

# The road to language learning is not entirely iconic: Iconicity, neighborhood density, and frequency facilitate sign language acquisition

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The road to language learning is not entirely iconic:  
Iconicity, neighborhood density, and frequency facilitate sign language acquisition

#### Author Note

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## NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION

**Abstract (130 words)**

Iconic mappings between words and their meanings are far more prevalent than once estimated, and seem to support children's acquisition of new words, spoken or signed. We asked whether iconicity's prevalence in sign language overshadows other factors known to support spoken vocabulary development, including neighborhood density (the number of lexical items phonologically similar to the target), and lexical frequency. Using mixed-effects logistic regressions, we reanalyzed 58 parental reports of native-signing deaf children's American Sign Language (ASL) productive acquisition of 332 signs (Anderson & Reilly, 2002), and found that iconicity, neighborhood density, and lexical frequency independently facilitated vocabulary acquisition. Despite differences in iconicity and phonological structure, signing children, like children learning a spoken language, track statistical information about lexical items and their phonological properties and leverage them to expand their vocabulary.

*Keywords: phonological neighborhood density, iconicity, frequency, sign language, vocabulary acquisition*

## NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION

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Iconicity, neighborhood density, and frequency facilitate sign language acquisition

Learning a new word requires mapping information about its form to its meaning. In spoken languages, children use phonological structure to facilitate this mapping; for example, phonological neighborhood density (the number of lexical items that are phonologically related to a target) supports word learning (Carlson, Sonderegger, & Bane, 2014; Coady & Aslin, 2003; Storkel, 2004; Storkel, 2009). Although lexical forms in both spoken and signed languages have phonological structure, many are also iconically tied to their meaning (see Perniss, Thompson, Vigliocco, 2010 for a review). Mounting evidence suggests that iconicity may play a modality-general role in supporting signed and spoken vocabulary development (Perry, Perlman, & Lupyan, 2015; Thompson, Vinson, Woll, & Vigliocco, 2012). In the current study, we examined the effects of iconicity, neighborhood density, and lexical frequency on early vocabulary development in a sign language. We asked whether the prevalence of iconicity in sign language means that iconicity alone is sufficient for children to learn new signs, drowning out any benefit that could be derived from phonological or lexical properties; or whether, in addition to iconicity, the statistical occurrence of lexical items and their phonological properties remains a powerful predictor of early language development.

### **Iconicity in Vocabulary Development**

Due to the pervasiveness of iconicity in sign languages (Perniss et al., 2010), some have hypothesized that it should be an especially useful tool to acquire new signs (Brown, 1978). Surprisingly, most research has found no role for iconicity in sign language acquisition. In vocabulary production, children make frequent phonological substitutions that diminish rather than enhance iconic features of signs (Meier, Mauk, Cheek, & Moreland, 2008). Further, less than one-third of children's expressive sign vocabulary is transparently iconic (compared to metonymic or arbitrary; Orlansky & Bonvillian, 1984). This corresponds to the rate of iconic signs in the American Sign Language (ASL) lexicon more broadly, where 30% of signs are rated as highly iconic (greater than a 4 on a 7-point scale; Caselli, Sevcikova Sehyr, Cohen-Goldberg, & Emmorey, 2016). Instead, children's first signs include MOMMY, COOKIE, and MILK (Anderson & Reilly, 2002), which vary in degree of iconicity in ASL (see Figure 1). Yet a recent

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION study countered this early work and showed that iconicity predicted parental reports of native deaf children's British Sign Language (BSL) acquisition (Thompson et al., 2012).



**Fig. 1.** The ASL signs (a) MOMMY, (b) COOKIE, and (c) MILK have iconicity ratings of 1.2, 3.3, and 4.2 respectively on a 7-point scale.

Notably, iconicity seems an important factor in spoken vocabulary development. Adults rate the words that children learn earliest as highly iconic (Perry et al., 2015). Further, Japanese three-year-olds acquire novel iconic, sound-symbolic verbs more reliably than novel non-sound-symbolic verbs, suggesting that they can leverage the iconic form-meaning mapping to learn novel verbs (Imai, Kita, Nagumo, & Okada, 2008).

The role of iconicity, however, may shift as children develop. For children learning BSL, the effect of iconicity was more prominent with age (Thompson et al., 2012), indicating that older children, between the ages of two and three, may have developed cognitive tools to better leverage the iconic form-meaning mapping (e.g., Gentner & Namy, 2006; Meier, 1982). Further, systematic sound-meaning relationships are stronger among spoken words frequently acquired between the ages of two and six than among later-acquired words, suggesting an early use of iconicity that is later sacrificed for communicative efficiency (Monaghan, Shillcock, Christiansen, & Kirby, 2014).

Although Perry et al. (2015) and Thompson et al. (2012) converge to provide tantalizing evidence that iconicity shapes early vocabulary, regardless of modality, their results must be interpreted with caution because neither study controlled for phonological neighborhood density, which robustly predicts spoken vocabulary development (Coady & Aslin, 2003; Storkel, 2004;

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION (Storkel, 2009). Eliminating this confound is critical for sign languages because signed phonology and iconicity are interdependent (e.g., Taub, 2001; Emmorey, 2014) and neighborhood density can be correlated with iconicity (Caselli et al., 2016).

### **Neighborhood Density in Vocabulary Development**

Children learning spoken languages use distributional information about the phonological properties of words to build a lexicon (Saffran, Aslin, & Newport, 1996; Thiessen, 2007). Their early vocabularies contain a greater proportion of high-density words than adults' vocabularies (Coady & Aslin, 2003; Storkel, 2004; Storkel, 2009), and children produce high-density words more accurately than low-density words (Sosa, 2008). However, the role of neighborhood density is not straightforward. While dense neighborhoods support the configuration of new lexical representations, words from sparse neighborhoods may be more easily identified as novel, thus triggering word learning (Storkel & Lee, 2011).

Signed languages differ from spoken languages in three important ways that may make children less likely to unpack phonological information. First, iconicity may be so salient in sign language that it alone is sufficient for sign learning, circumventing the usefulness of phonology. Second, unlike the sequences of sounds in spoken phonology, signed phonology often includes *simultaneously* produced features (e.g., handshapes, locations, movements; Brentari, 1998). In spoken language, children may be sensitive to distributional information about phonology in order to make predictions about upcoming sounds and word boundaries (Saffran, Aslin, & Newport, 1996). Young signing children may initially ignore phonological structure and treat signs holistically because the simultaneous production of phonological elements may have less predictive value. Third, the absence of many minimal pairs (Brentari, 1998) means that most signs have relatively few phonological neighbors; sparse neighborhoods may not support the configuration of new lexical representations. Even if children attend to phonological structure (e.g., Siedleki & Bonvillian, 1998), it remains unclear whether the phonology of most sign languages would itself support sign acquisition. For all of these reasons, we might expect to find no effect of neighborhood density on sign acquisition. Alternatively, because adults treat signs compositionally during language processing (e.g., Baus, Gutiérrez-Sigut, Quer, & Carreiras, 2008; Carreiras, Gutiérrez-Sigut, Baquero, & Corina, 2008; Caselli & Cohen-Goldberg, 2014, Mayberry & Witcher, 2005), children may make use of neighborhood density as well.

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### **Lexical Frequency in Vocabulary Development**

Children are sensitive to how frequently words appear in their input; common words are acquired more rapidly than uncommon words (Goodman, Dale, & Li, 2008). To date, the only study examining the role of frequency<sup>1</sup> in sign acquisition found no effect (Thompson et al., 2012) either because iconicity is so useful that frequency has little additive value or because the range of frequency values was insufficient to detect an effect.

#### **The Current Project**

We examined the structure of the emerging productive signed lexicon by reanalyzing a dataset drawn from parental reports of early ASL vocabulary production (ASL-CDI; Anderson & Reilly, 2002). We used ASL-LEX, a newly available lexical database for ASL that includes the first publicly available measure of neighborhood density in any signed language, and information about iconicity and lexical frequency for nearly 1,000 signs (Caselli et al., 2016). With ASL-LEX, we could for the first time examine the individual contributions of iconicity, neighborhood density, and lexical frequency on signed vocabulary development.

We considered three competing predictions. First, we investigated whether signing children exclusively relied on iconicity. Under this scenario, iconicity should positively affect acquisition even when neighborhood density and frequency are controlled, and neighborhood density and frequency should exert no effect. Second, we tested whether signing children relied only on phonological information. If so, then neighborhood density should positively affect sign acquisition, but iconicity should have no effect. Finally, we asked whether signing children use iconicity, phonology, and lexical frequency to learn new signs. In this case, we predicted independent effects of iconicity, neighborhood density, and frequency.

#### **Methods**

##### **Participants**

This study included a subset<sup>2</sup> of only one parental report for each of 64 ASL-exposed deaf children from the original ASL-CDI norming study (Anderson & Reilly, 2002). The ASL-

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<sup>1</sup> Called “familiarity” by Thompson et al. (2012)

<sup>2</sup> Anderson and Reilly (2002) reported a sample of 69 participants, 110 reports, and 537 items. They used three different versions of the ASL-CDI, across which there were some discrepancies; 654 items appeared across forms.

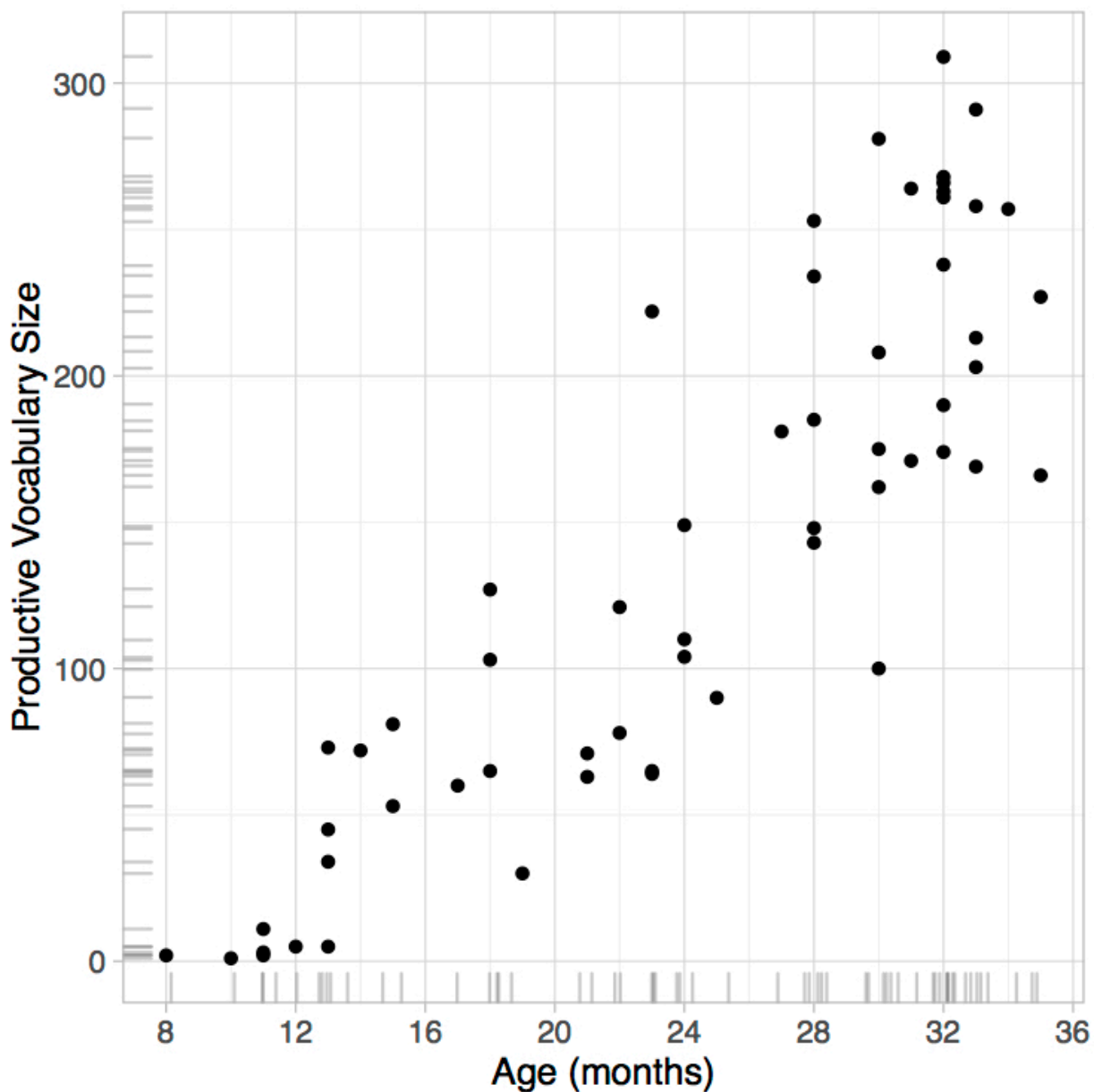
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CDI was modeled after Fenson et al. (1993). As described in Anderson and Reilly (2002), one parent was given a list of glosses of ASL signs, and reported whether their child used each sign. We excluded children from the original dataset who were not deaf ( $n = 3$ ), and for whom we did not know the age ( $n = 2$ ) or parental hearing status ( $n = 1$ ). This resulted in 58 children ( $M_{\text{age}}=24$  months;  $Mdn = 26$ ; range 8-35 months). All children had a deaf mother, and all but three had a deaf father.

**Materials**

Our analyses included only the 373 (57%) ASL-CDI items for which we had neighborhood density, iconicity, and subjective frequency ratings from the ASL-LEX database (Caselli et al., 2016). A subset of 46 items were repeated on the ASL-CDI forms, and only the first presentation of each item was included in our analyses. Because the ASL-CDI does not include reference videos, items were matched to ASL-LEX on the basis of an identical or plausibly matching English gloss (e.g. CROCODILE was matched with ALLIGATOR). A handful of ASL-LEX items matched multiple ASL-CDI glosses (e.g., the CDI items BATH and BATHTUB were both matched to the ASL-LEX item BATH), resulting in 361 unique items. The signs included 231 nouns, 51 verbs, 38 adjectives, 10 adverbs, 2 number words, and 29 function words, as defined by ASL-LEX. Because function words are acquired on a very different trajectory than open-class words (e.g., Storkel, 2004), these words were excluded from all analyses, leaving a total of 332 items (18,404 trials; see Supplementary Material for items), yielding a dataset that was more than seven times larger than the BSL dataset (Thompson et al., 2012). As reported in Anderson and Reilly (2002), vocabulary size and age were correlated ( $r_s = 0.86, p < 0.001$ ; see Figure 2).

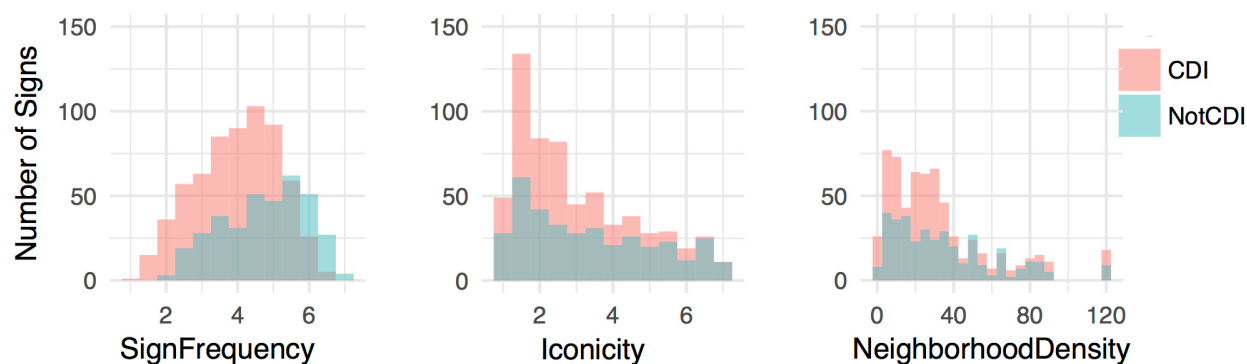
## NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION



**Fig. 2. Vocabulary size by age.** As reported in Anderson and Reilly (2002), age and vocabulary size are positively correlated. Vocabulary size was calculated over the 332 items used in the current analyses.

Three variables were drawn from ASL-LEX (Caselli et al, 2016). The summary statistics that follow were calculated over the 332 items analyzed. Deaf adult signers rated the *Subjective Frequency* of each sign in everyday conversation on a scale of 1 to 7 ( $M = 4.7$ ,  $SD = 1.2$ ,  $Min = 1.8$ ,  $Max = 7.0$ ). Hearing non-signers rated *Iconicity* (how much each sign looked like its

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION referent) on a scale of 1 to 7 ( $M = 3.4$ ,  $SD = 1.8$ ,  $Min = 1.0$ ,  $Max = 7.0$ ).<sup>3</sup> *Neighborhood Density*<sup>4</sup> was defined as the number of signs that shared at least four of five phonological properties, by (selected fingers, major location, flexion, movement, and sign type;  $M = 34$ ,  $SD = 27$ ,  $Min = 0$ ,  $Max = 118$ ). We chose this definition of Neighborhood Density, called Maximal Neighborhood Density by Caselli et al. (2016), over the other two neighborhood density estimates available in ASL-LEX because it is the most similar to definitions of neighbors used in spoken language (words that differ by one phoneme). The phonological coding system used to estimate Maximal Neighborhood Density was based on the Prosodic Model (Brentari, 1996). The distributions of the items in the CDI relative to the non-CDI items in ASL-LEX (Caselli et al, 2016 is illustrated in Figure 3. In the current dataset, frequency and neighborhood density were correlated ( $r_s = 0.13$ ,  $p = 0.015$ ), as were frequency and iconicity ( $r_s = -0.20$ ,  $p < 0.001$ ), and neighborhood density and iconicity ( $r_s = 0.14$ ,  $p = 0.009$ ).



**Fig. 3. Distribution of lexical properties in the items on the CDI versus the items from ASL-LEX that are not on the CDI.** The shape of the distributions are generally similar, though Wilcoxon tests indicate that the distributions of frequency and iconicity in the CDI items are significantly higher than the other items in the ASL-LEX database ( $M_{\text{Frequency}} = 3.99$ ,  $p < 0.01$ ;  $M_{\text{Iconicity}} = 3.03$ ,  $p = 0.01$ ;  $M_{\text{NeighborhoodDensity}} = 32$ ,  $p = 0.03$ ).

### Modeling Procedure

We ran a mixed-effects logistic regression because it simultaneously accounts for child-specific and item-specific variability, and allows for generalization beyond both the sample of

<sup>3</sup> We report average raw scores, not z-scores, for ease of interpretation.

<sup>4</sup> While this estimate of neighborhood density is the best available, it is based on the available phonological descriptions in ASL-LEX, which only partially describe each sign. Neighbors are often not true minimal pairs as they may differ on more than one not-coded phonological property.

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION children and the set of vocabulary items. The dependent variable was acquisition (can produce the sign = 1, cannot = 0). The model included two-way interactions between each variable of interest (neighborhood density, iconicity, and lexical frequency) and age (months), as well as random effects of participants and items. By-participant random slopes for the three variables of interest were also included. All continuous variables were z-transformed, except iconicity and subjective frequency because the values imported from ASL-LEX were already on a z-scale. To address issues of collinearity, significant effects of variables of interest were confirmed using a log-likelihood test to compare a model containing the variable of interest to a model excluding it to determine whether its inclusion was justified. This helps us to confirm that each variable has an effect above and beyond the others despite correlations among variables. The p-values reported below correspond to the results of the log-likelihood comparisons.

### Results

There were significant positive main effects of age ( $\beta = 2.32$ , s.e. = 0.18,  $\chi = 85.08(1)$ ,  $p < 0.001$ ), sign frequency ( $\beta = 0.57$ , s.e. = 0.20,  $z = 2.82$ ,  $p = 0.005$ ;  $\chi = 8.56(1)$ ,  $p = 0.003$ ), iconicity ( $\beta = 0.36$ , s.e. = 0.15,  $\chi = 6.06(1)$ ,  $p = 0.014$ ), and neighborhood density ( $\beta = 0.26$ , s.e. = 0.12,  $\chi = 4.92(1)$ ,  $p = 0.026$ , see Figure 4). In order to confirm the direction and size of the effects, which can be obfuscated by collinearity, we also ran models with only one lexical variable (and the age by lexical variable interaction) in turn. The direction and magnitude of the effects were qualitatively the same (frequency:  $\beta = 0.52$ , s.e. = 0.20,  $\chi = 7.53(1)$ ,  $p < 0.01$ , iconicity:  $\beta = 0.30$ , s.e. = 0.15,  $\chi = 4.42(1)$ ,  $p = 0.036$ , neighborhood density:  $\beta = 0.34$ , s.e. = 0.12,  $\chi = 8.57(1)$ ,  $p < 0.01$ ). This suggests that, unsurprisingly, children knew more words as they got older. Further they were more likely to know signs that were more common, signs that were more iconic, and signs that had more neighbors. There was a marginally significant interaction between age and iconicity ( $\beta = -0.10$ , s.e. = 0.05,  $\chi = 3.36(1)$ ,  $p = 0.067$ ; see Figure 4). Visual inspection of this interaction suggests that there may have been a ceiling effect, whereby the oldest children knew most of the words on the CDI and thus iconicity exerted a smaller effect. We investigated the age by iconicity interaction by dividing the data into the oldest group ( $\geq 32$  months) that appeared to reach a ceiling, and the youngest group ( $< 32$  months). We reran a model with the same structure on each of the subsets of data, and found an effect of iconicity in the youngest children ( $\beta = 0.39$ , s.e. = 0.15,  $\chi = 7.30(1)$ ,  $p = 0.007$ ), but not

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the oldest children ( $\beta = -0.77$ ,  $s.e. = 0.61$ ,  $\chi = 1.60(1)$ ,  $p = 0.21$ ). This finding must be interpreted with caution, in light of the marginally-significant interaction. There was no interaction between age and neighborhood density ( $\beta = 0.03$ ,  $s.e. = 0.03$ ,  $z = 0.79$ ,  $p = 0.43$ ), or between age and frequency ( $\beta = 0.11$ ,  $s.e. = 0.07$ ,  $\chi = 2.10(1)$ ,  $p = 0.15$ ) indicating that neighborhood density and frequency had consistent facilitative effects across development.

Because ASL-LEX contains two other estimates of neighborhood density, we wanted to validate the choice to use Maximal Neighborhood Density. We compared it to Parameter-Based Neighborhood Density (the number of signs that share *all* of the following phonological properties: selected fingers, flexion, major location, and path movement) and Minimal Neighborhood Density (the number of signs that share at least *one of five* phonological properties: selected fingers, flexion, major location, path movement, and sign type). The model using Maximal Neighborhood Density had the best fit, as indicated by the lowest Akaike Information Criteria ( $AIC_{\text{MaximalNeighborhoodDensity}} = 13,641.11$ ,  $AIC_{\text{Parameter-BasedNeighborhoodDensity}} = 13,642.34$ ,  $AIC_{\text{MinimalNeighborhoodDensity}} = 13,643.54$ ), though the differences between models was not significant.

Though the distribution of ages was roughly flat, there was a spike in the number of participants between the ages of 32-33-months-old (See Figure 2). To rule out the possibility that this spike had a disproportionate effect on the results, we removed seven random participants from this age range and re-ran the analyses. The results were qualitatively the same: iconicity, neighborhood density, and frequency facilitated acquisition, and there was an age by iconicity interaction.

To examine whether any of the variables of interest had non-linear effects on acquisition we ran models that were identical to the one reported but substituted age, frequency, neighborhood density, and iconicity with log, square root, and multiplicative inverse transformations of each variable in turn. Model comparisons indicate that none of these models outperformed the model with untransformed variables described above.

We conducted a final Monte Carlo analysis to investigate the possibility that the effects of iconicity, neighborhood density, and frequency stemmed from the distribution of the limited set of signs that appear on the CDI. For each participant, we randomly sampled from all of the CDI items the number of signs that child knew (without replacement) and calculated the average

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iconicity, neighborhood density, and frequency for this randomly generated vocabulary. We did this 10,000 times for each of the 58 children. The distribution of these vocabularies is illustrated in Figure 6. If the observed data were no different from chance, we would expect five percent (~3) of the observed means to fall above the 95<sup>th</sup> percentile of the distribution of randomly generated means. In this dataset, two-tailed one-proportion z tests with the Yates continuity correction revealed that the number of observed averages that fell outside the distribution of the randomly generated means significantly exceeded the expected rate of 5% for each of the variables: 17 of the observed average iconicity ratings (29%;  $z = 8.19$ ,  $p < 0.01$ ), 24 of the observed average neighborhood densities (41%;  $z = 12.21$ ,  $p < 0.01$ ), and 22 of the observed average frequency ratings (38%;  $z = 12.41$ ,  $p < 0.01$ ; see Figure 6). The effects of iconicity, neighborhood density, and frequency cannot be attributed to their base rates among the CDI items relative to the rest of the lexicon of ASL; these effects indicate that highly iconic, frequent, and dense signs are overrepresented in children's early productive vocabularies.

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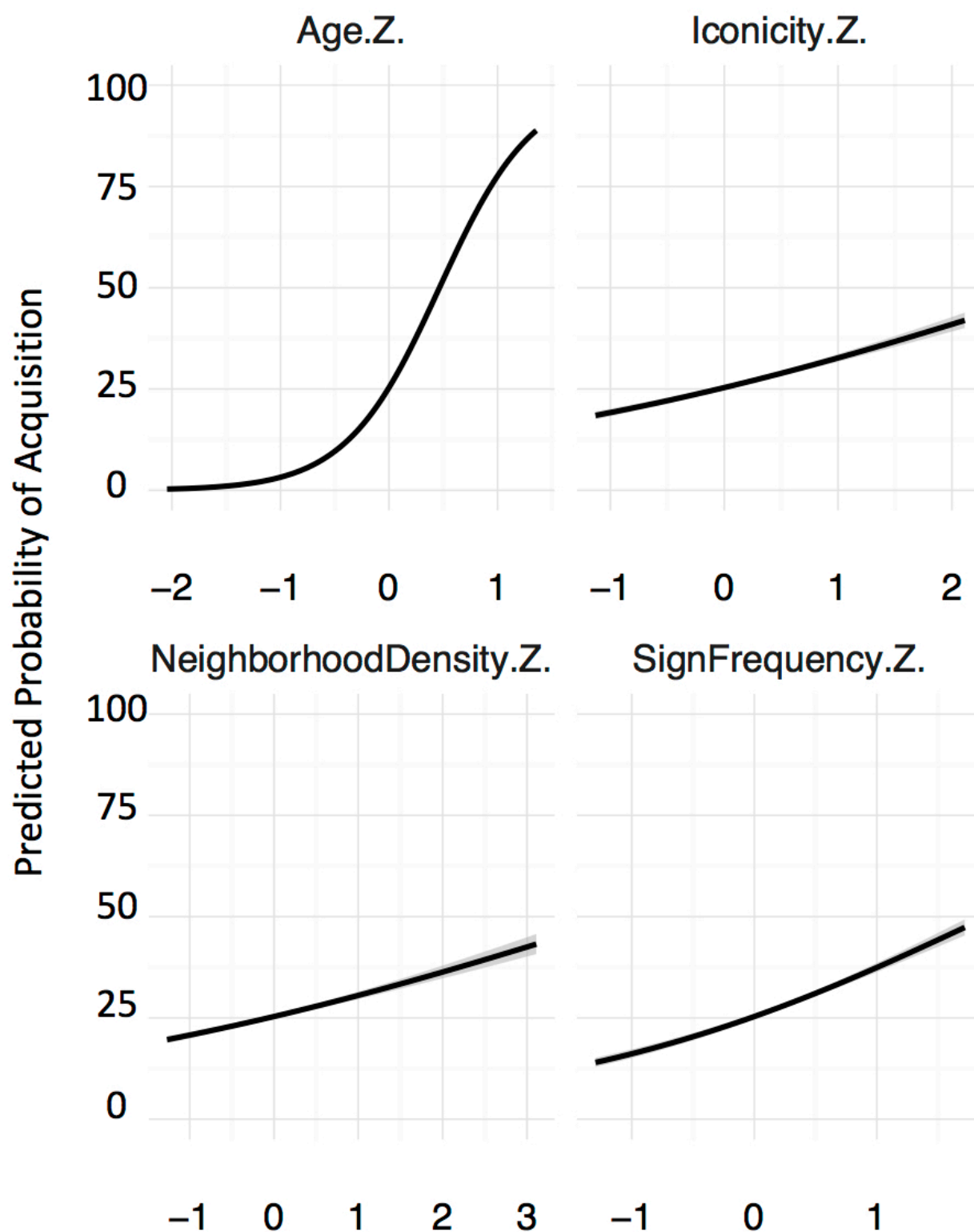
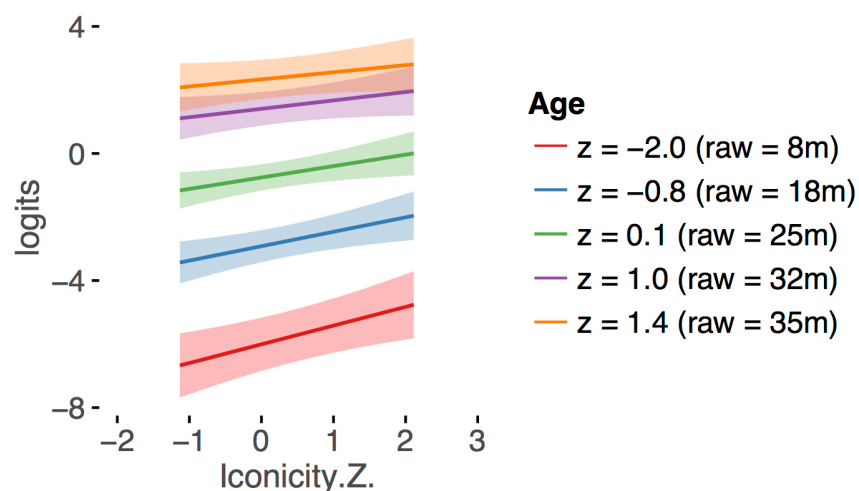


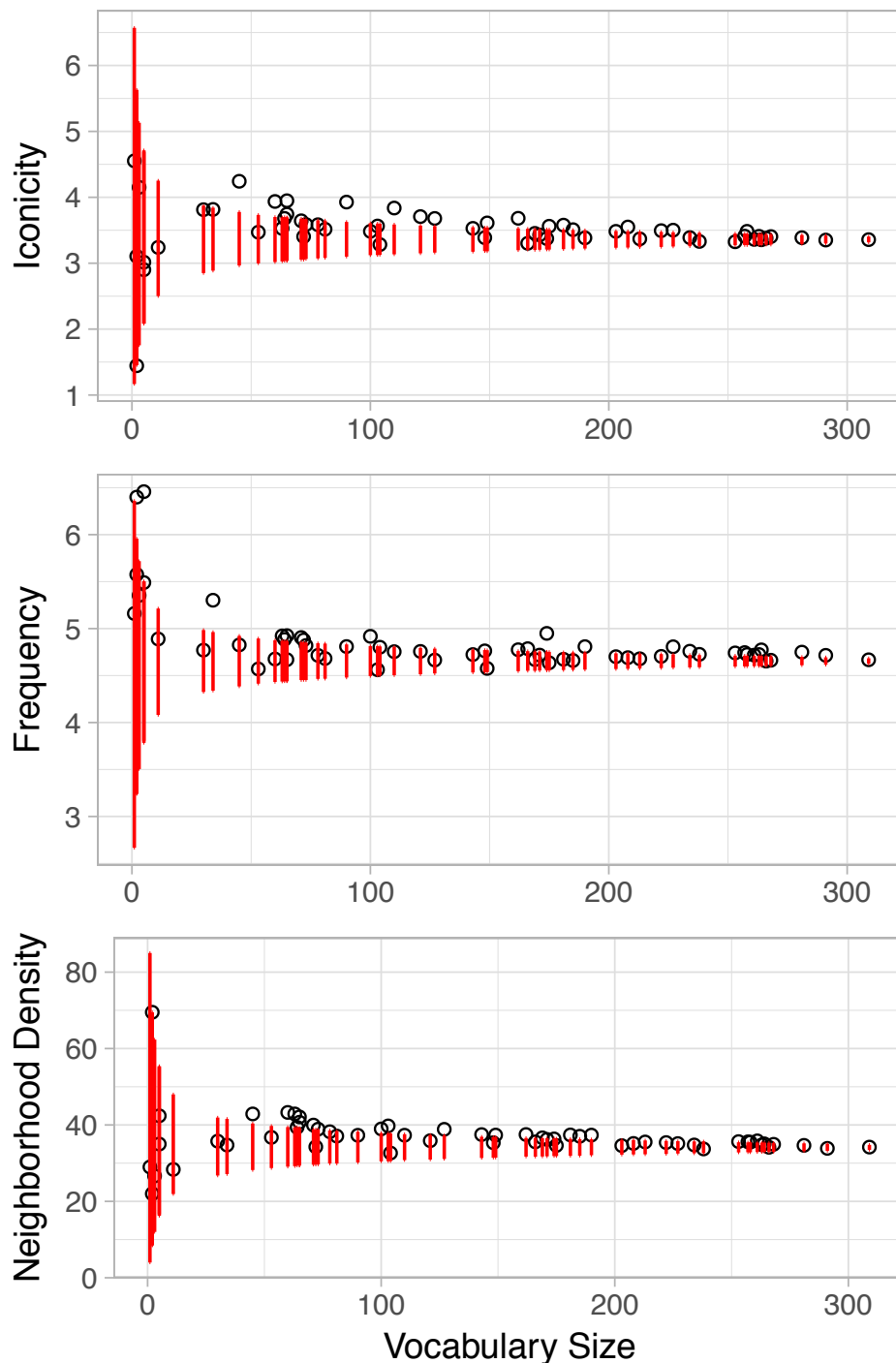
Fig. 4. Predicted probabilities of a child having acquired a word given the child's age, and the sign's iconicity, neighborhood density, and sign frequency. Predicted probabilities were

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION calculated using a link inverse function, and reflect the probability of an event (the ability to produce a sign). This graph reflects marginal effects, meaning all other predictors in the model were set to their mean. Age was positively correlated with sign knowledge. Children were more likely to know signs with high rather than low iconicity ratings, signs with high rather than low neighborhood density estimates, and signs with high than low frequency ratomgs.



**Fig. 5. Two-way interaction between age and iconicity.** Age was divided into quartiles plus the minimum and maximum values based on the z-transformed values, translations into raw ages are presented to facilitate interpretation. There were slight ceiling effects of iconicity, whereby weaker effects were found in the oldest children relative to the younger children. These results must be interpreted with caution, as the interactions were only marginally significant.

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**Fig. 6. Observed versus randomly generated iconicity, frequency, and neighborhood density estimates.** Non-transformed measures of frequency and iconicity are plotted for interpretability; the results are similar for the transformed measures. Red bars indicate the 95<sup>th</sup> percentile of the randomly generated vocabularies, and black dots indicate the observed estimates for each participant.

### Discussion

We tested three possible routes to sign acquisition: 1) exclusive reliance on iconicity, or 2) exclusive reliance on phonology, or 3) reliance on iconicity and the statistical features of signs. Our results are consistent with the third possibility. Iconicity promoted productive sign acquisition by native signing children learning ASL, replicating Thompson et al.'s (2012) BSL finding with a different sign language and with a much larger sample. The effect of iconicity held even when neighborhood density and frequency were controlled. Importantly, iconicity did not trump other factors that have been robustly shown to predict spoken vocabulary development. Despite vast differences in the forms of signs and words, sign-exposed children were sensitive to statistical properties of signs: high phonological neighborhood density and lexical frequency promoted sign acquisition, even after controlling for iconicity. This suggests that the road to vocabulary learning is not exclusively iconic, rather children also leverage statistical information about lexical items and their phonological properties to learn new signs.

The effect of neighborhood density suggests that signing children track sub-lexical structure and do not treat signs holistically, despite the simultaneity of phonological features and the prevalence of iconicity. The facilitative effect of neighborhood density is compatible with the idea that signed neighborhoods are sufficient to support configuration of new lexical items, even though signs have relatively fewer neighbors than words do (Brentari, 1998). Whether sign neighborhood density also triggers word learning is unclear (e.g., Storkel & Lee, 2011). Crucially, neighborhood density is related to other phonological properties (e.g., phonotactic probability, phonological complexity), and our work cannot specify to which phonological properties children attend. Thompson et al. (2012) observed asymmetries in the effect of phonological complexity on signed comprehension and production with effects restricted to young children's productive sign vocabulary. With our dataset we observed no significant age by neighborhood density effect indicating children make use of phonological properties to expand their productive vocabulary throughout their first years.

The iconicity effect suggests that children make use of iconic mappings to learn new words. This replicates the BSL work with two main differences. There was no difference in the

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iconicity effect among children 11-20 and 21-30 months, and we found a ceiling effect in children older than 32 months, who were not included in Thompson et al., (2012). The way children leverage iconicity is unclear. The effect of iconicity may be driven by signs that have a direct form and meaning mapping (see DeLoache, Kolstad, & Anderson, 1991 and Gentner & Ratterman, 1991 for work on non-linguistic analogical mappings). For example, children may be sensitive initially to direct iconic mappings (e.g., the handshape of the sign HAMMER shows a hand holding a hammer), but ignore distal mappings (e.g., the handshape of the sign HOUSE distally maps to the angle of the roof; see Magid & Pyers, in press). Relatedly, children prefer to produce iconic gestures and signs that represent actions rather than the perceptual features of the referent and tend to interpret them as actions (Marentette & Nicoladis, 2011; Ortega, Sumer, & Özyürek, 2016).

As in spoken languages, lexical frequency supports sign language acquisition. Our frequency estimates were based on adult-directed, not child-directed, signing and may not be the ideal measure of input frequency. In our dataset the earliest acquired signs included BATH and BALL, which are only moderately frequent in adult signing (4.92 and 4.63 respectively on a 7-point scale), but are likely more common in child-directed signing. Indeed, frequency in child-directed speech better predicts acquisition than frequency in adult-directed speech (Goodman et al., 2008). We await estimates of frequency in child-directed signing to better understand the role of frequency in sign acquisition.

While we found that native sign and spoken language acquisition are affected by similar lexical properties, the most common case of sign acquisition is among deaf children born to parents who do not know sign language, and thus have delayed exposure to language, signed or spoken (e.g., Spencer & Harris, 2005). It may be the case that children acquiring their first language later in childhood may rely to a greater degree on iconicity than on the phonological properties of the sign to learn their first signs. Indeed, hearing adult second-language learners of ASL are highly sensitive to iconicity (Baus, Carreiras, & Emmorey, 2013; Lieberth & Gamble, 1991), and deaf late learners do not efficiently process sign phonology (Mayberry & Fischer, 1989).

One central aim of the cross-linguistic study of language acquisition is to determine which properties of language development are relatively invariant, arising similarly across

NEIGHBORHOOD DENSITY, ICONICITY, AND FREQUENCY IN ASL ACQUISITION languages and regardless of modality, and which vary across languages and modalities. This work suggests that despite dramatic differences in phonology and iconicity in signed and spoken languages, signing children, like children learning spoken languages, track statistical information about lexical items and their phonological properties and leverage those features to expand their vocabulary.

### Author Contributions

J. Pyers and N. Caselli developed the study concept. Both authors contributed to the study and design. Data analysis was performed by N. Caselli. N. Caselli drafted the manuscript, and J. Pyers contributed substantial revisions. Both authors approved the final version of the manuscript for submission.

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 Supplemental Material. Stimuli used in analyses

ASL-LEX EntryID				
ARM	COOKIE	HAPPY	PANTS	SORRY
BABY	CORN_1	HAT	PAPER	SOUP
BACK	CRAZY	HAVE	PENCIL	SPIDER
BALL	CROCODILE	HEARING_AID	POLICEMAN	SPOON
BALLOON	CRY	HELICOPTER	PRETTY	STAIRS
BANANA	DANCE	HIGH	PULL	STOMACH
BASEBALL	DEER	HOUSE	PUSH	STOP
BASEMENT	DIAPER	HUNGRY	QUIET	STREET
BASKETBALL	DOCTOR	ICECREAM	RABBIT	SUN
BED	DOOR	IMAGINE	RADIO	SWEEP
BEDROOM	DRAW	JACKET	RAIN	SWING
BELT	DRAWER	JUMP	READ	TABLE
BICYCLE	DRINK	KEY	ROCK	TEA
BIRD	DROP	KNIFE	ROOM	TEAR
BLANKET	DRYER	LAMP	ROOSTER	TELEPHONE
BOOK	DUCK	LAWNMOWER	SAD	TELL
BOTTLE	EAR	LEARN	SALAD	THINK
BOWL	EARRING	LIGHTNING	SCARED	THIRSTY
BOX	EAT_1	LION	SCARF	THROW
BREAK	ELEPHANT	LOOK_FOR	SCISSORS	TIGER
BRUSH	EYES	MILK	SEE	TIME
BUTTERFLY	FIRST	MIRROR	SHIRT	TIRED
BUY	FISH	MONEY	SHORTS	TOOTHBRUSH
CAMERA	FLAG	MONKEY	SHOULDER	TREE
CAR	GET	MOP	SHOVEL	TURTLE
CARROT	GIRAFFE	MOTORCYCLE	SHOWER	UNDERWEAR
CAT	GLASSES	MOUTH	SICK	VACUUM
CITY	GLOVES	NAPKIN	SIT	VOLLEYBALL
CLOUD_1	GO	NECKLACE	SLEEP	WALK
CLOWN	GOLF	NOTHING	SMALL	WANT
COLD	HAIR	ONION	SMILE	WINDOW
COMB	HAMBURGER	OWL	SNAKE	WRISTWATCH
COOK	HAMMER	PAINT	SNOW	ZIPPER