Published in final edited form as:

Cognition. 2008 October ; 109(1): 41–53. doi:10.1016/j.cognition.2008.07.016.

Effects of language experience on the perception of American Sign Language

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Abstract

Perception of American Sign Language (ASL) handshape and place of articulation parameters was investigated in three groups of signers: deaf native signers, deaf non-native signers who acquired ASL between the ages of 10 and 18, hearing non-native signers who acquired ASL as a second language between the ages of 10 and 26. Participants were asked to identify and discriminate dynamic synthetic signs on forced choice identification and similarity judgement tasks. No differences were found in identification performance, but there were effects of language experience on discrimination of the handshape stimuli. Participants were significantly less likely to discriminate handshape stimuli drawn from the region of the category prototype than stimuli that were peripheral to the category or that straddled a category boundary. This pattern was significant for both groups of deaf signers, but was more pronounced for the native signers. The hearing L2 signers exhibited a similar pattern of discrimination, but results did not reach significance. An effect of category structure on the discrimination of place of articulation stimuli was also found, but it did not interact with language background. We conclude that early experience with a signed language magnifies the influence of category prototypes on the perceptual processing of handshape primes, leading to differences in the distribution of attentional resources between native and non-native signers during language comprehension.

Keywords

Sign language; Sign perception; Non-native first language acquisition; Second language acquisition

Introduction

Deaf individuals, unlike hearing individuals, vary considerably in the age of exposure to their first language. Auditory deprivation prevents exposure to a spoken language from birth, and a variety of social and demographic patterns prevent exposure to a signed language from birth for more than 90% of deaf individuals. Children who are exposed to a signed language from birth reach all of the language development milestones at similar ages to children acquiring spoken languages (Bonvillian & Folven, 1993; Newport & Meier, 1985; Petitto & Marentette, 1991). As adults, these individuals perform significantly better than deaf adults exposed to signed languages at later ages across a variety of language tasks. There is wide-ranging

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evidence that the variability in age of exposure to a signed language is related to language performance in adulthood (Boudreault & Mayberry, 2006; Emmorey et al., 1995; Emmorey & Corina, 1990; Mayberry & Fischer, 1989; Mayberry, 1993; Morford, 2003; Newport, 1990). What is not yet clear is whether age of exposure to a signed language affects all aspects of language acquisition and processing, or whether poor performance on a range of language tasks reflects difficulties with specific processes only. Mayberry (1994:84) hypothesized that disruptions in phonological processing may have cascading effects upon subsequent stages of sign language comprehension. The present study takes a first step toward investigating this hypothesis by isolating sign perception from other components of sign language processing.

American Sign Language (ASL) is the primary language used in the Deafⁱ communities of the United States and parts of Canada. It has a lexicon and grammar that are distinct from the spoken languages in use in the same communities (e.g., English). ASL is also distinct from other signed languages (e.g., British Sign Language). Signed languages exhibit a level of structure that has been analyzed within the framework of phonological theory. Signed language phonologists investigate the contrastive form units that combine to create lexical and grammatical units in signed languages (Brentari, 1998; Sandler, 1987). Research on signed languages is recent enough that there is still controversy about the minimal units of the language. However, the first widely known phonological analysis by William Stokoe (Stokoe, 1960; Stokoe, Casterline & Croneberg, 1965) identified a set of phonological parameters that are still core components of phonological descriptions of signed languages: handshape, place of articulation (POA) and movement. Two of these parameters, handshape & POA, were investigated in the present study.

A role for language experience in perception?

In spoken language processing, language experience influences the perception of some phoneme contrasts more than others. Stop consonant contrasts that differ only in voice onset time (e.g., /p/-/b/) appear to be fairly impervious to language experience. Human infants as well as non-human animals show a striking similarity to human adults in their greater sensitivity to acoustic variation in the perceptual region of stop consonant *boundaries* than to acoustic variation within these phoneme categories (Eimas et al., 1971; Kuhl & Miller, 1975). The precise location of the VOT boundary can be modified by language experience (Caramazza, Yeni-Komishian, & Zurif, 1973; Eilers, Gavin, & Wilson, 1979; MacKain, 1982; Zampini & Green, 2001), but there is no evidence that humans either lose sensitivity to these contrasts, or develop a heightened sensitivity to within-category variation if they are not exposed to them regularly.ⁱⁱ Other phoneme contrasts, such as the /r/-/l/ contrast in English and the retroflex /T/-/t/ contrast in Hindi, show strong effects of experience. Infants appear to be sensitive to these contrasts regardless of language background (Best & McRoberts, 2003; Kuhl et al., 1992; Werker & Tees, 1984), but adults have difficulties discriminating these phonemes reliably if they are not exposed to them frequently in childhood (Best & Strange, 1992; Iverson, Kuhl & Akahane-Yamada, 2003). One explanation of this pattern of development is that listeners form phoneme categories around central exemplars that are the most frequently heard. In this case, it is not sensitivity to the phoneme boundaries that drives the pattern of perception, but rather properties of the internal structure of the phoneme category (Kuhl, 1991).

There is no *a priori* reason to predict this same pattern to hold for signed language perception since the phonological parameters of signs are processed visually rather than auditorily.

ⁱNot all individuals with hearing loss participate in the sociolinguistic community made up of individuals who identify themselves as deaf, and who most typically use a signed language and socialize with other deaf individuals. Thus, a capitalized 'D' is used to distinguish the sociolinguistic community from the usage of 'deaf' as a reference to hearing loss (Padden & Humphries, 1988).

ⁱⁱSee Benkí (2005) for evidence that the experience-independent acoustic-phonetic cue that listeners respond to in VOT perception tasks is F1 transition patterns.

However, based on the spoken language literature, there are three logical possibilities for effects of language experience on sign perception. Language experience could influence:

1. the location of perceptual boundaries between phonological contrasts
2. the degree of sensitivity at perceptual boundaries
3. the degree of sensitivity to within-category phonetic variation

One or more of these effects could hold for one contrast, while a different set of effects holds for other contrasts, as is the case for spoken language.

The few studies on signed language perception that have been carried out to date have reported mixed results. Several early studies of sign perception indicated that the dimensions relevant to the perception of handshape and POA are the same for native signers of ASL and hearing individuals with no knowledge of a signed language, suggesting that they are perceived on a purely psychophysical basis. Lane, Boyes-Braem & Bellugi (1976, cf. Stungis, 1981) found that the same handshapes are confused by signers and non-signers when presented in visual noise, and Poizner & Lane (1978) found similarity in errors across these groups on a POA identification task. Poizner's (1981, 1983) study of movement perception, by contrast, found that despite overarching similarities in the dimensions important to movement discrimination, signers weighted these dimensions differently than non-signers, indicating that language experience shapes the perception of movement. Most importantly for present purposes, these early studies suggested that the perception of handshape and POA are not influenced by language experience, whereas perception of movement is.

More recently, three studies suggest a role of language experience for the perception of handshape, but not for POA. Two studies have reported that native signers perceive several handshape contrasts categorically while hearing participants with no knowledge of a signed language do not (Baker, 2003 [cf. Baker, Idsardi, Golinkoff & Petitto, 2005]; Emmorey, McCullough & Brentari, 2003). These studies contradict the first investigation of categorical perception in ASL, in which Supalla & Newport (1975, as reported in Newport, 1982) found no evidence of categorical perception of either handshape or POA by native signers. Subsequently, Baker, Golinkoff & Petitto (2006) tested discrimination of one handshape contrast by 4-month-old and 14-month old hearing infants with no prior sign exposure, and found that only the younger of these two groups discriminated the handshape contrast. These authors draw a parallel between studies showing sensitivity to spoken language contrasts in infancy that are subsequently lost in speakers without exposure to those contrasts, such as loss of sensitivity to the retroflex /T/-/t/ distinction by English speakers (cf. Werker & Tees, 1984). They conclude that from birth infants have the capacity to perceive the relevant distinctions in phoneme contrasts of all languages, irrespective of modality, but only maintain that sensitivity for phoneme contrasts in the native language, whether spoken or signed. The implication of their work is that exposure from birth, or at least prior to 14 months, is paramount to exhibiting categorical perception of handshape in a signed language. These studies do not, however, explore whether exposure to a signed language after childhood results in a different pattern of perceptual processing than for native signers. In order to explore how and when signed language experience shapes perception, we must investigate perception in signers with different types of signing backgrounds.

The present study examined identification and discrimination of handshape and POA contrasts in ASL by signers of different language backgrounds. Subsequently, performance on the two tasks was compared to evaluate whether the participants perceived these contrasts categorically. Deaf native signers who learned ASL from their parents as a first language, as well as deaf non-native signers who learned ASL in early adolescence from peers participated in the study. Further, a group of hearing individuals who learned ASL as a second language in

adolescence or adulthood formed a third group of participants. The participants were tested on three handshape contrasts and two POA contrasts that differed in perceptual similarity. We hypothesized that language experience would influence perception of handshape, but not of POA. Specifically, we predicted that deaf non-native and hearing L2 signers would perform similarly to native signers on the identification task, just as signers and non-signers have in past studies (Baker et al., 2005; Emmorey et al., 2003; Newport, 1982), but that deaf non-native and hearing L2 signers would have poorer discrimination of the tested handshape contrasts than native signers. Variation in perceptual similarity was predicted to interact with the effects of experience, such that more perceptually similar contrasts would show greater differences between groups.

Method

Participants

Thirteen deaf native ASL signers, thirteen deaf non-native signers of ASLⁱⁱⁱ, and thirteen hearing second language (L2) signers of ASL participated in the experiment. The data from four deaf non-native signers were excluded from the analysis because they performed at chance on the discrimination task described below. Since participants were matched for years of experience using ASL and for education level, data from four native signers and four hearing L2 signers were excluded as well. Subsequent descriptions of the participants refer only to the remaining nine individuals in each group. Participants were asked to fill out a questionnaire providing details of their background with ASL. This information is summarized in Table 1. All the native signers of ASL had 1 or 2 deaf parents except for one participant who reported learning ASL at the age of three. Members of this group reported that ASL alone or ASL and English were the primary languages they used on a daily basis. On average, participants in this group reported having 27.2 years of experience using ASL. The deaf non-native signers reported learning ASL on average at the age of 12 and a half (range: 10-18), and reported an average of 24.1 years of experience using ASL. The native and non-native deaf signers did not differ significantly in years of experience with ASL ($t(16) = .90, p = .38, ns$). With the exception of one participant, who reported a preference for using speech, the members of this group all reported using ASL on a daily basis, either alone or as one of their primary languages. Members of this group also reported using contact sign^{iv}, and English for daily communication. The deaf native and non-native signers were also closely matched for education level (see Table 1). The hearing L2 signers of ASL were all highly competent signers of ASL, but did not report using it as their primary language. This group had 23.2 years experience using ASL on average, which did not differ significantly either from the native signers ($t(16) = 1.69, p = .11, ns$), or the deaf non-native signers ($t(16) = .24, p = .81, ns$). They differed from the deaf non-native signers in the age of acquisition of ASL (mean = 21.3, range [10 - 26], $t(16) = 4.71, p < .01$). The hearing L2 signers as a group also had attained a slightly higher education level than either of the other groups (see Table 1). Thus, the hearing group consisted of highly competent second language learners of ASL who were still L1 dominant.

Materials

The stimuli were generated with a VRML-based (Virtual Reality Modelling Language 2.0) sign synthesis program (Grieve-Smith, 2001).^v Five continua were created based on three handshape contrasts and two POA contrasts. Actual ASL signs were selected as endpoints for each end of the stimulus continua. Each continuum consisted of nine dynamic, synthetic signs

ⁱⁱⁱAll of the deaf non-native signers reported that ASL was their first language, and that prior to their exposure to ASL, they had only limited knowledge of English.

^{iv}Contact sign is one of several terms that have been used to refer to the language variety that is used in situations of contact between signers of ASL and speakers of English. Generally this contact variety follows English syntax, but uses the lexicon of ASL.

varying continuously in handshape or POA relative to the two endpoints. All other phonological parameters were held constant across the stimuli in that continuum. Figure 1 is a series of three still images drawn from three signs varying only in handshape parameter from MY (handshape: /B-bar/) to COMPLAIN (handshape: /Claw/). Although Figure 1 displays still images, the actual stimuli were dynamic videos, each lasting approximately two seconds. The stimuli were presented as QuickTime movies in animation format at 720×480 pixels and approximately 13 frames per second.

Handshape contrasts

In an attempt to replicate the Emmorey et al. (2003) findings, the first handshape contrast selected was /B-bar/ vs. /A-bar/. The same signs used by Emmorey and colleagues to anchor the endpoints of the continuum were also used: PLEASE vs. SORRY.^{vi} Finger extension is one of the primary cues to the perception of handshape (Lane et al., 1976; Stungis, 1981). The /B-bar/ handshape has fully extended fingers whereas the /A-bar/ handshape only has extension of the thumb. Thus, these two handshapes are highly distinctive. The second handshape contrast selected was /B-bar/ vs. /Claw/. The signs MY and COMPLAIN were the endpoints of the second continuum (see Figure 1). This contrast is somewhat less distinctive than the first, because the fingers are fully extended in the /B-bar/ handshape and partially extended in the /Claw/ handshape. The third handshape contrast selected was /Flat-O/ vs. /8/. The signs WHITE and LIKE were the endpoints of the third continuum. This contrast is the least distinctive of all. In both handshapes, all the fingers are extended and bent at the third knuckle. The handshapes differ in that all four fingers contact the thumb in /Flat-O/, whereas only the middle finger contacts the thumb in the /8/ handshape. There is also handshape-internal movement in these signs, such that the thumb contacts the selected fingers at the end of the sign. We predicted that discrimination performance would differ across these three pairs, potentially leading to clearer effects of categorical perception in the least discriminable pair.

Place of articulation

Two contrasts were tested for the place of articulation parameter. Following Supalla & Newport (Newport, 1982) and Emmorey et al. (2003), we tested the contrast /chin/ vs. /temple/ using the signs APPLE and ONION as endpoints for the stimulus continuum. According to Poizner & Lane's (1978) study of the discrimination of POA, these two primes are closely related and should be difficult to discriminate. As a second contrast, we selected two primes that are not as closely related, specifically /chin/ vs. /chest/. We used the signs DISAPPOINT and ME as endpoints for the second POA continuum.

Procedure

All contact with participants was carried out by a Deaf research assistant including recruitment, setting appointments and running the experiment. After obtaining informed consent, participants were asked to fill out a background questionnaire. All experiments were run on a Macintosh PowerBook G3 Laptop using PowerLaboratory software (Chute, 1996).

^vThe use of synthetic stimuli is traditional in speech perception research. To date, all previous studies of sign perception have been carried out with still images or natural stimuli, in which the signer tried to move the hands in equal step sizes to create gradual changes in stimuli between category endpoints. We chose to use dynamic synthetic stimuli in order to have greater control over the physical dimensions of our stimulus continua, while preserving the movement component of the stimuli. Future work using natural stimuli or morphed videos would be a welcome addition and contrast to the current study.

^{vi}The stimulus continua were anchored by actual signs rather than nonce signs. Lexical status does influence the identification of phoneme boundaries for hearing individuals; specifically, when given a word vs. non-word continuum such as *peace-beace*, listeners identify some stimuli as *peace* even when the onset in isolation was identified as /b/ (Allen & Miller, 2001). We chose to use actual signs for two reasons. First, we intended to replicate a prior study that had used actual signs. Second, there is so little research on signed languages, that generating nonce signs is not without risk; most importantly, we were concerned that nonce signs might have phonotactic violations.

Identification task

The identification task was divided into two blocks. Each block was preceded by a brief practice session and an opportunity to ask questions. In the first block, participants identified the 27 stimuli from the handshape continua (3 continua $\times$ 9 exemplars) in random order. Each stimulus was presented four times for identification. Participants selected one of two labels at the bottom of the computer screen. The labels were counterbalanced for right- vs. left-handed response. During pilot testing, some participants identified a third sign in the handshape continuum PLEASE-SORRY. Namely, the sign DISGUST is produced using the same movement and location as PLEASE and SORRY, but with a /Claw/ handshape. We modified the experiment using a three-way identification task for this continuum. In the second block of the Identification task, participants identified the 18 stimuli from the POA continua (2 continua $\times$ 9 exemplars) in random order. Each stimulus was presented four times, counterbalanced for response hand.

Discrimination Task

We used a forced choice discrimination task, in which participants were presented with a target stimulus, as well as a pair of stimuli, one of which was identical to the target, and one that differed by two steps from the target stimulus on the continuum. Participants' ability to distinguish between the members of the stimulus pair was determined by their ability to select the appropriate match to the target stimulus. In pilot testing, participants expressed a strong preference for an XAB discrimination task. One participant in particular felt strongly that this ordering conformed to typical discourse processing structures for ASL signers, in which the topic is presented first, followed by information about the topic. We chose to follow the pilot study participants' feedback although this order is not typical of spoken language discrimination tasks.^{vii} The experiment began with a practice session and an opportunity to ask questions. Each trial began with the synthetic signer centered motionless on the computer screen for 1 second. Subsequently, participants saw the target stimulus followed by two signs from the stimulus continuum. Participants were instructed to decide whether the second sign or the third sign was the same as the first sign, and to respond with a button press indicating their choice. All signs were centered in the computer screen during presentation. Each sign began and ended with the signer's arms at rest at her sides. The inter-stimulus interval was 0 msec; in other words, as soon as the signer's hands had returned to her sides, the next sign began. The discrimination task was divided into four blocks. Each block included stimulus pairs from each of the five phonological contrasts. The discrimination judgements involved 2-step comparisons, so for each 9-step continuum there were seven comparisons (1-3, 2-4, 3-5, 4-6, 5-7, 6-8, 7-9). Each comparison was presented eight times (2 replications of 4 XAB orders: AAB, ABA, BAB, BBA), for a total of 280 trials across the four blocks (5 phonological contrasts $\times$ 7 comparisons $\times$ 8 judgements).

The duration of the entire experiment was approximately 1 hour.

Results

Identification task

The first analysis addresses the nature of the categories that emerged through the identification task. For every handshape and POA contrast and for all groups, participants consistently switched labels at a similar point along the stimulus continuum. The crossover from one category to another was well defined, with one or at most two stimuli that were not assigned

^{vii}A two-tailed t-test comparing performance on the two stimulus orders confirmed that the XAB ordering did not give participants an advantage when the matching stimuli were presented together (AAB and BBA, $M = .77$) as opposed to apart (ABA and BAB, $M = .78$), $t(139) = .74$, $p = .46$, *ns*.

to a single category 75% of the time or more. The location of the crossover was not at the same point in the stimulus continuum for all contrasts. Thus, separate one-way ANOVAs were carried out for each handshape and POA contrast to determine whether language background influenced the perceptual location of the phoneme contrast boundary. No significant differences were found. Table 2 reports the boundary location for each group. These values were computed by averaging the crossover stimulus for each participant in each group, that is, the stimulus on which identification fell below 75%. When no stimulus or two stimuli had identification rates below 75%, the value of two points on the continuum were averaged. These results suggest that signers group phonetic variants of ASL signs similarly despite differing acquisition histories. Thus, categorization abilities appear to be somewhat independent of language experience for the selected stimuli. However, the ability to categorize stimuli in a consistent manner does not imply that the stimuli are perceived categorically. This issue is addressed in a subsequent analysis.

Discrimination Task

Discrimination of handshape stimulus pairs, in contrast to identification, was affected by language background and phonological contrast as revealed by a 3×3 repeated measures mixed analysis of variance (ANOVA) with language background (native, non-native, L2) as a between-subjects factor and phonological contrast (/B-bar/ vs. /A-bar/, /B-bar/ vs. /Claw/, /Flat-O/ vs. /8/) as a within-subjects factor. Mean discrimination performance for each group and each contrast is shown in Table 3. There was a main effect of language experience, $F(2, 18) = 6.500$, $p < .01$, $\eta^2_p = .419$. The second language signers (91%) and the deaf non-native signers (84%) had the most accurate discrimination performance and did not differ from each other. Both groups discriminated significantly more contrasts than the native signers (79%), as revealed by post-hoc comparisons using the Bonferroni correction (native vs. non-native, $p < .016$; native vs. L2, $p < .019$).

There was also a main effect of phonological contrast for handshape, $F(2, 36) = 15.727$, $p < .001$, $\eta^2_p = .466$. As predicted, discrimination performance was better for perceptually different handshapes (92%) and poorer for perceptually similar handshapes (77%, see Table 3). There was an interaction between language background and phonological contrast, $F(4, 36) = 10.369$, $p < .001$, $\eta^2_p = .535$. The difference in performance between native signers and hearing L2 signers increased with increasing perceptual similarity of the handshape contrasts. Specifically, there was only a difference of 6% accuracy between these groups on the least perceptually similar handshape contrast, /B-bar/ vs. /A-bar/, but a difference of 16% accuracy for the most perceptually similar handshape contrast, /Flat-O/ vs. /8/.

Discrimination of POA contrasts was also affected by language experience, $F(2, 18) = 9.558$, $p < .01$, $\eta^2_p = .515$. The second language signers (96%) and the deaf non-native signers (95%) had the most accurate discrimination performance and did not differ from each other. Both groups discriminated significantly more contrasts than the native signers (91%; native vs. non-native, $p < .015$; native vs. L2, $p < .002$). There was no main effect of phonological contrast, $F(1, 18) = .003$, $p = .96$, ns , $\eta^2_p = .000$, possibly because of a ceiling effect. Both contrasts were discriminated at a high level of accuracy (94%). There was no interaction of language background and phonological contrast, $F(2, 18) = .369$, $p = .70$, ns , $\eta^2_p = .039$. Finally, POA contrasts (94%) were correctly discriminated more often than handshape contrasts (85%).

Categorical Perception

Turning now to the issue of categorical perception (CP), we address whether or not there was a discontinuity in discrimination performance when stimuli straddled the category boundary relative to discrimination performance within the category, as determined by performance in the identification task. Figure 2 illustrates an idealized CP function: Discrimination

performance is higher at the location of the perceptual boundary on the identification task than at all other locations on the stimulus continuum. Furthermore, discrimination performance on within-category contrasts is uniform. Figures 34, 5, 6, 7 present the identification and discrimination data for the five phonological contrasts, respectively. In each figure, identification performance is illustrated with the solid lines and discrimination performance with the dotted lines. Percent correct discrimination of two stimuli on the continuum is located at the midpoint between those stimuli (e.g., in Figure 4, discrimination of the first and third stimuli of the /B-bar/ vs. /Claw/ contrast that is anchored on the MY and COMPLAIN signs is located at MC2, midway between MC1 and MC3 on the X-axis).

A visual inspection of the data in Figures 3-7 reveals that discrimination performance is not always highest at the location of the identification boundary. Further, discrimination performance on within-category contrasts is not uniform. These two characteristics of the data suggest that categorical perception does not provide an adequate account of the perceptual behaviour exhibited by our participants. Nevertheless, in order to facilitate comparison of our results with past studies, we carried out an analysis directly comparing discrimination performance of stimulus pairs that straddled the identification boundary (between-category contrasts) with mean discrimination performance of all other stimulus pairs (within-category contrasts, see Figure 8). A 3×2 repeated measures mixed ANOVA with language background (native, non-native, L2) as the between-groups variable and contrast type (between-category, within-category) as the within-group variable revealed a significant main effect of language background ($F(2,24) = 7.425$, $p < .01$, $\eta^2_p = .382$) and of contrast type ($F(1,24) = 20.402$, $p < .001$, $\eta^2_p = .459$) on handshape discrimination performance. Performance was better on stimulus pairs that straddled identification boundaries as opposed to mean discrimination performance on all stimulus pairs drawn from within a category. Further, the interaction of language background and contrast type ($F(2,24) = 2.862$, $p = .077$, $\eta^2_p = .193$) approached significance. Pairwise comparisons revealed that discrimination performance was significantly better on between-category stimulus pairs than on within-category stimulus pairs only for the deaf native and non-native signers, but not for the hearing L2 signers.

A similar analysis of POA discrimination performance revealed a marginal effect of language background ($F(2,24) = 3.291$, $p = .055$, $\eta^2_p = .215$) and no effect of contrast type ($F(1,24) = 1.613$, $p = .216$, *ns*, $\eta^2_p = .063$) and no interaction ($F(2,24) = .235$, $p = .793$, *ns*, $\eta^2_p = .019$). These results seem to suggest that deaf native and non-native signers exhibit categorical perception of handshape, but not of POA, and that the hearing L2 signers do not exhibit categorical perception of either parameter. However, note that the variability between the groups occurs not on how well the signers discriminate stimuli at category boundaries, but rather on how poorly they discriminate stimuli within the categories (see Figure 8). This indicates that the differences between the groups is caused by a loss of sensitivity to phonetic variation within the phoneme category, rather than by the maintenance of a phoneme contrast through exposure to the contrast in early infancy.

Two previous studies that reported categorical perception for ASL handshape contrasts both relied on statistical analyses, like the one provided here, that do not evaluate whether variability in discrimination performance within a category can account for the group differences observed. In one case, discrimination of between-category contrasts was compared to a mean of discrimination performance on within-category contrasts (Emmorey et al., 2003), identical to the analysis reported here, while in the other case a single within-category contrast was selected for comparison to a between-category contrast rather than using all of the within-category contrasts from the continuum (Baker, 2003; cf. Baker et al., 2005, a report of the same dataset, which also treats within-category discrimination performance as homogenous by comparing the average d' on within-category contrasts to d' on between-category contrasts).

In order to compare the discrimination performance of the groups on stimuli drawn from within a handshape or POA category, we analyzed the data in an alternative manner. This approach allowed us to evaluate whether the degree of change in performance seen at the category boundary was also found within the category. We averaged performance across three regions of interest. Specifically, performance was compared for stimulus pairs that straddled the identification boundary (*boundary*), stimulus pairs that were drawn from within a single category, just adjacent to the identification boundaries, and hence, peripheral to the center of the category (*peripheral*), and stimulus pairs from within a single category that were not adjacent to the boundary, and hence, closest to the category prototype (*central*). Figure 9 displays discrimination performance categorized in this way, collapsed across the three handshape continua (top) and the two POA continua (bottom). As becomes apparent in this figure, the greatest change in discrimination performance occurs within the category (i.e., between peripheral and central stimulus pairs) and not in the region of the identification boundary. A repeated measures 3×3 mixed ANOVA with language background (native, non-native, L2) as a between-groups variable and contrast type (boundary, peripheral, central) as a within-groups variable revealed a main effect of language background ($F(2,24) = 8.614$, $p < .01$, $\eta^2_p = .418$) as well as a main effect of contrast type ($F(2, 48) = 46.919$, $p < .001$, $\eta^2_p = .662$) on handshape discrimination performance. Discrimination was progressively worse for stimulus pairs that were farther from the boundary and closer to the category prototype. Moreover, there was an interaction of language background and contrast type ($F(4, 48) = 4.811$, $p < .01$, $\eta^2_p = .286$) indicating that this trend was greatest for native signers, somewhat mitigated for deaf non-native signers, and only marginal for the hearing L2 signers (see Figure 9). Pairwise comparisons revealed that discrimination performance differed for native signers from boundary to peripheral to central exemplars (boundary vs. peripheral, $p < .05$; peripheral vs. central, $p < .001$; boundary vs. central, $p < .001$). The non-native signers did not differ in their discrimination of contrasts at the boundary relative to those adjacent to the boundary ($p = .379$, *ns*), but their discrimination was significantly poorer for contrasts close to the category prototype relative to other contrasts (peripheral vs. central, $p < .001$; boundary vs. central, $p < .001$). None of the contrast types differed significantly for the L2 signers (boundary vs. peripheral, $p = .705$, peripheral vs. central, $p = .067$, boundary vs. central, $p = .070$).

A comparable repeated measures 3×3 mixed ANOVA of the POA discrimination performance revealed a main effect of contrast type ($F(2,48) = 4.551$, $p < .05$, $\eta^2_p = .159$), but no effect of language background ($F(2,24) = 2.596$, $p = .095$, *ns*, $\eta^2_p = .178$), and no interaction ($F(4,48) = .955$, $p = .441$, *ns*, $\eta^2_p = .07$). Interestingly, although there is little variability in POA discrimination performance across the three groups of participants, the same pattern of discrimination performance dropping between peripheral and central pairs of stimuli was found. Discrimination performance did not differ between the boundary and the peripheral region ($p = .743$, *ns*), but it did differ between peripheral and the central regions ($p < .01$) as well as between the boundary and the central region ($p < .05$).

Discussion

Sign language experience clearly affects the perception of handshape in ASL, but not as we had predicted at the onset of this study. All of the participants, regardless of language background, revealed discontinuities in their ability to discriminate between phonetic variants of handshape primes. Discrimination of handshape stimuli was poorest in regions close to a category prototype, and better for more peripheral phonetic variants as well as for actual phoneme contrasts. The degree to which this pattern was observed was influenced by age of first exposure to ASL. Native signers showed the greatest discontinuities in discrimination performance. Discrimination ability was best for handshape stimuli straddling a category boundary, and dropped when participants were presented with handshape exemplars drawn from the periphery of a single phoneme category. But discrimination performance was much

lower when native signers were presented with handshape stimuli that varied little from the category prototype. Deaf non-native signers did not display significant differences in discrimination performance for between-category stimulus pairs relative to within-category peripheral stimulus pairs. They did, however, show a significant drop in discrimination performance between peripheral and central stimulus pairs, indicating that their phoneme categories are also structured by perceptual experience, but less so than is the case for native signers. Hearing second language signers were the most attentive to phonetic detail of the three groups, and exhibited the most uniform discrimination performance across the three perceptual regions that were compared. The hearing L2 signers' discrimination performance was poorest for stimuli drawn from the category center, but not significantly so, indicating that the perceptual experience they gained later in life was not restructuring their perception of handshape exemplars to the extent that the earlier experience of the native and deaf non-native signers had. Moreover, early experience with spoken language perception did not allow the hearing L2 learners of ASL to develop more native-like perceptual mechanisms for a signed language relative to the deaf non-native signers. Although all participants had similar experience with ASL in terms of the number of years of exposure, the point in development when that exposure occurred was different. The evidence demonstrates that the earlier in life participants were exposed to ASL, the more their perception skills are optimized to the linguistically relevant variation in the signed language signal.

Perception of POA did not reveal effects of age of exposure. Discrimination performance was almost at ceiling for all three groups of participants for all stimulus pairs. However, even for POA, participants exhibited less perceptual sensitivity in the region of the category prototype than in the region of the phoneme boundary, suggesting that sign language experience is more likely to lead to a loss of sensitivity to phonetic variability rather than to the maintenance of phoneme contrasts, but without respect to the age at which that experience is obtained.

The results of this study have important implications for three broader theoretical issues that we will address in turn. First, the results have implications for the recent issue of whether or not ASL handshape is perceived categorically. We conclude that it is not. Second, we propose an alternative explanation for the results of our study and the results of previous studies, demonstrating that all data reported to date are consistent with a modality-independent distributional learning model. Finally, we address whether differences in handshape perception that are related to language experience can account for the comprehension problems of non-native signers.

At the outset of the study, we proposed three ways that language experience might influence perception: 1) by influencing the location of perceptual boundaries between phonological contrasts; 2) by influencing the degree of sensitivity at perceptual boundaries; 3) by influencing the degree of sensitivity to within-category phonetic variation. If handshape were perceived categorically by native signers, but not by either of the non-native groups that we tested, we would have expected to see differences on the first or second of these aspects of perception. However, no differences were found in either case. With respect to the location of perceptual boundaries, we found that participants from all three groups categorized both handshape and POA stimuli in similar ways on the identification task. Further, we did not observe a heightening of sensitivity to important contrasts for either handshape or POA in the native signers. All three groups tested were able to discriminate stimuli that straddled perceptual boundaries with a high rate of accuracy. Effects of language experience were found only on sensitivity to within-category variation, and only for handshape.

Two recent studies have reported that ASL handshape is perceived categorically by native signers (Baker et al., 2005; Emmorey et al., 2003). The results of this study are for the most part consistent with the findings of those studies, yet we do not interpret our data as providing

support for the position that ASL handshape is perceived categorically by native signers. In all three studies identification performance was similar across all participants, regardless of language experience; and discrimination performance was good for both within- and between-category contrasts for all participants. Further, in all three studies, native signers demonstrated significantly better discrimination performance of between-category stimulus pairs than within-category stimulus pairs. However, the previous two studies did not investigate variability in performance on within-category stimulus pairs. By investigating performance within the category, we found that the greatest difference in discrimination occurs close to the prototype or central member of the category rather than at the boundary.

Further, our study provides an additional crucial comparison in the form of control groups who have experience with a signed language, but not from birth. In our view, it is the data from the deaf non-native and hearing L2 signers that rules out an interpretation of the native signers' data as evidence of categorical perception. This brings us to the issue of developmental accounts of perceptual learning (Werker, 1994). If categorical perception of handshape contrasts is present from birth, as Baker et al. (2006) have argued, and is subsequently lost by 14 months of age in individuals without exposure to sign, then we should find low levels of discrimination performance on both within- and between-category contrasts for deaf non-native and hearing L2 signers. By this account, the native signers should distinguish themselves as the only group with unusually good discrimination at identification boundaries. Instead, we find excellent sensitivity to within- and between-category phonetic variation in deaf non-native and in hearing L2 signers. How can we explain an increase in sensitivity in these groups, beyond the level of sensitivity in native signers, who have been exposed to sign language across the lifespan? A more parsimonious explanation of our results is that sensitivity to visual changes in handshape develops from birth in all humans, and is maintained to some degree across the lifespan. Exposure to language, especially early in development, shapes the nature of that sensitivity.

Both deaf non-native signers and hearing L2 signers presumably had experience with co-speech gesture prior to their acquisition of ASL, and the deaf non-native signers may have also had extensive experience with idiosyncratic gesture systems, called homesign (Goldin-Meadow, 2003). Whether or not this experience influenced the development of their perceptual abilities with ASL must be investigated in a future study. We can conclude, however, that co-speech gesture or homesign alone is not sufficient to shape handshape perception in the way that early exposure to a signed language does.

We propose an alternative account for the way that language experience affects sign perception than the proposals made by Emmorey et al. (2003) and Baker et al. (2006). The pattern of discrimination performance is most consistent with distributional learning accounts, such as Kuhl's Native Language Magnet/Neural Commitment model (Kuhl, 2004).^{viii} According to such models, infants are sensitive to distributional patterns of sensory input, and as responses to these regularities become neurally encoded, infants develop resistance to competing patterns that do not conform entirely to the typical sensory pattern. Perceptual experience is not evenly distributed across perceptual space, but instead is disproportionately clustered around the central exemplars of native language phoneme inventories, thus introducing a bias toward perceiving stimuli as central members of a category. Changes in discrimination abilities can even be induced in infants by modifying the distribution of phonetic tokens they are exposed to (Maye, Werker & Gerkin, 2002). This type of model would predict that after seeing the /A-bar/ handshape (similar to a fist with the thumb extended) repeatedly, infants would lose sensitivity to a handshape in which there was a slight opening of the fist and respond to this

^{viii}See Best & McRoberts (2003) and Pierrehumbert (2003) for additional perspectives on perceptual learning that could also account for these results.

variant as though they had seen the prototypical /A-bar/ handshape. However, a handshape in which the fingers were opened enough that it shared features with both the /A-bar/ and the /Claw/ handshape would not be assimilated into the /A-bar/ category. In other words, phonetic variability close to the central exemplar of a phoneme category is not detected as readily as phonetic variability near the category boundary.

This account has several advantages relative to the claim that native signers perceive handshape categorically while non-signers do not. First, it is consistent with the data of all studies reported to date. It predicts that experience will lead to differences in perceptual performance close to category prototypes rather than at category boundaries, as is predicted by categorical perception. Figures 3 & 4 in Emmorey et al. (2003: 30-31) indicate that performance on handshape discrimination was poorest for central exemplars of their categories, as was the case in our study. Further, differences in visual acuity between 4 and 14 month old infants may have allowed the older infants in the Baker et al. (2006) study to detect finer distinctions in their handshape stimuli, leading to a more distributed pattern of responding than in the 4 month olds. Thus, the older infants in the Baker et al. study may be in the process of developing the perceptual sensitivity that we see in the hearing L2 signers. If those infants were to be immersed in an ASL setting in the future, they would presumably develop more internal structure to their visual perceptual categories, but in such a way that they would continue to show sensitivity to phonetic variability (cf. McMurray & Aslin, 2005). Second, the fact that differences in the present study were related to age of acquisition rather than years of experience with ASL can be accounted for by the proposal that neural commitment to frequent and predictable sensory patterns suppresses responses to competing sensory patterns. A more straightforward learning account would not be able to explain why the non-native groups did not learn the category structure as well as the native signers given the same amount of experience with ASL in terms of years of use. Finally, and perhaps most importantly, this explanation permits a single account of perceptual behaviour in both the auditory and the visual domains for both signers and non-signers, because the mechanism is not tied to modality-specific processing characteristics. Infants are sensitive to distributional patterns of both auditory and visual sensory stimulation, and are able to develop perceptual categories in either modality.

Corroborating evidence is beginning to emerge from other laboratories that suggests that signers do not perceive handshape categorically, and that non-native signers are particularly adept at handshape discrimination (Mathur & Best, 2006). Nevertheless, there remains much to be investigated with respect to the perception of signed languages. Very few handshape and POA primes have been used across the few studies completed to date. Further, we know almost nothing about the role of experience on the perception of movement (but see Poizner, 1981, 1983), nor how manipulating several parameters of signs simultaneously, such as handshape and movement, would influence perceptual performance.

Because we followed Supalla & Newport (1975, as reported in Newport, 1988) and Emmorey et al. (2003) in using actual signs as endpoints for our continua rather than using nonsense syllables as is prevalent in spoken language studies, effects of lexical processing are also a potential factor in the results of this study. Lexical effects can shift the location of a phoneme boundary in perception tasks. This seems not to have influenced one of the groups more than the others in this study since handshape and POA identification performance did not differ across groups. It is possible, however, that the deaf non-native signers and the L2 signers exhibited superior performance on the discrimination task because their access of the lexicon is less rapid and automated than for the native signers (Emmorey & Corina, 1990). Native signers may have performed these tasks post-lexical access, while non-native signers were able to focus on perceptual detail without the distraction of lexical activation. Further, in everyday use of ASL, non-native signers may focus a great deal of attention on the sign signal. This could have affected their approach to the discrimination task, leading them to focus on phonetic

variability more than the native signers. It would be instructive to carry out additional investigations of perceptual processing with these populations using stimuli that had no semantic associations.

This brings us to the final issue we wish to address, and the original motivation for pursuing this study. Within the context of the history of studies showing poorer language comprehension by deaf signers who begin acquisition of ASL in adolescence or later relative to native signers, this study makes an important contribution. Past studies have consistently demonstrated differences in lexical and grammatical processing between native and non-native signers (Boudreault & Mayberry, 2006; Emmorey et al., 1995; Emmorey & Corina, 1990, 1992; Mayberry & Fischer, 1989; Mayberry, 1993; Mayberry & Eichen, 1991; Morford, 2003; Newport, 1990; Singleton & Newport, 2004), but we have known little about the perceptual processing of non-native signers and how that might impact their comprehension abilities. The results of this study suggest that both deaf and hearing non-native signers have excellent perceptual acuity with respect to handshape and POA, but that their sign perception abilities differ from those of native signers because their perception is not influenced as much by perceptual category structure. We can rule out an explanation of comprehension difficulties that is caused by perceptual inaccuracy. Instead, non-native signers may be “overly accurate” in their perception of handshape primes. In other words, the greater attention to fine phonetic distinctions observed within the deaf non-native and the hearing L2 groups relative to the native signers may be detrimental to lexical and grammatical processing within contexts of face-to-face interaction, when processing language efficiently is essential.

This interpretation of the data is consistent with a long line of research carried out by Rachel Mayberry and colleagues, documenting a variety of effects of delayed exposure to signed language on ASL comprehension. One of the first clues that the language comprehension difficulties of non-native signers might be rooted in perception was the report of a high rate of phonological errors during sentence shadowing (Mayberry & Fischer, 1989). Non-native signers in that study produced signs that had no semantic relation to the target sentence, but that were phonologically similar in form (e.g., producing the ASL sign *SLEEP* instead of *AND*). Mayberry (1994: 84) proposed that a single mechanism could account for the pattern of errors she has found in her work, specifically that later learners of signed languages may depend on “controlled phonological processing, that is, nonautomatic and effortful phonological processing.” Our study provides an explicit demonstration of one way in which phonological processing may be less automated for deaf non-native and hearing L2 signers who first acquire ASL in adolescence. These signers are responsive to phonetic detail that native signers have learned to ignore. Although this difference in perception is clearly less efficient, it is not the case that non-native signers are functioning with different phoneme categories than native signers, or that they are unable to correctly identify phoneme primes. Thus, we are doubtful that the perception differences described here can account for the large range of differences on comprehension tasks reported to date. Instead, lexical, grammatical and discourse processing may be the central locus of the acute differences in comprehension between these populations.

Acknowledgements

We would like to thank the participants of our research, as well as Sarah Hafer for help in collecting data, and Caroline Smith and several anonymous reviewers for very helpful comments on previous versions of the manuscript. Portions of this study were presented at the 2005 Meeting of the Linguistic Society of America in Oakland, CA. This research was supported by NIH Grant R03 DC03865 to Jill P. Morford, and by the National Science Foundation under grant number SBE-0541953 awarded to Thomas Allen to establish the Science of Learning Center for Visual Language and Visual Learning (VL2). Any opinions, findings, and conclusions or recommendations expressed are those of the authors and do not necessarily reflect the views of the National Institutes of Health or the National Science Foundation.

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Figure 1.
Still images drawn from the dynamic signs varying from MY to COMPLAIN. From left to right: Endpoint MY, 5th step on the continuum, Endpoint COMPLAIN.

Figure 2.

Idealized Categorical Perception function. Identification performance plots proportion of stimuli identified with the label associated with stimulus 9. Discrimination performance plots proportion correct on a forced choice XAB task comparing the stimulus prior to and following the position of the plotted point, e.g., discrimination accuracy of stimulus 4 vs. stimulus 6 is plotted at point 5 on the X axis.

Figure 3. Identification and Discrimination functions for the PLEASE-DISGUST-SORRY continuum, /B-bar/ vs. /Claw/ vs. /A-bar/ handshake contrasts. There are two identification functions. The identification function for /B-bar/ (PLEASE) begins at 100% correct. The identification function for /A-bar/ (SORRY) begins at 0% correct. Participants identified the stimulus as /Claw/ (DISGUST) when both identification functions are below 50% (PDS2, PDS3 & PDS4).

Figure 4.
Identification and Discrimination functions for the MY- COMPLAIN continuum, /B-bar/ vs. /
Claw/ handshape contrast.

Figure 5. Identification and Discrimination functions for the WHITE-LIKE continuum, /Flat-O/ vs. /8/ handshape contrast.

Figure 6.

Identification and Discrimination functions for the APPLE-ONION continuum, /CHEEK/ vs. /TEMPLE/ place of articulation contrast.

Figure 7. Identification and Discrimination functions for the DISAPPOINT-ME continuum, /CHIN/ vs. /CHEST/ place of articulation contrast.

Figure 8. Discrimination performance on between-category (white bars) vs. within-category (grey bars) stimulus pairs collapsed across three handshape contrasts (top) and across the two POA contrasts (bottom).

Figure 9.

Discrimination performance on stimulus pairs straddling the identification boundary (boundary), at the periphery of the category (peripheral), and at the center of the category (central), collapsed across three handshape contrasts (top) and two POA contrasts (bottom).

Table 1

Background characteristics of participant groups: Native signers, deaf non-native signers, and hearing L2 signers of ASL.

	Native	Non-native	L2
N	9	9	9
Female	7	6	6
Mean Age	28	37	45
Range	[21, 40]	[23, 51]	[43, 49]
Age of Acquisition of ASL	Birth	12.5	21.3
Range		[10, 18]	[10, 26]
Years Experience ASL	27.2	24.1	23.2
Range	[21, 40]	[12, 40]	[19, 34]
Education			
High School or GED	3	2	2
B.A., B.S. or Vocational	4	5	3
M.A.	2	2	4

Table 2

Boundary locations as determined by identification performance. F-statistics for analyses comparing the location of the boundary crossover by participant group (Native, Non-native, L2) are reported for each phonological contrast

	Native	Non-native	L2	F-value
Handshape				
/B-bar/-/Claw/-/A-bar/ ^a	1.8	1.9	2.0	F(2, 24) = .34, n.s.
	4.9	5.3	4.4	F(2,24) = 1.13, n.s.
/B-bar/-/Claw/	4.9	4.6	4.4	F(2,24) = .90, n.s.
/Flat-O/-/8/	1.8	2.1	2.1	F(2,24) = .27, n.s.
Place of Articulation				
/Chin/ vs. /Temple/	4.8	5.2	4.8	F(2,24) = 1.44, n.s.
/Chin/ vs. /Chest/	3.3	3.2	3.4	F(2,24) = .05, n.s.

^aNote: There are two boundaries for this handshape continuum since participants assigned stimuli to three categories.

Table 3

Mean percent correct performance on discrimination by phonological contrast and participant group (s.d.)

	Native	Non-native	L2	MEAN
Handshape				
/B-bar/-/Claw/-/A-bar/	88.0 (.06)	93.5 (.03)	95.7 (.05)	92.4 (.06)
/B-bar/-/Claw/	78.6 (.04)	83.3 (.04)	90.5 (.06)	84.1 (.07)
/Flat-O/-/8/	69.8 (.12)	76.0 (.13)	85.7 (.08)	77.2 (.13)
Place of Articulation				
/Chin/ vs. /Temple/	91.7 (.04)	94.4 (.03)	96.8 (.04)	94.3 (.04)
/Chin/ vs. /Chest/	91.1 (.04)	96.0 (.02)	96.0 (.04)	94.4 (.04)