i.e., letter-name knowledge and phonological awareness) with data from 653 English-speaking kindergartners in the beginning of the year. We examined (a) the contribution of phonological awareness to facilitating letter-sound acquisition from letter names and (b) the probabilities of letter-sound acquisition as a function of letter characteristics (i.e., consonant–vowel letters, vowel–consonant letters, letters with no sound cues, and vowel letters). The results show that letter-name knowledge had a large impact on letter-sound acquisition. Phonological awareness had a larger effect on letter-sound knowledge when letter names were known than when letter names were unknown. Furthermore, students were more likely to know the sounds of consonant–vowel letters (e.g., *b* and *d*) than vowel–consonant letters (e.g., *l* and *m*) and letters with no sound cues (e.g., *h* and *y*) when the letter name was known and phonological awareness was accounted for. Sounds were least likely to be known for letters with no sound cues, but reliable differences from other groups of letters depended on students' levels of phonological awareness and letter-name knowledge.

Keywords: kindergarten, emergent literacy, letter-name knowledge, letter-sound knowledge, phonological awareness

Across a large body of research, scientists have shown that alphabetic knowledge (letter-name and letter-sound knowledge) and phonological awareness (PA) are critical for students' reading acquisition in languages with alphabetic orthographies (Adams, 1990; Ehri, 1998; Kim, 2009; Levin, Shatil-Carmon, & Asif-Rave, 2006; McBride-Chang, 1999; Muter, Hulme, Snowling, & Stevenson, 2004; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Storch & Whitehurst, 2002). Letter names provide critical cues about letter sounds (McBride-Chang, 1999; Treiman & Kessler, 2003) that, in turn, are critical for word decoding. Children's letter-name knowledge also has a direct relationship with word reading such that letter names provide a link between letters and print and help children understand that spellings are not arbitrary strings of letters (Treiman & Kessler, 2003; Treiman & Rodriguez, 1999). Children's ability to detect and manipulate sounds (i.e., PA) is also crucial in understanding the alphabetic principle (e.g., Adams, 1990; Muter & Snowling, 1998; Stanovich, 1994; Wagner & Torgesen, 1987). Given the central role of alphabetic knowledge and PA in early literacy acquisition, it is important to have a precise understanding about the interrelationship among letter-name and letter-sound knowledge and PA. Thus, our primary goals of the present study were to examine the contributions of letter-name knowledge, PA, letter characteristics (i.e., consonant–vowel [CV] letters, vowel–consonant [VC] letters, letters with no sound cues, and vowel letters), and interactions among them to letter-sound acquisition. We addressed these questions using cross-classified multilevel models (CCMLMs) that allow for correct partitioning of variation among students (i.e., PA and letter-name knowledge) and among letter characteristics (e.g., CV, VC, no sound, and vowel letters).

Context and Background

One of the important properties of letter names is iconicity (Treiman & Kessler, 2003)—most of letter names in English include the phoneme that the letter represents. For example, the letter name /ti/ for the letter *t* contains the /t/ phoneme. Numerous studies have suggested that children utilize the iconic characteristics of letter names in letter-sound acquisition. A significant positive relationship has been observed between children's letter-name knowledge and letter-sound knowledge, with correlation coefficients ranging from .57 (Burgess & Lonigan, 1998) to as high as .86 for preschoolers and kindergartners (Evans, Bell,

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Shaw, Moretti, & Page, 2006). In addition, some evidence suggests that the relationship may be causal. Kindergartners' and first graders' letter-name knowledge predicted their later letter-sound knowledge, whereas the reverse (letter-sound knowledge predicting letter-name knowledge) was not found. Children also learned associated sounds more readily when they knew letter names than when they did not (Ehri, 1983; Treiman, Tincoff, Rodgriguez, Mouzaki, & Francis, 1998). In an experimental study with Israeli kindergartners (Share, 2004), experimental group children were taught letter names and letter sounds for letterlike symbols (names for some letters contained letter sounds, whereas others did not), whereas control group children were taught phonologically unrelated but meaningful real-word labels. Results showed that children in the experimental group knew more letter sounds than those in the control group and also performed better on the letter names that contained relevant letter-sound information than those that did not.

Although iconic in nature, letters vary in the amount of information their names provide for letter sounds, and this variation appears to be related to children's letter-sound acquisition (Foy & Mann, 2006; Treiman, Pennington, Shriberg, & Boada, 2008). Children, both typically developing and those with speech-sound disorders, performed better on the letter-sound task with letters that have their sounds at the beginnings of their names (i.e., those with CV name structures such as *v*) than letters that have their sounds at the ends of their letter names (i.e., those with VC name structures such as *m*) or those that do not contain sounds in names (e.g., *h*; Justice, Pence, Bowles, & Wiggins, 2006; McBride-Chang, 1999; Treiman & Kessler, 2003; Treiman et al., 1998, 2008). Furthermore, the results of Foy and Mann's (2006) study suggested that PA may be differentially related to letter-sound knowledge as a function of letter-name characteristics. Specifically, the strength of the relationship between phoneme awareness and letter-sound knowledge was stronger for letters with inconsistent phonological patterning (i.e., vowels and *j*, *k*, *q*, *y*, *h*, *r*, and *w*) than letters whose names had consistent phonological patterning (i.e., letters with onset +/i/ name structure [*b*, *c*, *d*, *g*, *p*, *t*, *v*, and *z*] and with /ɛ/+coda structure [*f*, *l*, *m*, *n*, *s*, and *x*]).

A critical question with regard to letter-sound acquisition as a function of letter-name knowledge involves individual differences in the extent to which children accrue letter-sound knowledge from letter-name knowledge (Treiman & Kessler, 2003). It has been hypothesized that PA may play a critical role in taking advantage of the connection between a letter's name and its sound (e.g., de Jong, 2007; Foulin, 2005; Share, 2004; Treiman et al., 1998). Children with sophisticated PA may readily recognize phonological cues in letter names and be able to abstract the relationship between letter names and sounds. As PA is considered a necessary skill for learning to read and spell words (e.g., Ehri et al., 2001), it is hypothesized that children should have some level of PA to derive the letter sound /t/ from the letter name /ti/, for example. Interestingly, empirical studies have found mixed results about the role of PA in the induction of letter sounds from letter names. On the one hand, evidence supports the fact that PA facilitates extraction of letter sounds from letter names (de Jong, 2007; Foy & Mann, 2006; Share, 2004). Moderate correlations have been found between letter-sound knowledge and PA (e.g., *r*s ranging from .25 to .49 in Burgess & Lonigan, 1998). In addition, in an experimental study conducted by Share (2004), children's pretest phonemic awareness was positively related to their letter-sound knowledge at posttest ($r = .36$) only for children who were taught letter names and phonologically related letter sounds, but not for children who were taught letter names and phonologically unrelated letter sounds.

Evidence also suggests that PA may not be necessary for letter-sound acquisition. Evans and her colleagues' (2006) study with 149 kindergartners showed that children's PA was related to their letter-sound knowledge, but the positive relationship disappeared once letter-name knowledge was taken into consideration. Furthermore, Treiman and her colleagues (2008) found that for children with speech-sound disorders, PA may not be required in the acquisition of letter sounds because even children with very low levels of PA utilize letter-name properties (i.e., letters that have CV and VC names and letters that do not contain letter-sound information) in letter-sound acquisition rather than rote memorize letter sounds. Given these inconsistent results, the role of PA in the acquisition of letter-sound knowledge requires further elucidation. In the present study, we investigated whether and, if so, to what extent PA plays a role in the learning of letter sounds as a function of letter-name knowledge.

In the present study, we addressed variation in two levels simultaneously—variation among students (i.e., letter-name and letter-sound knowledge and PA) and among letters (i.e., letter characteristics such as those with CV letter names and VC letter names). Previously, researchers addressed these variations in two levels separately. For example, one model was examined with PA as a predictor and the other model with letter characteristics as a predictor. However, this approach of separating the levels is limited because it may incorrectly estimate in each level variance components, standard errors, and, consequently, *p* values. In the present study, we used a multilevel cross-classified model to accommodate the cross-classified structures of the data (see Data Analyses for further details).

Present Study

In summary, we investigated differences in predicted probabilities of knowing letter sounds as a function of children's letter-name knowledge, PA, and letter-name characteristics, and interactions between them. Letters were classified into four categories: letters with a CV name pattern (CV letters), letters with a VC name pattern (VC letters), letters with no sound information (no-sound letters), and vowel letters. CV letters included *b*, *c*, *d*, *g*, *j*, *k*, *p*, *t*, *v*, and *z*; VC letters included *f*, *l*, *m*, *n*, *r*, and *s*; no-sound letters included *q*, *h*, *x*, *y*, and, *w*; and vowel letters included *a*, *e*, *i*, *o*, and *u*. Vowels (*a*, *e*, *i*, *o*, and *u*) were examined as a separate category, following Evans et al.'s (2006) recommendation. Vowels have one-to-many mappings between letter names and letter sounds because vowel letter names provide sounds clues for only one of the multiple sounds (long vowel sounds) vowel letters represent. Furthermore, analyses were conducted with *c*, *g*, *q*, and *x* removed from these classifications because they do not "neatly fit into" these categories (Treiman et al., 2008, p. 1328; e.g., *q* and *x* represent two phonemes instead of one; see Appendices A and B for results). The following research questions guided the present study.

> ***Research question 1:*** Are children more likely to know letter sounds as a function of letter-name knowledge and PA?

Research question 2: Does children's letter-sound knowledge differ as a function of letter-name characteristics, i.e., CV letter names, VC letter names, letters with no sound information, and vowel letters? Does the effect of PA on letter-sound acquisition vary as a function of these letter characteristics?

Method

Participants and Sites

Participants in this study were 653 kindergarteners (52% boys) from three school districts involved with field testing items for the Florida Assessments for Instruction in Reading (Florida Department of Education, 2009). The sample included 45% White, 26.3% Black, and 16.1% Latino students; the rest were identified as *other* or had no information. These students were drawn from nine elementary schools in urban, semiurban, and rural counties in Florida. Approximately 40% of the students had a free or reduced-price lunch status, 7.5% of students were English language learners, and 5.7% had a learning disability status.

Measures and Procedure

PA. Testers administered onset-rime and phoneme blending items to the children individually in the beginning of the school year (mid-September to early October 2007). Each item was dichotomously scored with a total maximum score of 40. Cronbach's alpha was estimated to be .87.

Letter-name and letter-sound knowledge. Testers administered the letter-names and letter-sounds task in the same session in which they administered the PA task in one of three randomized orders of the 26 letters. Testers asked the child for the name of the letter and then the sound. Both uppercase and lowercase letters were presented simultaneously. For consonant letters that represent multiple sound values, any appropriate response was scored correct (e.g., /k/ or /s/ for letter *c*). For vowel letters, only short phonemes were counted as correct (e.g., æ for letter *A* or *a*). If the child repeated the name (i.e., long vowel), then the tester thanked the child and asked for another sound. This is a common procedure for early reading assessments such as the Texas Primary Reading Inventory (Foorman, Fletcher, & Francis, 2004) and the Phonological Awareness Literacy Screening (Invernizzi, Meier, Swank, & Juel, 1999). For each of the tasks, the maximum score was 26. Cronbach's alpha was estimated to be .97 for letter names and .96 for letter sounds.

Data Analyses

We used a CCMLM to address the research questions because in this study we essentially examined variation among students (i.e., letter-name and letter-sound knowledge and PA) and among letters (i.e., letter features) simultaneously. This approach has recently been used in modeling the development of literacy skills pertaining to alphabetic knowledge (Piasta & Wagner, 2010).

Typically, published articles using multilevel models (MLMs) report a natural contextual relationship in nested structures, such as a two-level MLM where students may be nested within classrooms. Further nesting could be modeled of the classes within schools, thereby representing a traditional three-level model. Although such models allow for the partitioning of variance to the various levels of interest, they may be insufficient to describe more specific information that occurs in other contexts. For example, whereas students may be nested within a school, they may attend multiple classes, each instructed by a different teacher within that school. Thus, students are simultaneously nested within a given level as variance at the classroom level could be partitioned among the different classes the student attends. Such instances are referred to as cross-classification, and when not considered in the MLM context, the variance estimates between levels may be biased (Raudenbush & Bryk, 2002). An additional feature of a CCMLM is that a CCMLM allows one to model data with participants treated as raters of similar items. In the current study, all participants were exposed to all items (e.g., letter sounds); thus the scores are crossed by children and letters but not nested (if nested, only some letters would have been exposed to the children). The cross-classified approach then correctly and reliably partitions the variance in letter-sound knowledge to differences across letters and differences across students. Moreover, given the nature of the cross-classified data structure, interactions between characteristics of letters (e.g., letter features) and individuals (e.g., phonological blending) may be fit. An equally important feature of the cross-classified model is the ability to correctly estimate the standard errors of the estimated coefficients, and ignoring such clustering can lead to an increase in Type I errors. Recent research in comparing basic MLMs with ones that incorporated cross-classification using reading data demonstrated that the standard errors of coefficients were deflated by nearly 40% in the basic MLM (Gilbert, Petscher, Compton, & Schatschneider, 2009). These findings corroborate other studies using outcomes in other domains (e.g., Meyers & Beretvas, 2006; Raudenbush & Bryk, 2002).

The structure of the CCMLM is such that the Level 1 component included the dependent variable, which was the students' ability to correctly say the letter sound (0 = incorrect, 1 = correct). Cross-classification occurred at Level 2, and was between students and letters (i.e., CV letters, VC letters, no-sound letters, and vowels). Because the dependent variable was dichotomously scored, the model was fit using a Bernoulli distribution. The grand mean coefficient produced by the CCMLM in the logistic model becomes a log-odds value, which may be converted to an odds ratio or predicted probability to facilitate interpretation. In addition to estimating the grand mean, it was important to describe the amount of variance in letter-sound knowledge that was due to differences among participants and differences between letters.

In the present study, all CCMLM analyses were conducted using PROC GLIMMIX in SAS 9.2. Two separate CCMLMs were generated for different classifications of letters (those including and excluding *c*, *g*, *q*, and *x*). Within each of the general CCMLMs, a taxonomy of models was constructed, where four cumulative models were analyzed in a sequential manner. Specific information about each model specification is found in Appendix B, and interpretation is found in the Results section. Initially, an unconditional or within-cell model (Model 1) was fitted to describe the overall mean log-odds of knowing a letter sound (see Results for interpretation). If the model showed that significant variability existed among students and among letters, a second model was fitted that included a Level 1 dummy code representing letter-name knowledge. The grand mean estimate from this model (θ_0; see Model 2 in Table 2) would indicate the log-odds of knowing a letter sound conditional on not knowing the letter name. The marginal mean for letter names (i.e., θ_1) represented the log-odds of knowing the letter sound conditional on correctly saying the letter name. From this model, the reduction of variance explained could be calculated by using the Model 1 and Model 2 variance components for students and letters, taking the respective difference, and dividing by the Model 1 variance component. This resulting value represents the amount of reduction in variance after we controlled for letter-name knowledge. In addition to the reduction value, the between-students and between-letters variance was reestimated to indicate the amount unexplained that remained after we controlled for letter-name knowledge.

Model 3 included both student-level predictors (i.e., PA and letter-name knowledge). In this case scores on the PA task were set to interact with letter-name knowledge. Lastly, Model 4 incorporated the letter-level predictors, which were dummy codes that identified letters as CV letters, VC letters, no-sound letters, or vowels. Model 4 used vowels as the referent; thus, the statistical significance testing (i.e., *p* values) for the remaining three dummy codes indicated if the marginal mean for each feature was significantly different from vowels (i.e., CV vs. vowel letters, VC vs. vowel letters, and no sound vs. vowel letters). As we were also interested in comparing the marginal means among the four letter groups, and not just compared to vowels, post hoc contrasts among the letter features were generated (i.e., to compare whether predicted probabilities were different for CV vs. VC letters, CV vs. no-sound letters, etc.).

Results

Preliminary Analysis

Descriptive statistics and correlations for the measures are reported in Table 1. On average, students correctly named 19 letters ($SD = 8.60$), were able to correctly say 13 letter sounds ($SD = 9.12$), and their average PA total score was 11.77 ($SD = 12.32$). The large standard deviation for the PA task was a possible indication that floor effects existed in the distribution of scores. Although floor effects may sometimes be quantified by skew and kurtosis statistics, it is often easier to examine the percentage of students that are at the floor (Catts, Petscher, Schatschneider, Bridges, & Mendoza, 2009). Because a range of scores may be overestimated by outliers, the PA scores were converted to *z* scores, with values between –3 and 3 retained. This accounted for 99.5% of the sample scores. Within a normal distribution, 7% of the scores would be expected to fall within the lowest quarter of the –3 to 3 range (i.e., –1.5 *SD* below). In the current sample, 59.6% of the sample ($n = 174$) fell below the lowest quarter, representing a strong floor effect. Of these participants, 77 (approximately 12%) had a total score of zero. Despite the strong floor effect, the level of skew was relatively low (0.74), suggesting that a data transformation would not correct the preponderance of zero scores.[1] Such instances of floor effects for early literacy measures have been observed previously (e.g., Catts et al., 2009; Missall et al., 2007). Based on the presence of floor effects, it was expected that heteroscedasticity would exist in the lower end of the distribution of PA when predicting total score performance on the letter-sound task. Examination of the scatterplot in Figure 1 demonstrated that at the bottom of the distribution of PA scores, more variability existed in letter-sound total scores than at the top part of the PA distribution. That is, there was a heteroscedastic relationship between PA and letter-sound knowledge for children whose PA scores were low. This suggested that when predicting individual letter sounds, incremental increases in PA total scores at the lower end of the distribution could translate into larger gains in predicted probabilities compared to incremental increase at the upper end of the distribution.

The strengths of association among the measures were generally moderate in nature. Although the correlation between letter names and sounds was strong ($r = .78$), the PA was less strongly but moderately related to the letter-name task ($r = .36$) and the letter-sound task ($r = .49$). Although PA was positively related to all of the four letter categories in moderate degree, it tended to be somewhat more strongly related to letter-sound knowledge than to letter-name knowledge for each letter category.

Research Question 1: What Are the Probabilities of Knowing Letter Sounds as a Function of Letter-Name Knowledge and PA?

Fixed effects and variance components of the models are presented in Tables 2 and 3, respectively. Variance components from the unconditional model (i.e., Model 1; see Table 3) showed that significant variability occurred between students, as well as between letters. The largest variance component was for students (6.25), and resulted in an intraclass correlation of .88, indicating that 88% of the variability in letter-sound knowledge was attributed to between students. The remaining variance of 0.87 for letters translated to an intraclass correlation of .12. The mean log-odds from Model 1 was –0.20 (see Table 2). This indicated, when converted to a predicted probability, that on average, students had a .45 probability of correctly knowing the sound of a given letter. This estimate, however, has a relatively large standard error, resulting in a nonsignificant term. Despite the large standard error, the random effects suggested that the significant variability in the log-odds warranted further modeling.

The grand mean log-odds for Model 2 was –3.13 but is interpreted differently from the Model 1 grand mean. With the inclusion of the letter-name knowledge predictor, the intercept now represented the log-odds of knowing a letter sound if the student did not know the letter name. Thus, the log-odds of –3.13 with an associated probability of .04 suggested that students who did not know the name of the letter only had a 4% chance of knowing the sound and this was significantly different from zero ($p < .000$). This value is in stark contrast to the fitted mean log-odds of 0.53 (i.e., $\theta_0 + \theta_1 = -3.13 + 3.66 = 0.53$), which as a probability indicated that students who correctly knew the name of the letter

[1] It should be noted that when a floor effect is largely due to the high presence of zeros, transformations are not useful and are rarely conducted (see, e.g., Missall et al., 2007). Furthermore, it should be noted that results from various transformations (i.e., log and square-root transformations) yielded a highly similar pattern of results when letter name was known. When letter name was unknown, the predicted probabilities for the CV and VC letters were estimated to be higher than when PA was average and above average.

Table 1
Descriptive Statistics and Correlations for Model Predictors

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Letter names (total)	—										
2. Letter sounds (total)	.78	—									
3. Phonological awareness	.36	.49	—								
Consonant–vowel letters											
4. Names	.97	.75	.34	—							
5. Sounds	.81	.95	.46	.80	—						
Vowel–consonant letters											
6. Names	.95	.76	.36	.88	.78	—					
7. Sounds	.69	.93	.47	.65	.83	.70	—				
No sound letters											
8. Names	.92	.73	.35	.85	.74	.85	.64	—			
9. Sounds	.62	.89	.46	.59	.77	.61	.82	.61	—		
Vowel letters											
10. Names	.94	.72	.32	.89	.74	.89	.62	.83	.56	—	
11. Sounds	.64	.88	.43	.61	.77	.61	.79	.61	.77	.61	—
N	26	26	40	10	10	6	6	5	5	5	5
M	18.97	12.63	11.77	7.25	5.67	4.20	2.65	3.67	1.83	3.84	2.21
SD	8.60	9.12	12.32	3.49	3.81	2.24	2.42	1.68	1.84	1.62	1.85
α	.97	.96	.87	.93	.92	.90	.90	.83	.82	.84	.82

Note. α = internal consistency of scores.

had a 63% chance of correctly knowing the sound ($p < .000$). Inclusion of letter-name knowledge in the model (Model 2) reduced the amount of variance between students by 38% (i.e., 6.25 in Model 1 to 3.86 in Model 2). Thus, whereas 88% of the variance in letter-sound scores was attributed to student differences, 38% of that 88% was explained by letter-name knowledge. It was of supplementary interest to also account for the amount of variance explained in letters. However, by covarying letter-name knowledge the amount of variance in letter-sound knowledge increased from 0.87 to 1.05. This observation is not a unique occurrence and may happen frequently in MLMs when variance estimates in the unconditional model start out small (Roberts & Monaco, 2006). In the current study, the increase in variance at the letter level was not surprising because letter-name knowledge was largely a student covariate, and the associated decrease in variance was expected to be for student variance components.

Model 3, which added PA to the model, demonstrated the grand mean log-odds (−3.66) and the corresponding probability of −.03, similar to that in Model 2. However, the relationship between PA and letter-sound knowledge conditional on not knowing the name indicates that as students increased their PA score by 1, an associated difference in the letter-sound knowledge log-odds was 0.04. Though this difference was statistically significant (primarily due to a large sample size), a referent student in this example (i.e., did not know the letter name) who increased his total PA score by 1 point would not fundamentally change his probability of knowing the letter sound. In fact, a referent student who increased his PA score from 1 to 40 would still only increase his probability to a value of .11 from .03, indicating that letter-name knowledge was a much stronger predictor of letter-sound knowledge than was PA. Similarly, when considering the condition where students did know the letter name (i.e., the main effect of letter-name knowledge), the fitted mean log-odds for a student who was average on PA was –0.46 (–3.66 + 3.20 in Model 3) with a resulting probability of letter-sound knowledge of .39. The interaction between letter-name knowledge and PA was positive and statistically significant such that increases in PA also increased the log-odds for students who knew letter names ($\gamma_{11} = .05$, $p = .004$). When the student knew the name of the letter and also increased his PA from 1 to 40, there was a substantial increase in the probability of letter-sound knowledge from .40 to .82. These results from Model 3 suggest that PA is more strongly beneficial to those students who have letter-name knowledge than to those that do not. Random effects from Model 3 (see Table 3) were statistically significant and indicated that variability in students' letter-sound knowledge still existed after we controlled for both letter-name knowledge and PA. Additional between-students variance accounted for by PA and letter-name knowledge was 0.22 from Model 2, bringing the total amount of variance reduced by both letter-name knowledge and PA from Model 1 to 52%.

Research Question 2: Do the Probabilities of Knowing Letter Sounds Differ as a Function of Letter Characteristics?

The final model, Model 4, in Table 2 included letter features as predictors of letter-sound acquisition. Figure 2 represents results of Model 4 depicting predicted probabilities of the four letter categories as a function of PA and letter-name knowledge. As mentioned previously, Model 4 set the referent letter feature group as vowels; thus, the context for the full referent in the grand mean is the log-odds of knowing a vowel letter sound when the letter name is unknown, and the student is average with regard to PA scores. In other words, results in Model 4 provide statistical contrasts of vowel letter sounds to other letter categories (i.e., CV letters, VC letters, and no-sound letters). We conducted further statistical contrasts to test whether predicted probabilities are statistically different for other letter categories (e.g., CV letters vs. VC letters, CV letters vs. no-sound letters, etc.; shown in Table 4). We further conducted post hoc general linear hypothesis tests to examine

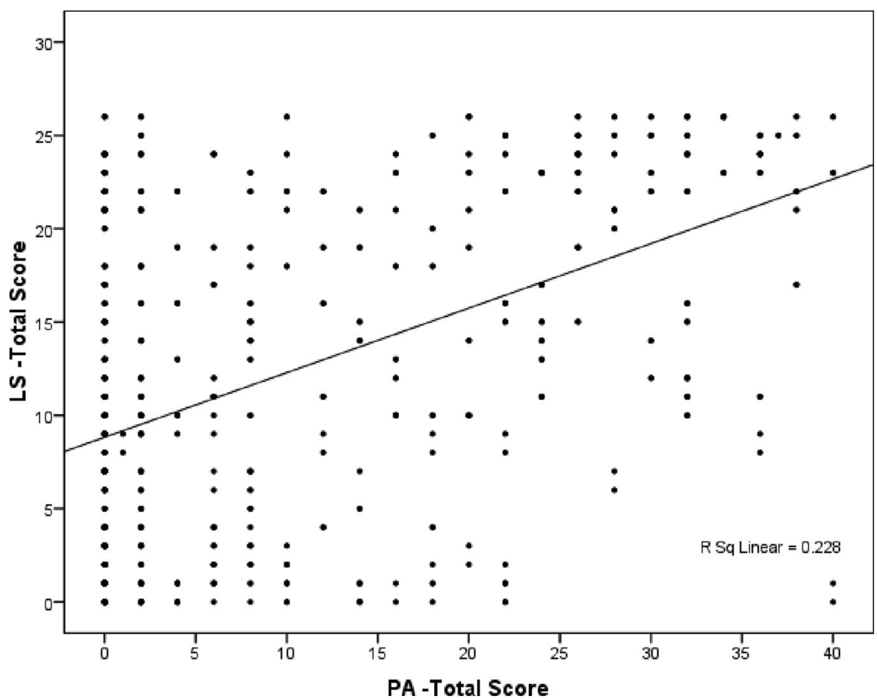

Figure 1. Scatterplot of phonological awareness (PA) total score with letter sounds (LS) total score.

whether the statistical significance of predicted probabilities of different letter groups may differ when students' PA was minimal (i.e., PA score = 1) and sophisticated (i.e., PA score = 40)[2] (see Table 4). Thus, we draw from both Model 4 of Table 2 and contrast tests results in Table 4 in the following presentation of results.

The grand mean value was –2.73, with an associated probability of .06 (see Table 2). When letter name was not known and PA was average (see Model 4 in Table 2), the probability of knowing a vowel sound (.05) was not significantly different from the predicted probability of knowing a CV letter sound (predicted probability = .03, p = .137) but was significantly greater than VC sounds (predicted probability = .01, p = .029) and letters with no sounds (predicted probability = .01, p = .049). Fixed effect contrasts (see the top panel of Table 4) indicated that whereas no differences were observed for CV–VC (p = .306) and VC–no sound (p = .261) comparisons, the probability of knowing a CV sound was significantly greater than that of the letters with no sounds (F = 2.07, p = .039). The interactions among letter characteristics and performance on the PA task (Model 4 in Table 2) revealed that PA had a stronger relationship for CV letters (p = .034) and VC letters (p = .031) than for vowel letters, but the relationship was not different for letters with no sounds (p = .886).

When letter name was not known and PA was minimal (i.e., PA = 1; see the top panel of Table 4), vowel letters had greater probabilities than VC letters (p = .035) and letters with no sounds (p = .046). When letter name was not known and PA was highly developed (i.e., PA = 40), there was no statistically significant differences in the predicted probabilities, but a trend that CV letters had greater probabilities than letters with no sounds (p = .056).

A much different relationship was observed for students who correctly knew the name of the letter. The mean log-odds for these students was 3.04 units greater than those who did not know the name (Model 4 in Table 2), with an associated predicted probability of .58, indicating that students who knew the name of a vowel letter and were average on PA had a 58% chance of knowing the vowel sound, when we controlled for the other variables in the model. As in Model 3, the interaction between letter-name knowledge and PA was statistically significant such that PA had a greater effect on letter-sound knowledge when letter names were known. When comparing the sound knowledge of CV letters, VC letters, and letters with no sounds to vowel letters when the letter name was known and PA was average, we found that CV letters showed a predicted probability of .91, VC letters had predicted probability of .73, and no-sound letters demonstrated a predicted probability of .54. Although both CV and VC sound knowledge were significantly different from vowel sounds ($p < .001$ and p = .031, respectively), letters with no sounds were not (p = .399). The fixed effect contrasts (see the bottom panel of Table 4) indicated that a significant difference was observed between the predicted probabilities for CV–no sound ($p < .001$), whereas the contrasts for CV–VC and VC–no sound approached significance (p = .050 and p = .054, respectively). Additionally, no interaction existed between letter features and PA when the

[2] In a nonlinear relationship (as shown in Figure 1) the slope estimates of predicted probabilities in the outcome (i.e., knowing the sound of the letter) differ for every value of the predictor (e.g., phonological awareness). Therefore, the results from Model 4 of Table 2 do not tell us about the predicted probabilities in the letter-sound knowledge of the four letter groups when PA values are other than the average.

Table 2
Fixed Effect Results From Cross-Classified Models

Model and components	Coefficient	*SE*	*t*	*df*	*p*	OR	Predicted probability
Model 1							
LSK, θ_0	−0.20	0.24	−0.85	16978	.405	0.82	.45
Model 2							
LSK, θ_0	−3.13	0.28	−11.36	16977	.000	0.04	.04
LNK, θ_1	3.66	0.16	22.34	16977	.000	38.86	.63
Model 3							
LSK, θ_0	−3.66	0.31	−11.89	16975	.000	0.03	.03
PA, γ_{01}	0.04	0.02	2.14	16975	.032	1.04	.04
LNK, θ_1	3.20	0.20	15.70	16975	.000	24.53	.39
LNK × PA, γ_{11}	0.05	0.02	2.96	16975	.004	1.05	.65
Model 4							
LSK, θ_0	−2.73	0.49	−5.58	16971	.000	0.07	.05
CV, β_{01}	−0.87	0.58	−1.49	16971	.137	0.42	.03
VC, β_{02}	−1.53	0.70	−2.18	16971	.029	0.22	.01
NS, β_{03}	−1.50	0.76	−1.97	16971	.049	0.22	.01
PA, γ_{01}	−0.02	0.03	−0.60	16971	.547	0.98	.05
CV × PA, θ_2	0.07	0.03	2.12	16969	.034	1.07	.05
VC × PA, θ_3	0.08	0.04	2.16	16969	.031	1.08	.03
NS × PA, θ_4	0.01	0.05	0.14	16969	.886	1.01	.01
LNK, θ_1	3.04	0.34	8.94	16971	.000	20.90	.58
LNK × CV, β_{11}	1.70	0.42	4.02	16971	.000	5.47	.76
LNK × VC, β_{12}	1.16	0.54	2.16	16971	.031	3.19	.49
LNK × NS, β_{13}	0.51	0.60	0.84	16971	.399	1.67	.34
LNK × PA, γ_{11}	0.09	0.03	2.89	16971	.004	1.09	.76
LNK × CV × PA, θ_5	−0.04	0.03	−1.26	16967	.208	0.96	.91
LNK × VC × PA, θ_6	−0.06	0.04	−1.61	16967	.107	0.94	.73
LNK × NS × PA, θ_7	0.002	0.05	0.03	16967	.974	1.00	.54

Note. In Model 4, the referent letter group is vowels. For predicted probability estimates, please see text for correct interpretations. OR = odds ratio; LSK = letter-sound knowledge (intercept); LNK = letter-name knowledge; PA = phonological awareness; CV = consonant–vowel letters; VC = vowel–consonant letters; NS = letters with no sound information.

letter name was known ($p > 0.05$; Model 4 in Table 2), indicating that the probability of knowing sounds of varying letter characteristics, regardless of knowing letter names, was not differentially affected by PA.

When students' PA was minimal and letter name was known (see the bottom panel of Table 4), students had a higher probability of knowing CV letters than VC letters ($p < .005$) and letters with no sounds ($p < .001$). There was also a nonsignificant trend that predicted probabilities were greater for vowels than no-sound letters ($p = .061$). When letter-name was known and students' PA was highly developed, CV letters had greater probabilities than VC letters ($p = .002$), vowel letters ($p < .001$), and no-sound letters ($p < .001$). A nonsignficant trend was observed between no-sound letters and VC letters ($p = .07$).

Table 3
Random Effect Results From Cross-Classified Models

Model and cross-classification	Variance component	*SE*	Wald 95% confidence interval: Lower limit	Wald 95% confidence interval: Upper limit
Model 1				
student	6.25	0.62	5.19	7.67
Letter	0.87	0.26	0.52	1.70
Model 2				
student	3.86	0.41	3.17	4.80
Letter	1.05	0.31	0.64	2.07
Model 3				
student	3.01	0.32	2.47	3.76
Letter	1.06	0.31	0.64	2.09
Model 4				
student	3.11	0.33	2.55	3.89
Letter	0.62	0.20	0.36	1.31

By covarying the letter features in Model 4, we estimated the proportion of reduction in variance for the difference in Models 1 and 4. When considering the student variance, we found that the inclusion of letter characteristics increased the variance from 3.01 (Model 3) to 3.11 in Model 4. However, the overall reduction in variance between Models 1 and 4 was 50%, indicating that half of the variance between students was explained by the model. Similarly, whereas the variance in letters increased from Model 1 (0.87) to Model 3 (1.06) due to covarying student features, the overall decrease in variance between Models 1 and 4 was 0.29. Thus, nearly 30% of the variance in scores across the letters was accounted for by letter characteristics.

As previously discussed, due to a floor effect in the PA task, it was expected that the amount of variability in letter-sound knowledge conditional on PA performance might differentially contribute to the probability of knowing letter sounds as a function of PA performance (low vs. high). Extracting the predicted probabilities from Figure 2 into tabular format (see Table 5) revealed that when letter names were known, incremental increases in PA when the total score was low resulted in larger gains in the probability of letter-sound knowledge than when the total score was high. For

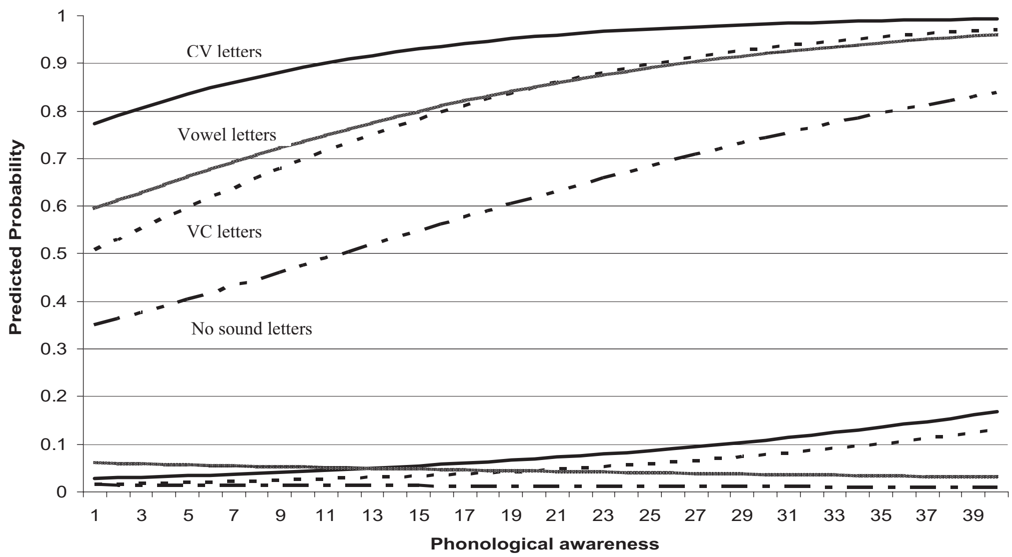

Figure 2. Predicted probability of letter-sound knowledge as a function of letter-name knowledge, phonological awareness, and letter characteristics. The top four lines represent predicted probabilities when letter name was known, and the bottom four lines represent predicted probabilities when letter name was not known. CV = consonant–vowel; VC = vowel–consonant.

example, the probability of knowing a VC sound increased by .19 when PA total scores increased from 1 to 10. In contrast, a 10-point increase in total score from 30 to 40 only changed the probability from .93 to .97. Such findings were consistent across all levels of letter features when the letter name was known.

Discussion

Alphabet knowledge and PA are the essential building blocks of early literacy acquisition in languages that have alphabetic writing systems. In the present study, we investigated the interplay between these important skills with two primary questions: (a) the contribution of PA in exploiting letter-name information to accrue letter-sound information and (b) the probabilities of knowing letter sounds as a function of letter characteristics.

The results from the present study confirm that letter names in English do not just provide verbal labels to refer to letters, but provide crucial clues about the sound(s) each letter contains (Treiman & Kessler, 2003). These results indicate that students take advantage of letter names in inducing letter-sound information (Adams, 1990; Evans et al., 2006; Foulin, 2005), and letter-name knowledge has a large impact on letter-sound knowledge. The probability of knowing letter sounds, on average, increased drastically from 4% when students did not know letter names to 63% when student knew letter names. Although previous studies have shown strong correlations between letter-name knowledge and letter-sound knowledge, the present study adds to researchers' understanding of the impact of letter-name knowledge on letter-sound knowledge with predicted probability estimates.

PA also made a significant contribution to letter-sound knowledge, supporting the previous hypothesis that PA does facilitate the abstraction of letter sounds from letter names (Foy & Mann, 2006; Jorm & Share, 1983; Share, 2004; Treiman et al., 1998; Wagner & Torgesen, 1987). The results of this study extend previous studies in two important ways. First, the impact of PA on letter-sound acquisition was much larger when letter names were known than when they were unknown. When letter names were known, the likelihood of knowing letter sounds increased from 40% to 82% when the student's PA increased from minimal to highly developed. When letter names were unknown, predicted probability of letter-sound knowledge increased from a 3% chance to an 11% chance when the student's PA increased from minimal to highly developed. This finding provides unambiguous support for the hypothesis that PA helps accrue letter sounds from phonetic cues in letter names. Second, the interaction between letter features (i.e., CV, VC, no sound, or vowels) and PA differed as a function of whether letter name was known or unknown. When letter name was known, interactions were not significant, suggesting that the facilitative role of PA for letter-sound acquisition from letter names did not differ as a function of letter-name features. When letter name was not known, PA had a larger effect on CV and VC letters than vowel letters. These findings are discrepant from what Foy and Mann's (2006) study suggested, that is, that PA (and phoneme awareness in particular) was more strongly related to letters that had nonsystematic phonological patterning (i.e., vowels and *q*, *y*, *h*, *r*, *w*, *j*, and *k*). However, the results cannot be directly compared because of differences in the study design (e.g., different classification of letters, analytical approach, and predictors included in the model).

Despite the contribution of PA to letter-sound acquisition, less clear from the present findings is whether PA is required for letter-sound abstraction from letter names. Although, on average, the probability of knowing letter sounds increases with higher PA, given the correlational nature of the study, it is not possible to draw any causal conclusion. The findings of the present study in con-

Table 4
Predictor Contrasts for Mean Log-Odds When Letter Name Was Known Versus Unknown and Phonological Awareness Was Minimal (i.e., 1), Average (i.e., 11.77), or Sophisticated (i.e., 40)

Condition and contrast	Mean log−odds difference	*SE*	*F*	*p*
When letter name was unknown				
PA = 1				
CV-V	−0.80	0.57	1.96	.163
VC-V	−1.45	0.69	4.45	.035
NS-V	−1.49	0.75	4.00	.046
CV-VC	0.65	0.61	1.14	.286
CV-NS	0.69	0.67	1.06	.305
VC-NS	0.04	0.77	0.00	.954
PA = 11.77				
CV-VC	0.55	0.54	1.02	.306
CV-NS	1.36	0.66	2.07	.039
VC-NS	0.81	0.72	1.12	.261
PA = 40				
CV-V	1.91	1.21	2.46	.116
VC-V	1.61	1.30	1.54	.215
NS-V	−1.21	1.81	0.45	.503
CV-VC	0.29	1.02	0.08	.775
CV-NS	3.12	1.63	3.65	.056
VC-NS	2.83	1.71	2.76	.098
When letter name was known				
PA = 1				
CV-V	0.85	0.45	3.53	.600
VC-V	−0.35	0.50	0.48	.488
NS-V	−0.98	0.52	3.53	.061
CV-VC	1.20	0.43	7.84	.005
CV-NS	1.83	0.46	16.24	<.001
VC-NS	0.63	0.50	1.59	.206
PA = 11.77				
CV-VC	1.08	0.55	1.96	.050
CV-NS	2.55	0.71	3.61	.000
VC-NS	1.46	0.76	1.92	.054
PA = 40				
CV-V	1.88	0.53	12.89	<.001
VC-V	0.35	0.56	0.40	.527
NS-V	−0.64	0.57	1.23	.265
CV-VC	1.53	0.50	9.30	.002
CV-NS	2.52	0.52	23.33	<.001
VC-NS	0.99	0.55	3.20	.073

Note. When PA = 11.77, any contrasts that involve vowel letters are not included in Table 4 because those are found in Model 4 of Table 2. PA = phonological awareness; CV = consonant–vowel letters; VC = vowel–consonant letters; NS = letters with no sound information.

junction with previous studies appear to suggest that PA may play a facilitative role in letter-sound abstraction from letter names for many students, but may not be required for all children (Bowey, 2005; Treiman et al., 2008). Preliminary evidence from a recent experimental study (Share, 2004) showed that the correlation between letter-sound knowledge and phonemic awareness for children who received training in letter names and their phonologically related letter sounds was only moderate (*r*s = .36 for bivariate and .47 when partialing out vocabulary). These results suggest that there are many children who may not use PA to extract letter sounds from letter names, thus supporting the speculation that PA may not be necessary to learn letter sounds for some children. However, further work is necessary to confirm and establish causal inferences regarding this speculation. First, it will be important for a future experimental study to replicate the results with a larger sample, given the fairly small sample in Share's (2004) study (*n* = 24 in the experimental condition). Second, it will also be illuminating for a future study to include multiple measures of PA to prevent a potential floor effect that is frequently found in phonemic awareness tasks and to understand better awareness of various phonological units (i.e., syllable, rime, and phoneme) that facilitates abstraction of letter sounds from letter names. Third, a further study should investigate what skills, other than PA, promote children's learning of letter sounds from letter names (e.g., phonological memory; see Share, 2004).

Consistent with previous studies, the present study shows that letter features play an important role in letter-sound acquisition (McBride-Chang, 1999; Treiman & Kessler, 2003). CV letters, which provide letter-sound cues in the initial position of the names, consistently were more readily acquired than were other letters in English (i.e., VC letters, vowels,[3] and letters with no sound information) when students knew letter names across the levels of PA (minimal, sample average, or highly developed). In contrast, the sounds of letters that did not contain letter-sound cues were most difficult to acquire regardless of whether letter names were known or not, on average. However, unlike previous studies, the present study shows that whether predicted probabilities of letters with no sound cues were reliably different from other letter categories depended on levels of PA and letter-name knowledge. For example, students were less likely to know letter-sound values for no-sound letters than CV letters across PA levels, whereas predicted probabilities were not different from those of vowel letters when PA was average or high. These results are mostly in line with previous studies that showed that North American children generally perform better on letters that have CV phonological patterning, followed by VC patterning, and those without letter-sound cues (e.g., Foy & Mann, 2006; Treiman & Kessler, 2003). Furthermore, predicted probabilities of knowing letter sounds did not differ between VC letters and vowel letters regardless of knowing letter names or the level of students' PA, suggesting that the probabilities of abstracting letter sounds from letter names are not different for vowel letters and VC letters once letter-name knowledge and PA are taken into account (Evans et al., 2006; McBride-Chang, 1999; Treiman & Kessler, 2003; Treiman et al., 2008).

Finally, it should be noted that kindergartners in the present study knew letter sounds for vowel letters significantly less than CV letters when letter name was known and PA was average or highly developed. This is in contrast to English-speaking Canadian kindergartners who performed best on vowels compared to CV or VC letters (Evans et al., 2006). This is likely due to differences in how vowels were scored in Evans et al's (2006) study and the present study. In the former, both short and long vowel phonemes were counted as correct (e.g., /e/ or /æ/ for letter *A*, *a*), whereas in the present study only short vowel phonemes were counted as correct. In the present study, long vowel phonemes were considered incorrect because long vowel phonemes are identical to letter names and as such it was not deemed a clear indication of students' knowledge of letter-sound knowledge.

[3] The differences between CV letters and vowels were statistically significant when letter name was known, and PA was average and highly developed but not when PA was minimal.

Table 5
Difference in Predicted Probabilities of Letter-Sound Knowledge Conditional on Phonological Awareness by Letter Feature

Phonological awareness total correct	Letter name known				Letter name unknown			
	CV	VC	NS	Vowel	CV	VC	NS	Vowel
1	.77	.51	.35	.59	.03	.01	.01	.06
2	.79	.53	.36	.61	.03	.02	.01	.06
3	.81	.55	.38	.63	.03	.02	.01	.06
4	.82	.57	.39	.64	.03	.02	.01	.06
5	.83	.60	.40	.66	.03	.02	.01	.06
10	.89	.70	.47	.73	.04	.02	.01	.05
15	.93	.78	.55	.80	.05	.03	.01	.05
20	.96	.85	.62	.85	.07	.04	.01	.04
25	.97	.90	.68	.89	.09	.06	.01	.04
30	.98	.93	.74	.92	.11	.08	.01	.04
35	.99	.96	.79	.94	.14	.10	.01	.03
40	.99	.97	.84	.96	.17	.13	.01	.03

Note. CV = consonant–vowel letters; VC = vowel–consonant letters; NS = letters with no sound information.

Overall, the results of the present study suggest that children do take advantage of the iconicity in the learning of letter sounds (Foulin, 2005; McBride-Chang, 1999; Share, 2004; Treiman et al., 1999), and their sensitivity to sound structures in English does enhance probability of learning letter sounds. However, the results of the present study, as with other correlational studies, do not indicate direction of relationships. Specifically, previous studies have suggested a bidirectional relationship between PA and alphabet knowledge (both letter-name and letter-sound knowledge; Carroll, Snowling, Hulme, & Stevenson, 2003; Foy & Mann, 2006). It has been suggested that letter-name knowledge causally influences the emergence of children's phoneme awareness (Foulin, 2005; Wagner et al., 1997) and PA facilitates acquisition of letter names (Burgess & Lonigan, 1998). Furthermore, PA is critical for letter-sound acquisition, which in turn appears to help students develop PA, particularly phoneme awareness (Burgess & Lonigan, 1998; Foy & Mann, 2006). Although beyond the scope of the present article, the question of reciprocal influences is worth future investigation. For instance, a well-designed experimental study would reveal whether instruction in letter names results in improvement not only in letter names but also in PA, and whether instruction in PA results in improvement in letter-name knowledge in addition to PA. The results would reveal how the two critical skills in early literacy, alphabet knowledge and PA, bootstrap each other and develop in tandem.

Furthermore, this study was limited in that the PA task in the present study suffered from a floor effect. Although a similar pattern of results was observed when a logarithmic inflection was applied to the PA task, future replication is warranted with a phonological task without floor effects. Finally, based on previous studies (Evans et al., 2006; Treiman et al., 2008) and the fact that a substantial amount of variance is still left unexplained for letter-sound acquisition after accounting for letter-name knowledge and PA, future studies should investigate what factors other than letter-name knowledge and PA are involved in explaining individual differences in understanding letter sounds. For example, Lonigan, Burgess, and Anthony (2000) found that children's oral language (receptive and expressive vocabulary) and exposure to environmental print were positively related to their alphabet knowledge. Furthermore, literacy acquisition experience may promote children's awareness of letter-sound relations (Ehri, 2000; Lonigan, Schatschneider, & Westberg, 2008; Treiman, 1998).

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(*Appendices follow*)

Appendix A

Results From Recoding of Consonants

In order to examine any differences in the predicted probabilities of letter-sound knowledge from the alternative consideration of consonant structures, we reclassified the letters. Specifically, in this alternative coding, letters *c* and *g* were excluded from the consonant–vowel (CV) letter category, and letters *q* and *x* were excluded from the no-sound category. Similar to the previous sets of analyses, the cross-classified multilevel model was run for Model 4, which accounted for the letter features. Results for the mean log-odds of these models are reported in Table A1 below. When comparing the grand mean values between Models 4 in Tables A1 and 2, we observed that slight differences existed in the log-odds for students who did not know letter names using the original coding (−2.73) or the revised scheme (−3.23) with corresponding predicted probabilities of .06 and .04, respectively. Similarly, nearly identical mean log-odds existed for students who knew letter names in the original (3.04) and revised (3.22) models. The overall patterns of relationships were similar between the original and alternative classifications; that is, (a) overall phonological awareness (PA) had a larger impact on letter-sound acquisition when letter name was known, and (b) CV letters had greater predicted probabilities than letters with no sound information, when PA was minimal (i.e., 1), average, and high. However, some differences were observed in the associated predicted probabilities. Not surprisingly, without letters *c* and *g*, CV letters had slightly greater predicted probabilities in letter-sound knowledge when letter name was known than when CV letters included *c* and *g*. Likewise, without letters *q* and *x*, the no-sound category had slightly enhanced predicted probabilities when letter name was known. These results entailed some differences in the contrast tests using alternative classifications as shown in Table A2. Specifically, when we used the alternative coding, CV letters had significantly greater predicted probabilities in abstracting sounds than vowel letters when letter name was known and PA was minimal (i.e., 1), as well as when letter name was not known and PA was highly developed (i.e., 40). Another major difference in alternative classification of letters was that when letter name was not known and PA was minimal, no differences were observed between letter categories.

Table A1
Fixed Effect Results From Cross-Classified Models Excluding Letters c, g, q, and x

Model 4 component	Coefficient	*SE*	*t*	*df*	*p*	OR	Predicted probability
LSK, θ_0	−3.23	0.37	−8.86	16971	.000	0.04	.04
CV, β_{01}	−0.08	0.47	−0.18	16971	.858	0.92	.04
VC, β_{02}	−1.01	0.58	−1.72	16971	.085	0.36	.01
NS, β_{03}	−0.82	0.73	−1.12	16971	.262	0.44	.02
PA, γ_{01}	−0.02	0.03	−0.63	16971	−.526	0.98	.03
CV × PA, θ_2	0.07	0.03	2.38	16971	.017	1.07	.06
VC × PA, θ_3	0.08	0.03	2.29	16971	.022	1.08	.03
NS × PA, θ_4	0.03	0.05	0.59	16971	.556	1.03	.02
LNK, θ_1	3.22	0.37	10.84	16969	.000	25.02	.50
LNK × CV, β_{11}	1.69	0.40	4.28	16969	.000	5.42	.83
LNK × VC, β_{12}	1.04	0.51	2.06	16967	.039	2.83	.50
LNK × NS, β_{13}	0.26	0.63	0.42	16967	.676	1.30	.36
LNK × PA, γ_{11}	0.09	0.03	3.43	16967	.001	1.09	.69
LNK × CV × PA, θ_5	−0.04	0.03	−1.32	16967	.187	0.96	.94
LNK × VC × PA, θ_6	−0.07	0.03	−1.88	16967	.061	0.93	.72
LNK × NS × PA, θ_7	−0.03	0.05	−0.54	16967	.587	0.97	.56

Note. The referent letter group is vowels. OR = odds ratio; LSK = letter-sound knowledge (intercept); LNK = letter-name knowledge; PA = phonological awareness; CV = consonant–vowel letters; VC = vowel–consonant letters; NS = letters with no sound information.

Table A2

Predictor Contrasts for Mean Log-Odds When Letter Name Was Known Versus Unknown and Phonological Awareness Was Minimal (i.e., 1), Average (i.e., 11.77), or Sophisticated (i.e., 40) Excluding Letters c, g, q, and x

Condition and contrast	Mean log-odds difference	*SE*	*F*	*p*
When letter name was unknown				
PA = 1				
CV-V	−0.01	0.46	0.00	.978
VC-V	−0.93	0.57	2.69	.101
NS-V	−0.79	0.71	1.23	.265
CV-VC	0.92	0.56	2.62	.104
CV-NS	0.77	0.70	1.21	.271
VC-NS	−0.14	0.77	0.03	.855
PA = 11.77				
CV-VC	0.85	0.48	3.11	.078
CV-NS	1.22	0.68	3.27	.071
VC-NS	0.37	0.72	0.27	.606
PA = 40				
CV-V	2.79	1.08	6.66	.009
VC-V	2.10	1.17	3.24	.072
NS-V	0.39	1.82	0.04	.831
CV-VC	0.69	0.99	0.48	.489
CV-NS	2.41	1.72	1.96	.163
VC-NS	1.72	1.78	0.92	.336
When letter name was known				
PA = 1				
CV-V	1.64	0.32	25.05	<.001
VC-V	0.05	0.35	0.02	.890
NS-V	−0.55	0.44	1.59	.209
CV-VC	1.59	0.36	19.44	<.001
CV-NS	2.19	0.45	23.52	<.001
VC-NS	0.60	0.47	1.64	.101
PA = 11.77				
CV-VC	1.51	0.51	8.87	.003
CV-NS	2.66	0.73	13.18	.0003
VC-NS	1.15	0.76	2.26	.132
PA = 40				
CV-V	2.80	0.45	39.06	<.001
VC-V	0.52	0.41	1.61	.203
NS-V	−0.48	0.50	0.94	.334
CV-VC	2.28	0.49	21.99	<.001
CV-NS	3.28	0.57	33.18	<.001
VC-NS	1.00	0.54	3.50	.062

Note. PA = phonological awareness; CV = consonant–vowel letters; VC = vowel–consonant letters; NS = letters with no sound information.

(*Appendices continue*)

Appendix B

Equations for Models 1, 2, 3, and 4

Generalized Linear Model

$$\text{Prob}(Y_{ijk} = 1|B_{ijk}) = \varphi_{ijk}$$

$$\log\left[\frac{\varphi_{ijk}}{1 - \varphi_{ijk}}\right] = \eta_{ijk} = B_{0jk}$$

Model 1

$$B_{0jk} = \theta_0 + b_{00j} + c_{00k} + e_{ijk}$$

Model 2

$$B_{0jk} = \theta_0 + \theta_1(\text{Letter Name})_{ijk} + b_{00j} + c_{00k} + e_{ijk}$$

Model 3

$$\begin{aligned} B_{0jk} = \theta_0 &+ \theta_1(\text{Letter Name})_{ijk} + \gamma_{01}(\text{PA})_j \\ &+ \gamma_{11}(\text{Letter Name} * \text{PA})_j + b_{00j} + c_{00k} + e_{ijk} \end{aligned}$$

Model 4

$$\begin{aligned} B_{0jk} = \theta_0 &+ \beta_{01}(\text{CV})_k + \beta_{02}(\text{VC})_k + \beta_{03}(\text{NS})_k \\ &+ \gamma_{01}(\text{PA})_j + \theta_1(\text{Letter Name})_{ijk} \\ &+ \beta_{11}(\text{Letter Name} * \text{CV})_j \\ &+ \beta_{12}(\text{Letter Name} * \text{VC})_j \\ &+ \beta_{13}(\text{Letter Name} * \text{NS})_j \\ &+ \gamma_{11}(\text{Letter Name} * \text{PA})_j + \theta_2(\text{CV} * \text{PA})_{ijk} \\ &+ \theta_3(\text{VC} * \text{PA})_{ijk} + \theta_4(\text{NS} * \text{PA})_{ijk} \\ &+ \theta_5(\text{Letter Name} * \text{CV} * \text{PA})_{ijk} \\ &+ \theta_6(\text{Letter Name} * \text{VC} * \text{PA})_{ijk} \\ &+ \theta_7(\text{Letter Name} * \text{NS} * \text{PA})_{ijk} + b_{00j} + c_{00k} + e_{ijk} \end{aligned}$$

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