Frequency Analyses of Prephonological Spellings as Predictors of Success in Conventional Spelling

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Abstract

The present study explored how children's prephonological writing foretells differential learning outcomes in primary school. We asked Portuguese-speaking preschool children in Brazil (mean age 4 1/4 years) to spell 12 words. Monte Carlo tests were used to identify the 31 children whose writing was not based on spellings or sounds of the target words. 2 1/2 years later, the children took a standardized spelling test. The more closely the digram (2-letter sequence) frequencies in the preschool task correlated with those in children's books, the better scores the children had in primary school; and the more preschoolers used letters from their own name, the lower their subsequent scores. Thus, preschoolers whose prephonological writing revealed attentiveness to the statistical properties of text subsequently performed better in conventional spelling. These analytic techniques may, therefore, help in the early identification of children at risk for spelling difficulties.

Keywords: spelling, dyslexia, precursors, preschool, longitudinal

Frequency Analyses of Prephonological Spellings as Predictors of Success in Conventional Spelling

Much work has been devoted to identifying factors that can help educators to identify children who may be at risk of poor or delayed acquisition of literacy skills. Several techniques have been developed for learners of alphabetic writing systems, typically emphasizing core skills that are prerequisite to working with such systems, including phonological awareness and knowledge of letter names and sounds (e.g., Caravolas, Hulme, & Snowling, 2001; Cardoso-Martins & Pennington, 2004; Leppänen, Nieme, Aunola, & Nurmi, 2006; Lervåg & Hulme, 2010; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). A more direct approach is to measure children's performance in literacy tasks. Such measures are not only useful in evaluating children's current capabilities, but they also are among the best techniques for estimating future accomplishments.

When it comes to predicting children's future successes or difficulties in spelling, the specific literacy skill of interest here, one very useful technique is to analyze their current spelling. Spellings in first grade, for example, can prognosticate spelling performance several years later (e.g., Garcia, Abbott, & Berninger, 2010). A natural question is how early such predictions can be made on the basis of writing performance. Prior to entering primary school, most children rarely spell any words correctly. At first consideration it may seem impossible to differentiate future spelling performance among children who score zero on all spelling tests, but substantial progress has been made by using various schemes for scoring degrees of partial correctness (e.g., Caravolas et al., 2001). For example, a child who spells *cat* as ‹C› is credited with a more advanced production than one who spells it as ‹B›, because at least one letter was written correctly. Such schemes often go a step further by giving partial credit for using letters that are not correct but are phonologically plausible; for example, spelling *cat* as ‹K› is better than spelling it as ‹B›, because the former at least uses a letter that sometimes spells [k], the first sound of the target word. Such scoring acknowledges that children who are beginning to use letters to represent sounds in the target words—*phonological spellers*—are applying the alphabetic principle, which is generally considered to be the key cognitive concept underlying reading and writing (Ehri, 2005).

However, even the basic strategy of using letters to represent sounds–*phonological* spelling–has to begin sometime. Is it conceivable that there is prognosticative value in even earlier, *prephonological*, spellings that show no evidence at all of conventional spelling or the most rudimentary sound-to-letter mappings? It is clear enough that young children in modern literate societies may generate strings of letters well before they understand how text encodes sound. In the study presented in this paper, for example, one child, when asked to spell the Portuguese word *bicicleta* 'bicycle', wrote ‹ORP›. But such spellings have no communicative efficacy and would clearly score at the bottom in any measure of spelling competence, even in schemes that give generous partial credit for imperfect encoding of even a single sound in the target word.

Theories of spelling development all acknowledge the existence of such prephonological spellings, which are called *prealphabetic* in the influential phase theory of Ehri (2005). Typically, prephonological spellings are characterized as random strings of letters that lack any application of the *alphabetic* principle, that written symbols represent phonemes (Ehri; Gentry, 1982; Gough & Hillinger, 1980). Because the alphabetic principle is the keystone of spelling, such perspectives suggest that prephonological spellings do not have enough structural properties to predict anything at all. In constructivist approaches to literacy acquisition, such as that of Ferreiro (Ferreiro, 1990; Vernon & Ferreiro, 1999), children's early spelling is characterized by cognitive stages, many or most of which comprise false hypotheses about writing. For example, Ferreiro's theory states that early spellers believe that words must have at least three letters and that each written symbol must correspond to an entire syllable (Ferreiro, Pontecorvo, & Zucchermaglio, 1996; Ferreiro & Teberosky, 1982; but for counterclaims see Cardoso-Martins, Corrêa, Lemos, & Napoleão, 2006; Pollo, Kessler, & Treiman, 2009). If progress in spelling consists largely of discarding earlier ideas about writing, one would not expect very early spelling to have much to do with later, conventional, spelling.

Other researchers, however, have drawn attention to aspects in which children's prephonological spellings often bear similarities to conventional texts. A recent theme in writing acquisition explores how children learn to differentiate writing from drawing and produce increasingly conventional, letter-like forms as their understanding of writing grows (Levin & Bus, 2003; Treiman & Yin, 2011). It has often been pointed out that beginning writers have a strong tendency to spell words by drawing on letters found in their own name, a piece of text with which most children are particularly familiar (Bloodgood, 1999, for English; Gombert & Fayol, 1992, for French). More recently, Pollo et al. (2009) have shown that the invented spellings of prephonological children in Brazil and the United States (mean age approximately 4 years, 8 months) contained patterns that mimicked the patterns of text that children find in their respective environments. Instead of only picking letters at random from the alphabet, children tended to use letters and letter combinations with relative frequencies that approximated the frequencies with which such letters and combinations appear in children's books written in the local language—Portuguese or English.

Pollo et al. (2009) attributed the frequency patterns in preschoolers' productions to statistical learning. Although at first consideration it would appear unlikely that 4-year-old children would count how often letters occur and co-occur with each other in writing they encounter, it is now well accepted that even infants are powerful statistical learners, capable of learning what sequences of syllables co-occur in a spoken text (Saffran, Aslin, & Newport, 1996). Such learning often occurs without conscious effort or awareness. Most research in statistical learning of natural language patterns has concentrated on the aural domain, but there is much evidence that children and adults learn visual patterns and sequences (Arciuli & Simpson, in press), including the relative frequencies with which letters occur in different contexts (Kessler, 2009).

Under the statistical learning theory, therefore, there are reasons to expect that the nature of children’s prephonological spellings could predict future success in conventional spelling. The patterns that prephonological children pick up may be useful later on, or they may be building blocks for more powerful or general spelling patterns. Further, children who prove to have been particularly successful statistical learners of text even at an early age would be those who are most likely to continue to be successful statistical learners of ever more patterns as they continue their acquisition of literacy.

In the current study we sought, first, to check whether statistical learning of textual patterns occurs in Brazilians averaging 4 years, 3 months of age: a group of children even younger than those tested by Pollo et al. (2009). If so, we wished to see if variation among the children in the degree to which their spellings reflected such patterns correlated with success in later conventional spelling, some 30 months later. We hypothesized that children whose productions of text more closely paralleled the patterns observable in their environment would prove to be better statistical learners of other orthographic information essential to later conventional spelling. Such an outcome would not only have a practical benefit in prognosticating success or difficulty in conventional spelling, but would also constitute evidence for the statistical learning theory.

At the beginning of preschool, children were asked to spell a short list of words. Later, in the first year of primary school, they were given a standardized spelling test, the TDE (*Teste de Desempenho Escolar*, Stein, 1994). For those 31 children whose invented spellings in preschool used recognizable letters of the alphabet but did not use the letters to represent their sounds—the prephonological spellers—we computed three types of frequency counts:

- *monograms*: frequencies of individual letters (*mono*- 'one', *gram* 'letter')
- *digrams*: frequencies of pairs of letters (*di*- 'two')
- *idiograms*: letters that appear in the child's own name (*idio*- 'one's own')

Each of these three measures was reduced to a single number for each child. In the case of monograms and digrams, we used the correlation between the child's frequencies and the frequencies found in a printed corpus of children's books. Idiograms were expressed as the fraction of letters children used that were found in their own name. In all cases, higher numbers (maximum 1.0) mean the child's productions were statistically more like the relevant text.

These frequency measures were used in a linear regression to predict accuracy on the TDE spelling test taken by the same children in primary school. Our main research goal was to see whether children with low frequency measures in preschool would have problems with spelling later on. Instead of treating spelling difficulty as a categorical outcome with a specific cutoff (dyslexic vs. nondyslexic), we treated spelling performance as a gradient, using the frequency measures to predict the number of correct trials in the spelling test. Such an approach is more flexible and is supported by findings that dyslexia is part of a continuum that also includes normal reading ability (Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). Supporting this view for the case of spelling, spelling errors in children with dyslexia are very similar or identical to those of typically developing children at a younger age (e.g., Bourassa, Treiman, & Kessler, 2006; Cassar, Treiman, Moats, Pollo, & Kessler, 2005).

Method

Participants

We recruited 76 children in the first year of preschool in private schools in Belo Horizonte, Minas Gerais, Brazil. Eight children dropped out of the study before the primary school test was administered. Characteristics of the remaining children are summarized in Table 1. The left side of the table gives data for all children. The right side shows information for the subset of children who were classified as prephonological by the method described below; only their productions were analyzed in subsequent analyses. All children were monolingual speakers of Portuguese and were from upper-middle-class families. Their preschool teachers reported that none had been diagnosed as having a learning or sensory disability.

Of the characteristics listed in the table, the TDE writing score is the response variable in the study and is discussed below under Procedure. The other measures are provided in order to give a better idea of the background of the participants:

Words read. Children were asked to attempt to read a series of 12 words that were selected as being of high frequency in books read by children (Pinheiro, 1996). Words were presented in uppercase on cards, one at a time. Preschoolers in Brazil, as in many other countries such as the United States (Treiman, Cohen, Mulqueeny, Kessler, & Schechtman, 2007; Worden & Boettcher, 1990) are much more familiar with uppercase letters than lowercase ones. This was confirmed by the fact that almost all of the spellings we elicited from them were produced in uppercase. In addition, 6 readily recognizable logos, such as that of Coca-Cola, were included as fillers, to allay frustration. Most children could read no words at the preschool testing, and the maximum number of words read by any of the nonphonological spellers was two.

Letter names. Children were asked to name letters of the Portuguese alphabet when shown to them in uppercase on a single card. The maximum score is 23, because the letters ‹K›, ‹W›, and ‹Y› are very rare in Portuguese and were not presented.

Letter sounds. The experimenter presented different Portuguese phonemes, and on each of 23 trials asked the participant to point to which of six uppercase letters makes that sound. Thus, children who made any selection would get a score of about 4 by chance.

General intelligence. Three months prior to the primary school testing, children's general intelligence was estimated by administering the vocabulary and cubes subtests from the Brazilian version of the WISC-III (Wechsler, 2002). Reported reliability coefficients (internal consistency measured by Guttman's λ_2) are .79 for the vocabulary test and .82 for the cubes test. The standardized scores are presented in Table 1.

TDE reading. In the reading subtest of the TDE, 70 words were individually presented for naming. The raw score, presented here, is the number of words read correctly. Reported reliability of this subtest (Cronbach's α) is .988 (Stein, 1994).

Preschool attendance is optional in Brazil. In the preschools attended by the participants in this study, children learn about the shapes and names of the letters of the alphabet, and they practice invented spellings. They see a good deal of text and are read to by their teachers. Formal instruction in reading and spelling begins in the first year of primary school.

The participants were recruited as part of an ongoing longitudinal study of spelling development. We report here the first time the children performed the 12-word spelling task in preschool and the first time they took the TDE spelling test in primary school.

Procedure

The preschool spelling task, which was administered near the beginning of the school year, consisted of spelling to dictation the 12 words listed in Table 2. The same order, which was selected randomly, was used for all participants. The criteria by which the words were chosen included the requirements that they be content words of varying lengths, familiar to children in oral contexts, but not overwhelmingly frequent in written text. Children were tested individually in a quiet room in their schools. They were asked to spell the words as best they could. When children replied that they did not know how to write, we assured them that it was OK to make mistakes.

The TDE (Stein, 1994) was administered to the same children 30 months later. At this point, the children were well into the first year of primary school (*ensino fundamental*), and had had a substantial amount of literacy instruction. We administered the reading subtest for background information on the participants (Table 1). The writing subtest provided the data whose relationship with the preschool spelling task was our main object of research. The children were asked to spell 34 individual words, which were presented orally, followed by a sentence illustrating the use of the word in context. Scoring on this subtest is binary: Each of the 34 words is either totally correct (one point) or incorrect (zero points). Reported reliability of this subtest (Cronbach's α) is .945 (Stein, 1994). As Table 1 shows, the children on average got almost half of the items correct. The range of correct responses was from 4 to 26.

Analysis

Standardization of spellings. The preschoolers in our study wrote almost entirely in uppercase letters. Diacritical marks, such as the acute accent used in the standard spelling of *pé* 'foot', were extremely rare; only 16 instances of identifiable Portuguese accent marks were produced in the entire study. Therefore we effectively ignored those aspects of spelling by converting all letters to one case and deleting diacritics. The data of the seven children who did not produce any identifiable letters at all were dropped from our analysis. Two judges who independently transcribed 120 responses agreed on their interpretation of 88% of the preschoolers' productions.

Identification of prephonological spellers. Despite their youth, some of the preschool students were already phonological spellers. In some cases their phonological status was obvious: One boy spelled *cigarro* /siˈgahu/ 'cigarette' as ‹SIGARO›, using phonologically plausible letters for each sound in the word, in order. But what about the girl who spelled it as ‹COİP›? Perhaps some of those letters were attempts to spell sounds in *cigarro*, but it is also possible that the girl was selecting letters by a quasi-random process: There being a fairly small number of letters in the alphabet, it would not be unusual for even random spellings to have some letters that seem phonologically plausible. As is typical of 4-year-olds, most of our participants produced a very large number of spellings that could not confidently be classified as definitely phonological or definitely nonphonological.

In order to determine whether a given child produced phonological spellings with greater-than-chance frequency, we modified a statistical technique introduced by Pollo et al. (2009). This technique has two components. The first is a scoring function, which determines how badly the child’s spelling represents the pronunciation of the word. The second component is a rearrangement test, which randomly matches up a child’s spellings with different target words and applies the scoring function to the random rearrangements. If a child uses phonological principles, the error score on the real data set will be less than the error score on the vast majority of random rearrangements.

Scoring the spellings. The scoring function is an application of string-edit metrics (Levenshtein, 1965). It computes the distance between the pronunciation and the spelling by finding the best possible match between the sounds and the letters. Specifically, it considers every minimal sound–spelling correspondence found in Brazilian Portuguese orthography. Table 3 shows the correspondences that were needed for our data set. Some of these correspondences are rare in Portuguese, but we accepted all correspondences attested in a corpus of Brazilian children's literature (Pinheiro, 1996).

As is common in string-edit metrics, we assigned a base score of 0 to phonologically perfect spellings and assigned positive penalties for any divergences. This orientation reflects the fact that there is no limit to how bad a spelling can be, because it is always possible to add one more extraneous, implausible letter to the end of a production: Spelling *chá* 'tea' as ‹SAB› is better than ‹SABB›, which is better than ‹SABBB›, and so forth. Scoring a perfect spelling as 0 and using positive penalties allow us to have a mathematically conventional origin point and avoid using minus signs, but readers must keep in mind that under such schemes, lower numbers mean better performance.

Whenever the child inserted extraneous letters or digraphs, or omitted spelling a sound or diphone, a penalty of 1.0 was added. Any time a child spelled a sound or diphone using a letter or digraph that never spells that sound in real Portuguese words, a penalty of 1.4 was added to the spelling's error score; this number approximates the Euclidean distance between the omission of the plausible letter and the insertion of the implausible one: $\sqrt{(1^2 + 1^2)}$ by the Pythagorean theorem.

Matches between spelling and pronunciation were required to be in the correct order, although extraneous letters could intervene; that is, transpositions such as spelling *chá* ‘tea’ as ‹ÁCH› were penalized. There are usually many ways to apply these rules to give different scores for the same spelling; we followed the Levenshtein (1965) specification in always selecting the matching that gave the best score.

According to these principles, the spelling of *cigarro* /siˈgahu/ ‘cigarette’ as ‹COİP› received a penalty of 5.4, computed as follows: The spelling was processed as if lowercase ‹coip›. The letters ‹c› and ‹i› were accepted as phonologically plausible spellings of the sounds /s/ and /i/. The intervening ‹o› could not be analyzed as spelling any other sound in the word, such as the final /u/, because that would ignore the order of the phonemes; it was therefore treated as an extraneous insertion, for a penalty of 1. The remaining letter, ‹p›, is not a plausible spelling of any of the remaining phonemes, so it was arbitrarily aligned with one of them, for an implausible spelling penalty of 1.4. The rest of the phonemes were considered to be omitted, yielding omission penalties of 1 per phoneme:

Sounds:	s		i	g	a	h	u	
Child spelling:	c	o	i				p	
Penalty:	0 +	1 +	0 +	1 +	1 +	1 +	1.4	= 5.4

Rearrangement test. By summing the error scores across all of a child's spellings, we obtained the actual, attested, aggregate error score for that child: *e*. Our rearrangement component then randomly matched the child's spellings to target words and rescored the spellings as if they had been attempts to spell those words. This rearranged aggregate error score *r* gives one view of what the score would be if the child's spelling were not informed by the sounds or spelling of the target word. For example, one of the rearrangements might randomly treat ‹coip› as if it were the child's spelling of the stimulus *bico* 'beak' and treat her spelling of *bico*, ‹cipip›, as if it were her spelling for the stimulus *dedo* 'finger', and so forth. If the child's error rate on the rearranged spellings, *r*, is near the error rate on the real, original, arrangement, *e*, that indicates that any accuracy on the real task is due to chance.

We performed this rearranged scoring 999 times, computing two key statistics for each child. For each rearrangement, we determined whether the score *r* was at least as good as the real, original score *e*; the proportion of rearrangements for which that is the case is *p*, an estimate of the significance level used in classical Fisherian hypothesis testing (Good, 1994). A sufficiently low *p* means that chance rearrangements rarely produce scores as good as the child’s, thus encouraging us to accept the hypothesis that the child was spelling phonologically. We also computed the average score $\bar{r}$ across all rearrangements. Our statistic $m = (\bar{r} - e)/\bar{r}$ measures how much better the child’s real score is compared to that average chance score: Large numbers mean that the child’s spelling is much better than chance. Because we wanted to study children who are not spelling phonologically, we selected for high *p* values and low *m* values. Specifically, we classified a child as prephonological if the *p* values exceeded .05 and *m* was less than .01. By this criterion, we identified 31 of our 68 preschoolers as being prephonological spellers; their characteristics are summarized in the right half of Table 1.

Because we used a specific numeric cut-off, many of the children omitted from the prephonological group, such as the aforementioned girl who spelled ‹COİP›, produced spellings that were almost indistinguishable from the spellings of those included in the group. A more typical type of (partial) phonological speller was the child who spelled ‹CUI› for *cavalo*, ‹XI› for *chá*, ‹IUO› for *flor*, and ‹SOOIO› for *cigarro*, and so forth. Although the words taken individually are not readable, one can begin to discern a pattern whereby the speller used a phonologically plausible letter for the first phoneme much of the time, which undoubtedly contributed to the child's overall score of m = .117 and p = .009.

Frequency statistics. The writing of the prephonological spellers was further analyzed to see to what degree the frequency with which they used letters corresponded to the frequency they are found in text. We looked at two types of texts that children are likely to encounter frequently: children's books and their own name.

Correlations with corpus frequencies. We used the word counts of Pinheiro (1996) as estimates of the relative frequency of words in texts that children typically encounter in Brazilian preschools. To avoid including words with low dispersion across texts, we ignored words that Pinheiro did not also find in texts from the first year of primary school. For example, the word *Zuza* was omitted even though it appeared eight times in Pinheiro's preschool subcorpus. The fact that it did not appear at all in her larger Year 1 subcorpus suggests that *Zuza* is not really all that common in children's books and probably was just used repeatedly in one preschool text that happened to be about a character named *Zuza*. Children who do not happen to read that one specific book might not encounter the word *Zuza* at all. Thus the number eight almost certainly greatly exaggerates the frequency with which preschoolers will have seen this word and the monograms and digrams it contains.

The simpler of the two corpus statistics we used was monogram counts: the frequency with which each individual letter was found in preschool texts. The counts ignored case distinctions and were weighted by word frequency; for example, the word *Ana* was found 39 times in the texts, and so counted as 78 instances of ‹a› and 39 instances of ‹n›. Digram counts were computed in the same way as monogram counts, except that we counted the frequencies of immediately adjacent pairs of letters. Thus *Ana* contributed 39 instances of ‹an› and 39 instances of ‹na›. Words that are only one letter long, such as *o* 'the', do not have any digrams and therefore did not contribute to the digram counts.

For each child spelling, we counted monogram frequencies in a similar fashion. We then summed those counts across all 12 spellings the child produced, yielding a frequency count for each monogram. For each child, those frequencies were then correlated with the frequencies from the corpus, yielding a single Kendall rank correlation coefficient, τ, which expressed how similar the child’s monogram frequency profile was to the corpus.

Because of some evidence that children tend to learn the first two or three letters of the alphabet better than other comparable letters (Treiman, Levin, & Kessler, 2007, 2010), an anonymous reviewer expressed concern that an apparent effect of letter frequency might be due to some correlation between letter frequency and alphabetical position: After all, the most frequent letter in the children’s corpus is ‹a›, and the two least frequent letters are ‹x› and ‹z›. In order to factor out any effect of alphabetical order, the correlations we used were actually partial rank correlations between the child’s frequency and the text frequency, given the letters’ rank order in the alphabet.

An analogous process was used to compute a partial rank correlation coefficient between each child’s digram frequencies and the digram frequencies found in the corpus, given the sum of each of the two letters’ rank order in the alphabet.

Idiograms. The idiogram frequency measure that we computed was the proportion of letters that a child used that were found in the child’s own given name, out of all letters that the child used. Many children have given names that consist of two words that are seldom used independently. We determined whether this was the case for each child by observing how the child spelled her or his own given name at the end of preschool. Multiple instances of the same letter counted multiple times. Thus when Ana Clara spelled *chá* as ‹AVCRPMNIBAQOUICLFAQO›, we counted 8 letters from her own name (‹A›, ‹C›, ‹R›, ‹N›, ‹A›, ‹C›, ‹L›, ‹A›) out of 20 altogether. The idiogram measure used for each child was the grand proportion across all the spellings.

Regression tests. Linear regressions were performed to see how well the primary-school TDE test scores could be predicted from the frequency statistics. The TDE values were the raw number of words that the children spelled correctly. The idiogram proportion was squared in order to give a more linear relation to the response variable. The age of the child in months at the time of the TDE test was also entered as a predictor.

Results

Our first research question was whether our young Brazilian participants would reflect statistical patterns of Portuguese text in their prephonological invented spellings. Table 4 summarizes the partial Kendall rank correlation coefficients (τ) between child spelling frequencies and corpus frequencies. Eighteen of the 31 prephonological spellers have monogram correlations significantly greater than zero ($p < .05$ by a

Kendall correlation test). That is, by and large, the children in our experiment preferred using letters that are found comparatively often in Portuguese texts, even after one takes alphabetical order into account.

The digram correlation numbers are, on average, smaller than the monogram correlations, but all are nonnegative. The small size of the mean is due in part to the fact that seven spellers only wrote at most a single letter for each word, thus producing no digrams at all. The correlations for these spellers were treated as zero, bringing down the average. A second reason for fairly low correlations is that there are 529 possible digram types in Portuguese (23 × 23; neither the corpus nor any child used the letters ‹k›, ‹w›, or ‹y›). With only 12 words of text, children produced zero instances of most digrams, affording little opportunity for significant correlation. Under such circumstances, it is remarkable that correlations were as high as they were. They were also highly significant: Of the 24 prephonological spellers who produced spellings longer than one letter, 21 had digram correlation measures that were significantly above zero ($p < .05$), 18 of those at $p < .001$. Thus, most children in our sample used digrams that are found comparatively often in Portuguese texts.

Whether one counts by monograms or by digrams, the invented prephonological spellings of these Brazilian preschoolers reflected the statistical patterns of Portuguese text. The correlations did not closely approach the theoretical maximum of 1.0, but we did not ask the children to produce the massive amount of text that would be required to provide a closer fit to a sizable corpus. Even if it were reasonable to request such a large sample, it would be surprising indeed if the invented spellings of preliterate 4-year-olds perfectly matched the frequency patterns of texts in standard orthography.

The idiogram counts measured a rather different type of text sensitivity, in that the text under consideration, the child's given name, varies between subjects, and is limited to one or two words. On average, the children drew on their own name for almost half of the letters they wrote. Thus our first research question has the same answer both for public texts and for this very personal type of text: The invented spellings did indeed reflect the properties of texts to which the prephonological spellers had been exposed.

The second research question asked whether differences between preschoolers in these frequency measures could predict differences in the TDE, the conventional spelling test administered in primary school. Pearson product-moment correlations between the frequency measures and the TDE scores were .322 for monograms, .656 for digrams, and -.087 for idiograms; only the correlation for digrams was significant for these zero-order correlations, $p < .001$. All three frequency measures were then entered into a linear regression, along with the children's ages at the time of the primary school test. The contributions of age and monogram frequencies were both nonsignificant, and analyses of variance showed that both variables could be dropped from the model without significantly reducing its fit. Table 5 presents the results of the final, reduced model. The digram and idiogram frequencies significantly predicted a portion of the TDE spelling scores, $R^2 = .57$, $F(2, 21) = 13.91$, $p < .001$. The contribution of idiogram frequencies to predicting test scores was negative, and that of digram frequencies was positive. Thus, on average, the more preschoolers' invented spellings drew on digrams frequent in Portuguese text, the better their conventional spelling scores later on. But the more their spellings drew on letters from their own name, the worse their conventional spelling scores.

Discussion

Our study shows that even preschool children around 4 years, 3 months of age learn the statistical properties of text in their environment. This is the case even before children learn or apply the idea that letters in their spellings should represent sounds. Spellings like ‹VAVI› may not make phonological sense as a representation of *dedo* 'finger', but the evidence suggests that the girl who wrote it was not just pulling letters at random out of the alphabet. Like most of her peers, she has implicitly learned that certain letters are more frequent than others, and even that certain digrams are more frequent than others, and she favors the more frequent patterns in her own invented spellings. This finding extends to an earlier age the results of Pollo et al. (2009), who documented the phenomenon in a group of Brazilians who averaged 4 years, 10 months of age, with some being as old as 6 years.

We have also verified that our participants often used idiograms, that is, they invented spellings that were heavily based on letters from their own name. For example, Matheus generated the spellings ‹MDHIUS›, ‹MOHI›, ‹MHI›, and ‹AMOUS›, each time varying the pattern somewhat, but clearly favoring the monograms ‹M› and ‹H› and the digram ‹US› more than one would ordinarily expect. This general pattern too has been documented with other children (e.g., Bloodgood, 1999; Gombert & Fayol, 1992). Our study adds to these findings by using a rigorous method, the rearrangement test, to verify that such spellings were found among spellers who were not yet using phonological spellings.

A reasonable interpretation of these facts is that children, in general, attend to texts in their environment and implicitly internalize some of the patterns found in those texts. The fact that children may start this process in preschool provides continuity with, on one side, the now classic observations that even infants are statistical learners of spoken language patterns (Saffran et al., 1996) and, on the other side, the accumulating evidence that older children and adults implicitly learn and employ in their spelling a wide range of frequency and context patterns that they are never formally taught (e.g., Kessler, 2009). Our claim that children learn the statistical patterns of text at such an early age may be surprising in light of findings that 4- and 5-year-olds spend less than a second looking at the text on a page when read to by adults (Evans & Saint-Aubin, 2005). However, young children frequently engage in many other types of literacy experiences, active participation in which has been found to correlate with their understanding of properties of text such as letter shapes. Such activities include practicing letter names and trying to read and write words. The high proportion of idiograms in our subjects' spelling comes as no surprise when one considers that, in terms of the degree to which young children initiate and spend time on practicing literacy skills, the foremost activity is writing the child’s own name (Levy, Gong, Hessels, Evans, & Jared, 2006).

A new question that we pursue here is the predictive power of differences between children’s use of the frequency patterns found in texts. Among our participants, a clear pattern is that prephonological preschoolers who tended to use relatively frequent digrams in their invented spellings performed better on standard spelling tests administered 2 1/2 years later than those who used less frequent digrams. However, contrary to our expectations, monogram frequency correlations with the later spelling test were weaker than digram correlations and had no predictive capability. This lack of significance may be a result of a fairly small sample size; we were surprised that at four years of age more than half of our preschoolers had to be omitted from the analyses because they already spelled phonologically. A more substantive explanation is that the better spellers among our participants were ones who 30 months earlier had already progressed to the point where simple letter frequencies had relatively less influence on their productions than more complicated, higher-order frequencies. ‹A›, for example, is the most common single letter in the Portuguese children’s corpus, but the digram ‹AA› does not occur at all. The preschoolers who used infrequent digrams like ‹AA› in their productions appear to have had worse outcomes later on, despite the high frequency of their separate components.

Idiogram usage pointed in the opposite direction from digram usage: Children who used many letters from their own names in their invented spellings performed comparatively worse on the primary school spelling test than same-age children whose productions looked more like text, especially in terms of higher-order (digrammatic) statistics.

A reasonable interpretation of these findings is that children who attend to a wide range of texts–not limited to their own names–have begun a profitable process of implicitly learning the statistical patterns of their native language orthography, which will stand them in good stead when they are later expected to spell words conventionally. Such a pattern of learning would not be predicted by constructivist or phase theories of literacy acquisition, which posit a progression through different cognitive approaches to reading and spelling. Ehri’s model (2005) recognizes the existence of a prealphabetic phase, where some printed words can be recognized, and in part written, by learning their visual patterns. Ehri cited examples such as recognizing the written word ‹camel› because it has humps in the middle, or recognizing the bright yellow ‹M› of McDonald’s logo. Her model, however, rejects any connection between visual learning in those early stages and the knowledge of sound–letter correspondences, which is the hallmark of the subsequent, full-alphabetic, phase of development. As she put it: “Knowing how to read golden arches does not help them learn to read words alphabetically” (p. 176). The divide is even sharper in constructivist, stage-based, theories, where children are explicitly expected to cast off early hypotheses about the nature of writing as they consolidate the cognitive insight that letters represent individual sounds (Ferreiro, 1990).

We believe, in contrast, that our data show continuity between the spellings of prephonological preschoolers and the more fully developed phonological spellings attested in primary school. Greater skill at statistical learning can account for both a high degree of implicit learning of monogram, digram, and idiogram frequencies on the one hand, and, on the other hand, the skill at learning and applying sound–letter correspondences, graphotactic patterns, and exception words that is required for passing primary school spelling tests like those of the TDE. Some caution, of course, is called for when it comes to drawing very specific conclusions about causality. The children who went on to be better spellers may have done so in part because they had already learned certain orthographic patterns, which gave them a more secure platform for learning even more patterns. It is also possible that those children were better statistical learners, at least in the limited domain of alphabetic symbols; even if their preschool knowledge base itself is not very useful, their skill in learning spelling patterns could turn out to be advantageous later on. Such a conclusion is in line with research that shows that better statistical learners tend to be better readers (Arciuli & Simpson, in press). A final possibility is that the good spellers were not intrinsically better at statistical learning than the less successful spellers, but that they had the benefit of more exposure to books and other written text, which would provide more data from which statistical patterns could be inferred.

From a psychometric viewpoint, we believe it is worthwhile exploring further the possibility of incorporating digram frequency correlations and idiogram proportions into tests designed to identify preschoolers who are potentially at risk of low spelling performance in primary school. Of course, at the age of 6, it is rather early to diagnose any of our participants as dyslexic, even those who missed 30 out of 34 words on the TDE spelling test. But, when combined with the substantial body of existing and ongoing research devoted to prognosticating literacy outcomes in primary school, statistical measures of corpus and idiogram frequency correlations may help round out the picture of how dyslexia develops and strengthen the accuracy of predictions. Naturally, careful work will be needed to design and normalize such tests. It could be the case, for example, that heavy use of idiograms would be a positive, not negative, indicator of success in children who are much younger than those in our study, or in those who do not attend preschools that emphasize literacy education as heavily as those our participants attended. But for a first step, it is extremely encouraging that observations on prephonological invented spellings taken at the average age of 4 years, 3 months significantly predict spelling success 2 1/2 years later.

References

Arciuli, J., & Simpson, I. (in press). Statistical learning is related to reading ability in children and adults. *Cognitive Science*.

Bloodgood, J. W. (1999). What's in a name? Children's name writing and literacy acquisition. *Reading Research Quarterly, 34*, 342–367. doi:10.1598/RRQ.34.3.5

Bourassa, D. C., Treiman, R., & Kessler, B. (2006). Use of morphology in spelling by children with dyslexia and typically developing children. *Memory & Cognition, 34*, 703–714. doi:10.3758/BF03193589

Caravolas, M., Hulme, C., & Snowling, M. J. (2001). The foundations of spelling ability: Evidence from a 3-year longitudinal study. *Journal of Memory and Language, 45*, 751–774. doi:10.1006/jmla.2000.2785

Cardoso-Martins, C., Corrêa, M. F., Lemos, L. S., & Napoleâo, R. F. (2006). Is there a syllabic stage in spelling development? Evidence from Portuguese-speaking children. *Journal of Educational Psychology, 98*, 628–641. doi:10.1037/0022-0663.98.3.628

Cardoso-Martins, C., & Pennington, B. F. (2004). The relationship between phoneme awareness and rapid serial naming skills and literacy acquisition: The role of developmental period and reading ability. *Scientific Studies of Reading, 8*, 27–52. doi:10.1207/s1532799xssr0801_3

Cassar, M., Treiman, R., Moats, L., Pollo, T. C., & Kessler, B. (2005). How do the spellings of children with dyslexia compare with those of nondyslexic children? *Reading and Writing, 18*, 27–49. doi:10.1007/s11145-004-2345-x.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading, 9*, 167–188. doi:10.1207/s1532799xssr0902_4

Evans, M. A., & Saint-Aubin, J. (2005). What children are looking at during shared storybook reading. *Psychological Science, 16*, 913–920. doi:10.1111/j.1467-9280.2005.01636.x

Ferreiro, E. (1990). Literacy development: Psychogenesis. In Y. M. Goodman (Ed.), *How children construct literacy: Piagetian perspectives* (pp. 12–25). Newark, DE: International Reading Association.

Ferreiro, E., Pontecorvo, C., & Zucchermaglio, C. (1996). *Pizza* or *piza*? How children interpret the doubling of letters in writing. In C. Pontecorvo, M. Orsolini, B. Burge, & L. B. Resnick (Eds.), *Children's early text construction* (pp. 145–163). Mahwah, NJ: Erlbaum.

Ferreiro, E., & Teberosky, A. (1982). *Literacy before schooling.* Portsmouth, NH: Heinemann.

Garcia, N. P., Abbott, R. D., & Berninger, V. W. (2010). Predicting poor, average, and superior spellers in grades 1 to 6 from phonological, orthographic, and morphological, spelling, or reading composites. *Written Language & Literacy, 13*, 61–98. doi:10.1075/wll.13.1.03gar

Gentry, J. R. (1982). An analysis of developmental spelling in *GNYS AT WRK*. *The Reading Teacher, 36*, 192–200.

Gombert, J. E., & Fayol, M. (1992). Writing in preliterate children. *Language and Instruction, 2*, 23–41. doi:10.1016/0959-4752(92)90003-5

Good, P. (1994). *Permutation tests: A practical guide to resampling methods for testing hypotheses.* New York: Springer.

Gough, P. B., & Hillinger, M. L. (1980). Learning to read: An unnatural act. *Bulletin of the Orton Society, 30*, 179–196. doi:10.1007/BF02653717

Kessler, B. (2009). Statistical learning of conditional orthographic correspondences. *Writing Systems Research, 1*, 19–34. doi:10.1093/wsr/wsp004

Leppänen, U., Nieme, P., Aunola, K., & Nurmi, J. E. (2006). Development of reading and spelling Finnish from preschool to Grade 1 and Grade 2. *Scientific Studies of Reading, 10*, 3–30. doi:10.1207/s1532799xssr1001_2

Lervåg, A., & Hulme, C. (2010). Predicting the growth of early spelling skills: Are there heterogeneous developmental trajectories? *Scientific Studies of Reading, 14*, 485–513. doi:10.1080/10888431003623488

Levenshtein, V. I. (1965). Двоичные коды с исправлением выпадений, вставок и замещений символов. *Доклады Академий Наук СССР, 163*, 845–848. English version published in 1966 as: Binary codes capable of correcting deletions, insertions, and reversals. *Soviet Physics Doklady, 10*, 707–710.

Levin, I., & Bus, A. G. (2003). How is emergent writing based on drawing? Analyses of children’s products and their sorting by children and mothers. *Developmental Psychology, 39*, 891–905. doi:10.1037/0012-1649.39.5.891

Levy, B. A., Gong, Z., Hessels, S., Evans, M. A., & Jared, D. (2006). Understanding print: Early reading development and the contributions of home literacy experiences. *Journal of Experimental Child Psychology, 93*, 63–93. doi:10.1016/j.jecp.2005.07.003

Nikolopoulos, D., Goulandris, N., Hulme, C., & Snowling, M. J. (2006). The cognitive bases of learning to read and spell in Greek: Evidence from a longitudinal study. *Journal of Experimental Child Psychology, 94*, 1–17. doi:10.1016/j.jecp.2005.11.006

Pinheiro, A. M. V. (1996). *Contagem de freqüência de ocorrência de palavras expostas a crianças na faixa pré-escolar e séries iniciais do 1º grau* [Frequency count of words children are exposed to in preschool and the first years of primary education] [Computer software]. São Paulo, Brazil: Associação Brasileira de Dislexia.

Pollo, T. C., Kessler, B., & Treiman, R. (2009). Statistical patterns in children's early writing. *Journal of Experimental Child Psychology, 104*, 410–426. doi:10.1016/j.jecp.2009.07.003

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926–1928. doi:10.1126/science.274.5294.1926

Shaywitz, S. E., Escobar, M. D., Shaywitz, B. A., Fletcher, J. M., & Makuch, R. (1992). Evidence that dyslexia may represent the lower tail of a normal distribution of reading ability. *The New England Journal of Medicine, 326*, 145–150.

Stein, L. M. (1994). *TDE: Teste de desempenho escolar: Manual para aplicação e interpretação* [Test of scholastic performance: Administration and interpretation manual]. São Paulo: Casa do Psicólogo.

Treiman, R., Cohen, J., Mulqueeny, K., Kessler, B., & Schechtman, S. (2007). Young children's knowledge about printed names. *Child Development, 78*, 1458–1471. doi:10.1111/j.1467-8624.2007.01077.x

Treiman, R., Levin, I., & Kessler, B. (2007). Learning of letter names follows similar principles across languages: Evidence from Hebrew. *Journal of Experimental Child Psychology, 96*, 87–106. doi:10.1016/j.jecp.2006.08.002

Treiman, R., Levin, I., & Kessler, B. (2010). Linking the shapes of alphabet letters to their sounds: The case of Hebrew. *Reading and Writing.* Advance online publication. doi:10.1007/s11145-010-9286-3

Treiman, R., & Yin, L. (2011). Early differentiation between drawing and writing in Chinese children. *Journal of Experimental Child Psychology*, 108, 786–801. doi:10.1016/j.jecp.2010.08.013

Vernon, S. A., & Ferreiro, E. (1999). Writing development: A neglected variable in the consideration of phonological awareness. *Harvard Educational Review, 69*, 395–414.

Wechsler D. (2002). *WISC-III: Escala de inteligência Wechsler para crianças: Adaptação brasileira da 3ª edição* [Wechsler intelligence scale for children: Brazilian adaptation of the 3rd edition]. São Paulo: Casa do Psicólogo.

Worden, P. E., & Boettcher, W. (1990). Young children's acquisition of alphabet knowledge. *Journal of Reading Behavior, 22*, 277-295.

Table 1

Participant Characteristics

	All children[a]		Prephonological[b]	
Measure	*M*	*SD*	*M*	*SD*
In preschool				
Age in months	50.7	4.0	50.7	3.9
Words read	0.6	2.5	0.2	0.5
Letter names	12.7	7.5	11.7	7.0
Letter sounds	10.1	5.2	8.9	4.7
In primary school				
Age in months	81.1	3.9	81.1	3.8
TDE reading[c]	49.8	16.5	48.5	14.7
TDE writing[c]	15.6	6.7	14.7	5.9
Vocabulary[d]	15.1	3.6	14.6	4.0
Cubes[d]	14.1	3.6	14.5	3.5

[a]38 girls, 28 boys. [b]17 girls, 14 boys. [c]*Leitura* 'reading' and *escrita* 'writing' subtests of Stein (1994), number of correct words. [d]Brazilian WISC-III subtests (Wechsler, 2002), standardized scores. 3 children (1 prephonological) were unavailable for WISC testing.

Table 2

Words Dictated in the Preschool Spelling Task

Orthography	Pronunciation	Gloss
chá	ˈʃa	'tea'
flor	ˈfloh	'flower'
pé	ˈpɛ	'foot'
bico	ˈbiku	'beak', 'nipple'
dedo	ˈdedu	'finger'
lobo	ˈlobu	'wolf'
barata	baˈrata	'cockroach'
cavalo	kaˈvalu	'horse'
cigarro	siˈgahu	'cigarette'
bicicleta	bisiˈklɛta	'bicycle'
tartaruga	tahtaˈruga	'turtle'
telefone	teleˈfõni	'telephone'

Table 3

Spellings Accepted as Phonologically Plausible in Preschool Spelling Task

Sound	Spellings
a	a, ha, ah
b	b
bi	b
d	d
e	e, ei
ɛ	e, he
f	f
h	r, rr
i	i, hi, e, ih
k	c, q
l	l, lh
n	n
o	o, ho, oh
õ	o, om
p	p
r	r
s	s, c, x, z
ʃ	x, ch
t	t
u	u, o, uh
v	v

Table 4

Text Frequency Variables for Prephonological Preschoolers

Variable	Mean	*SD*	Largest
Monograms	.310	.129	.502
Digrams	.128	.062	.237
Idiograms	.451	.270	.920

Table 5

Linear Regression Predicting Primary School Spelling Scores From Preschool Text Frequency Correlations of Prephonological Spellers

Variable	Coefficient	SE
Digrams	71.38***	13.87
Idiograms[a]	-9.07*	3.47

[a]Idiogram proportions squared.

*p < .05. ***p < .001.