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The Long-Lasting Advantage of Learning Sign Language in Childhood: Another Look at the Critical Period for Language Acquisition

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We find the long-range outcome of sign language acquisition to depend upon when it first occurs. Subjects were 49 deaf signers who had used sign language for an average of 42 years but first acquired it at ages ranging from birth to 13. Subjects recalled signed digits and sentences presented at two rates, normal and 68% faster. Age of acquisition showed significant effects at all levels of linguistic structure, with the greatest effects being at the level of sentence meaning. Age of acquisition did not influence digit recall and sign production; rate had negligible effects. The results show that the childhood advantage for language acquisition is not unique to speech and is linked to inefficient sign (word) recognition.

Does the timing of language acquisition exert long-lasting effects on the ability to comprehend language? Although the question is old, we ask it here in a new context, that of sign language. The sign language community offers a special opportunity to address the question directly. This is because the age at which deaf signers first acquire sign language is highly heterogeneous, ranging from birth to adulthood. If the timing of *sign* language acquisition predicts comprehension skill in later life, then this would provide unique evidence that language acquisition is a developmentally time-locked phenomena, as Lenneberg (1967) first proposed. He theorized that *spoken* language is acquired more easily during childhood than anytime afterward. In the present study, we ask whether there is a critical period for language acquisition independent of the modality of the language being acquired. In other words, is comprehension of a language that is gestured and watched, such as American Sign Language (ASL), predicted by age of acquisition?

Before describing the study, we summarize previous research that has examined some effects of age of acquisition on the *long-range* outcome of spoken language acquisition. Two circumstances have been studied in detail in order to determine whether childhood acquisition produces a superior outcome as compared to language acquisition at later ages: second-language

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acquisition and social isolation during childhood.

Second-Language Acquisition

Reviewing the complex literature on bilingualism, Krashen, Long, and Scarella (1982) distill two generalizations about the timing of second-language learning in relation to its long-range outcome. Given equal tutelage and practice, adults are faster second-language learners than children over the short term. In the long run, however, childhood learners surpass adult learners in the eventual proficiency with which they can speak and comprehend a second language.

Three studies have documented a predictive relationship between age of second-language acquisition and its *long-range* outcome. Oyama (1976, 1978) found that the age at which Italian immigrants had arrived in New York correlated ($r = -.40$) with ability to comprehend and produce English. Coppieters (1987) found that even speakers who were extremely proficient in a second language, professors and authors who wrote regularly in French, performed two-standard deviations below the mean of native-French speakers on measures of syntax and paraphrase skill. Johnson and Newport (1989) found age of acquisition to predict the ability of Korean and Chinese speakers to judge the grammaticality of English sentences. These studies show that the outcome of second-language acquisition, when the language is spoken, is predicted by the age at which the acquisition first occurs at several levels of linguistic analysis.

The reasons for the childhood superiority for second-language acquisition are unclear, although many explanations point to sensory and motor origins. McLaughlin (1977) has proposed that oral-motor control underlies the childhood superiority for second-language acquisition. Alternatively, Cutler, Mehler, Norris, and Segui (1989) suggest an acoustic–phonetic (or perceptual) basis for the phenomenon. They found that even "balanced" French and English bilinguals show perceptual biases favoring one language over the other. Second-language acquisition may not be the best test of the critical period hypothesis, however. The outcome of second-language acquisition may be limited by the amount of first, or native, language already acquired, rather than age of acquisition *per se*. Once sensory and motor patterns are "set" to one particular language, they may be difficult to "reset" to another language. This interpretation is suggested by the work of Werker (1989; Werker & Lalonde, 1988) who finds that infants can initially discriminate phonemes from languages not spoken in their homes, a skill they quickly lose between 6 to 12 months. The confound of knowing more than one language is eliminated in the case of social isolation during childhood.

Social Isolation

There are several reports of children believed to have been isolated from humans during childhood (for example, see Lane, 1976; Singh & Zingg, 1966). A common thread across these reports is that the isolate could not speak upon discovery and never learned to speak well.

Koluchova (1972) studied twins who were locked in a closet from two to seven years of age. Yearly IQ testing showed the children's language to develop from below normal to normal performance (i.e., 43 to 100 IQ level) during the four years following their release. This suggests that normal language development following social isolation is possible, if it ends during childhood.

Curtiss and her colleagues (1977; Fromkin, Curtiss, Krashen, Rigler, & Rigler, 1974; Curtiss, Fromkin, Rigler, Rigler, & Krashen, 1975) studied the language development of a girl isolated from language due to extreme abuse. Genie was tied either to a bed or a potty chair for the first 13 years of life. Genie managed to acquire much English but her acquisition deviated from that of normal children in several ways. Her rate of acquisition was quite slow; her vocabulary learning outstripped syntactic learning; her comprehension significantly outpaced production; and she had persistent problems with some grammatical forms, including the auxiliary system, movement rules, and pro-forms (Curtiss, 1977, p. 210).

Genie's case demonstrates that if there is a critical period for language acquisition, it is not an "all or none" phenomenon (Fromkin et al., 1974). Rather, when language acquisition first begins after childhood, some ability to acquire language remains. However, Genie's case may not be the best test of the critical period hypothesis because her linguistic difficulties may have been compounded by the cognitive and emotional deprivation she additionally suffered.

A third situation can potentially shed light on whether there is a critical period for language acquisition. Children who are born severely and profoundly deaf often do not learn spoken language well, if at all. In addition, the age at which these children first acquire sign language is highly variable.

Childhood Deafness

Spoken language. Childhood deafness greatly impedes the acquisition of spoken language (Geers & Moog, 1978; Jensema, Karchmer, & Trybus, 1978; Quigley & King, 1980). The effects of congenital deafness on spoken language acquisition are not limited to the perception and production of speech. Deaf children also have difficulty comprehending visual forms of spoken language, such as lipreading and reading text (Conrad, 1979; Geers & Moog, 1989; Jensema, 1975; King & Quigley, 1985; Trybus & Karchmer, 1977; Waters & Doehring, 1990). Children whose hearing losses are severe to profound (i.e., $\geqslant$70 dB) do not spontaneously acquire spoken language, but require intensive instruction. Despite early and intense instruction, however, many deaf children do not achieve native proficiency in spoken language. This relatively poor facility in spoken language does not result from any general cognitive deficit associated with deafness. Deaf children show a normal distribution of performance on non-verbal intelligence scales (Sisco & Anderson, 1980) and normal achievement in mathematical computation (Allen, 1986).

Whether and how a critical period for language acquisition contributes to the poor outcome of deaf children's spoken language acquisition has not been systematically investigated. However, educators widely believe that deaf children's success in learning to speak is casually related to the age at which the instruction is begun (Fay; 1889; Fry, 1966; Hirsh, 1966; Ling, 1989).

Sign language. Unlike spoken language, deaf children have *no* difficulty perceiving sign language. Yet, until recently, sign language has typically been absent from the environment of the young deaf child for two reasons. Only 3 to 8% of deaf children have deaf parents (Rawlings & Jensema, 1977; Schein & Delk, 1974). This means that 92 to 97% of deaf children have normally hearing parents who neither know nor use sign language. In addition, most schools for deaf children, until the mid 1960s, implemented educational policies known as "oralism" which actively prohibited classroom use of sign language and gesture in early schooling (Lane, 1984). Consequently, a significant proportion of deaf signers who attended school 20 years ago or earlier were unable to acquire sign language until after childhood or later.

Native and non-native performance. Some research has found performance differences between *native signers* (those who have deaf parents and were first exposed to sign in infancy) and *non-native signers* (those who have normally hearing parents and were first exposed to sign outside the home after early childhood). Reported differences include movement perception (Poizner, 1981), novel sign learning (Siple, Caccamise, & Brewer, 1982), verb production (Woodward, 1975), and sentence comprehension (Hatfield, 1983). Because the critical period for language acquisition was not the focus of these studies, the results are confounded by factors such as amount and length of practice.

Some effects of sign language isolation in childhood. Deaf children who have not yet acquired spoken language and have not yet been exposed to sign language, spontaneously create gestural communication known as "home sign." Goldin-Meadow and Mylander (1984, 1991) find home sign to be highly structured, consisting of a lexicon with morphological organization and sentences with word order and cojoining rules. Whether home sign can function as a native language is unknown.

When deaf individuals have been isolated from sign language during childhood, they often learn it at later ages. Newport (1984, 1988, 1990) reports that the mean accuracy of deaf signers on selected ASL production and comprehension tasks coincides with age of acquisition such that native learners outperform early learners (4–6 years) who, in turn, outperform late learners (12 years and older).

Thus, there are many indications that age of acquisition has long-lasting effects on sign language comprehension and production, but the generality and nature of these effects has not yet been documented or described. In a series of studies leading to the present one, we have asked whether and how late learners of sign language differ from early learners in how they process lexical items given in sentential and narrative contexts.

Age of Acquisition Effects on Sign Language Processing

The locus of the effect. In the first study, in one task, we asked 48 congenitally deaf singers to recall and in another task to shadow (simultaneously watch and repeat verbatim) short grammatical and ungrammatical ASL sentences (Mayberry & Fischer, 1989). The signers were first exposed to sign at five different ages—infancy, 5, 9, 14, and 18 years. Performance accuracy declined linearly with age of acquisition. The grammaticality of the stimulus sentence did not interact with the effect, but the task did. When memory demands increased, the effects associated with age of acquisition also increased. This result suggests that age of acquisition affects memory and comprehension more than production.

The nature of the effect. The lexical errors the signers made on the recall task interacted with age of acquisition. As age of acquisition increased, the proportion of lexical errors that were semantically related to the stimulus decreased. Simultaneously, the proportion of lexical errors that were phonologically related to the stimulus increased. There was a trade-off between the two kinds of lexical errors between the ages of 9 and 14. Signers who first acquired sign in childhood made mostly semantic lexical errors whereas signers who first learned to sign after childhood made mostly phonological errors (Mayberry & Fischer, 1989).

These findings suggested to us that age of acquisition affects the efficiency with which the surface pattern structure of signs can be processed. Phonological lexical errors may arise because the signer has allocated attention to the recognition of phonological shape in order to identify signs. Focusing attention on pattern recognition means that less attention is available for retrieving and integrating the meaning of signs already identified. This reduces memory for semantic context. Consequently, the late learner of sign language may find it difficult to guess what was missed, or to fill the "lexical gaps."

Comprehension effects. In a second study, 16 deaf signers shadowed narratives given in ASL and Pidgin Sign English (PSE). PSE is a dialect likely to be more familiar to non-native signers than ASL because it is more frequently used in schools and public settings (Stokoe, 1970; Wilbur, 1987). Some of the narratives were embedded in masking visual white noise.

The native signers again outperformed the non-native signers on every processing measure, regardless of sign dialect or visual noise. As in the first study, native signers made predominantly semantic lexical changes, whereas non-native signers made predominantly phonological lexical changes. Semantic lexical changes were *positively* correlated with comprehension performance ($r = +.86$), whereas phonological lexical changes were *negatively* correlated ($r = -.84$). These findings show that the lexical error patterns associated with age of acquisition reflect varying degrees of comprehension. The unique lexical errors associated with age of acquisition are therefore not due to isolated problems with the production of sign language.

Although highly informative, these findings do not directly test the critical period hypothesis. This is because age of acquisition was confounded with amount of sign language practice. The late learners had less experience with sign than the early learners so that the different patterns of lexical errors we observed for early and late learners could simply be due to amount of practice.

In the present study, we unconfound age of acquisition from length of experience and ask four questions. First, do signers show different patterns of lexical processing as a function of age of acquisition even after they have had substantial practice with the language? Second, is the processing of bound morphology and syntactic and semantic structure in ASL sentences also affected by age of acquisition? Third, where are the effects of age of acquisition located in language processing? That is, are the effects located mainly in the initial sensory–perceptual stage of language processing or somewhere beyond this stage? Fourth, are some aspects of language processing *not* affected by age of acquisition?

General Method

In order to answer these questions, we examined the effects of age of acquisition on sign language processing in the context of sign presentation rate. We varied age of sign language acquisition by testing deaf signers who were first exposed to sign language at ages ranging from birth to 13 years. We unconfounded age of sign language acquisition from amount of practice by including only those signers who had used sign for a minimum of 20 years. We varied the presentation rate of the sign language stimulus to clarify the nature of the effects using the following rationale.

First, we speculated that the late learners, after such substantial practice, might have developed processing strategies that, although different from those of early learners, might appear native-like under normal conditions. Under difficult conditions, such as a speeded presentation rate, the processing of the late learners might break down to reveal differences. This explanation predicts an interaction between age of acquisition and stimulus presentation rate such that age of acquisition will show effects in the speeded condition but not in the normal one.

Our second rationale for varying the stimulus presentation rate was to locate more precisely the source of the age of acquisition effects in sign language processing. Research with speech has shown it to be highly intelligible to native speakers despite large increases in rate (as much as 2.5 times the original rate, Garvey, 1953). When an increased rate reduces speech intelligibility, the difficulty appears to be due to a degrading of the acoustic–phonetic portion of the stimulus (Slowiaczek & Nusbaum, 1985). If the processing difficulties shown by late learners of sign language are mainly due to problems at the first stage of (visual) phonetic identification, then a speeded sign rate should interact with lexical error production as a function of age of acquisition. Specifically, the speeded condition (but not the normal one) should prompt the early learners to produce phonological lexical changes because the stimulus is harder to perceive visually. The late learners should increase their production of phonological lexical changes.

We used immediate recall as the dependent measure of sign language processing because in previous work we have found it to be highly sensitive to the acquisitional history of the signer (Mayberry & Fischer, 1989). This procedure allowed us to replicate our original findings and extend them by determining whether the unique lexical error patterns associated with age of acquisition are related to age of acquisition rather than amount of practice.

In addition to the recall of signed sentences, we examined the recall of signed digits. This helped determine whether age of acquisition affects the processing of lexical items with minimal semantic content.

Last, we measured the subjects' self-assessment of their ability to comprehend sign language. This allowed us to determine whether the experimental measures were related in any way to the ease with which the subjects understand sign language outside the laboratory.

Stimuli and Design

Sentence stimuli. The stimulus sentences were eight long and complex ASL sentences. The sentences were extemporaneously created by a deaf, native ASL signer who was first exposed to sign from infancy in a deaf home consisting of deaf parents and several older and younger deaf siblings and an extended deaf family. Several weeks prior to videotaping the stimuli, we asked the signer to generate a list of ASL statements that deaf signers might use to describe everyday events and activities. Two additional criteria were that the statements be long and include a variety of ASL structures. (The appendix gives English translations of the ASL stimuli.) Our rationale for using long and complex sentences (ranging in length from 12 to 15 signs, with a median length of 14 signs) was to avoid ceiling effects. Previously we found that short sentences (3 to 8 signs) were too easy for native signers, who recalled sentences of this length perfectly.

Digit span stimuli. The digit span stimuli were two number sets, one for the forward sequence and another for the backward sequence. The sets were taken from the WAIS (Wechsler Adult Intelligence Scale, 1955). There were 14 lists of single digits that were random sequences of the numbers zero to nine. The lists increased in length from two to nine digits with two trials at each length. The lists were signed by a deaf, native signer and videotaped. The signer produced each digit at the rate of one per second with a normal list "intonation" in ASL, that is, with a slight pause between each digit and a return of the hand to resting position after the last digit of each list. The signer signed the digits without any voice or mouth movement and maintained a neutral facial expression throughout list presentation.

Experimental conditions. The eight target sentences were presented within an experimental list of 30 total sentences displayed at two sign rates, normal and speeded. The experimental list and rate conditions were produced in the following fashion. First, the native signer signed the list of 30 ASL sentences to an audience of three native signers while being videotaped. The speeded condition was created by re-recording the original videotape at a rate 68% faster than the original. To control for the video fading associated with re-recording, the original videotape was also re-recorded. This procedure resulted in two video copies of the stimulus sentences, one at the original sign rate and another at the speeded rate.

The experimental list contained 30 ASL sentences presented consecutively. Fifteen sentences were given at the rate at which they were originally signed. These sentences constituted the "normal" condition with a mean rate of 0.56 s/sign. Fifteen different sentences were given at the speeded rate and constituted the "speeded" condition, with a mean rate of 0.38 s/sign. The two sets of sentences were of similar length, structure, and thematic content. The experimental videotape was further edited so that there was a 60 s inter-stimulus interval. The 15 normal and 15 speeded sentences were mixed together randomly.

The stimulus sentences were nested within the two rate conditions and not counterbalanced across subjects. This procedure ensured that each subject saw each stimulus sentence only once. The procedure also ensured that the same number of subjects in each group saw each sentence. This precaution was necessary because we did not know in advance how many subjects we would be able to locate and recruit with the highly specific language backgrounds required for each of the experimental groups.

Subjects

Sign language background. Forty-nine signers participated. All led independent lives, which means that they had homes and families and supported themselves through a variety of occupations and endeavors. All reported being deaf from birth. In addition, all considered themselves to be members of the Deaf Community, which means that their primary identity was as a deaf person whose language was sign language (Padden & Humphries, 1988).

Each subject had used sign language for a *minimum* of 20 years, but as Table 1 shows, most subjects had had substantially more practice than this. The subjects varied in the age at which they were first exposed to sign language, which ranged from birth to 13 years. *Length of sign language practice* was computed by subtracting the age at which the subject was first exposed to sign (according to self-report) from his or her chronological age. The subjects ranged in age from 29 to 70 years, with a mean of 47.3 years. The amount of sign language practice the subjects had had ranged from 21 to 60 years, with a mean of 42.10 years.

We grouped the subjects according to the age at which they were *first exposed* to sign language, which we defined as the first opportunity the subject had to interact on a daily basis with deaf people who used sign language for interpersonal communication. The three groups were first exposed to sign during: (1) infancy—native signers; (2) childhood—5 to 8 years of age; and (3) adolescence—9 to 13 years of age.

Native learners. Sixteen subjects were exposed to sign language beginning at birth. They were raised in families headed by deaf parents and the primary language of the home was sign. Many also had deaf siblings who signed. All but two attended residential schools for deaf children where they communicated with other deaf children (and some deaf adults) in sign language outside the classroom. (Many reported that sign language was prohibited in selected classrooms.)

Childhood learners. Twenty subjects were first exposed to sign language in childhood between the ages of five and eight. All were born to families headed by hearing parents who, they reported, neither knew nor used any sign language with them. The childhood learners first learned to sign from other deaf children in an immersion situation in the dormitories of residential

TABLE 1
SAMPLE CHARACTERISTICS

Group	Age of initial exposure to sign		Length of sign language practice		Chronological age		
	Mean	Range	Mean	Range	Mean	Range	*n*
Native learners	0	0	40	30–60	40	30–60	16
Childhood learners	6	5–8	44	23–58	51	29–64	20
Adolescent learners	11	9–13	42	21–59	53	33–70	13

schools for deaf children. Some of their sign language models were from younger and older peers who were native signers (as described above). Other sign models were from younger and older deaf children who themselves first learned to sign in childhood or adolescence. These subjects reported that some sign models were deaf teachers and counselors, both native and non-native signers. The residential school was the first school experience for most of these subjects. Four subjects transferred to a residential school after a brief enrollment at either a neighborhood school for normally hearing children (where they received no special help and where no one knew or used sign language), or a day school or class for deaf children where the use of sign and gesture was prohibited (i.e., an "oral" training method).

Adolescent learners. Thirteen subjects were initially exposed to sign language in adolescence between the ages of 9 to 13.[1] All had families headed by normally hearing parents who neither knew nor used any sign language with them in childhood (or adolescence). Like the childhood learners, the adolescent learners were initially exposed to sign language in an immersion situation. These subjects first learned to sign when they were enrolled in a residential school for deaf children (as described above). Prior to attending the residential school, these subjects had attended a variety of schools where sign language was either not known (i.e., a public or private school for normally hearing children), or prohibited (i.e., an "oral" day class for deaf children within a private school for normally hearing children). One subject had attended no school before entering a residential school at 10 years of age.

Amount of sign language practice. Table 1 shows the background characteristics of the experimental sample grouped by age of *initial exposure to sign language:* native learners, childhood learners, and adolescent learners. The groups' mean length of sign language practice was 40, 44, and 42 years, respectively. A one-way analysis of variance showed *no* significant effect for length of sign language practice ($F(2,46) = 1.27$, n.s.). Thus, the groups differed primarily in the age at which they were first exposed to sign language and not in how long they had used it after their initial exposure to it.

Testing Procedure

Each subject was tested individually by three native signers, one deaf and two hearing. First the subject was interviewed about when and how he or she first learned sign language. Then the subject was asked to assess the ease with which he or she could comprehend ASL, fingerspelling, and speech. The subject ranked "comprehension ease" on a five point scale, with *5* representing "always understand" and *1* representing "seldom understand."[2]

Next the experimental tasks were explained. For the sentence-memory task, the subject was told that he or she would see videotaped sentences in two different presentation conditions, a normal rate and a speeded rate. The subject was instructed to repeat each stimulus verbatim immediately after watching it. The experimental list was

[1] Adolescence is defined as the beginning of puberty, or the onset of the ability to sexually reproduce. Recent surveys show the onset of puberty to range from 8½ to 13 years for girls and 9½ to 15 for boys (Sommer, 1978). Thus we call the subjects who were first exposed to sign between the ages of 9 and 13 the "adolescent" learners.

[2] Although no fingerspelled items were given in the stimulus sentences, we nevertheless probed the subjects about their ease of fingerspelling comprehension separately from ease of sign language comprehension. In previous research using a shadowing task (Mayberry, 1979), we found that accurate identification of stimulus fingerspelled items (nested within ASL and PSE narratives) significantly correlated with the amount of practice signers had had with sign language ($r = +.89$).

preceded by four practice sentences, two at the normal rate and two at the speeded rate.

For the digit-span task, the subject was instructed to watch the videotaped signer and repeat verbatim the signed digits in two conditions, same sequence and reversed. Testing followed standard procedure (Wechsler, 1955) and was stopped when the subject failed to recall correctly two trials of the same length.

Both the sentence and digit stimuli were presented on a 26-in color video monitor. A color video camera placed beside the monitor recorded the subject's performance.

Performance Analyses

Sentence recall. The transcription, coding, and analysis of the subjects' sentence recall consisted of several steps identical to those used in our previous work (Mayberry & Fischer, 1989). Sign performance was first transcribed independently by two coders, one native signer and one non-native signer (a native English speaker and sign linguist). Each coder used a transcription code previously developed for this purpose. The code is an elaborated gloss wherein a separate and unique English work represents each lexical stem and bound morpheme of the subject's response.

Each coder initially transcribed each subject's performance without knowledge of either the subject's age of initial exposure to sign language, or the transcription of the other coder. In the second step, the two transcriptions were compared stem by stem and bound morpheme by bound morpheme in the presence of, and in reference to, the original videotaped performance. Differences were resolved through discussion and repeated viewing of the performance by the two coders.[3]

Transcription reliability was quite high, ranging from 94 to 100% agreement across all signs and inflections. Reliability with this degree of accuracy was possible because both coders were highly practiced at the task and the signed utterances were highly predictable because all were variations of the same stimuli.

The coded performance was analyzed several ways in reference to the sentence stimuli at the levels of (1) lexical preservation and change, (2) preservation and change of bound morphology, (3) preservation and sequencing of syntactic constituents, (4) response grammaticality, and (5) response meaning, or paraphrase. Before describing the results, we explain the linguistic analyses.

Lexical preservation and change. Lexical matches and mismatches between the subject's recall performance and the stimuli were described in detail and then analyzed and categorized in a fashion identical to that used by Mayberry and Fischer (1989). Lexical 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. Lexical changes were then analyzed for possible linguistic relationships to the stimulus at the levels of both the sign and sentence. As in our previous work, the majority of such changes were highly regular and of two basic kinds, *semantic* or *phonological*.

Semantic lexical changes reflected the

[3] This kind of detailed sign language transcription is very time consuming. For example, the "first-pass" transcriptions entailed a detailed examination of more than 1568 sentences (8 Stimulus sentences × 49 Subjects × 2 Coders × 2 Examinations). The subjects' sign language performance was examined several additional times after the initial "first-pass" to record and measure, for example, accuracy of bound morphology and response duration. Thus, the data reported here are based on several thousand examinations of sign language performances. For this reason, we limited the data analyses to a subset of eight of the 30 original stimulus sentences (see the Appendix). The eight stimulus sentences we selected were (1) nearly identical in length (measured in base signs), (2) similar in grammatical structure, and (3) occurred in each of the four quartiles of the list.

meaning of either the target sign or sentence, but not any of the phonological characteristics of the target sign. For example, one stimulus sentence began, "The approaching *man* who is deaf . . ." One subject changed the sign MAN to the sign PERSON, producing the response translated as, "The approaching *person* who is deaf . . ." The target sign MAN and the changed sign PERSON are unrelated phonologically in ASL. Nonetheless, the changed sign, or mistake, is a meaningful one based on comprehension of the stimulus sentence up to the point of the lexical change. The semantic lexical change maintains the semantic coherence of the stimulus and results in a grammatical response, although not a verbatim one.

In contrast to semantic lexical changes, *phonological lexical changes* showed no relationship to the target sign or sentence at the level of meaning. Rather, these lexical changes were related to the phonological pattern structure of the stimulus sign. As in our previous work, we judged phonological similarity to be present if the changed sign shared two of three formational parameters with the stimulus sign, (1) handshape, (2) location, or (3) movement.

To fully appreciate these kinds of processing errors, it is important to know that the linguistic structure of sign language is multi-level and hierarchical like spoken language, even though it is watched and gestured instead of listened to and spoken. One level of structure is the gestural equivalent of a *phonology*. The phonology of a sign language is a sublexical and finite collection of meaningless and rule-governed articulatory units. These units constitute the building blocks of the sign lexicon (for detailed descriptions see Liddell & Johnson, 1989; Padden & Perlmutter, 1987; Wilbur, 1987). From a psycholinguistic standpoint, therefore, signers can produce signs that are correctly articulated (recognized as a sign by signers) or misarticulated (not recognized as a sign). Misarticulated signs can, in turn, be either *possible* or *impossible* signs. Possible signs are meaningless but phonologically permissible; impossible signs are meaningless and fall outside the phonological structure of a given sign language.

Consider again, for example, the stimulus sentence translated as, "The approaching man who is deaf doesn't know American *sign* because he lives in England." One subject changed the stimulus sign SIGN to the sign BUT producing the response translated as, "The approaching man doesn't know American *but* because . . ." The stimulus sign SIGN and the response sign BUT are highly related phonologically in ASL, differing only in movement. SIGN is made with a circling movement (two hands circle one another). BUT is made with a linear movement (two hands move in a straight line away from one another). Because this kind of lexical change is related solely to properties of sign phonology, and not to lexical or sentence meaning, it nearly always results in a meaningless response.

Although meaningless from the standpoint of the stimulus sentence, phonological changes are *real* signs; that is, they are actual items from the ASL lexicon. Phonological lexical changes are neither neologisms nor gibberish. In fact, a phonological lexical change shows that the subject has perceived and remembered most of the phonological structure of the stimulus lexical item but failed to identify the exact phonological shape and retrieve its associated meaning.[4] In addition, the subject has failed to use the semantic context of the sentence to catch or repair the error.

The lexical analyses were carried out on all lexical stems (i.e., open class morphemes) and excluded bound morphemes (or closed class morphemes). As described below, bound morphemes were analyzed separately to determine whether signers

[4] By "phonological shape" we refer to the sensory and temporal envelope of the lexical item; in the case of sign, this includes movement and location as well as (hand)shape.

made the same kinds of errors on this part of sign language structure.

Bound morpheme preservation and change. Bound morphemes were first broadly matched to those of the stimulus. Response bound morphemes were related to the stimuli in one of several ways: (1) *verbatim,* that is, identical to the target—same form *and* meaning as the stimulus bound inflection with either the same or changed stem; (2) *deleted*—same or changed stem with *no* bound morpheme attached; (3) *changed*—same or changed stem with a different bound morpheme; (4) *added*—a novel stem with a novel bound morpheme. This matching procedure showed the number of bound morphemes produced in recall that were identical to and different from those of the stimuli.

Constituent ordering. We examined the extent to which the grammatical structure of the subject's response reflected that of the stimuli (without regard to semantic content). First we determined the kind of constituents in the subject's response (that is, subject–noun phrase, object–noun phrase, verb phrase, adverbial phrase, and so forth). Then we noted the order in which the constituents were sequenced which we compared to the stimulus. This analysis showed the number of grammatical constituents the subject produced that were of the same kind and in the same sequence as that of the stimulus.

Response grammaticality. We assessed the subject's response for grammaticality (independent of whether the grammatical structure or semantic content were verbatim in reference to the stimulus). If the response was a grammatical utterance (or utterances) in any sign dialect (that is, either ASL or PSE), then the response was classified as grammatical. If the response was not grammatical in any dialect, it was classified as ungrammatical.

Response paraphrase. Last, we assessed the subject's response for the degree to which it maintained the intended meaning of the stimulus sentence (without regard to the verbatim nature of the lexical items, grammatical structure, or sequence of constituents). When the response paraphrased the intended meaning of the stimulus, it was classified as a paraphrase. When the response did not paraphrase the meaning of the stimulus, it was classified as a nonparaphrase.

Digit span. Subjects' forward and backward digit span was computed in the standard fashion (Weschler, 1955). Digit span was the longest list length the subject repeated in correct sequence for the forward and backward conditions.

Results

The subjects' performances were analyzed in several ways. Sentence recall was analyzed separately for lexical stem preservation and change, bound morpheme preservation and change, constituent ordering, sentence grammaticality and paraphrase, and response length and sign production rate. In some cases the raw score was converted to a proportion score. Forward and backward digit span was compared across the groups.

The group data (reported as F^1) were analyzed with two-way, repeated measures analyses of covariance, unless otherwise noted. The between-subjects factor was age of first exposure to sign language (henceforth *age of acquisition*) with three levels (native, childhood, and adolescent-learner groups, as shown in Table 1). The within-subjects factor was sign rate with two levels (normal and speeded). All post hoc measures (trend analyses, pairwise comparisons, analysis of simple effects, and proportion of variance accounted for) were derived from the group data, unless otherwise noted. To ensure that "aging" was not a factor in the results, the covariate was chronological age. In each analysis of covariance described below, the covariate showed no significant effects. Furthermore, the covariate showed homogeneity of regression with the independent variable, age of acquisition. These results mean that the effects of age of acquisition we report here are not due to the effects of aging and are not altered by the presence of any possible aging effects.

The item data (reported as F^2) were analyzed with two-way, repeated measures analyses of variance, unless otherwise noted. The between-item factor was presentation rate with two levels (normal and speeded). The within-item factor was age of acquisition with three levels (infancy, childhood, and adolescent-learner groups).

To ensure homogeneity of variance, any proportion scores were first transformed with the arc sin transformation (2 (arcsin $\sqrt{\%}$)), as recommended by Kirk (1982). Proportions of 0.00 and 1.00 were changed to 0.001 and 0.999, respectively, to fit the arc sin transformation. For ease of interpretation, we use the proportion and raw scores in the following description of the subjects' performance.

Processing of Lexical Stems

Verbatim lexical stems. We computed the proportion of signs in each stimulus sentence that the subject recalled verbatim (identical form and meaning). This measure gives an indication of overall recall accuracy for lexical items. After adjustment for chronological age, age of acquisition significantly affected subjects' tendency to recall the lexical stems of the stimulus sentences in a verbatim fashion, accounting for 14% of the variance ($F^1(2,45) = 3.447$, $p < .05$; $F^2(2,6) = 32.789$, $p < .001$). Trend analysis showed that the relationship between age of acquisition and verbatim lexical recall was primarily linear in nature ($F(1,46) = 16.587$, $p < .01$), with the native learners recalling a greater proportion of lexical stems verbatim from each stimulus sentence than either the childhood or adolescent learners ($p < .05$, Tukey HSD), as Table 2 shows. The effect of age of acquisition was, in turn, unaltered by the speeded condition, as indicated by the lack of significant main or interaction effects for this factor.

TABLE 2
ADJUSTED MEAN PROPORTION OF STIMULUS SENTENCE LEXICAL STEMS

	Verbatim		Forgotten	
Group	Mean	Range	Mean	Range
Native	.68	.87–.51	.27	.32–.08
Childhood	.60	.85–.42	.34	.56–.12
Adolescent	.56	.81–.32	.38	.65–.13

Deleted lexical stems. We computed the proportion of lexical stems in each stimulus the subject entirely forgot. That is, no semblance of the stimulus phonological shape or meaning was present in the response. After adjustment for chronological age, age of acquisition significantly affected the proportion of lexical stems the subjects completely forgot, accounting for 18% of the variance ($F^1(2,45) = 4.881$, $p < .01$; $F^2(2,6) = 25.720$, $p < .001$). Trend analysis showed the relationship to be primarily linear in nature ($F(1,46) = 9.617$, $p < .01$), as Table 2 shows, with the childhood and adolescent learners forgetting significantly more lexical items than the native learners ($p < .05$, Tukey HSD).

The effect of age of acquisition on the tendency to forget lexical stems was unaltered by the speeded condition as indicated by the nonsignificant interaction between the two factors. Independent of age of acquisition, however, the subjects forgot on average 15% more lexical items in the speeded condition as compared to the normal one ($F^1(1,45) = 5.492$, $p < .05$). However, the effect was not significant in the analysis of the data by items ($F^2(1,6) = 6.553$, n.s.) which indicates that the effect was not robust.

Predominant type of lexical change. We examined the lexical items the subjects "partially" remembered by analyzing the relationship between these lexical changes and the stimulus lexical items they replaced. As described above, most were of two basic types, phonologic and semantic. (The total number of lexical changes encompassed more categories than these two;

the other categories were "semantic/ phonological," "unexplainable," and "unintelligible.")

After adjustment for chronological age, age of acquisition showed significant effects on the tendency to misrecall the stimulus lexical items in terms of *phonological* surface structure independent of meaning, accounting for 24% of the variance ($F^1(2,45) = 7.055, p < .01; F^2(2,6) = 6.826, p < .05$), as Fig. 1 shows. Trend analysis showed the relationship between age of acquisition and phonological lexical changes to be primarily linear in nature ($F(1,46) = 13.814$, $p < .001$), with the adolescent learners making significantly more phonological lexical changes than the childhood and native learners ($p < .05$, Tukey HSD). The childhood learners, in turn, made significantly more phonological lexical changes than the native learners ($p < .05$, Tukey HSD). Finally, the relationship between age of acquisition and the tendency to produce phonological lexical changes was unaffected by the speeded condition, as indicated by the lack of significant main or interaction effects for this factor.

Semantic lexical changes appeared to show the opposite relationship to age of acquisition. After adjustment for chronological age, age of acquisition showed significant effects on the production of semantic lexical changes ($F^1(2,45) = 3.723, p < .05$) such that the native learners made significantly more semantic lexical changes than the adolescent learners ($p < .05$, Tukey HSD). However, the effect was not significant for the item analysis ($F^2(2,6) = 1.770$, n.s.) indicating that the effect was not present across all of the stimulus sentences. The production of semantic lexical changes was unaffected by the speeded condition, as indicated by the lack of significant main or interaction effects for this factor.

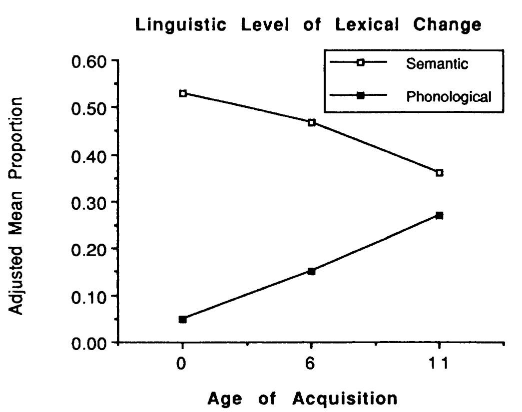

FIG. 1. Adjusted mean proportion of lexical changes the signers made in sentence recall that were related solely to phonological shape (phonological) or solely to sign and sentence meaning (semantic) as a function of age of acquisition.

These important results replicate and extend those of our previous research (Mayberry & Fischer, 1989). When age of acquisition is unconfounded from length of practice, age of acquisition remains highly associated with specific patterns of lexical error commission in ASL sentence processing. When signers who first acquired sign during childhood make lexical mistakes, they do so in reference to the meaning of the stimulus message independent of the surface phonological structure of the stimulus lexical items they are processing. Signers who first learned to sign *after* early childhood also make semantic errors. However, they are equally likely to make unique lexical mistakes—phonological errors that are derived from the surface pattern structure of the stimulus lexical items independent of stimulus meaning, both lexical and sentential.

The pattern of results for the speeded condition helps clarify the nature of these age of acquisition effects. The speeded condition tended to increase the number of stimulus lexical items that all signers completely forgot, regardless of age of acquisition. This indicates that stimulus presentation rate has some small effect on processing accuracy. The effect does not interact with age of acquisition, however. The speeded condition changes neither the magnitude nor shape of the lexical error patterns associated with age of acquisition. Thus, degrading the surface visual properties of the sign stimulus does not prompt the early learners to make lexical errors that are similar to those of the the late learners, nor does it worsen the processing problems of the late learner. This result suggests that the effects of age of acquisition are located somewhere beyond the initial stage of (visual) phonetic identification. The precise nature and locus of these effects is an important question to which we later return.

In the following analyses, we broaden our investigation of the age of acquisition effects by asking whether they are present at other levels of sign language structure, namely bound morphology, grammatical constituents, sentence grammaticality, and sentence meaning.

Processing of Bound Morphology

Bound morpheme recall. We scrutinized the subjects' recall of the bound morphology—both inflectional and derivational. (It is important to know that bound morphemes in ASL are nested internally *within* lexical stems, or signs, rather than attached sequentially as in English.) Because there was an unequal number of several different kinds of bound morphemes (i.e., classifier, adverbial, and aspectual) represented in the two conditions, we treated bound morphemes as a single response class for the statistical analyses by summing across the two conditions.

We analyzed the group data with one-way analyses of covariance and variance. The between-subjects variable was age of acquisition (with three levels, native, childhood, and adolescent learners) and the covariate was chronological age. We analyzed the item data with one-way analyses of variance. The between-item variable was age of acquisition (with three levels—the three groups). The items were the 21 multimorphemic signs contained in all the stimulus sentences.

Bound morpheme production and accuracy. After adjustment for chronological age, age of acquisition showed significant effects on the production of bound morphemes, accounting for 14% of the variance ($F^1(2,45) = 3.679$, $p < .05$; $F^2(2,20) = 4.031$, $p < .05$). As Table 3 shows, the results of trend analysis showed the effect to be primarily linear in nature ($F(1,48) = 7.334$, $p < .01$) with the native learners producing significantly more bound morphemes than either the childhood or adolescent learners ($p < .05$, Tukey HSD). However, age of acquisition showed no significant effects on the verbatim nature of the stimulus bound morpheme recall, as indicated by the lack of any significant effects for this factor.

These findings indicate that age of acquisition affects the processing of bound morphemes in addition to lexical stems. We further investigated the processing of bound morphemes by examining the specific kinds of errors the subjects made.

Bound Morpheme Processing Errors

Stripping and alteration. The mistakes the subjects made on the stimulus bound morphology reflected two general response proclivities, *stripping* and *alteration*. In a stripping error, the subject failed to reproduce the meaning (or form) of the stimulus bound morpheme in the response. In an alteration error, the subject changed both the meaning and form of the stimulus bound morpheme to something else, as we describe next.

Subtypes of morphemic errors. As Table 4 shows, stripping was the most common bound morpheme mistake, accounting for 67% of all the bound morpheme processing errors. Here the signer gave either a verbatim or a changed lexical item devoid or stripped of any bound morpheme. Alteration was the second most common error.

TABLE 3
ADJUSTED MEAN PROPORTION OF STIMULUS BOUND MORPHEMES

Group	Produced		Verbatim	
	Mean	Range	Mean	Range
Native	.90	.95–.62	.50	.62–.29
Childhood	.67	.90–.10	.44	.62–.05
Adolescent	.59	.76–.38	.39	.52–.24

TABLE 4
BOUND MORPHEME ERRORS IN REFERENCE TO THE STIMULUS

Lexical stem	Bound morpheme	Frequency of occurrence %	(n)
Verbatim	Deleted	49.02	(175)
Changed	Deleted	18.49	(66)
Verbatim	Changed	11.48	(41)
Verbatim	Lexicalized	8.96	(32)
Changed	Verbatim	7.84	(25)
Deleted	Lexicalized	1.96	(7)
Changed	Lexicalized	1.12	(4)
Verbatim	Unintelligible	1.12	(4)

Subjects altered the stimulus bound morphemes six ways.

The most frequent kind of alteration, as shown in Table 4, was a simple *change* or switch of only the bound morpheme. Here the subject reproduced the lexical stem verbatim but changed the bound morpheme to another equally acceptable one. For example, given the inflected stimulus, SIT (continuous), some subjects responded instead with SIT (back).[5]

The second most frequent kind of alteration was a *lexicalization* of the bound morpheme. Here the subject transformed the meaning of the stimulus bound morpheme into a separate lexical stem. Instead of producing one multimorphemic sign, as given in the stimulus, the subject instead produced two monomorphemic signs. For example, given the stimulus SIT (continuous), some subjects responded with ALWAYS SIT.

The third kind of alteration entailed changing the lexical stem while preserving the stimulus bound morpheme *verbatim*. For example, given the stimulus, SIT (continuous), some subjects responded instead with WATCH (continuous).

The last three kinds of alterations constituted less than 4% of the errors. In the first, the subject lexicalized the bound morpheme but deleted the lexical stem. For example, given the stimulus, SIT (continuous), one subject recalled ALWAYS without any verb. A related error involved lexicalizing the bound morpheme *and* changing the lexical stem. For example, given the stimulus SIT (continuous), one subject recalled ALWAYS WATCH. Least frequent, and most problematic, was an error where the lexical stem was verbatim but the bound morpheme was unintelligible, that is, unrecognizable as an ASL bound morpheme.

Quantitative analysis. For the statistical analyses, we grouped all instances of alteration and stripping errors. The alteration category included all subtypes of bound morpheme alterations (both changes and lexicalizations) independent of whether the lexical stem was verbatim (see Table 4). The stripping category included all instances of bound morpheme omission independent of whether the lexical stem was verbatim (see Table 4). We speculated that these two general kinds of errors might reflect varying degrees of linguistic sophistication and thus be associated with age of acquisition. Altering stimulus bound morphemes might require more ASL proficiency than simply stripping them. However, both error categories reflect a sensitivity to ASL morphological structure insofar as both entail isolating and separating the bound morpheme from the multimorphemic stimulus.

Morphemic stripping. After adjustment for chronological age, age of acquisition showed no significant effects on the deletion of bound morphemes for the group analysis ($F^1(2,45) = 2.094$, n.s.). For the item analysis, however, age of acquisition accounted for a significant 24% of the variance, ($F^2(2,20) = 6.222$, $p < .01$). As Table 5 shows, age of acquisition is associated

[5] In the examples given here, the lexical stem is written in upper case. The bound morpheme is written in lower case and enclosed in brackets. Thus, SIT (back) refers to the lexical stem translated as "sit" inflected (internally) with the bound morpheme meaning "to sit back in a chair."

TABLE 5
ADJUSTED MEAN PROPORTION OF BOUND MORPHEMES SEPARATED FROM MULTIMORPHEMIC SIGNS

	Stripped		Altered	
Group	Mean	Range	Mean	Range
Native	.18	.29–.05	.26	.29–.05
Childhood	.24	.33–.10	.22	.24–.05
Adolescent	.30	.48–.14	.19	.29–.05

with a tendency to strip bound morphemes during ASL processing, with later learners stripping more bound morphemes than early learners. The lack of a significant effect for the group analysis indicates that not all subjects show the effect, however.

Morphemic alteration. After adjustment for chronological age, age of acquisition showed no significant effects on the tendency to alter bound morphemes for the group analysis ($F^1(2,45) = 1.273$, n.s.). For the item analysis, however, age of acquisition accounted for a significant 22% of the variance ($F^2(2,20) = 5.705$, $p < .01$). As Table 5 shows, age of acquisition showed effects on the tendency to alter stimulus bound morphemes that was in the opposite direction of the stripping tendency. Early learners tend to alter more bound morphemes than they strip but late learners do the reverse. The lack of a significant effect for the group analysis indicates that not all subjects showed the effect.

There was one kind of error that never occurred. No subject ever changed a stimulus bound morpheme along phonological dimensions independent of meaning. Errors of a purely phonological nature are apparently tied to the processing of lexical stems but not to bound morphemes. This provides evidence that lexical stems and bound morphemes are processed in separate stages (by all signers regardless of age of acquisition), even though the two levels of linguistic structure are instantiated spatially in ASL rather than sequentially as is characteristic of spoken English.

In the following analyses, we ask whether and how age of acquisition affects phrasal and sentence-level aspects of sign language processing.

Constituent Recall

We examined the proportion of constituents in each response that were of the same type and sequenced in the same order as that of the stimulus independent of semantic content. After adjustment for chronological age, age of acquisition showed significant effects on the extent to which the subjects reproduced the grammatical constituents of the stimulus sentences, accounting for 21% of the variance ($F^1(2,45) = 6.008$, $p < .01$; $F^2(2,6) = 39.764$, $p < .001$). Trend analysis showed the effect to be primarily linear in nature ($F(1,48) = 11.499$, $p < .001$) with the native learners producing more identically ordered constituents than either the childhood or adolescent learners ($p < .05$, Tukey HSD), as Table 6 shows. The effect was unaltered by the speeded condition, as indicated by the lack of significant main or interaction effects for this factor.

Grammatical Responses

We assessed the grammaticality of each response without regard to its semantic content or syntactic structure. After adjustment for chronological age, age of acquisition showed significant effects on the subjects' tendency to give grammatical responses, accounting for 24% of the variance ($F^1(2,45) = 7.056$, $p < .01$; $F^2(2,6) = 30.337$, $p < .001$). The effect interacted with the speeded condition ($F^1(2,45) = 3.545$, $p < .05$; $F^2(2,6) = 12.757$, $p < .01$),

TABLE 6
ADJUSTED MEAN PROPORTION OF RESPONSE CONSTITUENTS FOLLOWING STIMULUS SEQUENCE

Group	Mean	Range
Native	.66	.80–.49
Childhood	.55	.78–.05
Adolescent	.50	.67–.10

but there was no main effect for the speeded condition.

As Fig. 2 shows, the nature of the interaction between age of acquisition and stimulus rate was such that the native and childhood learners were less grammatical in response to the speeded condition than the normal one (analysis of simple effects: for native learners, $F(1,46) = 4.762$, $p < .05$; for childhood learners, $F(1,46) = 10.684$, $p < .01$). By contrast, the adolescent learners were just as ungrammatical in the speeded condition as in the normal one (analysis of simple effects: $F(1,46) = 1.110$, $p = .298$, n.s.).

These findings indicate that age of acquisition is associated with the tendency to be grammatical in sign language processing, in addition to the tendencies to be lexically and syntactically accurate. Stimulus rate interacts with age of acquisition at the sentence level, but not at the lexical and phrasal levels.

Paraphrased Responses

In the final measure of linguistic performance, we examined the extent to which the subjects paraphrased the intended meaning of the stimulus sentences independent of grammatical structure. After adjustment for chronological age, age of acquisition showed significant effects on the subjects' ability to paraphrase the stimulus sentences, accounting for 39% of the variance ($F^1(2,45) = 14.673$, $p < .001$; $F^2(2,6) = 54.809$, $p < .001$). As Fig. 3 shows, trend analysis showed the effect to be mostly linear in nature ($F(1,46) = 26.793$, $p < .001$) with the native learners giving significantly more paraphrased responses than either the childhood or adolescent learners. The childhood learners, in turn, gave significantly more paraphrased responses than the adolescent learners ($p < .05$, Tukey HSD).

The speeded condition interacted with the age of acquisition effect, but the interaction was not robust. This was indicated by the significant interaction for the group analysis ($F^1(2,45) = 4.892$, $p < .05$) which was not significant for the item analysis ($F^2(2,6) = 3.022$, n.s.). The speeded condition reduced the number of paraphrases given by the native learners (−23%) to a greater extent than that of the childhood and adolescent learners (−12% and −15%, respectively). There was no significant main effect for the speeded condition.

Together, these findings demonstrate that age of acquisition has long-lasting effects on sign language processing at every level of ASL structure. Are these effects caused by problems specific to the processing of sentence structure, or are they due to more general problems with memory or

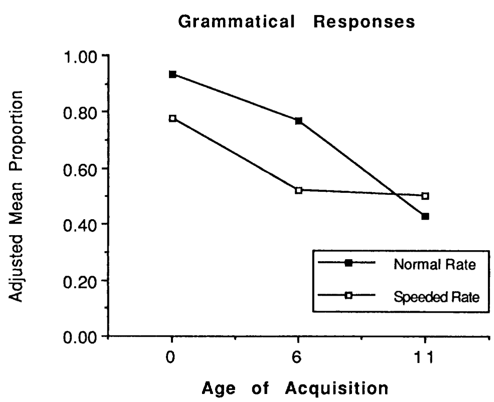

FIG. 2. Adjusted mean proportion of recall responses that were grammatical as a function of age of acquisition and sign presentation rate (normal and speeded).

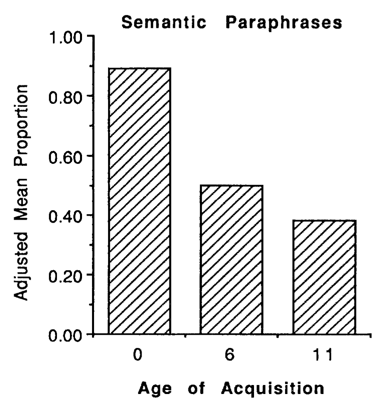

FIG. 3. Adjusted mean proportion of recall responses that paraphrased the intended meaning of the stimulus sentence as a function of age of acquisition.

motor production? To answer the question, we examined the subjects' short-term memory for digits and two aspects of their sign production—response length and articulation rate.

Short-Term Memory and Motor Production

Digit span. We analyzed the subjects' forward and backward digit span with a two-way analysis of covariance. The between-subjects factor was age of acquisition with three levels. The within-subjects factor was order of recall with two levels (forward and backward). The covariate was chronological age.

After adjustment for chronological age, age of acquisition showed no significant effects on short-term memory span for signed digits. Nor were there significant effects for order of recall. (The groups' adjusted mean digit span was 4.6, 4.6, and 4.3, respectively, averaged over both conditions.) Thus, the effects of age of acquisition on sign language processing are apparent for stimuli with syntactic and semantic content (such as sentences) but not for stimuli with limited semantic content lacking syntax (such as digits).

Response length. If the late learners had difficulty with the motor coordination required to sequence long sentences (13 to 15 signs in length), or if they simply could not remember the stimuli at all, then their responses should have been especially brief in comparison to those of the early learners. To determine whether this was so, we computed the number of signs each subject produced in each response.

After adjustment for chronological age, age of acquisition showed no effects on response length for the group analysis ($F^1(2,45) = 1.332$, n.s.), but it did show significant effects for the item analysis ($F^2(2,6) = 20.203, p < .01$). As Table 7 shows, however, the small differences among the groups showed no trend in relation to age of acquisition. The speeded condition had no effects on response length, as indicated by the lack of significant main or interaction effects for this factor.

TABLE 7
ADJUSTED MEAN RESPONSE LENGTH (SIGNS/RESPONSE)

Group	Mean	Range
Native	12.66	19–10
Childhood	13.36	19–10
Adolescent	12.00	15–7
Stimuli	13.63	15–13

These findings show that response brevity does not characterize the sign production of the late learner. Late learners are just as verbose as early learners. Thus, even when the late learner does not fully comprehend ASL sentences (see Fig. 3), he or she is nevertheless sensitive to the lexical length of the stimulus message. As Table 7 shows, late learners tend to approximate the lexical length of the stimulus in their responses. The finding indicates that late learners are sensitive to the lexical boundaries of signs contained in stimulus sentences and also remember the general number of signs given in the stimulus sentences.

Sign production rate. We also examined the subjects' sign production rate. First we measured response duration in hundredths of a second (beginning at the initiation of the lexical movement of the first sign and ending at the release of the last lexical movement of the last sign). Then we divided the response duration by the sum of signs (lexical items) in the response. This yielded a sign production rate in hundredths of a second per sign for each response.

After adjustment for chronological age, age of acquisition showed no significant main or interaction effects on the subjects' rate of sign articulation. Likewise, the speeded condition did not affect the subjects' rate of articulation as indicated by the lack of significant main and interaction effects for this factor. The groups produced signs at nearly identical rates (.63, .62, and

.62 s/sign, respectively). This indicates that the effects of age of acquisition are not caused by an underlying difficulty in the motor production and sequencing of signs.[6]

Together, this set of results elucidates the nature of age of acquisition effects on sign language processing. The effects are not due to basic memory problems or difficulties in motor articulation and sequencing. Rather, the effects arise from problems specific to the processing of linguistic structure located somewhere beyond the initial stage of visual–phonetic identification.

Self-Assessment of Sign Language Skill

Do our findings relate in any way to the signer's ability to comprehend sign language outside the laboratory on an everyday basis? A correspondence between the subjects' self-assessment of their sign language skill and performance on the experimental tasks would suggest that the answer is yes.

We compared the subjects' self-assessment of their ability to comprehend sign language, fingerspelling, and speech to the *paraphrase* measure because, as the results of a regression analysis showed, this measure was most closely associated with age of acquisition.[7] The subjects' self-assessment of both their ASL and fingerspelling comprehension was significantly correlated with their ability to paraphrase the ASL stimuli (for ASL, Spearman's rho $= +.42$, $p < .05$; for fingerspelling, rho $= +.40$, $p < .05$). The subjects' assessment of their speech comprehension was unrelated to their paraphrase ability (rho = .13, n.s.). These results indicate that performance on the processing task, although experimental in nature, corresponds to some degree to the ease with which the subjects judge themselves able to comprehend ASL and fingerspelling. The difficulties in sign language processing we document here may, in fact, impede sign language comprehension in everyday life.

In summary, signers show specific patterns of linguistic processing in relation to the age at which they were first exposed to sign language that are due neither to practice nor aging. Childhood learners primarily make lexical errors derived from the meaning of the message; late learners make unique lexical errors derived from the surface pattern structure of the message. Childhood learners tend to alter bound morphology; late learners tend to strip it. Childhood learners are typically grammatical and paraphrase the intended meaning of stimulus sentences; late learners are often ungrammatical and often miss the full meaning of stimulus sentences. These results demonstrate that the childhood advantage for language acquisition is long-lasting, not unique to speech, and permeates all levels of language processing.

Discussion

The results of this study clearly show that the late learner does not understand the meaning of ASL messages as well as the early learner. In fact, of all the experimental measures, the ability to recall the meaning of the stimulus ASL message was most closely associated with age of acquisition. How general are these findings with respect to sign language? That is, might the performance of the late learners have improved if the stimuli had been given in a sign dialect other than ASL, such as PSE (Pidigin Sign English)? We think not for several reasons.

[6] In other research we have found that children who are native learners of sign language articulate sign sequences significantly faster than their nonnative peers (Mayberry & Waters, 1991). Thus, the present results indicate that initial differences in the rate of sign production between native and nonnative signers disappear over time.

[7] The relative association of all the dependent measures to age of acquisition was compared with a stepwise regression. The two measures most closely associated with age of acquisition were (1) the ability to give a paraphrase of the stimulus sentence, which accounted for 36% of the variance, and (2) lexical changes of a semantic nature, which accounted for an additional 6% of the variation ($F(1,47) = 27.63$, $p < .01$).

First, the present results show age of acquisition to have major effects on lexical processing. We would thus expect age of acquisition to show similar effects on the processing of PSE *and* ASL sentences because the lexicons of the two dialects overlap considerably. (We are currently verifying this hypothesis in our laboratory.) Second, the subjects' self-assessment of their fingerspelling comprehension predicated their ASL performance. Fingerspelling plays a prominent role in PSE, much more so than in ASL, suggesting that the age of acquisition effects we report here are not dialect specific. Finally, in previous research we have found the effects of age of acquisition (confounded with practice) to be similar for both ASL and PSE (Mayberry & Fischer, 1989).

Age of acquisition seriously affects the late learner's ability to understand the meaning of ASL messages, but exactly how is comprehension impeded? Late learners make lexical errors indicative of effortful processing at the surface level of pattern structure (i.e., phonological substitutions). This finding suggests that the late learner is expending effort encoding, organizing, and recognizing signs so that he or she has difficulty interpreting and integrating meaning. The late learner's attention appears to be focused on the initial stages of language processing. Controlled phonological processing has several consequences for comprehension. Phonological shape is more active in short-term memory than meaning, so that errors, when they arise, tend to be phonological in nature. Less attention is available to retrieve the meanings of signs already identified, thereby reducing the ability to integrate meaning across the sentence. Semantic context is thus spotty so that comprehension is incomplete.

Within this framework, the present results suggest that the ease with which the surface pattern structure of language can be recognized and identified is more readily established during early childhood than anytime afterward. Failure to establish facile processing of phonological pattern structure during childhood appears to have long-lasting consequences for language processing.

Where exactly in the initial stages of language processing does the late learner experience difficulty? The alternatives, which are not mutually exclusive, include pattern encoding and segmentation, sign identification, and retrieval and integration of lexical meaning. Several findings argue against pattern encoding and segmentation as the main source of the problem. In both our previous and present studies, permutations at the level of the sign language signal (specifically visual white noise and a speeded presentation rate) did not interact with the effects of age of acquisition. These findings suggest that early and late learners do not differ in pattern encoding and segmentation ability. If pattern encoding and segmentation ability were the primary source of the processing difficulty, then factors which render the sign language signal difficult to perceive visually should have prompted the early learners to behave more like the late learners, that is, to make phonological lexical changes. This did not happen. Rather, in the present study, as in our previous work with visual noise, the speeded signal condition increased the error rate of all signers to some extent, but it did not alter the linguistic nature of their errors.

Two additional findings further argue against pattern segmentation and encoding as the major stumbling block for the late learner. In the present study, the mean number of lexical items the subjects gave in response to the stimuli tended to mirror the number of lexical items contained in the stimulus. Likewise, all signers tended to approximate the tempo of the stimuli regardless of age of acquisition. These findings indicate that age of acquisition does not affect the signer's ability to process the suprasegmental or prosodic properties of the sign language message. In other words, the highly practiced late learner can recognize the prosodic features of sign language pattern structure as well as the early learner but not the detailed segmental structure necessary for lexical processing. More work is needed to pinpoint the locus of the age of acquisition effects in language processing.

Age of acquisition affects the processing of bound morphemes in addition to lexical stems. Indeed, an important characteristic of the signers' bound morpheme errors was that phonological errors were not associated with this level of structure. The sign data thus parallel speech processing data. Both Garrett (1982) and Stemberger (1982, 1984) have observed that lexical stems and bound morphemes have unique error inventories in English production. Like the present findings, they have found that spoken bound morphemes are most typically deleted and that phonological errors occur exclusively on lexical stems, not on bound morphemes. Both researchers interpret the pattern as showing that these two levels of structure—lexical stems and bound morphology—are processed separately in speech. The present findings show that the same is true for sign language. These results converge with other research showing that signers treat ASL lexical stems and bound morphemes as separate units in sentence recognition and sign recall (Hanson & Bellugi, 1982; Poizner, Newkirk, Bellugi, & Klima, 1981). The two levels of structure in ASL are also differentially affected by brain damage (Poizner, Klima, & Bellugi, 1987).

The present results indicate that lexical stems and bound morphemes are processed separately by all signers, regardless of age of acquisition. Yet, early and late learners show contrastive error patterns for the two levels of structure. In addition to being less accurate than early learners, late learners tend to strip bound morphology rather than alter it. These results support Newport's (1984, 1988, 1990) finding that age of acquisition affects the mastery of ASL morphology. In fact, Newport has hypothesized (1984, 1988, pp. 152–163) that the childhood advantage for language acquisition derives from basic differences in how young children and adults learn morphology. She speculates that the young child learns morphology analytically, piece by piece, such that each morpheme represents a specific form/meaning relationship. The older learner, according to this view, learns morphology holistically such that multimorphemic constructions are represented as "frozen" unions devoid of internal morphology.

To our minds, Newport's hypothesis has specific predictions for language processing. The late learner should process lexical stems and any bound morphemes as a single unit (holistically) and consequently either forget the whole unit (stem plus bound morphemes) or, alternatively, substitute another whole unit (stem plus bound morphemes) for the multimorphemic stimulus. There was, however, no evidence in the present data that the late learners processed ASL morphology in a holistic fashion. Rather, the late learners were highly analytic. They unraveled the multimorphemic stimuli along morphological lines as frequently as did the early learners. Furthermore, although age of acquisition has significant effects on the processing of bound morphology, the magnitude of the effects is not greater than the effects for other levels of language structure. The present results suggest to us that the highly practiced late learner does not process some levels of language structure in a qualitatively different fashion from the early learner. Rather, the late learner appears to be intermittently stumped at the initial stages of language processing.

The most common interpretation of the childhood advantage for language acquisition is that children are better able to learn grammar (syntax and morphology) than are older children and adults (Bley-Vroman, 1989). In contrast, Coppieters (1987) has proposed that grammar is the easiest part of language structure for adults to learn because they have already mastered one grammar—that of their native language. Coppieters proposes instead that word knowledge is the hardest aspect of language structure for the late learner. The present results do not support one interpretation to the exclusion of the other. Rather, our data show that age of acquisition affects the processing of lexical items *and* grammatical structure.

Scovel (1989, p. 184) has hypothesized that the childhood advantage for language acquisition resides exclusively in the domain of speech production. He postulates that the ability to produce "accentless" speech is present only during the first decade of life but that the ability to produce "native-like" linguistic structure (other than sound patterns) is present throughout the life span. The hypothesis makes two clear predictions for sign language. One is that there should be *no* age of acquisition effects because no speech is involved. The second, and broader, prediction is that age of acquisition should affect sign language processing only at the level of phonological production and not at other levels of linguistic structure. The sign language data do not fit either prediction. The sign language data do fit Scovel's "timing" proposal for the childhood advantage, however. The child appears to be most advantaged for language acquisition during the first decade of life.

One way to reconcile these multiple viewpoints with the present results is to think of age of acquisition as exerting multiple and discrete effects at each level of language structure. A more parsimonious interpretation, however, is to conceive of age of acquisition as exerting one basic effect that reverberates throughout the processing of language structure.

The apparently multiple effects of age of acquisition may originate from a single source if we assume a model of language processing wherein identification of bound morphemes (both inflectional and derivational) and syntax occurs after the lexical stem has been identified (Taft & Forster, 1975; Dell, 1986). This would mean that when multi-morphemic signs are processed, some form of the lexical stem is isolated from its bound morpheme(s). Identification of the lexical stem yields an associated list of permissible bound morphemes and allowable syntactic roles. When sentences are being processed, the meaning of each lexical stem must be integrated with previously accessed meaning. Bound morphemes provide this interlexical integration. In order for the integration to be meaningful and grammatical, the bound morphemes must fit the previously constructed semantic context. Because the processed semantic context may not be verbatim, the bound morphemes will not be verbatim either. When lexical stems are misperceived in speech, the listener adds or changes closed class words and bound morphemes in order to construct a meaningful and grammatical context for the misperceived lexical stem (Bond & Garnes, 1980). The present results suggest that the same processes occur when sign language is processed.

This account explains the effects shown by age of acquisition on the processing of lexical stems and bound morphemes in the present study. Early learners easily access lexical meaning because they can process surface phonological structure automatically and effortlessly. They consequently have access to a semantic context that includes a syntactic context made up of interlexical links, or bound morphemes. The bound morphemes produced by early learners are not, however, verbatim because the semantic context they have derived from the stimulus sentence is not verbatim. Later learners, although they can identify lexical boundaries, cannot automatically process surface phonological structure. They thus have difficulty identifying the meaning of lexical items. When access to the lexical stem is blocked, access to bound morphemes is blocked too. As a consequence, late learners tend to strip bound morphemes.

The effects of age of acquisition on the processing of other levels of language structure, namely, constituent sequencing, grammatical structure, and sentence meaning, may also emanate from a single source—difficulty in lexical access. If signs cannot be identified, bound morphemes cannot be identified so that grammatical constituents and sequencing cannot be accessed either. Semantic context is fragmentary so that the original meaning of the sentence is incompletely represented and thus cannot be paraphrased. The final stage of language processing is meaning—lexical and sentential. When the initial stages of language processing are difficult, the final stage of language processing cannot be reached.

An important feature of these age of acquisition effects is their linear characteristic. This finding supports previous research showing that the critical period for language acquisition is not an "all or none" phenomenon. The present results show that this is true both across the population and within the individual. As age of acquisition increases, the proportion of stimulus sentences an individual signer can fully understand declines. Likewise, as age of acquisition increases, the proportion of individuals who fully understand sign language sentences declines. The linear nature of these effects suggests that the ability to establish efficient language processing diminishes with time. This fits Lenneberg's (1967) hypothesis that the capacity to acquire language as a native diminishes with age.

The present results appear to contradict two previous studies that have reported *no* age of acquisition effects for deaf signers. Krakow and Hanson (1985) and Bonvillian, Rea, Orlansky, and Slade (1987) found comparable performance for native and non-native signers on tasks involving recall of isolated signs and fingerspelled words. Important differences between these studies and the present one explain the apparent discrepency. First, our results show that age of acquisition effects are most pronounced for sentence tasks as compared to isolated word tasks. Second, the language backgrounds of the subjects are heterogeneous. The subjects of the previous studies were college students who, presumably, represent a select population of deaf signers (with respect to English skill and degree of bilingualism in ASL and English). The subjects of the present study were not college educated. Few had native English skills, and many had learned scant spoken language prior to acquiring ASL (according to self-report). The subjects of the present study may have been more mono- than bilingual, which, we believe, is an important factor in our findings.

The effects of age of acquisition on sign language processing appear to be greater in magnitude than those previously reported for spoken language when the tasks are comparable. For example, Oyama (1978) reported a correlation of $-.40$ between age of acquisition and Italian immigrants' recall of English sentences. Coppieters (1987) found that "near-native" French speakers perform three standard deviations below the native mean on measures of semantic paraphrase. In the present study, age of acquisition correlated $-.62$ with sign language recall. On the semantic paraphrase measure, the childhood learners performed four standard deviations below the native mean while the adolescent learners performed six standard deviations below the native mean.

Why might the timing of language acquisition have greater effects on sign language processing than spoken language processing? The reasons may relate not to the different modalities of the two kinds of language, but to the exceptional circumstances of language acquisition imposed by congenital deafness. When the normally hearing speaker acquires a foreign language after childhood, he or she has already acquired a native language. By contrast, the congenitally deaf individual often acquires sign language with little previous language acquisition. The deaf person's acquisition of sign language, however late in life the task is begun, is often delayed acquisition of a native or *first* language. Thus postchildhood acquisition of sign language is not the same as learning a foreign language late. Childhood may be more critical to first than second language acquisition.

Research currently underway in our laboratory suggests that this hypothesis is correct. Not all later learners of sign language perform poorly. Those who had normal hearing (hence normal acquisition of spoken English) until they became deaf *and* acquired sign language in adolescence (bilingual signers) outperform those who were born deaf and acquired sign language in adolescence with scant previously acquired language (monolingual signers). Likewise, the hearing thresholds of congenitally deaf signers correlate with measures of sign language processing (Mayberry, 1990). The correlation probably reflects childhood acquisition of some spoken language. These preliminary data suggest that the timing of language acquisition more completely predicts the outcome of first than second language acquisition.

In conclusion, the study of sign language provides new evidence in support of Lenneberg's (1967) hypothesis that language acquisition is a developmentally time-locked phenomenon. When the sensory and motor channels of language reception and transmission are switched to visual and manual ones (from the auditory and oral ones), the effects associated with the timing of language acquisition are neither circumvented nor diminished.

APPENDIX: ENGLISH TRANSLATIONS OF THE ASL STIMULI

Sentences Presented at the Normal Rate

1. The approaching man who is deaf doesn't know American sign because he lives in England.
2. On Sundays, men are much more likely than women to just sit and watch televised sports all day long.
3. My boyfriend's best friend, who is standing over there, really wants to date my sister, but she won't have anything to do with him.
4. That man's oldest daughter just had a baby boy, so he's a very proud grandfather right now.

Sentences Presented at the Fast Rate

1. When I was younger, I was very active in various Deaf Clubs located all over the city, but now I haven't any time.
2. Yesterday, I was surprised to bump into my two best childhood friends; I hadn't seen them for ten years.
3. Once when I had a terrible cold that wouldn't go away, the doctor gave me a new medicine that cured my nasal drip instantaneously.
4. In the past, very few people rode bikes to work, but since gas has gotten so expensive now, scads of people ride to work.

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