Similarities Among the Shapes of Writing and Their Effects on Learning

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Abstract

Writing systems are usually studied in terms of the level of language that they represent, with little attention to the shapes that are used to do so. Those shapes are not random or accidental, however. They tend to be similar to one another within a script. Many of the Latin letters have a roughly vertical stem or *hasta* with an appendage or *coda* to the right. This arrangement is more common than one with the coda on the left of the hasta. We present data to show that young children are generally better at copying and writing from memory shapes such as <b> and <F>, which have the typical arrangement with the coda on the right, than those such as <d> and <J>, which do not. The results suggest that children start to learn about the statistics of the letter shapes before they know how or that these shapes represent language.

Key words: letter shapes, letters, learning, Latin alphabet, children, reversal, left-right orientation, directionality

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1. Introduction

Writing systems are typically classified in terms of how they represent language. For example, a system is an alphabet if its basic symbols stand for phonemes and a syllabary if its symbols stand for syllables. Such typologies draw attention toward the linguistic units that the symbols of writing represent and away from the characteristics of the symbols themselves. Our goal, in this paper, is to return attention to the symbols' shapes. Sets of symbol shapes follow certain common principles across scripts, regardless of whether the writing system is alphabetic, syllabic, or logographic. One of these principles, and the one on which we focus here, is a tendency for the symbols of a script to look similar to one another. We investigate similarities in orientation among the letters of the Latin script and how those similarities affect children's learning of the shapes. We present new empirical evidence to show that children's knowledge about the orientation of the letter shapes causes them to learn certain shapes more easily than others and to make systematic reversal errors.

2. Similarity among the shapes of Latin letters

A well-designed script is not a random collection of shapes. The symbols share certain graphic features; they have a degree of homogeneity (Watt, 1983). For example, the Latin script includes <B> and <E> and the Devanagari script includes <र> and <द>. One would be surprised if a script included all four of these shapes.

In this paper, we focus on some of the similarities among the letters of the Latin alphabet. These letters consist of circles, semicircles, and lines. A number of the letters may be analyzed as composed of a vertical or semi-vertical stem together with appendages that are all or mostly on the right. The lowercase shape <b>—a vertical stem and roughly a circle on the right—is a good example of a letter with such a structure. Letters of this sort date back to the origins of the Latin alphabet. As Watt (1983) and Brekle (1994) discussed, many letters of the Phoenician alphabet already consisted of a long vertical stroke together with another portion. For example, the Phoenician letter <𐤄> had this form. Brekle used the terms *hasta* and *coda* to refer to the vertical stroke and the appendage, respectively, and we adopt that terminology here.

The hasta–coda structure has been maintained across the millennia as an organizing principle of the alphabet, even as it was successively borrowed and adapted by Greeks, Etruscans, Romans, and, in the form of the modern Latin alphabet, by speakers of hundreds of modern languages, including English. The uppercase letters of the classical Latin alphabet, as well as the lowercase forms that evolved later, more often than not begin with a hasta on the left side and have a coda to the right. This asymmetry results in what Brekle (1994) termed *vectoriality* for most letters: People perceive most of them as facing into the direction of writing. That is, a letter is perceived as looking at the next letter. This vectoriality holds also in production. Most individual letters tend to be written from left to right, starting with a downstroke constituting the hasta and concluding with the coda elements to the right side, near where the next letter will be written.

We refer to letters with a hasta to the right of the coda as b type letters. A minority of letters, the d type, show the reverse vectoriality. Table 1 lists the asymmetric letters that fall into the two categories. There are some differences across fonts and printing styles, and some of the most important variants are indicated in the table. The numbers of b and d type letters differ somewhat depending on the font, but it is clear that the b type letters outnumber the d type ones. We return later to the case of digits, where an examination of Table 1 shows the opposite situation.

INSERT TABLE 1 ABOUT HERE

3. Effects of similarity on learning

The symbols of a script may share certain graphic properties, but do these properties affect how people learn and use the shapes? Watt (1983) suggested that they do. Speaking about the alphabet as a system with homogeneity, he suggested that, although children could learn the system as individual elements unconnected with one another, they instead internalize some general principles. They unconsciously learn that the ideal letter has the hasta to the left and the coda to the right. If children remember that a letter has a hasta + coda structure but don't remember the side on which the coda goes, they may recall the general rule. For most letters, such as <B>, this gives the right result. For other letters, such as <J>, it gives the wrong result, a reversal. Watt (1983) cites unpublished data from David Jacobs to support the idea that children reverse letters such as <J> more often than letters such as <B>. However, he does not provide any details about the experiment, and no numbers or statistics. Nor does Watt consider the possibility that any observed asymmetries could actually reflect other properties of the letters, such as their frequency. For example, if children reverse <J> more often than <B>, perhaps this is because they have had less experience with the former letter.

Developmental and educational psychologists have conducted many studies of children's writing of letters, and these studies amply document the existence of reversal errors. However, most of these researchers have pooled across letters in their discussions of reversals, not considering the possibility that children may reverse some letters more often than others. Because the work of Watt (1983) comes from a semiotic tradition, and because it was in written in German, it has had little or no impact on the psychological and educational research on letter learning that has been carried out in North America. The study of Simner (1984) is one of the few in this tradition to have examined children's errors in the writing of letters as a function of the letters' vectoriality. Simner asked Canadian children to copy letters and numbers, and he reported that 5-year-olds are more likely to produce left–right reversals of forms such as <d> and <J> than forms such as <b> and <k>. Simner found this result in the course of testing some ideas about the printing of left-handed as compared to right-handed children. The predictions about handedness were not supported, and this may help to explain why Simner's results have not had much impact.

In the following sections, we present new empirical tests of the ideas put forward by Watt (1983) and Simner (1984). We explore the hypothesis that children who are exposed to the Latin letters notice, from an early age, that the b type pattern is more common than the d type pattern. Children's implicit knowledge of the typical pattern aids their performance with letters like *b*, which have the most common orientation, but it leads them to difficulties with letters like *d*. We provide new evidence for this idea by analyzing data from previous studies in which children were asked to copy and print letters. We go beyond the results presented by Simner in that we examine data on correct performance as well as data on reversal errors. In addition, we carry out analyses designed to determine whether any observed differences between b type and d type letters reflect their orientation or whether the differences may be due to other properties of the letters, such as how often they occur.

The current surge of interest in statistical learning (see Saffran 2010 for a review) makes this a good time to reexamine the ideas put forward by Watt (1983) and Simner (1984). Studies on the topic of statistical learning show that that people are attuned to the frequency distributions of events in their environments and that they use their knowledge of those statistics to make educated guesses. People supplement the knowledge that they have gained from experience with individual instances with general knowledge that they have abstracted across instances. Consider an everyday example. People who typically drive automobiles of certain makes notice that the fuel tank is more often on the driver's side than on the passenger's side. When such a person rents a vehicle he hasn't driven before, he will probably assume that it follows the same arrangement. He will pull up to a pump for refueling on the wrong side if the vehicle doesn't follow the typical pattern.

Statistical learning may be used in a variety of domains, including the domain of writing. Children in modern societies see writing in great abundance, including at home, in preschool, and on the street. They would be expected to apply their statistical learning skills to the graphic forms that they encounter, even before they know what these forms represent. Children who are exposed to the Latin script may implicitly notice that a number of symbols have a hasta on the left and a coda on the right, whereas fewer have the opposite orientation. When unsure of a letter's orientation, children may use the most common form. This should lead to more accurate performance on letters such as <b> and <L> than on letters such as <d> and <J>. It should also lead to an asymmetry in errors. Cases in which children write <d> as <b>or make the curve at the bottom of <J> point right instead of left should be more common than the opposite types of errors. With both letter components and fuel tanks, people may not be consciously aware of why they make the choices they do. The patterns in the environment may not have been pointed out to them in any explicit way. Nevertheless, we expect people to learn and use the patterns.

The hypothesis about directionality that has come out of the North American psychological and educational studies is that children—especially those with reading difficulties—have difficulty attending to and remembering left–right orientation (see Kaufman 1980 for a review). This view leads to the prediction that children will often confuse letters such as <b> and <d>, and many studies suggest that they do. If children don't attend to or remember left-right orientation, however, confusions should not be more common in one direction than the other. The present hypothesis, stemming from the work of Watt (1983) and

Simner (1984) and the recent work on statistical learning, is that such asymmetries should exist. Orientation should be more often correct for b type letters than for d type letters, and reversals should be more common for d type forms.

4. Data

To test the ideas outlined above, we present new analyses of data that have previously been reported on letter copying and printing in learners of the Latin alphabet. Although many previous researchers pooled data across letters, some reported results for individual letters. We used such data, when available, to carry out our own analyses of children's performance on different types of letters. There are advantages to using old data for new purposes. We can test hypotheses more quickly and economically than if starting from scratch. We don't have to worry that the experimenters showed an unconscious bias to verify our hypothesis, since the ideas being tested here were not in their minds when they collected the data. There are also some limitations in using previously collected data. For example, we did not locate any studies that were carried out in non-English-speaking countries that use the Latin alphabet. New data will need to be collected to fill this and other gaps. However, the analyses we report provide a foundation for future work.

4.1. Asymmetries in correctness and legibility of letter printing and copying

If children exposed to the Latin alphabet learn that the b type pattern is more common than the d type pattern, then they should perform better on letters that fit the typical pattern than on letters that do not. To find data that could be used to test this prediction, we searched for published studies in which children from countries that use the Latin script were asked to copy each letter of the alphabet or to print it from memory and in which data on the correctness or legibility of each letter were presented in the published report or available from the authors.

We used all such data we could find, with the exception of data from groups of children who were old enough and experienced enough to make few or no errors in these tasks.

We found four studies in which children were asked to copy or print from memory all of the letters of the Latin alphabet and in which data on correctness or legibility for each letter were available. The first such study (Coleman 1970) was carried out with 10 preschoolers who ranged in age from 4;4 (years;months) to 5;3 and who seem to have lived in the southwestern United States. The experimenter printed each lowercase letter while describing its shape, for example describing *c* as an “almost circle.” The child watched the experimenter write the letter and then copied it. This procedure was repeated eight times for each letter. Our analyses use the total number of correct productions for each letter over the eight trials.

A second study was that of Worden and Boettcher (1990). The experimenter said the name of each letter and the children were asked to print both its upper- and lowercase forms. The letters were not presented in alphabetical order. The participants whose data we analyze were 35 U.S. 4-year-olds (age range about 3;6 to 4;6), 38 5-year-olds (about 4;6 to 5;6), and 40 6-year-olds (about 5;6 to 6;6) from California. We use data on the proportion of correct responses to each letter in each case for each age group.

A third data set comes from Graham, Weintraub, and Berninger (2001). In this study, U.S. children from the Pacific Northwest were asked to print lowercase manuscript letters in alphabetical order as quickly as possible without making any mistakes. The authors reported the percentage of legible productions of each letter. These were cases in which the letter was clearly identifiable and could not be confused with another letter. We use data from 100 first graders, approximately 6 to 7 years old.

The fourth set of data come from a study by Ritchey (2008) in which 57 kindergartners from the northeastern United States with a mean age of approximately 5;9 were asked to print the upper- and lowercase forms of each letter. The letter names were dictated by the experimenter in a scrambled order. Ritchey scored the responses for legibility, as defined by whether the letter could be identified in isolation. She kindly sent us data on the proportion of legible responses for each letter.

For each study, we examined the results for unambiguous b type letters and d type letters. We also examined the results for symmetrical letters. Letters were classified based on the specific forms that were presented in each study, when provided in the published reports, or on knowledge of the printed sans serif letter shapes that are typically used with U.S. children. The classification also took into account the scoring procedures of each study. For example, one can write a legible lowercase *u* with or without a vertical stem on the right. In a study that measured legibility, this letter could fit either in the symmetrical or d type category and, given its ambiguity, would not be included in the analysis. Note that some letters, such as <c>, do not fall into any of the three categories of interest. Table 2 shows the results for each type of letter for each age group in each study.

INSERT TABLE 2 ABOUT HERE

The Coleman (1970) data were subjected to a one-way ANOVA (analysis of variance) with the factor of letter type (b type, d type, symmetrical). A main effect of letter type was found, $F(2, 16) = 5.99$, $p = .01$. Planned comparisons used one-tailed tests given the directional hypotheses, and they showed that children performed better on symmetrical than asymmetrical letters. The trend toward better performance on b type letters than d type letters was not statistically significant.

An ANOVA on the Worden and Boettcher (1990) data used the factors of letter type, case (upper, lower) and age group (4, 5, 6). There was a main effect of case, $F(1, 36) = 8.25$, $p = .007$, such that children did better on uppercase letters than lowercase letters. This is a common finding for young U.S. children (Treiman & Kessler 2004; Worden & Boettcher 1990), and it probably reflects in large part their greater experience with uppercase letters. We also saw the expected main effect of age, $F(2, 72) = 209.93$, $p < .001$, with older children performing better than younger ones. The main effect of letter type, $F(2, 36) = 11.64$, $p < .001$, was qualified by interaction with age, $F(4, 72) = 3.21$, $p = .018$. To help understand the interaction, we performed separate analyses for each age group using the factors of letter type and case. The 4-year-olds showed a main effect of letter type $F(2, 36) = 4.80$, $p = .014$, with planned comparisons showing better performance on symmetric than asymmetric letters. The trend toward better performance on b type letters than d type letters was not statistically significant by this test. The 5-year-olds showed a main effect of letter type $F(2,36) = 9.54$, $p < .001$, and planned comparisons showed better performance on symmetric than asymmetric letters and better performance on b type than d type letters. The 6-year-olds too showed a main effect of letter type $F(2,36) = 9.33$, $p = .001$, with significantly better performance on symmetric than asymmetric letters and significantly better performance on b type letters than d type letters. The effect of letter case was significant in the separate analyses of the 4- and 5-year-olds, $F(1, 36) = 13.80$, $p < .001$ and $F(1, 36) = 7.81$, $p = .008$, respectively, but was not significant for the 6-year-olds.

The Graham et al. (2001) data were submitted to a one-way ANOVA using the factor of letter type. There was a significant effect, $F(2,16) = 4.20$, $p = .034$. Planned comparisons showed better performance on symmetric than asymmetric letters and better performance on b type letters than d type letters.

The data from Ritchey (2008) were analyzed using the factors of letter type and case. The only significant effect was the main effect of letter type $F(2,33) = 7.50$, $p = .002$. Planned comparisons showed significantly better performance on symmetric than asymmetric letters and better performance on b type than d type letters.

The analyses reported so far used parametric statistical tests. We used these tests in part because there are no equivalent nonparametric tests when there is more than one variable, such as letter type and letter case. However, there is a concern that the assumptions of parametric tests might not be met in that some of the data sets showed more variability within the d type category than the other categories. We therefore carried out Kruskal-Wallis ANOVAs by ranks using the factor of letter type. These tests were performed separately for each study and age group, pooling over upper- and lowercase when both cases were used. These tests were followed up with Mann–Whitney one-tailed tests to compare symmetrical to nonsymmetrical letters and b type to d type letters. All of the effects involving letter type that were significant in the parametric analyses were significant in the nonparametric analyses. In addition, the 4-year-olds tested by Worden and Boettcher (1990) showed significantly better performance on b type than d type letters according to the nonparametric test ($p = .035$, one tailed), a difference that was not significant by the previously reported parametric test. Table 2 shows the differences that were significant by the nonparametric tests.

To summarize, children were more accurate on b type letters than d type letters when copying them and when printing them from memory. A numerical superiority for b type letters was found for all groups of children in all studies. Statistically, the difference between the two types of letters was least secure for the groups that were least experienced with the Latin letters—the children tested by Coleman (1970) and the 4-year-olds tested by Worden and Boettcher (1990). The differences were statistical significant for the more experienced children. The interaction between letter type and age in the Worden and Boettcher data further supports the idea that a certain amount of experience with letters is needed before children show a strong superiority for the b type pattern. Our results suggest that children who have had such experience pick up the fact that more letters have b type pattern than the d type pattern. Children who remember that a letter has a vertical or roughly vertical stem with some other form attached to it but who are unsure whether that other form is attached on the right or the left tend to assume that the letter has the more common pattern. As a result, children do better with b type letters than d type ones. Children do better with symmetrical letters than they do with either b type or d type letters, in part because no decisions about orientation are necessary with symmetrical letters. Our results suggest that children in literate societies that use the Latin script learn about the typical directionality of hasta + coda letters at a young age, well before they are formally taught to read and write (which normally begins around the age of six in North America). That is, children begin to learn about the visual properties of the letter forms before they know how letters represent sounds, or even that they represent sounds.

Before accepting the results as support for our hypothesis, we must ask whether they could be due to some confounding factor. Perhaps forms such as <b> and <L> are easier than others not because they have the coda on the right but for some other reason. One possible confounding factor is the number of segments in a letter. We counted the minimum number of segments that would be necessary to produce a correct or legible letter, for example counting <R> as 3 (the hasta, the semicircle, and the diagonal segment), and <p> as 2 (the hasta and the semicircle). For lowercase letters, there was a statistically significant negative correlation of moderate size between number of segments and accuracy in the Coleman (1970) data and the Worden and Boettcher (1990) data on 4-year-olds (r = -.50 and -.41, p = .018 and .005, one-tailed, respectively). The correlations between number of segments and performance were not statistically significant for the other lowercase letter data sets or for the uppercase letters. When we analyzed the number of segments in the symmetrical, b type, and d type letters of each study, we did not find any statistically reliable differences among them. Thus, the observed differences in performance among the three types of letters do not appear to reflect differences in complexity, at least when measured as done here.

Another possibility is that children perform better on letters that commonly occur in texts than on letters that do not and that letter frequency might be confounded with letter type. To address this possibility, we used the frequency counts of Jones and Mewhort (2004) for letters in each case. These counts are based on adult reading material, counts of this sort not being available for reading materials designed for children. Using the logarithms of the frequency counts to make the distributions more normal, we found significant, moderate correlations between frequency and lowercase letter performance for the Worden and Boettcher (1990) 6-year-olds ($r = .49$, $p = .006$, one-tailed), the Graham et al. (2001) first graders ($r = .59$, $p = .001$, one-tailed), and the Ritchey (2008) kindergartners ($r = .43$, $p = .014$, one-tailed). The correlations were not statistically significant for the Worden and Boettcher (1990) 4- and 5-year-olds or Coleman (1970) preschoolers. For uppercase letters, there were significant correlations for the Worden and Boettcher 5-year-olds ($r = .41$, $p = .020$, one-tailed) and the Worden and Boettcher 6-year-olds ($r = .34$, $p = .045$, one-tailed), but no significant correlation for the Worden et al. 4-year-olds. The lack of significant effects for younger children may reflect the fact that these children's experiences with letters are somewhat idiosyncratic, determined not so much by the letters' frequencies in texts as by such things as the letters in their own names (Treiman, Kessler, & Pollo 2006). Further analyses showed that the b type, d type, and symmetrical letters did not differ significantly from one another in frequency. It would be thus difficult to argue that children do better on the b type letters than the d type letters because the former are more common in the writing that they see.

Another factor that needs to be considered is the presence of descenders, or parts of a letter that go below the line of print. Five Latin lowercase letters have descenders, and four of these are of the d type. If descenders are difficult for children, this could contribute to poor performance on lowercase d type letters. The most obvious problem that could occur in writing letters with descenders is incorrect placement relative to the line of print. For example, children could write lowercase *p* on the line rather than with a tail extending below the line. However, two of the studies that we looked at measured legibility, which would not be impaired by such errors. Indeed, Ritchey (2008) specifically mentioned that the children did not write on lined paper, meaning that misplacements relative to the line of print could not have been a problem. Although several lowercase letters have descenders, no uppercase ones do. The fact that we found similar patterns of results with the two cases further militates against the idea that the presence of descenders can explain away all of our results.

In part because North American children have a good deal of experience with the uppercase letters before they master the lowercase ones, these children tend to perform better on lowercase letters that are like their uppercase counterparts in shape (Treiman & Kessler 2004). The proportion of lowercase letters that are similar to their uppercase forms does not appear to be much different for the b type letters than the d type ones, though, speaking against the idea that this factor explains our results. Also, similarity between the upper- and lowercase forms influences the performance of North American children primarily on lowercase letters. We found similar results for uppercase letters and for lowercase ones, and so it appears that the superiority for b type over d type letters cannot be explained away on the basis of differences between the two types of letters in the similarity of their uppercase and lowercase forms.

In additional analyses, we examined children's performance on pairs of letters that are similar or identical except for orientation. Such analyses provide a good way to determine whether other aspects of letter form, beyond the position of the coda to the left or right of the hasta, can explain the results. We examined the pairs *b/d*, *p/q*, and *L/J*, asking whether the children in each age group in each study did better on the first member of the pair (the b type letter) than the second member of the pair (the d type letter). There was one tie (*b* vs. *d* for the 4-year-olds of Worden and Boettcher 1990) and 15 comparisons that went in the predicted direction. The difference was significant at the .001 level by a sign test.

4.2 Asymmetries in letter reversals

We have seen that children make more errors in copying and writing d type letters than b type letters. The difference arises, we presume, because the former letters are more susceptible to reversal than the latter. To test this idea directly, we looked for studies in which children in countries that use the Latin script were asked to print or copy all of the letters of the alphabet and in which the researchers reported data on reversal errors for individual letters. We predicted that left–right reversal errors would be more common for d type letters than b type letters. Note that some of these reversals yield other letters, as when <d> is miscopied as <b>, and some do not, as when <y> is copied backwards. We located three studies in which learners of the Latin alphabet were tested on all letters of the alphabet and in which error data for individual letters were reported.

The first set of data was that of Simner (1984). These data came from 72 Canadian kindergartners with a mean age of 5;6. Each upper- and lowercase letter was shown for 2.5 seconds and then removed, and the child was asked to print the letter from memory. The letters were presented in a random order. Numbers were also included in the study, and we discuss the results on these in a later section. (The analyses that Simner himself presented pooled over letters and numbers, and Simner defined **b** type and **d** type forms a bit differently than we did.) We also used the reversal data from Ritchey (2008). As described above, this study involved 57 U.S. kindergartners with a mean age of 5;9.

The third set of data was from Lewis and Lewis (1965), who tested 354 first graders from California in the U.S. Each child was tested at the beginning of the school year and again near the end. The authors reported the data pooled across the two testing points. The children's ages were not reported, but they are likely to have been between 6 and 7 years of age. The children saw model uppercase and lowercase letters and copied each model onto lined paper. They began at a randomly selected point in the alphabet and proceeded in alphabetical order. Lewis and Lewis classified the errors into a number of categories, one of which was mirror-image reversals. If a child made more than one type of error on a letter, the error was scored in all of the relevant categories. We examined the data on mirror-image reversals and all of the other types of errors that may occur on each of the letters that is not vertically symmetrical. These include: partial omission (any part of a letter shown in the model was missing), addition (inclusion of a part not shown in the model), incorrect size (the whole letter form or any part of it was judged too large or too small), rotation (the form was rotated more than 15 degrees from a vertical line drawn through its axis), reconstruction (all or part of the letter was reconstructed after an initial effort), and not attempted (the child did not try to copy the letter).

The letter reversal data from each study, which are shown in Table 3, were subjected to ANOVAs using the factors of letter case (upper, lower) and letter type (**b** type, **d** type). Case did not participate in any statistically significant effects in any of the studies. There were reliable effects of letter type in the data of Simner (1984), $F(1, 20) = 11.72$, $p = .003$, and Lewis and Lewis (1965), $F(1, 17) = 18.04$, $p < .001$; the effect was at the .06 level in the Ritchey (2008) data, $F(1, 17) = 4.06$. Parametric analyses may be problematic here because they assume equal variances, and there was a tendency in all data sets for more variability among the d type than the b type letters. We therefore performed nonparametric analyses, pooling across upper- and lowercase and then using one-tailed Mann–Whitney tests to compare d type and b type letters. These showed significantly more reversals on d type letters than b type letters in all three studies ($p = .007$ for Simner, $p = .013$ for Ritchey, $p < .001$ for Lewis and Lewis).

INSERT TABLE 3 ABOUT HERE

Among the d type letters, <d> had the highest reversal rate in all studies. This is probably because it is a familiar form when reversed. There was some tendency for relatively low reversal rates for <ɑ>, which when written in the form typically used with children has a short stem on the right, and <u>, which has the same short stem. The reversal rate was also relatively low for <g>, which is a d type letter in the form typically used with children and where both the semicircle and the curve at the bottom of the tail would need to be wrongly oriented in order to yield a reversal. However, we cannot draw firm conclusions about differences among letters in the d category because the rankings differ in some respects across the studies.

Lewis and Lewis (1965) reported data not just on reversals but on other types of errors. We performed Mann–Whitney tests to determine if those types of errors occurred at different rates on the d type and b type letters. We used two-tailed tests because we did not have directional predictions for most of these errors. The d type letters showed more incorrect placement relative to the line of print, $p = .004$, and more reconstructions, $p = .005$. Incorrect placement relative to the line of print may be more common on d type letters than b type letters because, as mentioned above, more d type letters have descenders. The difference in incorrect placement relative to the line of print was no longer significant when letters with descenders were excluded from the analysis. The greater number of reconstructions of d type letters might possibly reflect initial misplacements of the coda that were then erased or crossed out. Other types of errors, such as omitting part of a letter or making part of it the wrong size, did not differ reliably for the b type and d type letters.

We also examined the results in each study for pairs that are similar in most respects other than orientation: <b>/<d>, <p>/<q>, and <L>/<J>. There were 9 comparisons in all, and in 7 of these comparisons the results went in the predicted direction. The two exceptions involved <p> and <q> in the Simner (1984) and Ritchey (2008) studies, the two studies in which kindergartners wrote letters that were not in view. The letter <q> may be so uncommon that some kindergarten children don't know enough about its shape to produce a reversal. The difference in reversals for the matched pairs of letters results missed significance by a Wilcoxon signed ranks test ($p = .09$, one tailed).

Overall, the results are consistent with our hypothesis that children who are exposed to the Latin alphabet implicitly learn that a number of these letters have a hasta–coda structure with the coda on the right. Children who are unsure of a letter's form tend to assume that it has the most common one and so they may write <d> as <b> or write <J> with the bottom curve going to the right. Such errors begin to occur, it appears, when children know a certain amount about letters. These results suggest that children need some experience with letters in order to abstract the patterns that occur across the set. It will be important to collect additional data from children younger than those examined here in order to study the developmental course of the errors.

4.3. Asymmetries with forms other than letters

What is the set over which children implicitly calculate statistics on left–right orientation? Is it the set of letters or is it some broader set? To address this issue, we examined the case of numeric digits. The Latin letters and the Hindu-Arabic digits are visually similar in many ways, and they are often mixed in texts. It takes some time for children to learn that there are actually two sets of shapes—one that notates language and another that notates numbers. Testifying to children's confusions between the two sets, 5- and 6-year-olds sometimes accept a string that mixes letters and digits as a word (Bastien-Toniazzo 1992). These considerations lead to the idea that children may calculate statistics over the combined set of letters and numerals rather than over just the set of letters. Although the Latin letters and the Hindu–Arabic numerals share certain design principles, the digits are more likely to have d type arrangements, as Table 1 shows. Do young children learn about the left–right vectoriality of digits separately from letters, or do they pool over the two?

Watt (1983) reported that children evince both types of strategies, but he did not provide any quantitative or statistical data to support his conclusion or permit retrospective analysis. We found two studies that examined children's writing or copying of all of the digits from 0 to 9 and that reported data on left-right reversals for each digit. Simner (1984), as mentioned earlier, asked Canadian children with a mean age of 5;6 to copy digits as well as letters. Suggate, Aubrey, and Pettit (1997) showed arrays of different quantities of bricks (from 1 to 10) to 35 children in England aged 4;0 to 5;0 and asked them to put something on paper to show how many bricks there were. The authors reported the number of reversals for each numeral. No reversal errors were reported on the b type digit <5> in either study. Both studies reported some such errors on the d type numbers (a mean of 17% in the Simner study, a mean of 11 errors in Suggate et al.). In another study, Frith (1971) asked 251 English 4- to 9-year-olds to copy the digits <5>, <4>, and <7>, among some other items. Frith reported a higher percentage of reversals on the d type digits <4> (3.7%) and <7> (1.4%) than on the b type <5> (0.5%). There are just a few data points, but the results suggest that young children show the same reversal tendencies with digits that they do with letters. That is, children may pool digits and letters and calculate frequency statistics over the combined set. With that combined set, as with the set of letters, b type forms are more common than d type ones.

Moving from letters to digits to forms that are somewhat similar to these but that belong to neither set, we turn to a study by Goodnow and Levine (1973) in which children copied geometric designs that were placed in front of them. Across two experiments, there were five pairs of designs in which there was a hasta with a coda on the right in one member of the pair and a hasta with the same or similar coda to the left in the other member. One of the designs, <L>, was actually a letter. Nursery school children (mean age 4;5) and kindergarten children (mean age about 5;4) from the eastern United States participated. We carried out the Wilcoxon signed ranks test, pooling the data that the authors reported for all children who were asked to copy each pair; there were between 23 and 52 children, depending on the pair. The children made were significantly more reversal errors for the d type than the b type forms, $p = .034$ one-tailed for all 5 pairs; $p = .055$ one-tailed for the 4 pairs that did not include a real letter. The children apparently treated the forms they saw as similar to letters; indeed, they may not have known that most were not real letters. These results suggest that young children have the same reversal tendencies with certain geometric forms that they do with letters.

5. Summary of results

Learners of the Latin alphabet appear to notice that a number of its symbols have a vertical stem with an appendage attached to its right and that relatively few symbols have the opposite pattern. When shown a form that appears to belong to the set of writing symbols and asked to produce it themselves, children may place the appendage on the more typical side, even when the form is directly in front of them when they copy it. Similar tendencies are found when children write letters from memory: They tend to do better on letters that have the more common directional pattern than on letters that have the less common pattern, and they may reverse a form that has the less common pattern so as to make it more typical. Based on the data we examined, children show the same asymmetries with certain forms that look like letters, including digits and simple geometric forms. Thus, children show an elevated reversal rate for digits such as ＜7＞ as well as letters such as ＜d＞. The results suggest that children learn about the graphic patterns of the writing symbols that they see, even before they can read that writing. The results further suggest that, for certain purposes, young children place digits in the same category as letters.

6. Conclusions

Linguists who have studied writing systems have concentrated on the way in which they notate language. This is important, but it is also important to examine the characteristics of the symbols that are used to do so. These shapes are of interest not only when portions of them relate to language (as with the ＜゛＞ that consistently represents obstruent voicing in Japanese syllabograms like ＜が＞, ＜ぎ＞, and ＜げ＞; see Primus 2004 for ideas about similar phenomena in the Latin alphabet) but also when they do not. We have focused here on one property of the shapes: their tendency to be similar to one another within a system.

The specific aspect of similarity we examined—similarity among the letters of the Latin script in the typical directionality of the hasta–coda structure—influences children's learning of the letter shapes. Learners of the Latin alphabet implicitly pick up on the fact that letters that have the coda on the right are more common than letters that have the coda on the left. When copying letters and when writing them from memory, children tend to perform better on letters that have the more common directional pattern than on letters that have the less common pattern. They change uncommon patterns such as ＜d＞ into common patterns such as ＜b＞

more often than they make the opposite sort of error. These findings show that children supplement their memory for specific letter forms with knowledge of general patterns that they have abstracted across forms. That general knowledge boosts the rate of correct responses on letters such as <b>, but it can lead to errors on letters such as <d>. The set across which young children abstract patterns, our results suggest, includes digits as well as letters.

The mechanisms that give rise to these effects are the same mechanisms that are involved in many aspects of learning. People track what is more common and what is less common in their environments. When their memory for a specific instance is incomplete, they use the general knowledge that they have abstracted from exposure to a set of instances, and this leads them to favor the more common patterns. This explains why a friend of ours sometimes drives a rented car up to a fuel pump on the wrong side. It also explains why the majority of U.S. university students in one study, when asked to draw a penny, drew Lincoln's head facing to their left (Rubin & Kontis 1983). Lincoln's head actually faces right, but all the other U.S. coins in use at the time the study was performed had heads that faced left. Implicit statistical learning has been invoked in the learning of relationships between letters and sounds and in other more advanced aspects of spelling (Deacon, Conrad, & Pacton, 2008; Treiman & Kessler 2006), just as it has been invoked in other areas of learning (Saffran, 2010). The present results suggest that statistical learning plays a role in the initial learning of letter shapes.

Early work on letter reversal errors suggested that young children—especially those with reading problems—don't pay attention to or don't remember left–right orientation (e.g., Kaufman 1980). Many researchers have documented young children's reversal errors, but few have thought to ask whether the errors are symmetric or asymmetric. The asymmetry that we and a few other researchers (Simner, 1984; Watt, 1983) have observed points to a different idea: that children track orientation from an early age. They see the difference between forms such as <b> and <d> and they store information about the differences well enough to learn that forms of the former sort are more common than forms of the latter sort. However, it takes some time for children to learn that a form such as <b> and a form such as <d> must be placed into different categories for the purpose of reading and writing.

The present discussion of letter shapes has been confined to one aspect of the shapes, similarity in the left–right vectoriality of certain forms, and one script, the Latin alphabet. Similarity is just one of the principles that underlie systems of letter shapes across languages. As Watt (1983) pointed out, the similarity among the shapes of a system's symbols cannot go too far. Shapes need to contrast with one another in order to be distinguishable. This is the principle of contrast. In addition, shapes should be economical, easy to perceive and easy to produce. They should have a degree of redundancy, allowing a shape to be identified even if one portion has been overlooked. Conservatism is yet another principle behind systems of symbol shapes: Shapes should be similar to those that have come before. Finally, people want the symbols of their writing system to be attractive and expressive. Future studies are needed to explore the effects of these principles on the learning and use of symbol shapes, both in the Latin alphabet and in other systems.

When we look across scripts, we see many differences in the shapes of the symbols and in how the shapes are learned and used. We hope to have drawn attention to some of the underlying similarities that hold across scripts. Those similarities reflect the fact that systems of symbol shapes follow common principles across scripts, one of which is a tendency for the symbols of a script to share certain graphic features. Those similarities also reflect basic principles of learning. One of these, as we have seen, is that learners abstract patterns that hold across a set of instances and use those patterns to supplement their memory for the individual instances.

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Table 1

b *and* d type *Letters and Numbers*

	b type			d type		
	Lowercase	Uppercase	Digits	Lowercase	Uppercase	Digits
Forms found in most fonts	b, f, h, k, m, n, p, r	B, D, E, F, K, L, P, R	5	d, j, q, u, y	J	4, 7
Less common forms				ɑ, g	U	1, 9

Table 2

Children's Correctness or Legibility in Letter Printing and Copying Tasks as a Function of Letter Type

Study	Letter type			Significant differences (Mann–Whitney one-tailed tests)
	d type	b type	Symmetrical	
Coleman 1970 preschoolers	.31	.34	.57	Symmetrical > nonsymmetrical
Worden & Boettcher 1990, 4-year-olds	.06	.13	.24	Symmetrical > nonsymmetrical, b type > d type
Worden & Boettcher 1990, 5-year-olds	.14	.41	.52	Symmetrical > nonsymmetrical, b type > d type
Worden & Boettcher 1990, 6- year-olds	.55	.76	.87	Symmetrical > nonsymmetrical, b type > d type
Graham, Weintraub, & Berninger 2001	.68	.83	.87	Symmetrical > nonsymmetrical, b type > d type
Ritchey 2008	.69	.84	.88	Symmetrical > nonsymmetrical, b type > d type

Table 3

Children's Reversal Rates on b *and* d *Type Letters*

Study	Reversal rates	
	d type	b type
Simner 1984 kindergartners	.09	.03
Ritchey 2008 kindergartners	.11	.06
Lewis and Lewis 1965 first graders	.04	.01