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Linking the shapes of alphabet letters to their sounds: the case of Hebrew

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Abstract Learning the sounds of letters is an important part of learning a writing system. Most previous studies of this process have examined English, focusing on variations in the phonetic iconicity of letter names as a reason why some letter sounds (such as that of *b*, where the sound is at the beginning of the letter's name) are easier to learn than others (such as that of *w*, where the sound is not in the name). The present study examined Hebrew, where variations in the phonetic iconicity of letter names are minimal. In a study of 391 Israeli children with a mean age of 5 years, 10 months, we used multilevel models to examine the factors that are associated with knowledge of letter sounds. One set of factors involved letter names: Children sometimes attributed to a letter a consonant–vowel sound consisting of the first phonemes of the letter's name. A second set of factors involved contrast: Children had difficulty when there was relatively little contrast in shape between one letter and others. Frequency was also important, encompassing both child-specific effects, such as a benefit for the first letter of a child's forename, and effects that held true across children, such as a benefit for the first letters of the alphabet. These factors reflect general properties of human learning.

Keywords Alphabet · Hebrew · Letter names · Letter sounds

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Introduction

The building blocks of an alphabetic writing system are the letters. Each letter has a visual form, and each symbolizes one or more phonemes. The letters are referred to by labels which are different from the phonemes that they represent. For example, the shape ר stands for /r/ in Hebrew and is conventionally referred to as *resh*. Learning about the links between the shapes of letters and their sounds is an important foundation stone for learning to read and write (e.g., Snow, Burns, & Griffin, 1998). Children's knowledge of these links is often assessed by a letter-sound task in which they are shown isolated letters and are asked to provide the sound that is associated with each. In this paper, we examine young Israeli children's performance on the letter-sound task as a way of learning about the factors that are associated with knowledge of the relationships between letter shapes and sounds. Our primary interest was in properties of the letters themselves—why some letters are easier to learn than others.

Most previous studies of letter learning have been confined to English, a single and arguably unusual writing system (Share, 2008). One would not want to draw strong conclusions based on studies of one writing system, and so it is important to extend research on letter learning and literacy learning more generally to other orthographies. The present study was motivated by the hypothesis that letter-sound learning follows the same general principles that govern the learning of all types of associations. We thus expected many of the same factors to be important in Hebrew and in English.

We begin by describing some relevant aspects of early education in Israel. In the state schools that serve the majority of Israeli children, most children attend a program called *gan* starting from the age of 3. In the fall after they have passed their sixth birthday, children normally begin the first grade of primary education. In many kindergartens, including the ones attended by the children in the present study, children who are 1 and 2 years away from entering primary school are in the same classrooms and are exposed to the same activities and the same curricula. We examined children of these ages in the present study. Teaching of letters before first grade was traditionally frowned upon in Israel, but literacy-related activities such as learning about letters and learning to write one's name are now increasingly included in the pre-first grade curriculum. The Israeli children in our study were exposed to some such activities. These activities tend to focus more on letters' names than sounds, with the result that Israeli children are more knowledgeable about the former than the latter (Levin & Aram, 2004; Levin, Shatil-Carmon, & Asif-Rave, 2006). Israel is thus similar to many other modern literate societies, including the U.S., in that children begin to learn about letters, especially about their names, several years before they are formally taught to read and spell.

The Hebrew writing system is alphabetic (Ravid, 2006). All of the letters stand for consonants, but several letters can represent vowels as well. In the type of writing that is normally used with adults, many vowel phonemes are not symbolized. For example, the name *Rami* is written from right to left using the letters *resh* ר for /r/, *mem* מ for /m/, and *jud* י for /i/. The /a/ in the first syllable is not written. The term *abjad* is sometimes used to describe Hebrew and other writing systems that often do not write vowels. Hebrew does have a system, pointing, that may be used to symbolize vowels. In pointed writing, all of the vowel phonemes are indicated using diacritic marks. This type of writing is typically used in materials for children. Pointing also helps to disambiguate the pronunciations of certain Hebrew letters that, like English *c*, have more than one possible sound. For example, כ in unpointed script represents either /k/ or /x/. In pointed script, however, a dot is added to disambiguate the pronunciations, כּ as compared to כ.

Hebrew differs from English in other ways that are relevant to the present study as well. One difference is that Hebrew does not have separate sets of uppercase and lowercase letter shapes. However, five Hebrew letters have special forms that appear only at the ends of words. For example, ם is the form of מ *mem* that appears in this position. The two shapes look different, but both correspond to /m/. Conventionalized variation in letter shape as a function of position in word is not unique to Hebrew; it is also found in Greek and Arabic.

Hebrew differs from English in the nature of its letter names as well. Across writing systems, letter names are generally phonetically iconic: The name includes the sound that the letter represents (Treiman & Kessler, 2003). However, iconicity manifests itself somewhat differently across languages. In many languages, including Hebrew, the names of all or almost all letters are acrophonic. That is, the letter name begins with the phoneme that the letter symbolizes. For example, the Hebrew letter that stands for /r/ is named *resh*. In English, some letter names are acrophonic and others are not. Many English letters have their typical sounds at the beginnings of their names, as with *v*. Others, such as *l*, have their sounds at the ends of their names, a less accessible position. And a few letters do not have their sounds in their names at all, as with the name of *h*. Another difference between the letter names of Hebrew and English is that the former often contain three or more phonemes, whereas the latter normally contain one or two phonemes.

The fact that Hebrew often does not write vowels has implications for the learning of letter sounds. In English, the correct response to a letter such as *v* in the letter-sound task is considered to be the single phoneme /v/ or that phoneme followed by a reduced vowel, /və/. In contrast, users of Hebrew often consider that a letter stands for either a consonant (C) or a consonant–vowel syllable with a full vowel (CV). For instance, an Israeli adult who is asked about the sounds that the letters represent in the name *Rami* would usually say that the initial ר represents /ra/. When asked about the sounds that the letters represent in the name *Regev*, the adult would say that the initial ר represents /re/. A child therefore hears CV syllables with a variety of full vowels as the sound of the letter ר. This degree of variability is not found with English and other alphabets that typically write vowels. Israeli children often produce CV responses when asked about the sounds of isolated letters (Levin et al., 2006). One goal of the present study was to learn more about when and why children do this, and we therefore examined CV responses and C responses separately.

Children who are familiar with the name of a letter before learning its sound, as North American children typically are, use their knowledge of the name to make the link between the letter and the sound less arbitrary than it would otherwise be. Thus, U.S. and Canadian children of about 4–6 years of age tend to do better at providing the sounds of acrophonic letters than of letters that have their sound at the end of their name or letters that do not have their sound in their name at all (Ellefson, Treiman, & Kessler, 2009; Evans, Bell, Shaw, Moretti, & Page, 2006; Foy & Mann, 2006; Kim, Petscher, Foorman, & Zhou, 2010; McBride-Chang, 1999; Piasta & Wagner, 2010; Treiman & Broderick, 1998; Treiman, Pennington, Shriberg, & Boada, 2008; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). Variations in phonetic iconicity are such a prominent feature of English letter names that many of the studies just cited have focused on it to the exclusion of other properties of letters. The study of Hebrew forces us to consider seriously other factors because variations in phonetic iconicity are minimal in this system.

One class of factors that may be important involves the shapes of letters. The basic symbols of a writing system tend to be similar to one another in shape (Treiman & Kessler, in press). Hebrew letter shapes show this tendency toward similarity in that many have a vertical line and one or more attached horizontals, as with ך, ד, ר, ז, and ן. A high degree of similarity can make items hard to tell apart, hindering the assignment of distinct names and sounds to individual letters. Indeed, learners sometimes interchange the names of similar-looking letters (Levin, Saiegh-Haddad, Hende, & Ziv, 2008 for Arabic; Treiman, Levin, & Kessler, 2007 for Hebrew; Treiman, Kessler, & Pollo, 2006 for English and Portuguese). We would expect the same sorts of errors in the letter-sound task, but this has not been systematically investigated. We did so in the present study by analyzing replacement errors, as when children produce a response for ן that should be associated with ז.

Another aspect of letter shape that we examined with Hebrew involves the special word-final forms that were mentioned earlier. Learners of Hebrew perform worse on these final forms than on ordinary forms in the letter-name task (Treiman et al., 2007). Such differences have been attributed to a variety of factors, including the visual similarity between many of the final forms and other letters. In the present study, we asked whether children have special difficulty with final forms in the sound task as well. Because these letters almost always represent the final sounds of words, not followed by vowel sounds, adults who are explaining the sounds of letters would not be expected to provide a variety of CV syllables for final letters in the way that they do for ordinary letters. This lack of variability might benefit performance on final letters in the letter-sound task.

Frequency of exposure is an important determinant of learning: People are most apt to learn what they experience and attend to most often. If letter-sound learning is influenced by the same factors that affect learning in general, as we hypothesize, then frequency should be important. Some researchers have looked for frequency effects in children's learning of letter names by examining the frequency with which letters occur in books, or specifically in books that are designed for children. Such effects are small and in some cases not statistically significant among 3- to 5-year-old learners of the Latin alphabet (Ecalle, 2004 for French; Evans et al., 2006; Treiman & Kessler 2004; Treiman et al., 2006, 2007; Turnbull, Bowles, Skibbe, Justice, & Wiggins, in press for English). However, the effects appear to increase with age (Bouchière, Ponce, & Foulin, 2010 for French), and a study of Israeli 5- and 6-year-olds found statistically significant frequency effects in letter naming (Treiman et al., 2007). Two studies that examined effects of printed letter frequency in a letter-sound task did not find significant differences between more and less common letters for 5-year-old learners of the Latin alphabet (Ecalle, 2004; Evans et al., 2006).

These frequency effects may be weak for young children because, for them, exposure to letters in books is not a major source of input. Indeed, young children spend little time looking at the print in books while they are being read to (Evans & Saint-Aubin, 2005; Justice, Skibbe, Canning, & Lankford, 2005). Other interactions may be more important, as when adults talk about letters on signs, write letters and words for children, and so on. Such experiences often involve the first few letters of the alphabet. For example, children hear labels such as *alef-bet* for the Hebrew alphabet and ABCs for the English alphabet and see listings of the alphabet starting from the beginning. Treiman et al., (2007) found that Israeli children performed better on *alef* and *bet* in the letter-name task than anticipated on the basis of other factors. We asked in the present study whether the first letters of the alphabet also yield good performance in the letter-sound task.

Many of a child's experiences with print involve the child's first name. For example, parents and preschool teachers may write a child's name for him or help him write it, may talk with the child about the letters in the name, and may point out these letters when they occur in other words. This, coupled with the child's interest in his name, may explain the boost in letter-name knowledge that has been found for the letters in a child's first name, especially its first letter (Bouchière et al., 2010 for French; Justice, Pence, Bowles, & Wiggins, 2006, Treiman & Broderick, 1998, Treiman & Kessler, 2004 for English; Levin & Aram, 2004; Treiman et al., 2007 for Hebrew; Treiman et al., 2006 for English and Portuguese). There is mixed evidence on whether the letters in a child's name show an advantage in letter-sound learning. Treiman and Broderick (1998) found that U.S. and Australian learners of English did not show a significant benefit for the letters of their first name on a letter-sound task, whereas Levin and Aram (2004) found a benefit for Israeli learners of Hebrew. The few studies that have looked for effects of surnames have not found an own-name advantage in either the letter-name or the letter-sound task (Levin & Aram, 2004; Treiman & Broderick, 1998).

Treiman et al. (2007) speculated that personal factors such as whether a letter belongs to a child's name may be quite important at younger ages, with the frequency of letters in books becoming more important at older ages. However, that hypothesis has not been directly tested in the case of letter-sound knowledge. We did so in the present study by testing for interactions between children's age and such factors as own-name membership and letter frequency in books.

Small advantages have been observed for girls over boys in early language development (Wallentin, 2009), and some researchers have observed differences in letter-name knowledge (Iversen, Silberberg, & Silberberg, 1970; Treiman et al., 2007). We asked in the present study whether girls show an advantage over boys in the early learning of letter sounds.

The factors that we wish to investigate include properties of letters, such as the degree to which a particular letter looks similar to other letters; properties of children, such as a child's age and sex; and properties that reflect the combined characteristics of a particular letter and a particular child, such as whether a letter is the first letter of a child's forename. Many studies have examined letter-level, child-level, and child × letter variables separately. To examine letter-level characteristics, for example, researchers often pool responses of different children to each letter and compare letters to one another. To examine child-level characteristics, they pool data across letters for each child and compare children to one another. Statistical and conceptual problems can arise when characteristics of items—letters, in the present case—are examined separately from characteristics of participants. Multilevel models, which model the effects of item-level and participant-level characteristics simultaneously and which can also incorporate characteristics that depend on the joint properties of items and participants, provide a way of solving these problems (see Locker, Hoffman, & Bovaird, 2007). These models are increasingly used in psycholinguistic research with adults. In studies of children's letter learning, they have been used so far only with English and only with the dependent variable of correct responses (Justice et al., 2006; Kim et al., 2010; Piasta & Wagner, 2010; Turnbull et al., in press). In the present study, we used multilevel models to analyze several types of responses in the letter-sound task, including both C and CV responses as defined earlier. Moreover, we examined a language that has not heretofore been studied in this manner, Hebrew.

Method

Participants

We analyzed data from a total of 391 Israeli pre-first graders, 202 girls and 189 boys. The children attended schools that served urban populations of primarily low socioeconomic status. They ranged in age from 4;10 (years;months) to 7;4, with a mean age of 5;10 (SD = 0;5).

Materials and procedure

Children were tested individually. They were presented with all of the letters of the Hebrew alphabet in a bold Aharoni typeface. Each letter was printed on a 7 cm × 11 cm card, with the height of a typical letter approximately 0.6 cm. The cards were reshuffled for each child. Children were asked to say each letter's sound. They were encouraged to provide a response to each letter. If children said the name of a letter, they were encouraged to provide the sound instead. If children produced a CV syllable, they were asked to provide a shorter sound. In such cases, or in cases in which children stated that they did not know the correct answer, the examiner provided the required response. Children were provided with this type of feedback five times, after which point feedback was discontinued.

Results

We classified responses into several categories. C responses, such as /m/ or /mə/ for the sound of *mem*, consist of the appropriate consonant followed optionally by a reduced vowel. For letters that have two possible consonant pronunciations, as indicated in Table 1, either one was scored as correct. For example, both /kə/ and /x/ count as C responses to כ. CV responses contain the appropriate consonant, or one of the consonants in the case of letters that have more than one possible consonant pronunciation, together with a full vowel. For example, /ma/, /me/, /mi/, /mo/, and /mu/ are CV responses for *mem*. We did not include the letters ע *ajin*, א *alef*, ה *hei*, י *jud*, and ו *vav* in our main analyses of C and CV responses because some of these letters may represent vowels as well as consonants and because some of them may be construed as silent in some words. The primary analyses of C and CV responses thus included those 22 letters that regularly represent consonant phonemes. Averaging over all 8,602 trials on these letters, the mean proportion of C responses was .29 (SD = .45) and the mean proportion of CV responses was .24 (SD = .43). Another fairly common type of response was “don’t know” or failure to provide an answer. Such responses suggest a lack of knowledge of the letter sound that is more profound than in other types of errors, and it was thus of interest to examine these responses separately. Moreover, the analyses of “don’t know” responses could be carried out on all 27 letters. The mean proportion of “don’t know” responses across the 10,557 trials was .16 (SD = .36).

We analyzed the data on C, CV, and “don’t know” responses using a multilevel model that included letter-level, child-level, and child × letter variables. The analysis with each dependent variable was carried out at the trial level with a binary response variable: A response either fit the category of interest or did not. We used the software package lme4 (Bates, 2009), selecting a generalized mixed-effects model with a logit link function. We treated children as a random effect. Letter and child × letter variables were treated as fixed effects because we did not present a subset of Hebrew letters that was randomly chosen from a larger set of such letters. All nonbinary measures were centered at their grand mean.

A number of letter characteristics were included in the models. One was whether the letter was a final form (coded as 1) or an ordinary letter (coded as 0). Another was whether the letter was *alef* or *bet/vet* (1) or not (0). (For the analyses of C and CV responses, in which *alef* was not included for reasons mentioned above, only *bet/vet* was coded as 1.) We examined the effect of letter frequency in books by using the number of occurrences of each letter in a corpus of 137 popular books designed for Israeli toddlers through kindergartners, a corpus that included a total of 250,653 letters. Frequencies were log transformed before inclusion in the analyses. To capture the visual distinctiveness of each letter, we calculated its mean visual similarity with all of the other letters of the Hebrew alphabet, using data from a study (Treiman et al., 2007) in which Israeli university students rated the visual similarity of each pair of letters on a scale from 1 (not at all similar) to 7 (very similar). According to this measure, *alef* א is the most distinctive Hebrew letter, least similar to the other letters, and *resh* ר is the least distinctive. Additional factors in the model pertain to the interaction between the specific child and the specific letter. We coded for whether a letter was in the initial position of the child’s forename (or commonly used nickname), assigning a code of 1 if the letter was in initial position of the name and 0 if not. We also coded for whether a letter appeared in a later position of the forename and for whether it appeared in the initial and later

Table 1 Hebrew letters that stand only for consonants and that were included in analyses of C and CV responses

Colloquial names(s)	Shape	Sound(s) counted as correct
Ordinary forms		
bet/vet	ב	/b/, /v/
gimel	ג	/g/
daled	ד	/d/
zajin	ז	/z/
xet	ח	/x/
tet	ט	/t/
kaf/xaf	כ	/k/, /x/
lamed	ל	/l/
mem	מ	/m/
nun	נ	/n/
samex	ס	/s/
pei/fei	פ	/p/, /f/
tsadik	צ	/ts/
kuf	ק	/k/
resh	ר	/r/
shin/sin	ש	/ʃ/, /s/
taf	ת	/t/
Word-final letter forms		
xaf	ך	/x/
mem	ם	/m/
nun	ן	/n/
fei	ף	/f/
tsadik	ץ	/ts/

positions of the surname. Table 2 shows the mean, standard deviation, and range for each of these variables for the full set of 27 letters, and Table 3 shows the correlations among them. The child-level factors in the analyses were the child's age in months and the child's sex, with girls coded as 1 and boys as 0. We also included interactions of each letter-level variable with child age. All of the main effects and interactions just mentioned were included simultaneously in the models.

The first model was carried out with C responses. Table 4 shows the log-odds coefficients for the variables that had a significant effect after the contributions of all other variables in the model were statistically controlled ($p < .05$). Ordinary letters gave rise to more C responses than final forms, even after controlling for other factors. C responses were more common for frequent letters than for infrequent ones. Letters that are visually similar to other letters were less likely to give rise to C responses than letters that were more visually distinctive. Children were more likely to produce a C response if a letter was in their first name than if it was not, with the effect particularly strong for the first letter of the child's name. Whether a letter was in the child's last name did not have a significant effect. In addition, older children

Table 2 Letter variables included in analyses and information about each variable for full set of 27 letters (10,557 trials)

Variable	Mean	SD	Range
Final letter form	.19	.39	0, 1
Beginning of alphabet (1 for *alef* and *bet/vet*)	.16	.36	0, 1
Letter frequency ($\log_{10}$) in children's book corpus	3.81	.41	2.81–4.40
Mean visual similarity of letter to all others	2.80	.43	1.73–3.66
In child's forename			
Initial	.04	.19	0, 1
Non-initial	.11	.31	0, 1
In child's surname			
Initial	.04	.19	0, 1
Non-initial	.14	.35	0, 1

Table 3 Correlations among letter-related variables for full set of 27 letters

	Final letter form	Beginning of alphabet	Frequency	Visual similarity	Initial letter of forename	Later letter of forename	Initial letter of surname
Final letter form	1.00						
Beginning of alphabet	−.14	1.00					
Frequency	−.63	.26	1.00				
Visual similarity	.06	−.24	.16	1.00			
Initial letter of forename	−.09	.11	.12	−.12	1.00		
Later latter of forename	−.09	.02	.25	.05	.00	1.00	
Initial letter of surname	−.09	.15	.08	−.08	.04	.02	1.00
Later letter of surname	−.13	.08	.26	.06	.03	.17	−.01

produced more C responses than younger children. None of the interactions between age and the letter-level variables was significant.

The results for CV responses appear in Table 5. CV responses were more common for ordinary letters than for final forms. They were also more common for *bet/vet* than for letters that are later in the alphabet. More frequent letters gave rise to a larger number of CV responses than less frequent letters. Also, letters that were visually similar to many other letters of the alphabet gave rise to fewer CV responses than letters that were more distinctive. Children were more likely to produce a CV response when a letter was in their first name than when it was not, and the effect of own-name membership was larger for the first letter of the first name than for later letters. As with C responses, no significant effects were observed for surname membership. The results for CV responses differed from those for C

Table 4 Significant predictors in analysis of C responses

Effect	Correlation[a]	Coefficient	Standard error	*p*
Final letter form	−.15	−1.26	0.13	<.001
Letter frequency ($\log_{10}$)	.13	1.12	0.15	<.001
Mean visual similarity of letter to all others	−.01	−0.55	0.11	<.001
Initial letter of forename	.03	0.64	0.22	.004
Non-initial letter of forename	.04	0.44	0.16	.006
Age	.14	0.17	0.03	<.001

[a] Zero-order product-moment correlation of the predictor with accuracy

Table 5 Significant predictors in analysis of CV responses

Effect	Correlation[a]	Coefficient	Standard error	*p*
Final letter form	−.21	−1.95	0.14	<.001
Alef or *bet/vet*	.09	0.97	0.15	<.001
Letter frequency ($\log_{10}$)	.18	0.87	0.14	<.001
Mean visual similarity of letter to all others	−.01	−0.51	0.09	<.001
Initial letter of forename	.06	0.76	0.18	<.001
Non-initial letter of forename	.04	0.45	0.14	.001
Sex	.08	0.66	0.24	.006

[a] Zero-order product-moment correlation of the predictor with accuracy

responses, however, in that age was significantly associated with C responses but not with CV responses. Although older children did not produce significantly more CV responses than younger children, girls produced more such responses than boys. None of the interactions between age and the letter-level variables was statistically significant.

A potential concern with the preceding analyses is that the *alef/bet* variable captured the results for a single letter only, *alef* not being included in the analyses of C and CV responses. When the analyses were run without this variable, the results for the other variables were little changed.

For some letters, as mentioned previously, more than one possible consonant was allowed for C and CV responses. For *bet/vet*, *pei/fei*, and *shin/sin*, children almost always (98% or more of the time) used /b/, /p/, and /ʃ/, respectively, in their C and CV responses. For *kaf/xaf*, /k/ occurred 65% of the time and /x/ the remaining 35%. The frequency of response correlates with the frequency with which children produce the corresponding letter names. When *kaf/xaf* is presented in isolation in a naming task, both /kaf/ and /xaf/ responses occur, with the former more common than the latter. Specifically, for the 260 children in the letter naming study of Treiman et al. (2007) for whom details about letter name pronunciation were recorded, 59% of the correct responses to this letter were /kaf/. With *bet/vet*, *pei/fei*, and *shin/sin*, 99% or more of the correct responses in the letter name task began with /b/, /p/, and /ʃ/, respectively. The close correspondence between the consonant sounds produced in the letter name task and the consonant sounds produced in the current letter sound task is consistent with the idea that children derive the sound of a letter, in part, from its name.

Further support for the idea that children derive the sound of a letter from its name comes from an examination of the vowels in children's CV responses. The large majority of these, 82%, were the vowel in the letter's name (or one of the names, in the case of *kuf/kof*). For example, children were more likely to produce /te/ than /ta/ or /tu/ for the sound of *tet*. When children used a vowel phoneme that was not in the letter's name, /a/ was the most common choice. Indeed, responses with /a/ occurred 75% of the time for letters that did not have /a/ in the second position of their name. For example, children were more likely to say that *tet* has the sound /ta/ than /tu/. One potential explanation for this latter outcome is that /a/ is more common than other Hebrew vowels (Bolozky, 1999). In addition, we have observed that Israeli teachers sometimes use /a/ when explaining the sounds of isolated letters, saying for example that *gimel* has the sound /ga/.

Responses on the sound task to the letters *ajin*, *alef*, *hei*, *jud*, and *vav*, which were not included in the preceding analyses of CV responses, also appeared to be influenced by the letters' names. Specifically, syllables that consisted of the first phonemes of the letter's name, such as /va/ for *vav* and /al/ for *alef*, outnumbered syllables that began the same way but that had a different following phoneme, such as /ve/ for *vav* or /an/ for *alef*.

We analyzed the "don't know" responses in a similar fashion to C and CV responses, this time including all 27 letters in the analysis. The results are shown in Table 6. Children were more likely to deny knowledge of the sound of a final form than of an ordinary letter, and they were less likely to deny knowledge of the sounds of *alef* and *bet/vet* than of other letters. The more frequent a letter, the less often children professed ignorance of its sound. This effect was less strong for older children than for younger ones. This latter result may reflect the fact that "don't know" responses were closer to floor level for the older children, as shown by the main effect of age. "Don't know" responses were more common for letters that were visually similar to many other letters of the alphabet than for letters that were more distinctive. When children were asked about the first letter of their first name, they were less likely to say that they didn't know its sound than when they were asked about some other letter. Smaller but significant effects were observed for the later letters of the first name. We also found a significant effect for the first letter of the last name in the analysis of "don't know" responses, unlike in the analyses of C and CV responses.

In some cases, children produced a response that corresponded to some other letter(s) than the one that was presented, making what we call a replacement error. For example, children sometimes said that the final form of *nun*, ן, had the sound /z/, which is actually associated with *zayin* ז. Analyses of replacement errors are complicated by the fact that many responses cannot be unambiguously linked to a single letter. For example, a child who gave /ka/ as the sound of *lamed* ל could have confused *lamed* with either *kuf* ק or *kaf/xaf* כ. To avoid such ambiguities, we focused on errors that were associated with one of the letters (*daled*, *gimel*, *zayin*, *lamed*, or *resh*) that has a single sound that is not also the sound of some other letter. An error

Table 6 Significant predictors in analysis of "Don't Know" responses

Effect	Correlation[a]	Coefficient	Standard error	*p*
Final letter form	.12	0.39	0.12	<.001
Alef or *bet/vet*	−.09	−1.75	0.28	<.001
Letter frequency ($\log_{10}$)	−.14	−0.94	0.13	<.001
Letter frequency × age	.01	−0.05	0.02	.021
Mean visual similarity of letter to all others	.03	0.39	0.10	<.001
Initial letter of forename	−.07	−2.03	0.34	<.001
Non-initial letter of forename	−.06	−0.67	0.15	<.001
Initial letter of surname	−.04	−0.79	0.27	.003
Age	−.15	−0.10	0.03	<.001

[a] Zero-order product-moment correlation of the predictor with accuracy

was coded as being associated with one of these letters if it was a C or CV response to that letter or if it was the letter's name. We analyzed replacement errors using the same variables as in the preceding analyses, except that in place of the mean visual similarity between the presented letter and all other Hebrew letters we used the visual similarity between the presented letter and the specific letter with which it was confused. The results, shown in Table 7, reveal that children made more replacement errors on final forms than on ordinary letters and fewer on frequent letters than on less frequent ones. Girls made fewer replacement errors than boys. Replacement errors were more likely to involve visually similar letters than visually dissimilar letters, and the effect of visual similarity was stronger for older children than younger children.

Discussion

In any domain, learning is influenced by the properties of system to be learned and the properties of the learner. The domain of interest here is letters, specifically links between letters' shapes and sounds. Knowledge of these associations sets the stage for learning to read and write, and so it is important to understand the characteristics of the associations and how they are learned. The present study was motivated by the need to go beyond the Latin alphabet, which has been the focus of most previous research on letter learning and literacy development more generally (Share, 2008).

One important property of letters, and one that has been central to much previous research on letter learning, is the phonetic iconicity of their names. In English and certain other languages, letter names vary among themselves in iconicity: whether they contain the sound that they represent and, if so, the position of the sound. However, English is somewhat atypical in this regard. In many other writing systems, including Hebrew, letter names are always or almost always acrophonic. The name of a letter begins with the sound that the letter represents, and there is little or no variation among letter names in this regard. Because all Hebrew consonant letters are acrophonic, we do not see differences of the sort that we see

Table 7 Significant predictors in analysis of replacement errors

Effect	Correlation[a]	Coefficient	Standard error	p
Final letter form (1 = final)	.06	0.63	0.13	<.001
Letter frequency ($\log_{10}$)	−.04	−0.51	0.15	<.001
Visual similarity of pair of confused letters	.09	0.56	0.03	<.001
Visual similarity × age	.01	0.01	0.01	.020
Sex	−.01	−0.30	0.15	.042

[a] Zero-order product-moment correlation of the predictor with accuracy

between letters like *v* and *h* in American English (Ellefson et al., 2009; Foy & Mann, 2006; Kim et al., 2010; McBride-Chang, 1999; Treiman & Broderick, 1998; Treiman et al., 1998, 2008). However, we see other signs that learners of Hebrew use their knowledge of letter names to make inferences about letters' sounds. For example, confirming the report of Levin et al. (2006), Israeli children often attribute to letters CV sounds that are the first two phonemes of the letter's name. Moreover, they occasionally produce responses like /al/ for *alef* which they are unlikely to have heard from adults. We found that CV responses, which come in part from letter names, were more common relative to C responses for younger children than for older children.

The combined pattern of results across Hebrew and English suggests that children who are familiar with the names of letters use this knowledge to help learn letter sounds. The underlying principle is the same, but it manifests differently in languages with different properties. The results reflect a basic fact about learning: Motivated associations are easier to learn and remember than arbitrary associations. Writing systems evolved with the needs of learners as a consideration, and this probably explains why letter names are phonetically iconic in so many writing systems and why the letter sound is so often at the beginning of the name, the most accessible position. Of course, children cannot use letters' names to learn the sounds if they do not know the names. In cultures in which letter names are not emphasized with young children, as is currently the case in England, effects of letter-name knowledge on the learning of sounds are decreased (Ellefson et al., 2009).

Variations in the phonetic iconicity of letter names are such a salient property of English that other properties of letters have sometimes been ignored in studies of this language. The present results suggest that letters' shapes affect the learning of shape-sound associations. Children produced more C and CV responses and fewer "don't know" responses to letters that looked relatively dissimilar to other letters of the Hebrew alphabet than to letters that were more similar. When children produced a response that was appropriate for some letter other than the one that was presented, the wrong letter tended to be visually similar to the correct one. Previous studies have shown effects of visual similarity in letter-name learning (Levin et al., 2008; Treiman et al., 2006, 2007), and the present study extends these findings to letter sounds.

The effects of visual confusability reflect the importance of contrast in learning. A second basic fact about learning, in addition to the difficulty of arbitrary associations, is that it is easier to attach distinctive labels to things that contrast greatly with one another than to things that are more alike. Our results show that this applies in the learning of letter names and sounds. Why aren't the shapes of the letters in a writing system more different from one another, then, if confusability hurts learning? One counteracting factor is that similar shapes are easier to group together. From an early age, children appear to recognize letters as members of a set (e.g., Lavine, 1977), and the similarity of the shapes appears to help them do so. Another counteracting factor is that similar shapes are easier to produce: They contain shared graphic components that can be learned and produced as units. Systems of letter shapes have been molded by an attempt to strike a balance between shapes that are similar to one another and shapes that look different. We saw the drawbacks of similarity here, but there are also some benefits.

Previous studies have found that Israeli children perform poorly on final forms in letter-name tasks (Treiman et al., 2007). The present results show that children perform poorly on final forms in the letter-sound task too. These forms are less common in books, on the whole, than ordinary forms. They tend to be less distinctive in shape, and they do not appear at the beginning of any child's name. Although these factors help explain children's poor performance on final forms, the present results show that they do not explain all of it. That is, there was a significant decrement for final letters above and beyond visual similarity, frequency in print, and other factors. This was so even though final letters, not being followed by other letters within words, probably do not yield the variety of CV sounds from adults that other letters do. Children's poor performance on final forms may reflect, in part, the fact that they are not separately included in alphabet songs and early alphabet books. Parents and teachers, giving priority to the normal, unconditioned shapes of letters, may point out and talk about final forms less. Thus, the frequency with which children experience the final forms may be lower than expected given their frequency in books.

This discussion brings up a third basic fact about learning: Exposure and interest matter. Our results show an effect of frequency in that children produced more C and CV responses and fewer "don't know" responses for letters that appeared frequently in children's books than for less common letters. Moreover, children were less likely to confuse common letters with other letters. Frequency in book print did not have a significant relationship with letter-sound knowledge in two previous studies of children similar in age to those tested here (Ecalle, 2004 with learners of French; Evans et al., 2006 with learners of English). The differences, we suspect, reflect in large part the smaller number of participants in those studies as compared to the current one, together with the fact that the French study examined only a subset of letters. Although there appears to be a relationship between the frequency of a letter in books and children's knowledge of the letter's sound before formal reading instruction begins, this relationship does not necessarily mean that children learn about the sounds of letters when adults read to them from books. Indeed, as mentioned earlier, young children spend little time looking at the words in books when they are being read to (Evans & Saint-Aubin, 2005; Justice et al., 2005). Outside the context of book reading, though, adults probably talk more about common letters than about uncommon letters.

The additional advantage for *alef* and *bet/vet* that appeared in some of the analyses, as in some previous analyses of letter naming (Treiman et al., 2007), may also reflect frequency of exposure. Children sometimes hear or see the letters of the alphabet starting from the beginning, as in alphabet songs or posters that show the letters. Moreover, the first two letter names in the Hebrew sequence form the name for the sequence as a whole. Thus, children probably have more experience with the first two letters than anticipated given the frequencies of these letters in books. In addition, people often remember the first items of a sequence well: the primacy effect.

The benefits that we saw for the letters in children's forenames also reflect frequency and interest. In the analyses of C, CV, and "don't know" responses, these effects were larger for the first letter of the first name than for the later letters. There was a significant own-name benefit for the last name only in the analysis of "don't know" responses, and only for its first letter, showing that children's forenames are more influential than their surnames. Within the age range examined here, the effects of own name membership were no weaker for older children than younger ones. Previous studies have found that children perform well on the first letter of their forename in the letter-name task (Bouchière et al., 2010; Justice et al., 2006; Levin & Aram, 2004; Treiman & Broderick, 1998; Treiman & Kessler, 2004; Treiman et al., 2006, 2007), and one study found a significant effect in the letter-sound task as well (Levin & Aram, 2004). Another study did not find a statistically significant effect in a letter-sound task (Treiman & Broderick, 1998), but it did find trends in the same direction. The large sample size and the better statistical methods of the present study make it more sensitive than that previous study, and we thus suggest that own-name effects occur in letter-sound learning as well as letter-name learning. When talking about printed words, parents and teachers probably devote special attention to a child's first name and, within the name, to the initial letter. Children, in turn, are especially interested in their written name.

We must qualify our statements that adults talk more about letters in children's names, those that are common in the words of the language, and those that occur early in the alphabet because researchers have not systematically examined the input that children receive. Interactions between children and adults surrounding letters and writing can be difficult to study, although analyses of parent–child conversations are beginning to provide useful information (Levin & Aram, 2004; Robins & Treiman, 2009). As better measures of the input to young children become available, we may find closer links between frequency and performance than previously observed. It is possible that differences in amount or quality of input contribute to the small superiority in performance for girls over boys that was observed in some of the present analyses and some past work (Iversen et al., 1970; Treiman et al., 2007).

The factors that we have identified as determinants of letter-sound learning—motivated associations, contrast, frequency of input, and attention to input—are not specific to Hebrew and not specific to the learning of letters. They are general principles that influence the learning of all types of associations. Letter-sound learning plays out somewhat differently in different writing systems, in line with differences in their characteristics. However, the underlying processes are fundamentally the same.

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