Memory & Cognition
1989, 17 (6), 740-754

Looking through phonological shape to lexical meaning: The bottleneck of non-native sign language processing

RACHEL I. MAYBERRY
The University of Chicago, Chicago, Illinois

and

SUSAN D. FISCHER
National Technical Institute for the Deaf
Rochester Institute of Technology, Rochester, New York

In two studies, we find that native and non-native acquisition show different effects on sign language processing. Subjects were all born deaf and used sign language for interpersonal communication, but first acquired it at ages ranging from birth to 18. In the first study, deaf signers shadowed (simultaneously watched and reproduced) sign language narratives given in two dialects, American Sign Language (ASL) and Pidgin Sign English (PSE), in both good and poor viewing conditions. In the second study, deaf signers recalled and shadowed grammatical and ungrammatical ASL sentences. In comparison with non-native signers, natives were more accurate, comprehended better, and made different kinds of lexical changes; natives primarily changed signs in relation to sign meaning independent of the phonological characteristics of the stimulus. In contrast, non-native signers primarily changed signs in relation to the phonological characteristics of the stimulus independent of lexical and sentential meaning. Semantic lexical changes were positively correlated to processing accuracy and comprehension, whereas phonological lexical changes were negatively correlated. The effects of non-native acquisition were similar across variations in the sign dialect, viewing condition, and processing task. The results suggest that native signers process lexical structure automatically, such that they can attend to and remember lexical and sentential meaning. In contrast, non-native signers appear to allocate more attention to the task of identifying phonological shape such that they have less attention available for retrieval and memory of lexical meaning.

Recent research has uncovered numerous linguistic and psychological parallels between speech and sign language. These striking similarities demonstrate that the process of deriving meaning from linguistic form is very abstract. Changing the peripheral sensory and motor channel of language expression and comprehension from audition and oral articulation to vision and manual articulation does not appear to alter the basic way in which language is processed (Grosjean, 1980; Poizner, Klima, & Bellugi, 1987; Siple, 1982). However, the recent discoveries about sign language characterize the processing of the most proficient signers—native signers, individuals who have first learned to sign in infancy from their caretakers in circumstances analogous to those of native speakers. The effect of non-native language acquisition on normally hearing speakers' language processing has not been described well, nor is it well understood. The specific effects that non-native acquisition may have on sign language processing have not been investigated.

In fact, sign language communities offer a special case with which we can examine the effects of non-native acquisition on language processing. Congenitally deaf individuals typically learn sign language in circumstances radically unlike those in which normally hearing people acquire speech. Hearing speakers typically learn their native tongue at home, beginning in infancy. By contrast, most deaf signers first learn sign language from peers outside the home, frequently after early childhood. This unique situation is the product of two factors. First, only 3%-8% of deaf children have deaf parents (Brown, 1986; Rawlings & Jensema, 1977; Schein & Delk, 1974), which means that 92%-97% of deaf children are born into normally hearing families where no one knows or uses any sign language. Second, until recently, a majority of

The research reported here was supported by NIH Grant NS20142 to R. Mayberry, and by the U.S. Department of Education through an agreement with the National Technical Institute for the Deaf at the Rochester Institute of Technology. We thank the several individuals whose help in carrying out these studies was indispensable: Keith Cagel, Sharon Lott Cagel, Dale Kennedy, Sally Koziar, Ellen Eichen Koot, Barbara Ray, and Frank Woolsey. We also thank Susan Goldin-Meadow and Gloria Waters for helpful comments on earlier versions of this paper, and Alice Healy and Howard Nusbaum for thoughtful questions and insights. Requests for reprints should be sent to R. Mayberry, School of Human Communication Disorders, McGill University, 1266 Pine Ave West, Montreal, P.Q., H3G 1A8, Canada.

schools for deaf children implemented educational policies that prohibited sign language in classrooms during the primary grades ("oralism"). Such schools simultaneously discouraged parents from learning or using any sign language (or gesture) with their young deaf children in the belief that sign language and gestures impeded deaf children's speech learning. The net consequence of these educational and genetic factors is that deaf signers acquire sign language under much more heterogeneous circumstances than those under which normally hearing speakers acquire spoken language (Mayberry, Wodlinger-Cohen, & Goldin-Meadow, 1987).

In two studies, we examine three factors in order to investigate whether non-native sign language acquisition affects sign language processing. The first factor is the age at which the deaf signer has first acquired sign language. The second factor is the clarity of the sign language signal. The third factor is the dialect and the linguistic structure of the sign language stimulus. Before describing current knowledge about sign language comprehension and production, we briefly describe the linguistic and social variation that characterizes sign language usage, variation that motivates the questions we ask.

Sign Language Dialects

American Sign Language. Sign language is a generic term referring to a variety of gestured communication used by deaf people in place of speech. *American Sign Language* (ASL) in particular refers to the sign language that has evolved among deaf people in the United States. Recent investigation has shown ASL to be structured like a natural language, but unlike English. For example, the ASL lexicon is constructed from a finite set of articulatory units such that signed words are decomposable into meaningless units (Liddell, 1984; Liddell & Johnson, 1985; Wilbur, 1987). ASL syntax and inflectional morphology are highly spatial. Case relations and pronominal reference are signaled by the use of movement to and from locations in space. ASL verbs are complex in comparison to English verbs because of the large number of nested inflections they require. Inflecting verbs, for example, are marked with obligatory and optional inflections for person, number, case, and aspect (Padden, 1983). Spatial, or classifier, verbs are complex because they are marked for inflections for nominal class, location, and movement path and manner (McDonald, 1982; Schick, in press; Supalla, 1982).

Unlike English, which relies on word order, ASL's reliance on word order to convey case relations varies as a function of verb class. Inflecting verbs use movement and location morphemes to show case relations, instead of word order. However, transitive and noninflecting (or plain) verbs use SVO word order (Fischer, 1974; Padden, 1983). Also, unlike English, ASL marks some types of phrases and clauses (such as adverbial, adjectival, topic, and relative) with distinctive facial gestures (Liddell, 1980; Mayberry, 1979), which are produced simultaneously with the manual phrases and clauses that they mark.

Pidgin Sign English. Not all American deaf signers produce ASL grammatical structure when they sign. They use instead a mixture of ASL and English. Hence, linguists call this type of signing *pidgin sign English*, or PSE (Woodward, 1973b). In PSE, ASL lexical items are produced following English word order, or SVO, regardless of verb type. PSE uses some of the spatial syntactic devices of ASL, but it does so to a lesser extent and with less consistency (Reilly & McIntire, 1978). Thus verbs in PSE may or may not be inflected with ASL morphemes for person, number, aspect, and case, depending on the individual signer. PSE uses an uninflected copula and sometimes uses the English articles *a* and *the* (Woodward, 1973b). PSE uses little ASL facial gesture (Reilly & McIntire, 1978).

Sociolinguistic usage. A number of sociolinguistic variables that covary with ASL and PSE usage may be important factors underlying signers' proficiencies. Until recently, PSE has had higher prestige than ASL in some settings. Consequently, PSE is often used in formal situations and ASL in informal ones (Stokoe, 1970). PSE is typically used when deaf and hearing people converse, no doubt because its structure has many English elements. In contrast, ASL is most often learned as a first language by people with deaf parents or by those with hearing parents who have attended residential schools for deaf children before the age of 6 (Woodward, 1973a). However, both sign dialects are used within the same linguistic community. Many deaf signers switch back and forth between ASL and PSE, depending on the social situation and linguistic backgrounds of the interlocutors.

Educational signing. A third kind of sign may interact with any effect that non-native acquisition has on sign language processing. The signing currently used in classrooms for deaf children is a system of gesturing English that was explicitly created for educational purposes and is referred to as *signed English*, or *manually coded English*, MCE (Mayberry & Wodlinger-Cohen, 1987; Wilbur, 1987). MCE uses PSE lexical items with an invented system of gestures for English closed class and bound morphemes, such as *-s*, *-ed*, *-ing*. These are affixed to and interspersed among PSE open class signs to coincide with English speech. MCE verbs, then, are inflected sequentially with these invented and gestured morphemes rather than with the spatial verb morphemes of ASL. Word order is SVO as in PSE and spoken English. In addition, many lexical items are coined to represent the English lexicon. These coinages are amalgams of fingerspelling and ASL/PSE signs (Gustason, Pfetzing, & Zawolkow, 1972). The result is that some MCE lexical items are ungrammatical in both ASL and PSE. Linguists do not consider MCE to be a natural language (Wilbur, 1987). Nonetheless, it is the first kind of signing encountered by many deaf children today.

Although several varieties of sign are used within the deaf community, most psychological research examining sign language processing has focused on ASL. This is no doubt because ASL is considered to be a natural language, albeit one that has evolved in sensory and motor modalities atypical of speech (the hands and eyes), whereas the linguistic status of the other sign varieties is the subject of much debate.

Sign Language Processing

Levels of language processing. From a psychological standpoint, the primary question regarding sign language processing has been whether its visual structure is processed similarly to the acoustic structure of speech. Processing similarities between the two kinds of language would be important for two reasons. First, sign language is not acoustic. Second, to the naive observer, signs look like undecomposable gestalts.

Several studies have shown that, despite surface differences, sign language processing entails two levels of psycholinguistic analysis highly similar to those of speech: form and meaning. In short-term recall of unrelated signs, signers make errors based on the phonological pattern of signs, rather than on the meaning of the signs to be remembered (Bellugi, Klima, & Siple, 1975; Krakow & Hanson, 1985; Poizner, Newkirk, Bellugi, & Klima, 1981). Signers engage in this phonological pattern recognition even when the phonological shape of the stimulus signs appears to consist of pictures (or mime) to naive observers (Poizner, Bellugi, & Tweney, 1981). Such errors are the sign language analogue to the phonological errors that speakers make during short-term recall of words (Baddeley, 1966; Conrad, 1964). Conversely, when spontaneously signing, signers' lexical misconstructions are frequently phonological in nature (Newkirk, Klima, Petersen, & Bellugi, 1980). Such production errors are the sign analogue to the phonological "slips of the tongue" that speakers make during spontaneous speech (Fromkin, 1971). Together, these error phenomena show that sign processing requires a phonological stage of pattern analysis.

The notion that sign language processing is characterized by levels of analysis similar to those of speech is further supported by long-term memory studies. When recalling signs over several minutes, signers recognize the meaning of the stimulus signs, not their phonological shape (Siple, Fischer, & Bellugi, 1977). Similarly, when judging whether stimulus signed sentences are identical to previously presented ones, signers recognize meaning mismatches rather than phonological or syntactic mismatches (Hanson & Bellugi, 1982). These findings show that surface form is discarded and meaning is retained in sign language processing, as is the case in speech processing (Jarvella, 1971; Sachs, 1967).

Finally, signers use levels of both form and meaning in sign processing. When presented with portions of signs (with a gating procedure) and asked to identify them, signers are significantly faster and more accurate when the signs are given in sentential context rather than in isolation (Clark & Grosjean, 1982). This shows that signers use both "bottom up" (phonological) and "top down" (contextual) information in sign processing, as is also the case for speech processing (Marslen-Wilson & Tyler, 1980).

Prior experience and sign language processing. The above characterization of sign language processing describes that of the *native* signer. The sign language processing of the non-native signer, someone who first learns to sign outside the home after infancy, has not been described, however. Some studies have reported significant differences between the performances of native and non-native signers, but to explore these differences was not the goal of the work.

First, Poizner (1981) asked native signers and normally hearing people who had never seen sign language before to judge the similarity of movements extracted from signs. The two groups categorized the visual stimuli differently. Poizner interpreted the effect as being the visual analogue of the differential auditory perception that speakers show for phonemes from a "native" as opposed to a "foreign" language. In a learning study, Siple, Caccamise, and Brewer (1982) found the skill level of deaf and normally hearing signers (specifically, "skilled, intermediate, and unskilled") to predict the speed with which they could learn associations between written English words and nonsense signs. More importantly, the rank order of stimulus difficulty for the skilled signers was predicted by a set of distinctive features proposed for ASL handshapes (Lane, Boyes-Braem, & Bellugi, 1976), whereas the performance of the unskilled signers was not. This suggests that signers use their knowledge of sign phonology to learn new signs and that increasing practice with sign entails increasing familiarity with sign phonology.

Examining comprehension skills, Hatfield (1983) found that the number of years a signer had used ASL (as measured by years of use since age of acquisition) predicted comprehension accuracy (and reaction time) on the ASL sentences. Similarly, the signer's years of MCE usage predicted performance on the MCE sentences (as measured by educational history, which reflected the number of years MCE was used in the school setting).

Thus, previous research has found that variation in prior experience affects sign language perception, learning, and comprehension. However, previous research has not asked whether there is a specific and systematic relationship between native and non-native acquisition and sign language processing. If language is best acquired in early childhood rather than afterward, as Lenneberg (1967) first proposed, then we might expect the age at which signers first acquired sign language to affect their processing of it. In the following two studies, we asked whether native and non-native acquisition of sign language have systematic effects on sign language processing, and, if so, what the nature of these effects is.

STUDY 1

In the first study, we examined the possible effects of native and non-native acquisition on sign language processing within the context of two additional factors: sign language dialect and signal saliency. First, our rationale for comparing native and non-native sign language processing across two sign dialects was to determine the generality of the non-native acquisition effect. Native and non-native acquisition might interact with the dialects of ASL and PSE, depending on the specific background of the subject. Second, the rationale for manipulating the clarity of the sign language signal was to determine the stability of the non-native effect. Non-native signers might process sign language less well than natives only when the viewing conditions are difficult, but not when they are not. Finally, we used a shadowing task as the dependent measure of language processing. In a shadowing task in sign language, the subject simultaneously watches and signs verbatim the sign language stimulus. This gives an "on-line" measure of the signer's processing ability.

Method

Stimuli and Design. The stimuli were four sign language narratives. Two were given in ASL and two different ones were given in PSE. The narratives were composed by two congenitally deaf signers, one male and one female. Each narrator extemporaneously signed two personal incidents to an audience of other deaf signers No other instructions were given to the narrators, except that the narrative should last several minutes and contain a variety of sentence structures.

The narrators were selected for their contrasting native and non-native acquisition of sign language, following the sociolinguistic variables Woodward (1973a) proposed to differentiate ASL and PSE usage. The narrator of the two ASL narratives was a deaf native signer who (1) had learned to sign from birth, (2) was from a deaf family, and (3) had attended a residential school for deaf children before the age of 6. The narrator of the two PSE narratives was a deaf non-native signer who (1) had first learned to sign at the age of 16 from deaf signing friends outside of school, (2) had a normally hearing family, none of whom used sign language, and (3) had never attended residential school, but had instead attended a neighborhood public school where no sign language was used. Both narrators were college educated. Each narrative was videotaped.

The four sign language narratives had the following themes and lengths: The first, which was about a school holiday, consisted of 70 sentences. The second, which was about a deaf woman mistakenly committed to a mental institution, consisted of 46 sentences. The third, which was about a deaf dog who knew sign language, consisted of 58 sentences. The fourth, which was about a car catching on fire unbeknownst to the deaf driver, consisted of 80 sentences.

Five comprehension questions were constructed for each narrative. One question probed a presented fact, two asked about the central conflict, and two asked about the resolution of the conflict. In order to circumvent any comprehension problems that might be associated with native and non-native acquisition of sign language, the questions were given in written English. Although the subjects varied in terms of when and how they had acquired sign, their reading skills did not vary as much, because they were all postsecondary students. The questions were given in a multiple-choice format, with four alternatives also given in written English.

Two viewing conditions were created for each narrative, one good and one poor. The poor viewing condition was created by mixing video noise with the original signal. The visual noise consisted of randomized black and white dots, which looked like video "snow." Each sign language narrative was then rerecorded, with the black and white noise mixed with the original signal. Forty-one percent of the mixed video signal was original picture and 59% was noise This procedure produced two viewing conditions for each narrative, one without noise—the good viewing condition—and one containing noise—the poor viewing condition.

To control for any effects of practice or fatigue that might accrue from watching several sign narratives in sequence, the experimental conditions (sign language dialect and viewing condition) were counterbalanced. This produced one experimental block of four trials for each subject: two ASL narratives (one in good and one in poor viewing conditions) and two PSE narratives (one in good and one in poor viewing conditions). The experimental conditions were further counterbalanced with presentation order. This meant that the first and second narratives within each sign dialect were given in alternating viewing conditions across subjects. Half the subjects saw the first ASL story in the good viewing condition, and the remainder saw the same story in the poor viewing condition, and so forth. Finally, the presentation order of sign dialect and viewing condition was additionally counterbalanced, with Latin squares, across subjects This meant that each subject received a different order of viewing conditions and sign dialects.

Subjects. Sixteen subjects participated. All had been born severely or profoundly deaf and were students at the National Technical Institute for the Deaf (NTID). Eight were native signers. They had first learned to sign in early childhood from deaf families. Most attended residential schools for deaf children, but a few attended classes for deaf children in regular public schools while living at home. Most probably learned ASL at home (as contrasted with PSE). They ranged in age from 18 to 22 years. The average length of time they had used sign language was 20 years (measured in years of use beginning at the age of initial sign language acquisition—infancy, or zero, for these subjects).

Eight subjects were non-native signers. All had normally hearing families who neither knew sign language nor used it with them. All had first learned to sign between the ages of 9 and 16 years. No subject had ever received any formal sign language instruction. Some had learned to sign from deaf friends outside of school, and others had learned to sign when they changed schools from one in which no one used sign language to one in which everyone signed (in some cases PSE, and in others MCE). Like the native signers, these subjects ranged in age from 18 to 22 years, so the length of time they had used sign language ranged from 2 to 11 years.

At NTID, where both groups were currently enrolled, lectures were generally given in PSE with simultaneous speech. Consequently, both groups were highly familiar with this kind of sign dialect in the classroom environment.

Testing procedure. Each subject was tested individually and told that he or she would see four different stories in sign language in two different viewing conditions. (No mention was made of the two sign dialects.) The subject was instructed to copy verbatim the signing of the televised narrator while simultaneously watching the stimuli. No specific instructions about how to shadow were given, other than that the subject should not be concerned with mistakes. The subject was also told that comprehension questions would be asked. Instructions were given to the native subjects in ASL. Instructions to the non-native subjects were given in PSE and simultaneous speech. Each subject watched the stimuli on a 26-in. color video monitor. A video camera placed beside the video monitor recorded the subject's shadowing performance.

Transcription procedure. The transcription and coding of the subjects' shadowing performance consisted of several steps. First, two native signers transcribed the stimulus narratives into an English gloss. The gloss represented each sign with one English word and also described each inflection. Agreement between the two transcribers was quite high, averaging 96% across all signs. Disagreements were resolved through repeated viewing and discussion of the stimulus signs in question. Next, each subject's shadowing performance was transcribed in a manner identical to that of the stimuli.

Finally, the gloss of the subject's performance was compared to that of the stimulus narratives, sign for sign.

Mismatches between the subject's shadowing performance and the stimulus narratives were described in detail and then analyzed and categorized. Sign errors were first categorized broadly in terms of whether the error was a deletion or change of a stimulus sign, or an addition of a sign not present in the stimulus. The "lexical change" category was then analyzed in detail in terms of the linguistic relationship the changes showed to stimulus signs. The majority of such changes were highly regular and were of two basic kinds.

The first type of lexical change was semantic. These lexical changes were related to the meaning of either the target sign or the target sentence, but not to any of the phonological characteristics of the target sign. For example, one narrative contained the sentence translated as, "About midnight, many *children* came to my home." Some subjects replaced the stimulus sign CHILDREN with the sign FRIENDS, producing the response sentence translated as, "About midnight, many *friends* came to my home." The signs for the two words, *children* and *friends*, are unrelated phonologically in ASL and PSE (and in MCE). Importantly, though, the lexical change is a meaningful one based on comprehension of the stimulus sentence up to the point of the mistake. Note that the semantic lexical change produces a response sentence that is both grammatical and meaningful. This type of error maintains semantic coherence but changes the meaning of the sentence. Such semantic lexical changes are the same type of errors native signers are reported to make in studies of long-term memory for lists of signs as well as signed sentences (Hanson & Bellugi, 1982; Siple et al., 1977).

The second type of lexical change was phonological. Unlike the semantic lexical changes, the phonological sign changes bore no relationships to the stimulus signs or sentences at the level of meaning. Rather, these lexical changes were related only to the phonological shapes of stimulus signs. Phonological similarity was judged to be present if a changed sign (mistake) shared two of three formational parameters with the stimulus sign: handshape, location, or movement. For example, one stimulus narrative contained the sentence translated as, "I ate too much turkey *and* potato." One subject replaced the stimulus sign *and* with the sign *sleep*, producing instead the response, "I ate too much turkey *sleep* potato." The two signs, AND and SLEEP, are phonologically similar. The stimulus sign AND is made horizontally in front of the torso. The lexical change SLEEP is vertically made in front of the face. Because such mistakes were related solely to sign phonology and completely divorced from sign and sentence meaning, they always resulted in a nonmeaningful response sentence. These phonological lexical changes are the same type of lexical errors as are reported to occur in short-term memory for isolated signs (Bellugi et al., 1975; Krakow & Hanson, 1985; Poizner et al., 1981).

Most of the subjects' lexical changes during shadowing consisted of these two categories. Some few errors showed no linguistic relationship to the target words and sentences and were thus categorized as "random." Others simultaneously shared both semantic and phonological properties with the stimulus sign and were classified as such. Still other errors were unintelligible and were classified as such.

In the following analyses, the subjects' lexical changes are reported as proportions. Proportions were computed for each subject individually across each condition and refer to each subject's lexical changes summed across five categories: semantic, phonological, simultaneously semantic and phonological, random or unclassifiable, and unintelligible. Deletions were also computed as proportions. Proportions were computed for each subject individually across each condition and refer to each subject's lexical deletions divided by the sum of all lexical errors (deletions, changes, and additions). For this reason, reported group means do not necessarily sum to 100%.

Results and Discussion

The subjects' shadowing performance was analyzed in several ways. First, overall accuracy was measured by computing the proportion of narrative sentences shadowed without error (individually for each subject in each condition). Second, the general type of lexical error was measured by computing the proportion of mistakes that were deletions or changes. Third, the linguistic type of lexical change was examined by computing the proportion of lexical changes that were phonologically, as opposed to semantically, related to the stimulus signs and sentences. Finally, comprehension during shadowing was measured by computing the proportion of questions answered correctly.

For the statistical analyses, the proportions were transformed with $2(\arcsin\sqrt{\%})$ to ensure homogeneity of variance. (Proportions of 0.00 or 1.00 were transformed with Bartlett's correction: $x = .00$ was changed to $.25\ n$, and $x = 1.00$ was changed to $1.25\ n$, where n = the number of observations, here the sum of the subject's errors, as recommended by Kirk, 1982.) The transformed data were analyzed with analyses of variance and correlation as described next. For purposes of clarity, we describe the groups' performance in terms of the original data (i.e., proportions).

Shadowing accuracy. Table 1 shows the groups' shadowing accuracy in terms of the mean proportion of narrative sentences shadowed without error. The data were analyzed with a three-way, repeated measures analysis of variance for one between-groups factor, type of sign acquisition (native and non-native groups), and two within-groups factors, viewing condition (good and poor) and sign language dialect (ASL and PSE). There were significant effects of each main factor on shadowing accuracy, but no interactions among these factors.

Type of sign acquisition exerted a significant effect on shadowing accuracy. The native signers outperformed the non-native signers (with a mean of .60 sentences correctly shadowed as compared to .14 sentences) [$F(1,14) = 166.78$, $MS_e = 0.096$, $p < .001$]. In this experimental

Table 1
Narrative Sentences Shadowed without Error by Native and Non-native Signers

Sign Dialect	Viewing Condition	Mean	Range
	Native Signers		
ASL	Good	.57	.76-.36
ASL	Poor	.45	.60-.21
PSE	Good	.74	.96-.54
PSE	Poor	63	.74-.47
	Non-native Signers		
ASL	Good	.12	.21-.02
ASL	Poor	.09	.24-.02
PSE	Good	.39	.54-.13
PSE	Poor	.11	.19-.04

Note—Native signers first acquired sign language during early childhood; their average years of use equaled 20. Non-native signers first acquired sign language at ages from 9 to 16 years; their years of use ranged from 2 to 11.

sample, the type of sign acquisition accounted for 68% of the performance variance. This result shows that the way in which sign language is learned greatly affects the accuracy with which signers can process sign language.

Second, viewing condition also exerted a significant effect on shadowing accuracy. The subjects were more accurate in the good viewing condition (with .42 sentences correctly shadowed) as compared to the poor viewing condition (.29 sentences) [$F(1,14) = 18.60$, $MS_e = 0.0574$, $p < .001$]. Viewing condition did not interact with the main factors of type of sign acquisition or dialect. This indicates that the effect of visual noise on shadowing accuracy was similar for both the native and the non-native groups, regardless of dialect.

Third, sign language dialect significantly affected shadowing accuracy. The subjects shadowed the PSE narratives more accurately (with a mean of .43 sentences) than they did the ASL narratives (with a mean of .28 sentences) [$F(1,14) = 33.17$, $MS_e = 0.0483$, $p < .001$]. Sign language dialect did not interact with age of acquisition. This result indicates that both the native and the non-native signers shadowed the PSE narratives more accurately than they did the ASL narratives, as Table 1 shows. This finding may be due to the spatial nature of ASL as compared to the linear nature of PSE. In other words, shadowing spatially instantiated linguistic structure may be more difficult than shadowing sequentially arranged structure. Alternatively, the finding may reflect the frequency with which PSE and ASL have been and are currently used in these deaf subjects' educational environments (independent of whether they first learned ASL at home). As we previously noted, PSE is routinely used in academic settings—a formal situation. In contrast, ASL use in such settings is more rare.

Although the subjects shadowed the PSE narratives more accurately than they did the ASL narratives, it is important to note that performance in the two dialects was positively correlated (for the good viewing condition, $r = +.84$, $p < .01$; for the poor viewing condition, $r = +.86, p < .01$, one-tailed). This indicates that there is a substantial overlap between ASL and PSE in terms of language processing; that is, knowledge of one dialect can take the signer a long way toward understanding the other. This finding also fits the linguistic description of these two dialects given above.

General type of lexical errors. Table 2 shows the mean proportion of lexical errors that the subjects made during shadowing that were deletions and changes (computed for each subject individually over the three categories of lexical deletion, change, and addition, the latter being infrequent and therefore excluded from the table and from then following analysis). The general type of lexical errors that the signers made was analyzed with a three-way repeated measures analysis of variance. As before, the three factors were type of sign acquisition (native and non-native signers), sign language dialect (ASL and PSE), and lexical error type (deletion and change).

Table 2
Lexical Deletions and Changes in Narrative Shadowing for Native and Non-native Signers

Sign Dialect	Error Type	Mean	Range
	Native Signers		
ASL	Deletions	90	95- 80
ASL	Changes	10	.24-.03
PSE	Deletions	.75	.87- 61
PSE	Changes	.25	39-.11
	Non-native Signers		
ASL	Deletions	93	.97-.89
ASL	Changes	08	.14- 03
PSE	Deletions	84	.93- 70
PSE	Changes	15	30- 07

Note—Native signers acquired sign language during early childhood, their average years of use equaled 20. Non-native signers acquired sign language at ages from 9 to 16 years, their years of use ranged from 2 to 11

The results showed no main effects for type of sign acquisition or dialect. However, there was a significant effect of error type, which interacted with both type of sign acquisition and dialect [$F(1,14) = 7.885$, $MS_e = .031$, $p < .01$], as is shown in Table 2. In narrative shadowing, the most prevalent lexical error was deletion as compared to lexical change (with means of .86 and .14, respectively) [$F(1,14) = 863.402$, $MS_e = .098$, $p < .001$]. Error type interacted with type of sign acquisition, such that the native signers made proportionately fewer lexical deletions and more lexical changes (.81 and .18, respectively) than did the non-native signers (.90 and .10, respectively) [$F(1,14) = 18.576$, $MS_e = .098, p < .001$]. Similarly, error type interacted with dialect such that the subjects made proportionately more lexical deletions and fewer lexical changes on the ASL narratives (.91 and .10, respectively) as compared to the PSE narratives (.81 and .18, respectively).

These findings show that native and non-native signers do not differ greatly in performance at this basic level of error analysis. Both groups delete far more lexical items than they change. At the same time, however, the pattern of results suggests that lexical changes in shadowing reflect greater sign language knowledge than do lexical deletions (see Table 2). This is further shown by the negative correlation between lexical deletions and shadowing accuracy ($r = -.50$, $p < .05$), as well as the positive correlation between lexical changes and shadowing accuracy ($r = +.51$, $p < .01$, one-tailed).

Linguistic type of lexical changes. The linguistic nature of the lexical changes that the groups made were strikingly different, even though the overall proportion of lexical changes was small in comparison to deletions. As previously described, the majority of lexical changes were related to the stimuli in two ways, semantically (with no phonological relationship) and phonologically (with no semantic relationship). The proportion of lexical changes that the subjects made that were of the two types was analyzed with a three-way repeated measures analysis of variance. As before, the three main factors were type of sign acquisition (native and non-native signers), viewing condition (good and poor), and error type (semantic and phonological). The results showed that type of sign acquisition interacted with both viewing condition and linguistic error type.

First, viewing condition interacted with type of sign acquisition such that the poor viewing condition increased the rate at which the native signers made lexical changes (.18 and .30 for the good and poor viewing conditions, respectively), whereas this did not produce a similar effect for the non-natives (.34 and .35, respectively) [$F(1,14) = 7.484$, $MS_e = .062$, $p < 05$]. This indicates that the visual noise hindered the native signers' shadowing to a greater degree than it did the non-native signers', in the sense that the natives made relatively few lexical changes in the good condition, and significantly more in the poor one, whereas the non-natives made many lexical changes regardless of whether the viewing condition was poor or not.

Second, type of sign acquisition interacted with error type such that the primary kind of lexical changes that the two groups made was different [$F(1,14) = 98.908$, $MS_e = .455$, $p < .001$]. As Figure 1 shows, native signers predominately changed stimulus lexical items in relation to meaning (with no relationship to phonology). In contrast, the non-native signers predominately changed stimulus lexical items in relation to phonology (with no relationship to meaning). These error patterns characterized the two groups' performances on both the ASL and the PSE narratives in both the good and poor viewing conditions, as is indicated by the lack of significant interactions with these factors.

This striking difference in the pattern of lexical changes was not restricted to a few individuals in each group. Rather, every subject in the native group made more semantic lexical changes than phonological ones. Likewise, every subject in the non-native group made more phonological lexical changes than semantic ones ($\chi^2 = 10.859$, $p < .01$).

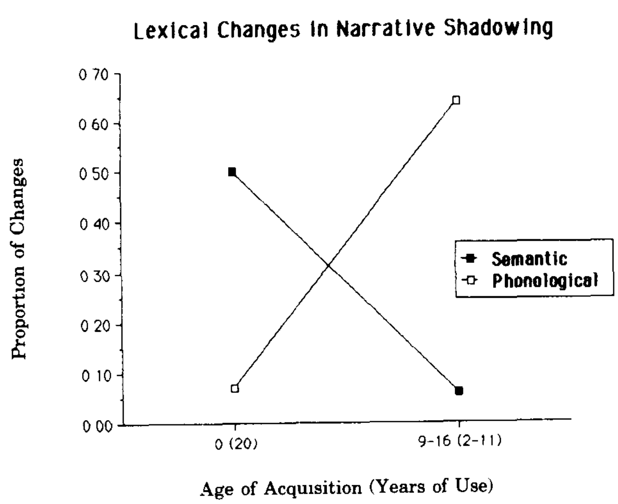

Figure 1. The mean proportion of lexical changes related to phonological shape or lexical meaning (semantic) produced by the subjects while shadowing narratives, as a function of age of sign language acquisition.

From a processing standpoint, semantic lexical changes imply that the signer has completely processed the sign language structural pattern. The semantic lexical change shows that the signer understood both the stimulus sign and the sentence. This interpretation is supported by the positive correlation between performance on the comprehension questions and the commission of semantic lexical changes (for ASL, $r = +.74$, $p < .01$; for PSE, $r = +.43$, $p < .05$, one-tailed). The better the signer understands the sign language narrative, the more likely he or she is to make semantic lexical changes. In a related fashion, semantic lexical changes are positively correlated to shadowing accuracy (for ASL, $r = +.86$, $p < .01$; for PSE, $r = +.55$, $p < .05$, one-tailed). The more accurately the signer performs the narrative shadowing task overall, the more likely he or she is to make semantic lexical changes.

On the other hand, the commission of phonological lexical errors (which bear no relationship to lexical and sentential meaning) indicates that the signer has had some difficulty in processing the sign language structure pattern. The problem might be located in sign language perception, memory, or production, but not necessarily in only one of these processing systems. The relationship between comprehension question performance and phonological lexical changes sheds some light on the locus of the non-native's processing difficulty. If the non-natives made phonological errors simply because they could not produce sign language with the same degree of facility as could the native signers, even though they understood it as well, then phonological lexical changes should not correlate with comprehension performance. This was not the case. The commission of phonological lexical changes was negatively correlated to comprehension question performance (for ASL, $r = -.84$, $p < .01$; for PSE, $r = -.71$, $p < .01$, one-tailed). This finding argues against the interpretation that the non-native signer's processing difficulty is solely due to faulty sign language production. Rather, sign language pattern recognition and memory are clearly difficult for the non-native signer.

It is important to note, however, that the phonological lexical change entails considerable linguistic sophistication, though not as much as does the semantic lexical change. To make a phonological lexical change, the signer must first recognize and remember nearly all of the phonological shape of the stimulus sign. Second, the signer must produce from the language an actual lexical item that shares many of the features and relations among features found in the stimulus; phonological lexical changes are real signs, not gibberish. In pilot work, we found that inexperienced signers (deaf individuals who had just completed a 10-week sign language course) could not perform the shadowing task. Their performances were best characterized as semirandom "hand waving." Their shadowing "errors" were neither phonologically nor semantically based, but rather uninterpretable nonsense that reflected little knowledge of either sign language phonology or the sign language lexicon (whether ASL or PSE).

In summary, the results of our first study show that the performances of native and non-native signers on a narrative shadowing task differ in several quantitative and linguistic ways. Native signers are highly accurate, and they change proportionately more signs and delete proportionately fewer signs than do non-natives, who, in turn, are less accurate. Native signers make lexical changes grounded in the semantic level of analysis, whereas non-natives make lexical changes based in the phonological level of analysis. Semantic lexical changes are positively correlated with accuracy and comprehension, whereas phonological changes are negatively correlated with comprehension. Sign language dialect does not alter the basic pattern of results, except that PSE narratives are easier for all signers than ASL narratives are. Finally, visual noise also does not alter this basic pattern, although it does reduce the shadowing accuracy of all signers and induces natives to make more semantic lexical changes. In the following study, we replicated and extended these results.

STUDY 2

We asked three questions about the effects of non-native acquisition on sign language processing in the second study. First, are the specific processing patterns associated with non-native acquisition restricted to "on-line" processing (the shadowing task), or do the patterns characterize sign language processing more generally? Replication of the effect with a task other than shadowing is important, because shadowing is an unusual language behavior (Levelt, 1978). When shadowing, the signer must simultaneously comprehend and produce language, a situation atypical of everyday language use. Perhaps non-natives perform poorly when their attention is divided, yet perform better when their attention is undivided. We addressed the question in the second study by comparing the shadowing task (on-line) with the immediate recall task (off-line).

The second question is whether the effect of non-native sign language acquisition on processing is, in fact, related to the age at which the signer first acquires sign language. Do small increments in age of acquisition produce concomitant decrements in processing accuracy? If so, then this would provide evidence that the effects of non-native sign acquisition on processing are related to a childhood advantage for language acquisition more generally. We address the question by including as subjects signers whose age of acquisition ranged from birth to 18 years.

The third question concerns the extent to which the differential effects of native and non-native acquisition on lexical processing interact with sentence processing. In the previous study, sign dialect did not interact with the effects of non-native acquisition on lexical processing, even though the sign dialects differed morphologically and syntactically. Does this mean that the non-native effects primarily involve lexical processing rather than sentential processing? We addressed this question in the second study by comparing signers' processing in the contexts of grammatical and ungrammatical sentences. If the primary source of processing difficulty for non-native signers is lexical in nature (in terms of identification of phonological form and retrieval of lexical meaning), then the grammaticality of the stimulus sentence should not change the non-natives' performance patterns.

Method

Stimuli and Design. The stimuli were short ASL sentences. Two reasons motivated our use of ASL rather than PSE. In the previous study, the effects of type of sign acquisition did not interact with the background of the subjects (that is, they were not contingent upon the type of sign language the subjects first learned, ASL or PSE). At the same time, however, all subjects performed more poorly on ASL than on PSE. Thus, using ASL sentences as stimuli was likely to garner more lexical changes than would be the case for PSE. The second reason we chose ASL rather than PSE is that ASL is considered to be a natural language, whereas the status of PSE is more controversial.

Although the stimuli were ASL sentences, the lexical items were chosen to be familiar to any deaf signer regardless of whether he or she primarily used (or had first learned) ASL, PSE, or MCE. First, the signs of the stimulus ASL sentences are identical in PSE. Of the 130 total types of stimulus lexical items in the ASL sentences, one hundred words, or 77%, are listed identically (same form and meaning) in dictionaries of ASL and MCE (Gustason et al., 1972; Stokoe, Casterline, & Croneberg, 1965).

The complete stimulus set consisted of 32 ASL sentences and 32 ungrammatical sentences. The ASL sentences were all declarative sentences ranging in length from three to eight signs. The ungrammatical sentences were scrambled strings of the same signs of the grammatical sentences.

The ungrammatical sentences were created by randomizing the order of signs in the ASL sentences with the stipulation that bound inflections not be separated from base signs. Each sign within each sentence was assigned a number. The order of signs in the scrambled condition was created by randomly drawing these numbers from a hat. Two examples of the stimulus sentences translated into English are, "Rabbits run faster than turtles which waddle on short legs," and, "When you pass the exam, you'll be excited about being able to drive around." The scrambled counterparts to these sentences might be translated as, "Faster rabbits than waddle on short legs run turtles which," and, "When you pass will be excited about being able to drive around you the exam." Note that the scrambled stimuli are partially meaningful in English. The same is true in ASL. This is probably due to maintaining the ASL inflections with their base signs. Because ASL is highly inflected, the sign scrambling in the present study may be more akin to a constituent, or phrase, reordering, rather than to a word reordering per se.

The videotaped stimuli were produced by a deaf native signer who signed the sentences with appropriate ASL phrasing patterns, including body shifts and facial expression. He signed the scrambled strings with normal ASL "intonation."

We scrutinized the videotaped stimuli in two ways to detect the presence of nonlinguistic cues that might distinguish the sentences from the scrambled strings aside from the experimental manipulation of grammaticality. First, we measured the duration of each stimulus sentence and scrambled string. The mean duration of the stimulus sentences was 4.59 sec and that of the nonsense strings was 4.71 sec. The duration of the two kinds of stimuli—sentences and scrambled strings—did not differ significantly ($t = 0.237$, $df = 30$, n.s.).

As a second check, we asked seven naive subjects (normally hearing individuals with no exposure to sign language) to judge the stimuli. These naive subjects were told that some of the signed stimuli were sentences and some were randomized strings of signs; they were asked to decide which stimuli were of each category. The naive subjects performed no better than chance ($t = 0.179$, $df = 1$, n.s.). Thus, it is improbable that the sentences could be distinguished from the scrambled strings solely on the basis of timing or other extraneous, nonlinguistic cues.

For the experimental presentation, we organized the stimuli into two lists. Each list contained 32 stimuli, half of them sentences (16 in number) and half of them scrambled strings (also 16 in number). The two lists were constructed so that no sentence appeared in the same list as its scrambled counterpart. Within each list, the sentences and scrambled strings were mixed randomly. For the experimental presentation, the two stimulus lists were counterbalanced with the two processing tasks (recall and shadowing) across subjects. This meant that half the subjects shadowed the first stimulus list and recalled the second, whereas the remaining subjects did the reverse. In addition, presentation order of the two tasks was counterbalanced across subjects. Half the subjects performed the shadowing task first and the recall task second, and the other half did the reverse.

Testing procedure. The subjects were tested individually. First, the general procedure was explained in either ASL or PSE and simultaneous speech. Next, the subject practiced either the shadowing or the recall task with two sentences and two scrambled strings. The subjects were instructed to copy each stimulus verbatim, either after watching it (recall) or while simultaneously watching it (shadowing). No other performance guidelines were given, except that the subject should not be concerned with mistakes. Next, the subject performed either the recall or the shadowing task followed by a second practice set and the remaining task. The subject's performance was videotaped with a camera placed beside the monitor on which the stimuli were presented.

Subjects. Fifty-five subjects participated. All were severely or profoundly deaf from birth and were enrolled at NTID. Only one had participated in the first study. All (but one, who was 38) ranged in age from 20 to 25 years. The subjects were placed into five groups, according to the age at which they had first learned sign language. Due to the homogeneity in the subjects' chronological age, years of sign language usage was correlated with age of sign language acquisition. (This is an important confound, which we discuss later.) The particular dialect or kind of sign language the subjects had first learned and used daily also varied: Some subjects had first learned ASL, but others had learned some form of PSE or MCE. Similarly, the type of people from whom the nonnative subjects had first learned to sign varied widely and included younger and older deaf peers both in and out of school, as well as, sometimes, deaf and/or normally hearing teachers. No subject had ever received any formal sign language instruction, except for the subjects in the fifth and least experienced group (as is described below).

The first group consisted of 11 native signers. All had first learned to sign from their deaf parents (both of whom used sign language) during early childhood. All had an average of 20 years' experience with sign language, except for 1 subject, who was 38 years old. (This subject's performance was indistinguishable from that of the other native signers, so he was included in the group.)

The second group consisted of 11 subjects, all of whom had first learned to sign at 5 years of age when they entered residential schools for deaf children. All had normally hearing parents and had learned to sign at school primarily from peers, probably ASL. They had an average of 15 years' experience with sign language.

The third group consisted of 11 subjects, all of whom first learned to sign between the ages of 8 and 10 years, approximately half in residential schools and the others in day schools for deaf children. All had normally hearing parents. The subjects who attended residential school had most likely learned ASL and PSE from peers and had been exposed to MCE by teachers. Those who attended public school were exposed to MCE by teachers. In addition to some MCE, they probably used PSE, and perhaps some ASL, with peers. These subjects had an average of 11 years' experience with sign language.

The fourth group consisted of 11 subjects, all of whom had first learned to sign between the ages of 13 and 15. All had normally hearing parents. In contrast to the previous group, nearly all had first learned to sign from peers and some teachers, in residential schools for deaf children. They had most likely learned ASL and PSE from their peers and some MCE from the teachers. These subjects had an average of 6 years' experience with sign language.

The fifth group consisted of 11 subjects, all of whom had first learned to sign at the age of 18, when they first enrolled in NTID. All had normally hearing parents. In contrast to the other groups, these subjects had attended either regular public schools with normally hearing children or schools for deaf children where no sign language was used (i.e., they had been in oral programs in which only spoken language was used). Upon enrolling at NTID, they received formal instruction in PSE and interacted with deaf students who used sign language, both ASL and PSE. These subjects had had 2 years' experience with sign language.

Transcription procedure. The transcription and coding of the subjects' shadowing and recall performance consisted of several steps identical to the procedure used in the first study, except that it was carried out by a new group of coders. First, two deaf ASL signers (one native and one early childhood learner) transcribed the videotaped performance of the subjects into an English gloss. Agreement between the two transcribers was quite high, ranging from 93% to 99% across all signs. Disagreements were resolved through repeated viewing and discussion of the stimulus signs in question. The gloss of the subject's performance was compared to that of each stimulus.

As in the first study, lexical mismatches between the subject's performance and the stimuli were described in detail and then categorized. Lexical errors were first categorized broadly in terms of whether the error was a lexical deletion or change, or the addition of a lexical item not present in the stimulus. The lexical change category was then further analyzed in terms of the linguistic relationship that the change showed to the stimulus signs. As in the previous study, the majority of such errors were of two kinds, semantic and phonological (see the Method section of the first study for a detailed description of these types of lexical changes). Again, as in the previous study, lexical changes are reported as proportions of lexical changes in each error category (semantic, formational, semantic and formational, random, and unintelligible) for each subject. (These were computed individually across each condition, so the group means do not necessarily sum to 100%).

Results and Discussion

For the statistical analyses, the error proportions computed for each subject were transformed with $2(\arcsin\sqrt{\%})$ to ensure homogeneity of variance. The transformed data were then analyzed with two- and three-way repeated measures analyses of variance, as will be described next.

Shadowing accuracy. Although the shadowing task elicited many errors from each subject in the first study, the same was not true in the second study. This is probably due to the fact that the stimuli were short, individual sentences rather than sentences connected in narrative discourse. Consequently, many subjects performed at ceiling; that is, they shadowed the entire stimulus set (sentences and scrambled strings) without error.

Table 3 shows the number of subjects in each group who made no mistakes on the shadowing task. These data show, first, that as the age of sign language acquisition increases there is a systematic decrease in the number of subjects in each group who performed at ceiling ($\chi^2 = 31.73$, $p < .001$). Another important feature of these data is that all 55 subjects repeated more sentences without error in the shadowing task than in the recall task. This shows that when memory demands are reduced, performance improves. This indicates that the primary source of the non-native's processing difficulty is not in sign language production. Rather, memorial aspects of sign language processing appear to be difficult for non-natives. (Due to the ceiling effects for the shadowing task, the subjects' shadowing performances were excluded from the following analyses.)

Recall accuracy. The proportion of stimuli (sentences and scrambled strings) that the subjects recalled without error was analyzed with a two-way repeated measures analysis of variance. The between-groups factor was age of sign language acquisition (five groups). The within-groups factor was sign order (sentences and scrambled strings). The results showed that age of acquisition significantly affected the subjects' recall accuracy, while sign order only slightly affected recall performance.

As Table 4 shows, recall accuracy increased with increasing age of acquisition [$F(4,50) = 20.74$, $MS_e = 0.134$, $p < .001$]. A linear trend accounted for 47% of the variance between age of acquisition and recall accuracy [$F(1,50) = 81.29$, $p < .001$] (using Gaito's procedure to compute linear trend coefficients for unequal intervals as recommended by Kirk, 1982). In addition, comparisons of each group with every other group showed that the performance differences between adjacent groups were not significant, but that those between nonadjacent groups were (Bonferroni pairwise comparisons at $p < .01$ for each).

Scrambling the sign order of the ASL sentences decreased accuracy, but only to a small extent. The mean accuracy for sentence recall was 54% as compared to 50% for the scrambled strings [$F(1,50) = 4.21$, $MS_e = 0.070$, $p < .05$]. The effect of scrambling sign order did not interact with age of acquisition. This means that all the groups, regardless of the age at which they had first learned to sign (and the kind of sign language they had first learned and regularly used) found the scrambled strings somewhat harder to recall than the sentences, but not much harder. For sentences as brief as the stimuli used here (three to eight signs), scrambling the order of an ASL sentence's signs still allows sentence meaning to be grasped, and hence recalled, in accordance with each signer's processing abilities.

Table 3
Subjects Making No Mistakes Shadowing ASL Sentences

Age of Acquisition	Years of Use	Percent	*n*
0	20	91%	10
5	15	55%	6
9	11	18%	2
14	6	0%	0
18	2	0%	0

Table 4
Sentence Stimuli Recalled without Error

Age of Acquisition	Years of Use	Mean	Range
0	20	.55	.88-.25
5	15	.41	.75-.13
9	11	.28	.56-.13
14	6	.23	.56-.06
18	2	13	.31-.02

These results replicate and extend the effects of non-native sign language acquisition for processing accuracy we found in the first study. Increased age of acquisition over a broad range (birth to 18 years) leads to concomitantly decreased processing accuracy over an equally broad range (2%-88%). In addition, these results suggest, as did those of the first study, that the effect of age of acquisition on processing accuracy is insensitive to linguistic structure. The effect of non-native acquisition on processing accuracy is comparable across both grammatical and ungrammatical ASL sentences, and across both ASL and PSE dialects.

General lexical errors. As was the case for narrative shadowing, in sentence recall, the subjects made general lexical errors of deletion and change. A three-way repeated measures analysis of variance was performed on the proportion of each type of lexical error. The between-groups factor was age of acquisition (five groups). The first within-groups factor was sign order (sentences and scrambled strings), and the second was general type of lexical error (deletion and change). The results showed a significant main effect for error type [$F(1,50) = 10.39$, $MS_e = 0.322$, $p < .01$], which interacted with age of acquisition and sign order.

As in narrative shadowing, in sentence recall, the subjects deleted significantly and proportionately more lexical items than they changed (a mean of .51 of all lexical errors were deletions and .39 were changes). Error type interacted with sign order such that the proportion of errors that were changes and deletions was not equivalent across the two types of stimuli. Subjects deleted fewer and altered more signs of the sentences (.47 and .43, respectively) than the scrambled strings (.55 and .34, respectively) [$F(1,50) = 11.05$, $MS_e = 0.973$, $p < .01$]. In addition, error type interacted with age of acquisition such that all the groups except for the latest learners (18 years) deleted proportionately more than they changed [$F(4,50) = 2.85$, $MS_e = 0.322$, $p < .05$], as Table 5 shows.

At this general level of error description, the tasks of narrative shadowing and sentence recall are not completely comparable. In the former task, lexical deletion

Table 5
Lexical Deletions and Changes in Sentence Recall

Age of Acquisition	Years of Use	Deletions	Changes
0	20	.57	.34
5	15	.53	.35
9	11	.52	.43
14	6	.53	.41
18	2	.41	.50

outweighs lexical change by a ratio of three to one. In sentence recall, lexical deletion and change occur with more balanced frequency.

Linguistic error type. The lexical changes that the subjects made on the recall task were analyzed in terms of the linguistic relationship they bore to the stimulus signs. As before, these were of two basic types: phonological and semantic. The proportion of lexical changes that the subjects made that were of these two types were analyzed with a three-way repeated measures analysis of variance. The between-groups factor was age of acquisition (five groups), the first within-groups factor was sign order (sentences and scrambled strings), and the second within-groups factor was linguistic error type (phonological and semantic). The results showed an important and significant interaction between age of acquisition and linguistic type of lexical change [$F(4,50) = 15.60$, $MS_e = 0.270$, $p < .001$], with no other significant effects.

As Figure 2 shows, as age of acquisition increased, the proportion of semantic lexical changes that the signers made decreased ($p < .01$ for each and every adjacent group, Tukey *HSD*). Conversely, as age of sign language acquisition decreased, the proportion of phonological lexical changes increased ($p < .01$ for each and every adjacent group, Tukey *HSD*). This striking result replicates the lexical error phenomenon discovered in the first study:

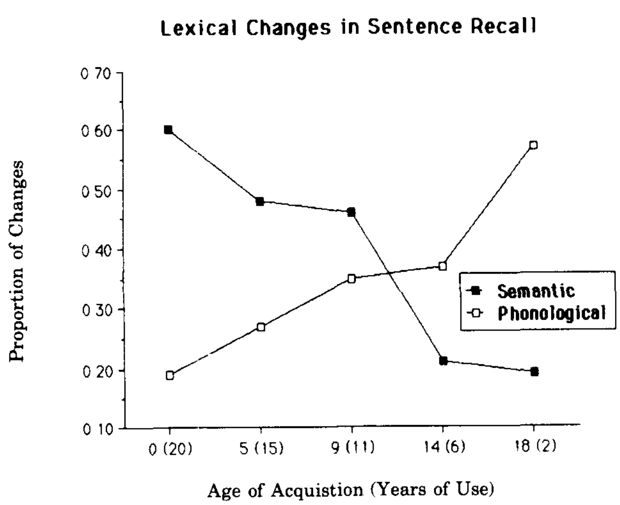

Figure 2. The mean proportion of lexical changes related to phonological shape or lexical meaning (semantic) produced by subjects while recalling sentences, as a function of age of sign language acquisition.

As age of sign language acquisition increases, the ability to completely process sign structure (and therefore make errors grounded in the semantic level of analysis rather than the phonologic level) decreases.

As in the first study, this result was not due to a few subjects. Rather, the proportion of subjects in each group who made predominately phonological as opposed to semantic lexical changes corresponded exactly with age of acquisition. The proportions of subjects making more semantic lexical changes than phonological ones (beginning with the native signers) were .73, .67, .56, .20, and .08, respectively ($\chi^2 = 14.632$, $p < .01$).

In the first study, the predominate type of lexical change that the signers made predicted their performance accuracy in narrative shadowing. In the second study, the same relationship held. Recall accuracy was significantly and positively correlated with the commission of semantic lexical changes ($r = +.55$, $p < .01$, one-tailed), and negatively correlated with the commission of phonological lexical changes ($r = -.46$, $p < .01$, one-tailed).

In summary, the results of the second study replicated and extended those of the first. As age of sign language acquisition increases, processing accuracy decreases, and lexical changes related to the semantic properties of the stimulus also decrease while phonological changes increase. Sentence shadowing was significantly easier than sentence recall, suggesting that non-native acquisition affects memorial aspects of processing rather than productive aspects. The grammaticality of the stimulus sentence did not interact with the age of acquisition effect in terms of either accuracy or predominate type of lexical change. This suggests that lexical processing, rather than syntactic processing, is difficult for the non-native signer.

GENERAL DISCUSSION

The results of these studies show that native and non-native acquisition exert systematic effects on sign language processing. The picture that emerges is that the younger the signer is upon beginning to acquire sign language, the more accurately he or she can process sign language structure. Likewise, the linguistic nature of signers' lexical changes corresponds to age of sign language acquisition: Childhood learners make changes predominately related to stimulus meaning, and older learners make changes predominately related to the phonological properties of the stimulus. The linguistic error patterns, in turn, predict comprehension.

Two important questions arise about this pattern of results: What is the nature of the effect of non-native acquisition on sign language processing? What characteristic of the signer's acquisitional experience is responsible for the effect?

First, the differences between native and non-native processing of sign are stable across a variety of perturbations originating in the task, the signal, and the linguistic structure of the stimulus. The effects appear in (1) the tasks of narrative shadowing and sentence recall, (2) clear and noisy viewing conditions, (3) isolated sentences and sentences connected in narration, (4) grammatical and ungrammatical sentences, and (5) the dialects of ASL and PSE. Such consistency suggests that these processing patterns are fundamental characteristics of the signers themselves. This is aptly illustrated by the finding that the non-native signers performed differently from natives even when the stimulus was a narrative told by one of their peers (the PSE condition of the first study). Despite these favorable conditions, the non-native signers nevertheless were less accurate, understood less, and made different kinds of linguistic mistakes than did the natives.

Another clue about the nature of the processing effects associated with age of acquisition is the finding that variation in the linguistic structure of the language stimulus (in terms of both sign dialect and sentence grammaticality) does not change it. This suggests that the source of the processing difficulty for the non-native signer is lexical. There are three possible and related loci for the processing difficulty: (1) misidentification of the phonological shape of the sign, (2) failure to retrieve the lexical meaning signified by the sign's phonological shape, and (3) faulty sign production.

Two findings argue against the alternative that the non-native effect is due to faulty sign production. In the first study, comprehension performance was negatively correlated with both phonological lexical errors and shadowing accuracy. Clearly these different processing patterns involve comprehension. Moreover, in the second study, when memory demands were reduced by our using isolated sentences instead of narratives, all the subjects performed better (that is, the subjects were highly accurate at shadowing short sentences as compared with recalling them). This means that when the non-native signer is not required to remember the sign language stimulus for very long, he or she reproduces sign sentences with fewer errors. If faulty sign production were the source of the problem, then the non-natives' performances should have remained the same regardless of memory demands.

Two possible explanations of the non-native processing problems remain—namely, misidentification of the phonological shape of the sign, and difficulty retrieving lexical meaning. First, if the difficulty is that the non-native simply misidentifies or misperceives the phonological shape of the stimulus signs, then this implies that phonological lexical changes arise because the signer has given a verbatim rendition of what he or she has mistakenly "seen." This interpretation fits Poizner's (1981) finding that native signers perceive ASL visual patterns uniquely in comparison to how naive subjects perceive them. This suggests a sensory-perceptual basis for the processing differences between native and non-native signers.

Two findings argue against a purely sensory-perceptual interpretation. First, mixing visual noise with the signal did not increase the number of phonological errors produced by the natives. If the non-natives differ from natives in pattern-recognition ability alone, impairing pattern recognition for the natives should have shifted their performance in the direction of the non-natives, but it did not. Rather, they made more semantic lexical changes. A related argument against the sensory-perceptual interpretation is the finding of Delhorne, Reed, and Durlach (1988; personal communication, November 1988) that non-native signers who are blind and deaf also make phonological lexical changes when remembering sign sentences through the sense of touch. This means that the mechanism responsible for phonological lexical changes cannot be solely sensory (visual) in origin. Rather, the problem must be linguistic in origin. The difficulty appears to lie in the retrieval and memory of lexical meaning.

Nusbaum and Schwab (1986) persuasively argue that speech processing is an active process that requires the allocation of attention across several tasks, including auditory sensation, phonological identification, and the integration of phonological shape with lexical meaning. The more automatized the processing of the form of speech becomes, the more attention available for the processing of the meaning of words.

If we assume that sign language processing is in general outline like speech processing, then it too is an active process that requires the allocation of attention across the tasks of visual sensation and pattern recognition, phonological (form) identification, and the integration of lexical meaning with phonological shape across all the signs of a sentence. Within this framework, native signers appear to process sign language automatically such that they can direct their attention to the processing of meaning and can therefore remember it. Non-native signers, by contrast, seem unable to process signs automatically. Rather, they must allocate relatively more attention to the tasks of phonological identification and the integration of phonological shape with lexical meaning, so that they have proportionately less attention available for the processing and integration of meaning. The two consequences of less automatized processing are that the non-native signer is (1) less able to extract meaning from the signal and (2) less able to remember and integrate the meanings that are already extracted. Because the non-native signer must focus more attention on phonological shape, more phonological shape than lexical meaning is being held in short-term memory so that comprehension is reduced and phonological lexical errors occur.

An earlier study by Liben, Nowell, and Posnansky (1978) supports the phenomena we report here and our interpretation of them. They examined the extent to which native and non-native signers used the phonological or semantic characteristics of signs to organize learning and long-term retention of sign lists. The stimuli of one set were highly similar in sign phonology and those of another were highly similar in semantic category. The responses of the non-native signers were related to the phonological characteristics of the stimulus signs—an effect that increased over trials. The native signers showed no phonological relationships in their responses. Liben et al.

speculated that non-native sign acquisition leads to ''reflective thinking'' about signs. Recast in terms of our interpretation, the non-native signers had to allocate more attention to the phonological shapes of the stimuli than did the native signers, and their response patterns reflected these biases in attentional focus.

The different lexical error patterns we report here are not unique to sign language. In several studies of spoken language, researchers have reported a similar shift in lexical errors from being primarily phonologically based to being primarily semantically based (in conjunction with increasing age and/or language sophistication); a variety of explanations have been given. For example, Biemiller (1970) reported an error shift as occurring in children's reading development; he proposed that the shift reflected increasing efficiency in letter perception. Cziko (1980) also reported an error shift for adolescents who were learning to read a non-native language; he proposed that beginning readers can use only a ''bottom-up'' means of language processing, perhaps because of the increased demands of word decoding and recognition.

In several studies of children's word recognition, researchers have also reported a shift in lexical errors from being primarily phonological in nature to being primarily semantic in nature. Bach and Underwood (1970) compared 7- and 11-year-olds' written word recognition, and Felzen and Anisfeld (1970) replicated this study with spoken words. Felzen and Anisfeld (1970) proposed that the error shift reflected the way in which young children's vocabularies are organized—that is, phonologically for young children and semantically for older ones. Toyota (1983) found a similar shift for Japenese Hiragana text; he interpreted this to mean that older children can use semantic contexts in understanding words, whereas younger ones cannot. Niccols (1987) reported that on a word-association task, 4-year-old children gave rhyming associations, whereas 7-year-old children gave semantic associations; she hypothesized that this shift from phonetic to semantic word associations was due to the reading instruction that younger children receive, which prompts them to focus attention on the phonological properties of words instead of the semantic properties.

Finally, Vihman (1981) observed that many speech errors of young children, in both comprehension and production, are related to phonological shape rather than lexical meaning. Analyzing errors from children learning Estonian, English, French, German, and Spanish, she noted that these errors are insensitive to context, be it syntactic, semantic, or pragmatic. Vihman hypothesized that the child tries to fit the phonological shape of the new words into his or her phonological system at its current level of development, which is less elaborated than the adult system.

These diverse studies provide cross-linguistic and developmental evidence that the shift from phonological shape errors to meaning errors characterizes the development of language processing generally, as the attention demands of language processing shift from focusing on form recognition to semantic integration. We propose that the beginning language learner focuses attention primarily on phonological shape, and, moreover, that this is crucial to language acquisition. As language is learned, as the phonological features of the language and their semantic mapping become increasingly familiar, processing gradually becomes automatized, by which we mean that the language user is able to allocate less attention to phonological shape and concomitantly more attention to the processing of lexical meaning. The results we report here add two new and important findings with respect to this phenomenon. First, these attentional demands clearly operate independently of the sensory and motor channel of language transmission and reception; this is a psycholinguistic phenomenon that transcends the specifics of sensory perception and motor production. Second, the focus of attention in language processing is remarkably tied to the timing of language acquisition.

This leads us to the second question raised by the present studies—namely, the extent to which the different processing patterns of native and non-native signers are the product of a childhood advantage for language acquisition, or a critical period for language acquisition. As we previously noted, in the present studies, age of sign language acquisition was correlated with amount of practice. Thus, the different processing patterns of native and non-native signers can be due either to the amount of practice the signers have had with sign language, or to the fact that the natives were very young children when they first learned to sign. Several pieces of evidence suggest that these effects are related to age of acquisition rather than amount of practice.

First, the results of the second study in particular are remarkable for the consistent relationship shown by age of acquisition in relation to processing. The native signers outperformed all other groups on overall accuracy, despite the considerable practice that some of the non-native groups possessed (i.e., 10 to 15 years of use). In addition, the groups who first learned to sign in late childhood and early adolescence (8 to 10 and 13 to 15 years of age) performed more similarly to each other on recall accuracy than might have been expected, given the difference in the amount and kind of practice they had had with sign language (i.e., 11 as contrasted to 6 years of use). Likewise, the marked shift in lexical error type from semantic to phonological errors appears in signers who first learn to sign in adolescence (see Figure 2). This is precisely the developmental time frame typically posited to mark the end of the childhood advantage for language acquisition (see, e.g., Lenneberg, 1967). It seems unlikely that such striking and consistent processing patterns are the simple product of practice effects, especially given the many and diverse situations within which the non-native signers learned to sign, and the many and diverse people from whom they learned to sign (as we previously described in the Method section).

Our hypothesis that the processing patterns associated with native and non-native acquisition are rooted in a childhood advantage for language acquisition has been confirmed by subsequent research. Mayberry and Eichen (1989) have found that deaf signers who have used sign language for an average of 42 years continue to show different processing patterns in relation to the timing of language acquisition. Approximately 50% of signers who had first learned to sign in adolescence displayed processing patterns identical to the ones we report here for non-native signers. Highly experienced non-natives who first learn to sign in adolescence are significantly less accurate, produce more lexical errors related to phonological shape than lexical meaning, and comprehend less well than their peers who first learned to sign in early childhood. Additional evidence that the timing of sign language acquisition affects its outcome has been provided by Newport (1984) and Newport and Meir (1985), who report that highly experienced native and non-native signers differentially produce and comprehend complex morphological constructions in ASL.

The hypothesis that the timing of language acquisition is a critical variable in the determination of its long-range outcome is not new, having characterized much psycholinguistic thinking for the past two decades. Yet most theorizing about how the timing of language acquisition affects its outcome has been structural in nature—that is, it has involved descriptions of the language structure that the childhood learner "knows" in contrast to that which the older learner does "not know." The results of the present studies demonstrate that an important ingredient of "knowing" a language is the processing of it. To know a language means to be able to see through its phonological shape to its lexical meaning, automatically.

REFERENCES

BACH, M. J., & UNDERWOOD, B. J. (1970). Developmental changes in memory attributes. *Journal of Educational Psychology*, **61**, 292-296.

BADDELEY, A. D. (1966). Short term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental Psychology*, **18**, 362-365.

BELLUGI, U., KLIMA, E. S., & SIPLE, P. (1975). Remembering in signs. *Cognition*, **3**, 93-125.

BIEMILLER, A. (1970). The development of the use of graphic and contextual information as children learn to read. *Reading Research Quarterly*, **6**, 75-96.

BROWN, S. C. (1986). Etiological trends, charcteristics, and distributions. In A. N. Schildroth & M. A. Karchmer (Eds.) *Deaf children in America* (pp. 33-54). San Diego, CA: College-Hill Press.

CLARK, L. E., & GROSJEAN, F. (1982). Sign recognition processes in American Sign Language: The effect of context. *Language & Speech*, **25**, 325-340.

CONRAD, R. (1964). Acoustic confusions in immediate recall. *British Journal of Psychology*, **55**, 75-84.

CZIKO, G. (1980). Language competence and reading strategies: A comparison of first- and second-language oral reading errors. *Language Learning*, **30**, 101-114.

DELHORNE, L. A., REED, C. M., & DURLACH, N. L. (1988, November). *The reception of sign language through the tactile sense*. Paper presented at the Annual Convention of the American Speech-Language-Hearing Association, Boston.

FELZEN, E., & ANISFELD, M. (1970) Semantic and phonetic relations in the false recognition of words by third- and sixth-grade children. *Developmental Psychology*, **3**, 163-168.

FISCHER, S. (1974). Sign language and linguistic universals In C Rohrer & N. Ruwet (Eds.), *Actes du Colloque Franco-Allemand de Grammaire Transformationelle: Band II. Études de Sémantique et Autres* (pp. 187-204). Tübingen.

FROMKIN, V. (1971). The non-anomalous nature of anomalous utterances. *Language*, **47**, 27-52.

GROSJEAN, F. (1980). Psycholinguistics of sign language. In H. Lane & F. Grosjean (Eds.), *Recent Perspectives on American Sign Language* (pp. 33-54) Hillsdale, NJ: Erlbaum.

GUSTASON, G , PFETZING, D., & ZAWOLKOW, E. (1972) *Signing exact English*. Silver Spring, MD: National Association of the Deaf.

HANSON, V. L., & BELLUGI, U. (1982). On the role of sign order and morphological structure in memory for American Sign Language sentences. *Journal of Verbal Learning & Verbal Behavior*, **21**, 621-633.

HATFIELD, N. (1983). *An investigation of bilingualism in two signed languages: American Sign Language and manually coded English* Unpublished doctoral dissertation, University of Rochester.

JARVELLA, R. J. (1971). Syntactic processing of connected speech. *Journal of Verbal Learning & Verbal Behavior*, **10**, 409-416.

KIRK, R. E. (1982). *Experimental design: Procedures for the behavioral sciences* (2nd ed.). Belmont, CA: Brooks/Cole.

KRAKOW, R. A., & HANSON, V. L. (1985). Deaf signers and serial recall in the visual modality: Memory for signs, fingerspelling, and print. *Memory & Cognition*, **13**, 265-272.

LANE, H., BOYES-BRAEM, P., & BELLUGI, U. (1976). Preliminaries to a distinctive feature analysis of handshape in American Sign Language *Cognitive Psychology*, **8**, 263-289.

LENNEBERG, E. J. (1967) *The biological foundations of language*. New York: Wiley.

LEVELT, W. J. M. (1978). A survey of studies in sentence perception: 1970-1976. In W. J. M. Levelt & G. B. Flores D'Arcais (Eds.), *Studies in the perception of language* New York: Wiley.

LIBEN, L. S., NOWELL, R. C., & POSNANSKY, C. J. (1978). Semantic and formational clustering in deaf and hearing subjects' free recall of signs. *Memory and Cognition*, **6**, 599-606.

LIDDELL, S. (1980). *American Sign Language syntax*. The Hague. Mouton.

LIDDELL, S. (1984). THINK and BELIEVE: Sequentiality in American Sign Language. *Language*, **60**, 372-399.

LIDDELL, S., & JOHNSON, R. (1985). *American Sign Language. The phonological base*. Unpublished manuscript, Gallaudet University, Washington, DC.

MARSLEN-WILSON, W., & TYLER, L. K. (1980). The temporal structure of spoken language understanding. *Cognition*, **8**, 1-71.

MAYBERRY, R. (1979). *Facial expression and redundancy in American Sign Language*. Unpublished doctoral dissertation, McGill University, Montreal.

MAYBERRY, R., & EICHEN, E. (1989). *The advantage of learning sign language in childhood: Another look at the critical period for language acquisition*. Unpublished manuscript.

MAYBERRY, R., & WODLINGER-COHEN, R. (1987). After the revolution: Educational practice and the deaf child's communication skills. In E. Mindel & M. Vernon (Eds.), *They grow in silence* (2nd ed., pp. 149-185). San Diego, CA: College-Hill Press.

MAYBERRY, R., WODLINGER-COHEN, R., & GOLDIN-MEADOW, S. (1987). Symbolic development in deaf children. In D. Cicchetti & M. Beeghly (Eds.), *Symbolic development in atypical children* (New Directions for Child Development, No. 36, pp. 109-126). San Francisco: Jossey-Bass.

MCDONALD, B. (1982). *Aspects of the American Sign Language predicate system*. Unpublished doctoral dissertation, University of Buffalo, NY.

NEWKIRK, D., KLIMA, E., PETERSEN, C., & BELLUGI, U. (1980). Linguistic evidence from slips of the hand. In V. Fromkin (Ed.), *Errors in linguistic performance* (pp. 165-197). New York: Academic Press.

NEWPORT, E. (1984). Constraints on learning: Studies in the acquisition of American Sign Language. *Papers and Reports on Child Language Development*, **23**, 1-22.

NEWPORT, E., & MEIR, R. (1985). The acquisition of American Sign Language. In D. I. Slobin (Ed.), *The crosslinguistic study of language acquisition· Vol. 1. The data* (pp. 881-939). Hillsdale, NJ: Erlbaum.

NICCOLS, A. (1987, April). *The development of metalinguistic ability* *and its relation to reading*. Paper presented at the meeting of the Society for Research in Child Development, Baltimore, MD.

NUSBAUM, H. C., & SCHWAB, E C. (1986) The role of attention and active processing in speech perception. In E. Schwab & H. Nusbaum (Eds.), *Pattern recognition by humans and machines. Speech perception* (Vol. 1, pp 113-157) New York: Academic Press

PADDEN, C. (1983). *Interaction of morphology and syntax in American Sign Language*. Unpublished doctoral dissertation, University of California, San Diego.

POIZNER, H (1981). Visual and "phonetic" coding of movement Evidence from American Sign Language. *Science*, **212**, 691-693.

POIZNER, H , BELLUGI, U., & TWENEY, R. D. (1981) Processing of formational, semantic, and iconic information in American Sign Language. *Journal of Experimental Psychology. Human Perception & Performance*, **7**, 1146-1159

POIZNER, H., KLIMA, E., & BELLUGI, U. (1987). *What the hands reveal about the brain* Cambridge, MA: MIT Press

POIZNER, H., NEWKIRK, D., BELLUGI, U , & KLIMA, E S (1981) Representation of inflected signs from American Sign Language in short-term memory *Memory & Cognition*, **9**, 121-131.

RAWLINGS, B., & JENSEMA, C. (1977) *Two studies of the families of hearing impaired children* (Research Bulletin, Series R No. 5) Washington, DC: Gallaudet University, Office of Demographic Studies

REILLY, J. S., & MCINTIRE, M. L. (1978). ASL and PSE· What's the difference? In F. Caccamise & D. Hicks (Eds.), *Proceedings of the Second National Symposium on Sign Language Research and Teaching* (pp. 85-113). Silver Spring, MD: National Association of the Deaf.

SACHS, J. S. (1967). Recognition memory for syntactic and semantic aspects of connected discourse *Perception & Psychophysics*, **2**(9), 437-442.

SCHEIN, J., & DELK, M. (1974). *The deaf population of the United States* Silver Spring, MD: National Association of the Deaf.

SCHICK, B S. (in press). The effects of morphosyntactic structure on the acquisition of classifier predicates in ASL. In C Lucas (Ed.), *Sign language research: Theoretical issues*. Washington, DC. Gallaudet University Press.

SIPLE, P. (1982). Signed language and linguistic theory. In L. Obler & L Menn (Eds), *Exceptional language and linguistics* (pp 313-338). New York: Academic Press.

SIPLE, P , CACCAMISE, F., & BREWER, L. (1982). Signs as pictures and signs as words. The effect of language knowledge on memory for new vocabulary *Journal of Experimental Psychology: Learning, Memory & Cognition*, **8**, 619-625.

SIPLE, P., FISCHER, S., & BELLUGI, U. (1977) Memory for nonsemantic attributes of American Sign Language signs and English words. *Journal of Verbal Learning & Verbal Behavior*, **16**, 561-574.

STOKOE, W. (1970). Sign language diglossia. *Studies in Linguistics*, **21**, 27-41

STOKOE, W , CASTERLINE, D., & CRONEBERG, C. (1965). *A dictionary of American Sign Language on linguistic principles*. Washington, DC Gallaudet University.

SUPALLA, T. (1982). *Structure and acquisition of verbs of motion and location in American Sign Language*. Unpublished doctoral dissertation, University of California, San Diego.

TOYOTA, H (1983). Effects of sentence context on memory attributes in children. *Psychological Reports*, **52**, 243-246.

VIHMAN, M. M. (1981). Phonology and the development of the lexicon· Evidence from children's errors *Journal of Child Language*, **8**, 239-264.

WILBUR, R. B. (1987). *American Sign Language. Linguistic and applied dimensions* (2nd ed.). Boston: College-Hill.

WOODWARD, J. C. (1973a). Inter-rule implication in American Sign Language *Sign Language Studies*, **3**, 47-56.

WOODWARD, J C (1973b). Some characteristics of Pidgin Sign English. *Sign Language Studies*, **3**, 39-46

(Manuscript received March 6, 1985,
revision accepted for publication May 22, 1989.)