

MODALITY-INDEPENDENT EFFECTS OF PHONOLOGICAL NEIGHBORHOOD STRUCTURE ON INITIAL L2 SIGN LANGUAGE LEARNING

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Abstract

The goal of the present study was to characterize how neighborhood structure in sign language influences lexical sign acquisition in order to extend our understanding of how the lexicon influences lexical acquisition in both sign and spoken languages. A referent-matching lexical sign learning paradigm was administered to a group of 29 hearing sign language learners in order to create a sign lexicon. The lexicon was constructed based on exposures to signs that resided in either sparse or dense handshape and location neighborhoods. The results of the current study indicated that during the creation of the lexicon signs that resided in sparse neighborhoods were learned better than signs that resided in dense neighborhoods. This pattern of results is similar to what is seen in child first language acquisition of spoken language. Therefore, despite differences in child first language and adult second language acquisition, these results contribute to a growing body of literature that implicates the phonological features that structure of the lexicon is influential in initial stages of lexical acquisition for both spoken and sign languages. This is the first study that uses an innovated lexicon-construction methodology to explore interactions between phonology and the lexicon in L2 acquisition of sign language.

Key words: American Sign Language, neighborhood density, lexical acquisition, second language, M2L2

1. Introduction

In the area of second language (L2) speech research, the manifestation of L1>L2 Language learning is an integral part of the human experience; from birth children are bombarded with language and as adults many start to explore acquiring additional languages. For decades, research has examined the processes that underlie child language (McNeill, 1970; Fletcher & MacWhinney, 1996; Slobin, 2014) and second language acquisition (Krashen, 1981; Juffs, 2011; McLaughlin, 2013). Only relatively recently in the time course of scientific inquiry has research been interested in first language acquisition of sign language (Newport & Meier, 1985; Mayberry, 2010). Given

theories of how the structure of the lexicon (Luce & Pisoni, 1998; Vitevitch & Luce, 1999) influences language acquisition, there is still much to be known about the generalizability to sign language acquisition. In the present study, we aim to explore how phonological neighborhood structure influences the emergence of a new lexicon and L2 acquisition of sign language in naïve hearing learners.

Language users whose first languages are a spoken language and are trying to acquire a sign language are known as second modality-second language (M2L2) learners. Unlike unimodal L2 learners, bimodal M2L2 learners are acquiring a new language that exists in another modality (i.e., manual-visual). The acquisition of a new language modality affords a unique opportunity to examine phonological processes because M2L2 learners do not run the risk cross-linguistic transfer. In this way, bimodal bilinguals must acquire a new phonological system. By studying the acquisition of a new phonological system, we can make parallels to the literature on child first language acquisition, as they are also acquiring a new phonological system despite the circumstances and neural architecture being different across acquisition contexts. In other words, the examination of sign language acquisition by naïve M2L2 learners opens up an opportunity to characterize how an emerging sign lexicon may be influenced by their new M2L2 phonological system.

Recent studies of adult and child spoken word recognition suggest that phonological and lexical characteristics (e.g., neighborhood density) influence the retrieval of lexical representations. In fact, many have suggested that the lexicon is organized in groups of similar lexical items based on these form-related characteristics called neighborhoods. Neighborhoods are composed of lexical items that differ by one phoneme (Luce & Pisoni, 1998). Often, neighbors are related to one another by addition, subtraction, or substitution of a single phoneme in that word (e.g., *mat* has *hat*, *bat*, *met*, *match* and *math* as some of its neighbors). Words that have many neighbors are said to be members of a dense neighborhood, whereas words that have few neighbors are said to be members of a sparse neighborhood (Vitevitch, 2003). Neighborhood density has been shown to affect speech recognition such that words that reside in sparse neighborhoods are often recognized faster and more accurately than those in dense neighborhoods (Luce & Pisoni, 1998, Vitevitch & Luce, 1999; Vitevitch, 2003). It is assumed that there is greater competition amongst neighbors in a dense neighborhood during word recognition, which slows word recognition latencies (Luce & Pisoni, 1998).

Neighborhood effects are also present in sign language lexical access, but differ slightly from those seen in spoken language. First, phonological similarity in sign languages is not derived in the same way as in spoken language. Sign languages (e.g., American Sign Language) are composed of sublexical features: handshape, location, and movement (Liddell & Johnson, 1989; Sandler, 1989; Brentari, 1998). Handshape is the shape and configuration the hands during sign production. Location refers to the place on the body where the sign is being articulated, which may be analogous to place of articulation. Movement is the directionality of the hands during sign production, which may be analogous to manner of articulation. Neighborhood density in sign language can be defined based on minimal pairs that share two of the three sublexical features (Mayberry and Witcher, 2005). Since there are few minimal pairs in sign language, other studies have taken different approaches to phonological similarity (van der Kooij, 2002) insofar as phonological similarity (i.e., neighborhood density) is defined as those signs that share only one sublexical feature (Carreiras et al., 2008; Caselli & Cohen-Goldberg,

2014). Definition of one-parameter overlap separates neighborhood density into different types: handshape, location, or movement neighborhood density. This definition diverges somewhat slightly from what is seen in the spoken language literature insofar as neighbors in sign language can only be defined through substitution and not also addition or subtraction.

Whether a sign resides in a handshape or location neighborhood has differential effects on its retrieval. Carreiras et al. (2008) investigated lexical access of Spanish Sign Language (*Lengua de Signos Española*; LSE) modulated by neighborhood density. The authors found that signs that reside in dense location neighborhoods (i.e., many neighbors that share the same location) are harder to identify than those in sparse location neighborhoods. Conversely, they found that signs in dense handshape neighborhoods are easier to identify than those in sparse handshape neighborhoods. In effect, neighbors that share the location feature create greater inhibition than those with handshape features. Corina & Emmorey (1993) found similar inhibitory effects when signs primed with neighbors that shared the location feature. Caselli and Cohen-Goldberg (2014) used computational models to simulate behavioral effects found in previous studies (e.g., Carreiras et al., 2008) and found that inhibitory effects of location arise due to the early identification in the time course of sign perception or their richer sublexical frequency. Early identification creates greater inhibition to the lexical sign over a longer period of time. On the other hand, handshape features are identified late in sign processing, which does not allow for increased inhibition through the time course of processing. Additionally, the authors implicated increased resting state activation for location because it has greater representational specificity within the lexicon. Conversely, handshape is less specified (evidenced by greater errors and variation in perception) and therefore has weaker resting state activation. From a more general perspective, Caselli and Cohen-Goldberg (2014) argued that strong neighbors (i.e., location) inhibit lexical access, whereas weak neighbors (i.e., handshape) facilitate lexical access, similar to what has been seen in the spoken language literature (see Chen & Mirman, 2012).

Phonological and lexical structure does not only influence perception and production, but also word learning (Storkel, 2001, 2002, 2004a, 2006; Storkel & Lee, 2011). The process of word learning and the interactions with the lexicon can be fractionated into multiple steps. Leach and Samuel (2007) put forth a well-composed call for clear distinctions in the lexicalization process to better contribute to our understanding of word learning. The authors delineate three theoretical processes in word learning: triggering, lexical configuration, and lexical engagement. Triggering compares incoming referential (semantic) and phonological input to already existing representations to make a decision as to whether a new lexical representation must be created. Lexical configuration is the attribution of new linguistic information to the newly allocated lexical representation (provided via triggering). Lexical engagement (also known as integration) integrates the newly allocated and configured representation with already existing representations within the lexicon (e.g., gains membership to a dense neighborhood based on phonological similarity), allowing for bidirectional influence on the processing of new and existing representations. Studies often show that the triggering and lexical configuration process happens fairly quickly, often only needs less than ten exposures (e.g., fast mapping; Storkel, 2001). Lexical configuration and engagement have also been explicitly investigated in first language acquisition (Storkel & Lee, 2011)

and in second language acquisition (Stamer & Vitevitch, 2012). Storkel and Lee (2011) attributed sublexical and lexical characteristics to these mechanisms.

Storkel and Lee (2011) explained triggering, configuration, and engagement in terms of neighborhood density in order to elucidate which is responsible for the three different lexicalization processes. The authors exposed thirty four-year-old children to nonwords with several repetitions during a picture-naming task. The children were tested at the end of the exposure and one week later task on a referent-matching task. Their results indicated that sparse words were learned significantly better than dense words. They suggested that sparse words create (triggers) a new representation, but the density advantage is not seen until later because engagement does not occur until after a delay period. Importantly, this study combined and extended Leach & Samuel's new theoretical framework with existing sublexical-lexical theories of word learning to characterize different lexical properties for different lexicalization processes.

Together, these studies suggest that density is responsible for both configuration and engagement. Despite the previous research in these areas, there is still a great amount of research that needs to be done, especially in regards to language modality and second language learning. In the current study, we aim to characterize the role of neighborhood density in the acquisition of signs by hearing M2L2 learners. By selecting participants who have no previous experience with sign language we can investigate how phonological characteristics influence the construction of a lexicon during the initial stages. Additionally, using an invented lexicon also makes it possible to study the effect of neighborhood density given that there is currently no corpus that includes phonological neighborhood density measures in any sign language (cf. CELEX or CLEARPOND, for example, in spoken languages). This is the first study of its kind to test neighborhood density effects in the acquisition of sign language.

We have two fundamental predictions that we aimed to investigate in the current study in relationship to phonological neighborhood structure and M2L2 lexical acquisition:

1. Since multiple studies have shown that words that reside in sparse neighborhoods are learned more quickly than words in dense neighborhoods for child L1 learners and M2L2 learners are also acquiring a new phonological system, we predict that these M2L2 learners will be more accurate at acquiring signs that reside in sparse neighborhoods than dense neighborhoods.
2. Since signs in handshape neighborhoods have been shown to facilitate lexical retrieval due to their weaker inhibitory feedback within the lexicon and lexical acquisition is reliant on positive feedback from memory traces, we predict that signs that reside in handshape neighborhoods will be acquired more accurately than those in location neighborhoods.

2. Method

2.1. Participants

Twenty-nine right-handed native English speakers (male = 14) from Indiana University participated in this study following Indiana University Institutional Review Board regulations. The participants mean age was 18.96 (1.28). None of the participants

reported to be bilingual or highly proficient in a second language. More importantly, no participants reported prior experience to American Sign Language (or any other sign language).

2.2. Materials

Fourteen pseudosigns were selected to construct sparse and dense neighborhoods based on the sublexical features of location and handshape (Brentari, 1998). There were five signs in each of the dense location and handshape neighborhoods and there were two signs in each of the sparse location and handshape neighborhoods for a total of fourteen signs. Therefore, signs in sparse neighborhoods made up 28.6% of the total number of signs to be learned, whereas signs in dense neighborhoods made up 71.4%. The small number of items per condition was required in order to not tax learner's ability to acquire the neighborhood structure due to too many signs. All of the signs within the sublexical neighborhood type (i.e., location vs. handshape) contained the same movement, but differed based on the other sublexical feature. For example, the signs in the sparse location neighborhoods shared the same location (i.e., shoulder) and movement (i.e., cross), but differed along the handshapes (i.e., F vs. K). Similarly, the signs in the sparse handshape neighborhoods shared the same handshape (i.e., B) and movement (i.e., tapping), but differed along the locations (i.e., nose vs. nondominant hand). All pseudosigns used in this study were adapted from real ASL signs by having one parameter (i.e., handshape, location, movement) changed to create phonotactically valid nonsigns. Additionally, all pseudosigns rated by a native signer of American Sign Language as phonological plausible, but non-existent.

Fourteen nonobjects were pseudo-randomly selected from Kroll and Potter (1984). Nonobjects were selected so that participants would be required to create a new semantic representation as well as to shield against imagability between sign and semantic representations. The nonobject differed from one another in terms of visual similarity as well. This method is similar to that in previous studies of spoken language learning (Showalter & Hayes-Harb, 2013, 2015).

2.3. Procedure

Semantic anchoring, or required referent mapping, has shown to improve in lexical acquisition (Leach & Samuel, 2007). As such, a referent-matching task provided enough semantic anchoring to encourage lexical acquisition in their experiment. Participants were seated in front of a 27-in widescreen iMac computer. The experiment was controlled by *PsychoPy* software (Pierce, 2007). At the beginning of each trial, the sign was presented and followed by a two-alternative force choice nonobject selection (i.e., referent matching). The correctly matching nonobject and a randomly selected foil were presented randomly on the left or right side of the screen. Participants were instructed to select the nonobject that they think matches the previously presented sign. Participants selected the corresponding nonobject on the left by pressing the '1' key and the nonobject on the right by pressing the '0' key. After their selection, they were given feedback as to whether their selection was correct or incorrect, where the word

“CORRECT!” appeared in green and the word “INCORRECT!” appeared in red. Each sign was presented once per set with each set repeated 30 times. Participants were instructed to guess the matching referent for the signs in the first learning set, but they were expected to learn from the feedback and aim to select the correct nonobject 100% of the time.

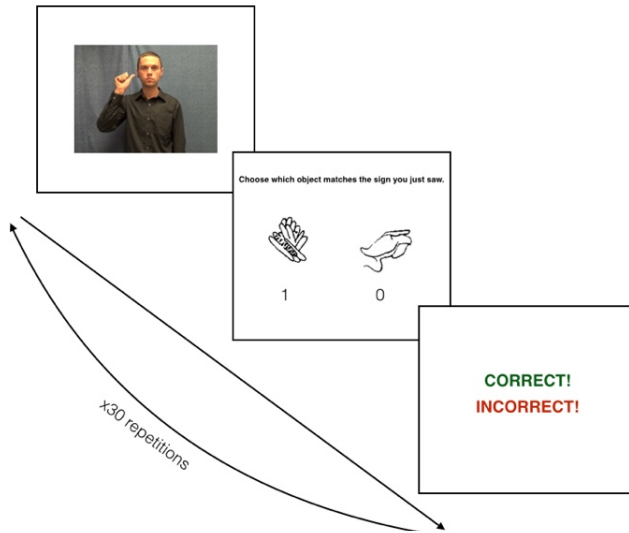


Figure 1. Referent-matching sign language paradigm.

2.4. Design

The data extracted were analyzed by examining the rate of acquisition for signs, specifically for those in sparse and dense neighborhoods. Furthermore, the rate of acquisition for signs in sparse or dense handshape neighborhoods were compared to those in sparse or dense location neighborhoods. We were only interested in accuracy of signs mapping (and not reaction times) because the research questions only address the ability to accurately match signs to referents. Additionally, we did not ask participants to make choices as quickly as possible, which prevents RT data from being informative. The statistical method that was chosen to examine the rates of acquisition (i.e., accuracy over learning set) was a generalized estimating equation (GEE). GEE allows for the analysis of how learning changes across each learning set for both neighborhood types (i.e., handshape vs. location) and density (i.e., sparse vs. dense). Since the accuracy of sign learning at one learning set is related to the success of the learning on a previous set, there are inherent correlations in the data. GEE models take into account the unknown correlations in order to estimate the parameters in the model (Hanley, Negassa, & Forrester, 2003). Additionally, GEE models can estimate the average response over the entire population relative to other general linear models that take into account the covariance in an individual (Hardin, 2005). GEE models are also explicitly adept at analyzing binary data (e.g., correct vs. incorrect responses in the 2AFC referent mapping design; Hanley et al., 2003). The GEE model used to analyze the response data (i.e.,

binary correct or incorrect accuracy data) was specified with Density and Neighborhood Type as factors and learning Set as a covariate. Specifying learning set as a covariate creates a model that treats learning set as a continuous variable (e.g., time). A continuous model (cf. discrete model where learning set would be specified as another factor) is more appropriate for this experiment because the number of 30 repetitions was somewhat arbitrarily chosen (although based on recommendations from Leach & Samuel, 2007) and the research questions are concerned with whether or not the conditions were different and/or behave differently after a given number of repetitions. Using a GEE also helps take into account the small number of items in each condition since it considers many instances across time and populations. The GEE model analyzes raw accuracy counts (i.e., correct or incorrect); however, the data were converted into proportions and smoothed using an exponential smoothing factor ($\alpha = 0.5$) for presentation purposes, which is often used for time series data (e.g., forecasting; Holt, 2004). We would also like to remind the reader that chance level performance is at 50% accuracy.

3. Results

Participants were able to learn a majority of the signs within the 30 learning sets. An average 10.15 (2.86) out of 14 signs were learned by learning set 30. There was a general increase in learning from below chance ($M = 6.13$, $SD = 1.46$) at learning set 1 and a leveling off around learning set 14 ($M = 10.05$, $SD = 2.25$).

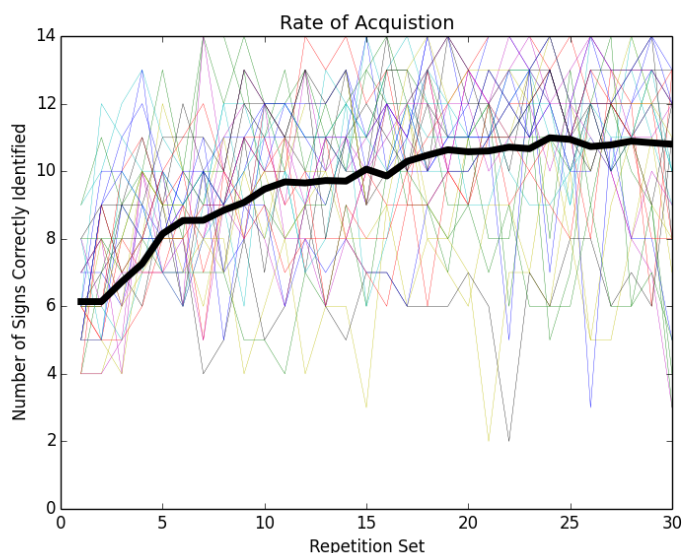


Figure 2. The number of signs scored correct in each set. Each subject is plotted with differently colored thin lines. The thick black line is the smoothed mean across repetitions.

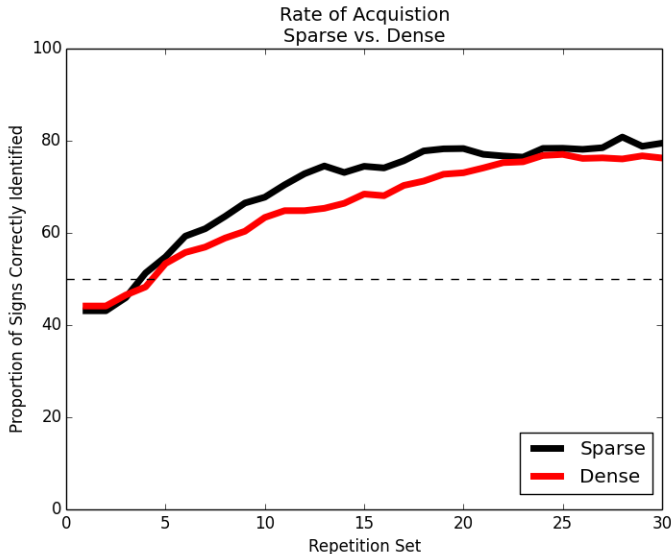


Figure 3. The trends in learning for signs that reside in sparse and dense neighborhoods collapsed across neighborhood type. Since there were different number of signs in sparse neighborhoods relative to dense neighborhoods, mean proportion correct across all subjects was calculated.

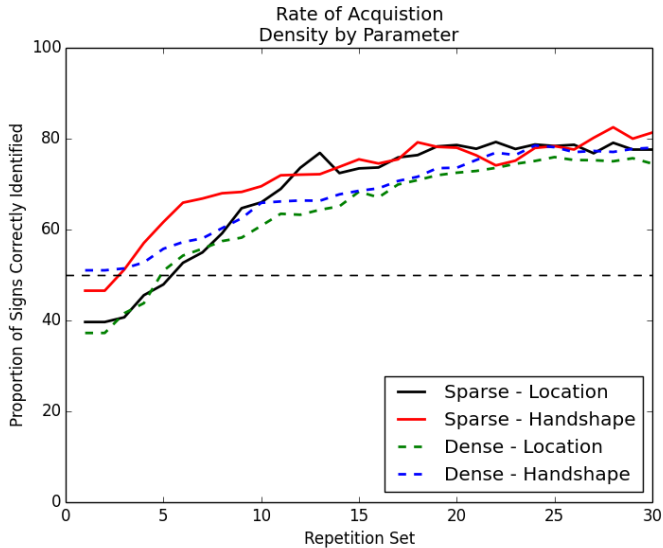


Figure 4. The figure shows a similar pattern to that of Figure 3, but breaks the neighborhoods down by type to show that the trends are relatively the same, with few interactions.

The generalized estimating equation (GEE) model had a quasi likelihood under independence model criterion value of 14452.3, which demonstrates that the model had a high goodness of fit. Tests of model effects revealed significant main effects of Density [$\theta(1) = 6.467, p < 0.05$], Neighborhood Type [$\theta(1) = 5.756, p < 0.05$] and learning Set

$[\theta(1) = 169.933, p < 0.001]$. In other words, acquisition accuracy for signs in dense neighborhoods followed the same trend (i.e., there was no interaction) as signs in sparse neighborhoods $[\theta(1) = 0.170, p = 0.680]$, but the mean accuracy values for signs in the sparse neighborhood were higher ($M = 74\%$, $SE = 12.8\%$; $\beta = 0.242$) than signs in dense neighborhoods ($M = 70\%$, $SE 9.1\%$) $[\theta(1) = 6.467, p < 0.05]$. That is, although there was increased accuracy for both sparse and dense signs over the sets, the participants consistently performed better for sparse signs than dense. Similarly, participants learned signs that shared location features in the same manner as signs that shared handshape features across the learning sets $[\theta(1) = 1.566, p = 0.211]$, but the signs residing in handshape neighborhoods ($M = 73\%$, $SE = 10.8\%$) were learned consistently better across the learning sets relative to signs in location neighborhoods ($M = 71\%$, $SE = 11.7\%$) $[\theta(1) = 5.756, p < 0.05]$. There was no significant interaction between Density and Neighborhood Type $[\theta(1) = 1.245, p = 0.264, \beta = -0.197]$. Together, these results indicate that sparse signs are learned better than dense signs and those signs that share location features were worse than those with handshape features. However, this sparse sign advantage is not due to the location advantage (i.e., not interaction). Therefore, our hypotheses are confirmed.

4. General discussion

The goal of the present study was to characterize how neighborhood structure in sign language influences lexical sign acquisition. Studies of child language acquisition have shown that neighborhood structure influences the rate of acquisition of newly acquired words (Storkel & Lee, 2011; Storkel, 2004). The role of neighborhood structure (i.e., phonological similarity) in word learning has been posited to arise from reinforcement from lexical representations in long-term memory (Demke et al., 2002). Much of the research in the area of language acquisition is restricted to spoken language acquisition. In the present study, we aimed to investigate the applicability of these theories to sign language acquisition. The results of the current study indicated that during the creation of the lexicon words that resided in sparse neighborhoods were learned more quickly than signs that resided in dense neighborhoods. This pattern mirrors what is seen for children during L1 acquisition of spoken language. Additionally, signs that shared location features were learned worse than those with handshape features.

Despite the fact that these were adult naïve M2L2 learners, they patterned much like monolingual children during first language acquisition. The use of hearing naïve M2L2 sign language learners is a unique and innovative tool to characterize *de novo* language learning. Unlike children being taught nonwords (Storkel & Morrisette, 2002) or adults learning a second language (Stamer & Vitevitch, 2012), hearing nonsigners acquiring sign language without any previous phonological exposure and no semantic representations to bootstrap can provide a glimpse into acquiring a new phonological system influences the construction of a lexicon during initial stages of sign language acquisition. Although adults are not completely the same as children, this comparison and the similarities seen herein suggest initial stages of M2L2 sign acquisition is similar to that of monolingual children acquiring a spoken language. In the present study hearing naïve M2L2 learners were exposed to fourteen novel signs that varied in their relationships to one another. The signs were paired with nonobjects and participants had

to learn their mappings over a course of 30 repetitions. The results indicated that the words that were unlike many of the other signs (i.e., resided in sparse neighborhoods) were learned faster than the signs that looked like many of the others (i.e., resided in dense neighborhoods).

Many argued that children have holistic representations during early acquisition (Charles-Luce & Luce, 1990; Metsala, 1997, Brooks & MacWhinney, 2000; Storkel, 2004; Storkel, 2002; Stoel-Gammon, 2011; De Cara & Goswami, 2003; Garlock et al., 2001; Gierut & Morrisett, 2012; Zamuner, 2009). Early computational studies provided some of the first evidence that the child lexicon might not parallel that of the fully developed adult (Charles-Luce & Luce, 1990, 1995). By calculating neighborhood densities in child and adult corpora, Charles-Luce and Luce were able to characterize the similarity between the words in the lexicon. They found that children often have distinctive words spread across various sparse neighborhoods, unlike adults who have many similar words residing in dense neighborhoods. Sparse neighborhoods are beneficial to children because children can holistically retrieve words in their lexicon. Rapid acquisition of sparse words relative to dense words could simply be due to the fact that there is less holistic confusability. Thus, the M2L2 learners in this study had an empty lexicon and with relatively little holistic competition from the other signs in the sparse neighborhoods, they were easily distinguishable. Therefore, phonologically similar signs (i.e., dense signs) are difficult to acquire because they are hard to distinguish.

There were also differences in the acquirability of the signs that were phonologically related by handshape or location sublexical features. Learners in this study were able to consistently learn signs that shared the handshape feature better than signs that shared the location feature regardless of neighborhood density. This may be counterintuitive from research in deaf child language learning. The location feature is often the easiest to acquire and the most perceptually salient feature (Marentette & Mayberry, 2000; Meier, 2000). Handshape is often later acquired and more difficult to perceive, especially for hearing second language learners (Morford & Carlson, 2011; Bochner, Christie, Houser & Searls, 2011). So, the question remains: why signs that shared location features were more difficult to acquire? The answer might lie in the fact that the learners quickly acquired the location feature and have not yet acquired the handshape feature. The acquisition of the location feature subsequently makes the other signs that share those location features much more confusable; whereas, not yet attuning to the handshape might advantage learners by not creating confusion. Another possible and convincing explanation is related to the structure of the sign lexicon itself. Previously, greater facilitative effects for handshape during lexical sign retrieval have been found, but greater inhibition for location features (Carreiras et al., 2008; Caselli & Cohen-Goldberg, 2014; Emmorey & Corina, 1990). Caselli & Cohen-Goldberg (2014) simulated computational activation of the sign lexicon and concluded that handshape neighbors have lower resting state activation and introduce inhibitory input for less time relative to location neighbors. These findings might be applicable to sign language learning as well insofar as decreased inhibition from sign neighbors relative to location neighbors aids in the acquisition of signs.

One limitation of the present study is that we cannot distinguish whether these effects are caused by handshape markedness or neighborhood density. Previous studies in spoken language literature have found a correlation between phonotactic probability and

neighborhood density and have found differential effects of both on child language acquisition (Storkel, 2004b; Storkel & Lee, 2011). As such, it is important to understand how these two factors might have also influenced lexical acquisition herein. Handshape markedness (i.e., the frequency at which a given handshape occurs) has been argued to be the analog to phonotactic probability in sign language and are similarly correlated to neighborhood density (Ann, 2006). Although we cannot address this concern in the current study, we can speculate that phonotactic probability may have little influence on the construction of the sign lexicon. Previous studies have demonstrated that markedness alone does not influence L2 acquisition of sign language (Pichler, 2012; Rosen, 2004). Therefore, we would argue that the phonological neighborhood structure is the main driving force of the effect seen in the present study; however, we are not able to completely rule out the influence of handshape markedness (i.e., phonotactic probability) either.

Taken together, the results from the current study significantly add to our understanding of language learning. First, this is the first account of how neighborhood density affects sign language learning. Evidence that sparse signs are acquired more easily than dense signs at early stages of acquisition and the opposite is true for later stages nicely parallels patterns of acquisition seen in spoken language. Thus, this study validates the generalizability of these theories across languages and across modalities. Secondly, the differentiation in acquisition of signs based on their overlapping sublexical features contribute to the small but growing field of the study of lexical access in sign language as well as concurrently reinforcing our understanding of the lexicon generally. Facilitated acquisition of signs that share handshape features relative to those with location features parallel previous findings that handshape neighbors facilitate lexical retrieval in deaf signers (Carreiras et al., 2008; Caselli & Cohen-Goldberg, 2014). In turn, these findings support previous theories that suggest the structure of the lexicon itself influence both first and second language acquisition.

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