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Age constraints on first versus second language acquisition: Evidence for linguistic plasticity and epigenesis☆

Rachel I. Mayberry* and Elizabeth Lock

School of Communication Sciences and Disorders, McGill University, 1266 Pine Avenue West, Montreal, Que., Canada H3G 1A8

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Abstract

Does age constrain the outcome of all language acquisition equally regardless of whether the language is a first or second one? To test this hypothesis, the English grammatical abilities of deaf and hearing adults who either did or did not have linguistic experience (spoken or signed) during early childhood were investigated with two tasks, timed grammatical judgement and untimed sentence to picture matching. Findings showed that adults who acquired a language in early life performed at near-native levels on a second language regardless of whether they were hearing or deaf or whether the early language was spoken or signed. By contrast, deaf adults who experienced little or no accessible language in early life performed poorly. These results indicate that the onset of language acquisition in early human development dramatically alters the capacity to learn language throughout life, independent of the sensory-motor form of the early experience.

Keywords: Critical period; Grammatical processing; Comprehension; First-language acquisition; Second-language acquisition; Signed language; ASL; Plasticity; Syntax

1. Introduction

An important question about the nature of language acquisition is the extent to which age constrains its outcome, otherwise known as a sensitive or critical period (CP) for language. The idea that languages must be learned in childhood to be learned successfully has been widely held by educators for over a century (Colombo, 1982). The specific neurolinguistic hypothesis that the outcome of language acquisition is tied to brain development has a more recent history. Penfield and Roberts (1959) first proposed that language acquisition was related to brain plasticity. Lenneberg (1967) later marshaled a variety of evidence linking the trajectory of language acquisition to brain growth curves in early development. Despite this long history, however, the nature of the postulated critical period for language is not well understood. Indeed, the existence of a critical period for language acquisition remains controversial. In the present study we investigate this important question with a new approach.

Investigating a possible CP for language requires identifying situations where the developmental onset of language acquisition varies naturally. Possible effects on the outcome of language acquisition associated with learning languages at various ages can then be measured. The most common test of the CP hypothesis has been spoken, second language (L2) learning because age of L2 learning varies widely in the hearing population (Birdsong, 1999). A less common situation is the signed language acquisition of individuals who are born deaf (Mayberry, 1994, 2002). We compare the outcome of these two situations in the present study to probe the nature of the postulated CP for language. Specifically,

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* Corresponding author. Fax: +514-398-8123.
E-mail address: rachel.mayberry@mcgill.ca (R.I. Mayberry).

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we ask whether the onset of language acquisition in early life is related to the subsequent ability to learn any other language for the remainder of life, independent of the sensory and motor modalities of the first or second languages. Positive evidence of this kind would suggest that the postulated CP for language is similar to other biological phenomena whereby early experience organizes the development of a genetically specified system and its neural underpinnings in an epigenetic fashion (Changeux, 1985) as we explain below. Before describing the present study, we turn to previous research on age of acquisition effects on the grammatical outcome of language acquisition beginning with the case of signed language, followed by spoken language.

Several studies have investigated age of acquisition effects on the outcome of American sign language (ASL). ASL is the most commonly used signed language in North America but only one of the world's many signed languages (Klima & Bellugi, 1979). Signed languages are natural languages that have evolved through generations of children's acquisition and adult use by Deaf communities worldwide (Baynton, 1996; Senghas & Coppola, 2001). Because they are natural languages independent of spoken languages, signed languages are neither universal nor gesture codes for speech (Morford & Kegl, 2000). The linguistic architecture of signed language is similar to that of spoken language in that it is characterized by rule-bound form at the levels of phonology, morphology and syntax, and semantics (for a review see Emmorey, 2002). Infants exposed to ASL by their parents acquire it in a fashion and on a timetable akin to hearing children's acquisition of spoken languages (Chamberlain, Morford, & Mayberry, 2000; Lillo-Martin, 1999; Petitto & Marentette, 1991).

In the first study of age constraints on ultimate attainment in ASL, Mayberry and Fischer (1989) found significant differences in the narrative shadowing performance and lexical error patterns of native signers (who learned ASL from their deaf parents) compared to that of non-native signers (who learned ASL between the ages of 9 and 16). In a second experiment, performance accuracy on ASL sentence shadowing and recall tasks showed a linear relation to age of acquisition (between the ages of birth to 15 years), when length of ASL experience was a confounding factor. In a third experiment controlling length of experience, age of acquisition continued to show a significant linear relation to performance accuracy and morphological error patterns on a task of complex ASL sentence recall (Mayberry & Eichen, 1991). Newport (1990) also found age of acquisition (from birth to older than 13 years) to correlate with ASL ultimate attainment using a composite score derived from a battery of expressive and receptive ASL tests. Finally, Emmorey, Bellugi, Friederici, and Horn (1995) found native ASL learners to outperform non-native learners on a sign monitoring task but not on a grammatical judgement task. Together these results indicate that age of acquisition is an important factor in the outcome of signed language acquisition. Clearly age constraints on language acquisition are not limited to spoken languages to which we now turn.

The most common method of investigating age constraints on the outcome of language acquisition has been to measure the grammatical ability of individuals who learned a second spoken language at varying ages. Some studies have investigated age constraints on the outcome of L2 phonological learning but, because the focus of the present study is grammatical ability, we do not discuss them here (see Flege, 1999). Several studies reported a negative correlation between age of spoken L2 acquisition and L2 grammatical outcome and/or significant differences in grammatical performance between native and non-native learners. These effects were found using a variety of language measures including: sentence shadowing (Oyama, 1978), assessment of written transcripts of spoken interviews (Patkowski, 1980), and assessment of tape-recorded interviews (White & Genesee, 1996). Other studies reported effects for age of acquisition on L2 grammatical outcome using judgement of grammatical and ungrammatical sentences presented in either auditory or written forms (Birdsong, 1992; Birdsong & Molis, 2001; Flege, Yeni-Komshian, & Liu, 1999; Johnson & Newport, 1991; Johnson, 1992; White & Genesee, 1996). In most studies the L2 tested was English; French was the L2 in one study (Birdsong, 1992). The first languages (L1) were Chinese, French, Italian, Korean, Spanish, or unspecified.[1]

Although a negative correlation between age of L2 acquisition and grammatical outcome has been replicated several times using a variety of language measures across a variety of first languages, controversy remains as to whether these findings provide positive evidence for the postulated CP for language. Most studies found L2 grammatical outcome to show a linear function in relation to age of acquisition; as age of acquisition increases, L2 grammatical outcome decreases after the age of 8 (e.g., Birdsong & Molis, 2001; Flege et al., 1999; Johnson & Newport, 1989; Oyama, 1978; Patkowski, 1980). However, some researchers have argued that the slope of the function between age of acquisition and grammatical outcome should be non-linear in nature and stop abruptly at some age coincident with the end of the CP (e.g., Bialystok & Hakuta, 1999).

A non-linear function between age of L2 acquisition and grammatical outcome was found by Johnson and Newport (1989), who tested native speakers of Chinese and Korean with an untimed, grammatical judgement

[1] Several studies claiming age of acquisition effects for L2 outcome are not cited here because they either did not control for practice effects or perform the necessary statistical tests.

task presented auditorally (with a written response) using a variety of English grammatical structures. Age of L2 acquisition correlated with grammatical judgement scores between the ages of 3 and 15 ($r = -.87$) but not between the ages of 17 and 39 ($r = -.16$). These findings were interpreted to mean that the ability to acquire any language, first or second, disappears with increasing maturation. Two subsequent studies failed to replicate this non-linear function between age of L2 acquisition and grammatical outcome, however.

First, Flege et al. (1999) tested Korean learners of English with procedures similar to those used by Johnson and Newport (1989). Pre-puberty ages of acquisition correlated with grammatical outcome (3–12 years, $r = -.52$) but, importantly, post-puberty ages also correlated with grammatical outcome (13–21 years, $r = -.27$). In another study, Birdsong and Molis (2001) used the same methods and English stimuli as Johnson and Newport (1989) but with native Spanish speakers. Age of L2 acquisition did not correlate with grammatical outcome between the ages of 3 and 15. This was primarily due to ceiling effects; many L2 learners performed within the range of the native English speakers. Moreover, age of L2 acquisition correlated with grammatical outcome at ages well beyond childhood, specifically, between the ages of 17 and 44 ($r = -.69$), corroborating the findings of Flege et al. (1999). These findings are counter to the maturation hypothesis.

The results of studies investigating the relation between age of acquisition and L2 grammatical outcome are thus inconclusive with respect to the existence of a CP for language acquisition. Declines in L2 grammatical performance associated with increasing age of L2 acquisition after age 8 have been reported in several studies. However, studies have also found that the decline in L2 grammatical performance associated with increasing age of L2 acquisition does not appear to stop at any age after maturation. An important factor in the L2 situation with respect to a possible CP for language is that it entails, by definition, prior acquisition of an L1 in early life. Some researchers have proposed that the scope of the CP for language is restricted to L1 outcome, citing as evidence the few available case studies of social isolation in early childhood (e.g., Eubank & Gregg, 1999, among others). Cases of childhood social isolation are difficult to interpret given the multiple additional deprivations often suffered by these children (Curtiss, 1977). Whether the postulated CP for language primarily affects L1 outcome as compared to L2 outcome is an empirical question with theoretically significant ramifications. We investigated this question in previous research (Mayberry, 1993, 1994). The goal of the present study was to replicate and extend these findings.

One naturally occurring situation where age of L1 acquisition varies naturally and widely is the signed language acquisition of individuals who are born deaf (Mayberry, 1994, 2002; Morford & Mayberry, 2000). Babies who hear normally are exposed to spoken language from birth nearly without exception. By contrast, infants who are born severely and profoundly deaf are isolated from the language spoken around them by virtue of their deafness. Except in a minority of cases where the parents use ASL (i.e., <10%, Schein & Delk, 1974) the majority of deaf children are not exposed to a signed language until older ages, often after enrolling in school. Deaf children's exposure to accessible language can be delayed for two reasons. Initial detection of deafness and the provision of rehabilitation services often occur at ages beyond early childhood. Signed language may also be withheld from deaf children in the belief that doing so will promote speech development. For many deaf children, language exposure restricted to speech provides insufficiently detailed linguistic input for language development to occur spontaneously (Lederberg & Everhart, 1998). This unique circumstance of language acquisition thus permits a novel test of the CP for language. Specifically, it allows us to investigate the effects of the onset of first as compared to second language acquisition on grammatical outcome.

We previously investigated the question of whether age constraints are greater for the outcome of L1 as compared to L2 (Mayberry, 1993). All participants were deaf adults. One group was born with normal hearing which they suddenly lost between the ages of 9 and 13 years due to various viral infections; after becoming deaf, they learned ASL as an L2. The contrast group was born deaf and acquired ASL at matched ages (9–13 years) but after little or no prior accessible language exposure; their ASL acquisition was clearly a case of significantly postponed first-language acquisition. Despite learning ASL at matched ages, the grammatical performance of the L2 learners was significantly higher and different (82%) from that of learners with no early language experience (43%) on a task requiring recall of complex ASL sentences (Mayberry, 1993). These results provided the first evidence that language acquisition in early life is necessary for the capacity to learn language to develop completely, in the case where the early language is spoken and the second language is signed.

The goal of the present study was to replicate and extend our previous findings to determine whether they generalize across sensory-motor modalities and languages. We asked whether the acquisition of a signed language during early life enables the subsequent acquisition of a spoken language. We also asked the corollary question of whether a paucity of language acquisition during early life attenuates the ability to acquire language in later life. Such findings would mean that the capacity to acquire language requires early input from the environment to develop fully.

In order to investigate these questions, we compared the grammatical skills of hearing and deaf individuals who learned English at similar ages but who had three contrasting types of language experience in early childhood: (a) early acquisition of a spoken language from birth; (b) early acquisition of a signed language from birth; and (c) little or no language acquisition during early childhood. Finding superior grammatical performance by the early language learners compared to the learners who experienced sparse early language would support the hypothesis that accessible language input during human development is necessary for the capacity to learn language to develop fully. By contrast, finding similar grammatical performance by the learners with and without early language experience would provide counter-evidence to our hypothesis and suggest instead that maturation alone underlies age constraints on the capacity to learn language. Finally, finding no performance differences between the hearing and deaf early language learners, whose first languages were spoken and signed, respectively, would mean that development of the language learning capacity is plastic with respect to the sensory and motor form of the early experience and hence not a factor in the critical period phenomenon.

2. Methods

2.1. Participants

Fifty-four adults with contrasting types of language experience in early life were recruited into the study from four Canadian cities and placed in four groups. Two groups were normally hearing and two groups were profoundly deaf. The groups consisted of approximately equal numbers of men and women with the language backgrounds described below and shown in Table 1.

2.1.1. Native English controls

Fourteen individuals who had normal hearing throughout life and were native speakers of English served as controls (henceforth native controls, NC). English was their native language which they used socially and at home, work, and school. All but one NC participant later received second-language instruction in elementary school, French in all cases. The eight men and six women had a mean age of 26.43 years with a range of 16–46 years.

2.1.2. Early signed language

Fourteen participants were born profoundly deaf and acquired ASL as a first language in early life (henceforth Early-Sign Lang). ASL was the maternal language of 11 Early-Sign Lang participants whose deaf parents used it with them from birth. Two participants had older deaf siblings who communicated with them in signed language prior to age three; one participant had normally hearing parents who learned and used signed language before the age of three. The Early-Sign Lang participants were later exposed to English as a second language when they enrolled in preschools and elementary schools where English was the language of instruction between the ages of 3 and 7 years.

The Early-Sign Lang participants were primarily taught English through a combination of signs and spoken English, in addition to lipreading, reading, and writing. The classroom language of instruction for the Early-Sign Lang participants was English, primarily in the form of simultaneously spoken English and signed Manually Coded English (MCE).[2] These participants reported that most of their hearing teachers spoke and simultaneously signed MCE but that a few deaf teachers used ASL.

The length of time the Early-Sign Lang participants had used English was computed by subtracting age of school enrollment from chronological age. Mean length of English use was 24.5 years with a range of 14–47 years. The eight men and six women ranged in age from 17 to 52 years with a mean of 25.5 years.

2.1.3. Early spoken language

Thirteen participants had normal hearing throughout life and acquired a spoken language other than English from birth; they later learned English as a second language after enrolling in a school where English was the language of instruction (henceforth Early-Spkn Lang). Urdu was the maternal language of eight Early-Spkn Lang participants; French was the maternal language of two participants; and German, Italian, and Greek were the maternal languages of three participants respectively. The Early-Spkn Lang participants began to learn English as a second language in schools where English was the language of instruction between the ages of 6 and 13 years with a mean age of 9 years. After enrolling in an English school, all the Early-Spkn Lang participants continued to use their maternal language at home and socially with friends. The Early-Spkn Lang participants had used English as an L2 for a mean of 23.46 years with a range of 12–50 years. The seven men and six women ranged in age from 17 to 57 with a mean age of 32.46 years.

[2] Pedagogical sign systems designed to teach English to deaf children go by a variety of names in North America, such as Manually Coded English (MCE) or signed English. Open class signs are borrowed from a natural signed language, ASL in this case, and produced in English word order along with invented signs for portions of English grammatical morphology. Using this communication method, known as Total Communication or TC, the teacher speaks English and simultaneously produces the signs of MCE. The grammatical structure of MCE is very different from that of ASL (see Schick & Moeller, 1992).

Table 1
Background characteristics of the experimental groups

Early language experience	*n*	Females/Males	Mean age of English exposure (range)	Mean years of English use (range)	Mean chronological age (range)
Early-Spkn English (native control)	14	6/8	Birth (0)	26.43 (16–46)	26.43 (16–46)
Early-Sign Lang (not English)	14	8/6	5.0 (4–7)	24.5 (14–47)	25.5 (17–52)
Early-Spoken Lang (not English)	13	6/7	9.00 (6–13)	23.46 (12–50)	32.46 (17–57)
No-Early Lang	13	8/6	9.40 (6–13)	26 (11–64)	35.23 (23–70)

2.1.4. No early language

Thirteen participants were born profoundly deaf and had normally hearing parents and siblings. Due to their deafness, however, the English spoken by their families was inaccessible to them in infancy and early childhood. In addition, their families neither knew nor used any form of signed language with them throughout early childhood. Twelve participants first attended preschools for deaf children where child/teacher interaction was restricted to speech (with no signs of any kind used) between the ages of 3 and 6 with a mean age of 4.1. However, due to a lack of speech development due to their profound deafness as described below (lipreading alone provides insufficient linguistic input for spoken language to develop spontaneously), they were subsequently switched to schools where sign was used, between the ages of 6 and 13 with a mean age of 9.4. This is a common educational occurrence arising from the priority frequently given to speech over sign by rehabilitation professionals and hearing parents. One participant attended no preschool and first enrolled in a school where sign was used at age 7. All these participants consequently had little accessible language exposure until age 6 or older (henceforth No-Early Lang).

After enrolling in a school where sign was used, the No-Early Lang participants were taught English in the same manner as the Early-Sign Lang participants, primarily through a combination of signs and spoken English (see Endnote 2). They were also taught English through lipreading, reading, and writing. Several of these participants attended the same schools as the Early-Sign Lang participants. The eight men and six women ranged in age from 23 to 70 with a mean age of 35.23 years. The mean length of time the No-Early Lang participants had used English was 26 years with a range of 11–64 years.

2.2. Group comparability

Educational background was controlled across the groups; all participants had completed high school but none had completed college. The following additional factors were also controlled.

2.2.1. Age of English exposure

Age of accessible English exposure was matched as closely as possible for the Early-Spkn Lang and No-Early Lang participants and considered to be the age of first enrollment in a school where the language of instruction was English, spoken English for the former group and MCE and simultaneously spoken English for the latter group. Approximately half the participants in each group were first exposed to accessible English between the ages of 6 and 8 years (Early-Spkn Lang group, $n = 8$; No- Early Lang group, $n = 6$); the remaining participants in each group were first exposed to English between the ages of 9 and 13 years (Early- Spkn Lang, $n = 6$; No-Early Lang, $n = 7$). There was no difference in age of first accessible English exposure between the two groups ($t = 1.047$, $df = 24$, *ns*). In addition, there was an overlap in the age of exposure to accessible English between the above groups and the Early-Sign group; six Early-Sign participants were first exposed to accessible English between the ages of 4 and 7 years; the remaining eight participants were first exposed at age 3.

2.2.2. Length of English use

To ensure that each participant had a baseline amount of English experience, defined as years of use, only individuals who had a minimum of 12 years of continuous English use were recruited into the study. Overall, the participants had substantially more experience than the minimum requirement, as Table 1 shows. Length of English experience was computed for each participant by subtracting age of first exposure to accessible English from chronological age. Age of first English exposure for the native controls was considered to be at birth. Mean length of English use for the four groups, NC, Early-Sign, Early-Spkn, and No-Early Lang, was 26.43, 24.50, 23.46, and 26.00 years, respectively. There were no significant differences in length of experience among the groups (one-way analysis of variance, $F[3, 50] = 0.157$, *ns*).

2.2.3. Deaf group comparability

Although the two deaf groups had strikingly different experiences with accessible language in early life, they did not differ with respect to the age of their first preschool experience. The Early-Sign participants first enrolled in preschool programs, where MCE and simultaneous spoken English was the mode of child/teacher communication, between the ages of 3 and 5 (one participant attended no preschool and entered primary school at age 7) with a mean entry age of 4.00 years. By comparison, the No- Early Lang participants first enrolled in preschool programs where only speech was used between the ages of 3 and 5 (three participants attended no preschool) with a mean entry age of 4.5 years. There was no difference between the groups in age of preschool entry ($t = 7.11,\ df = 22, ns$).

Additional measures of hearing loss and non-verbal IQ were taken on approximately half the groups who were deaf, six participants each. Audiometric testing of these 12 individuals confirmed all the participants' self-report of being profoundly deaf (mean pure-tone average, PTA, for 500, lK, and 2K Hz $\geqslant$90 dB for the better ear). There was no significant difference in mean PTA between the Early-Sign and No-Early Lang samples, 94.67 and 96.20 dB, respectively ($t = .55,\ df = 10,\ ns$).

Numerous IQ studies and a meta analysis (Braden, 1992) have found that congenital deafness does not affect non-verbal intelligence despite common delays in age of initial language exposure to accessible (Mayberry, 2000). This was confirmed by the deaf sample's performance on three subtests of the Wechsler Adult Intelligence Scale, WAIS (Wechsler, 1981). Both groups' performance was within the average range as compared to the hearing population, with no significant differences between the them (average scaled score for the hearing population is 10.00; mean scaled scores for the No-Early Lang and Early-Sign groups, respectively, were as follows: Picture Completion, 11.00 and 11.16, $t = -0.155,\ df = 10,\ ns$; Picture Arrangement, 10.50 and 11.33, $t = -33,\ df = 10,\ ns$; Block Design, 11.33 and 13.00, $t = -1.012,\ df = 10,\ ns$). The non-significant higher performance on the Block Design subtest by the group with early signed language input likely reflects the enhanced spatial abilities that have been found in association with learning a signed language both behaviorally (Emmorey, Kosslyn, & Bellugi, 1993) and neurocortically (Neville & Lawson, 1987).

Finally, employment surveys taken in the USA have found that the social-economic status (SES) of the deaf population is significantly lower than that of the hearing population primarily due to higher levels of both unemployment and underemployment among adults who are congenitally deaf. Median income of families headed by deaf adults is approximately 70% of that of families headed by hearing adults (Schein, 1989). Consequently, the childhood SES of the No-Early Lang participants (whose 26 parents were hearing) was likely to have been greater than that of the Early-Sign participants (22 of whose 28 parents were deaf). Thus, if SES were a biasing factor in the present study, the bias would favor the No-Early Lang group over the Early-Sign Lang group.

To summarize the experimental grouping, in addition to the native English controls, two groups had early language experience, one in spoken language and the other in signed language, and the fourth group had sparse, perceptible and accessible language experience during early life. The two deaf groups, one with and one without early accessible language, did not differ with respect to degree of hearing loss, non-verbal IQ, age of preschool entry, or method of English instruction (once enrolled in a school where sign was used). Importantly, the deaf group whose initial exposure to accessible language was delayed performed at normal levels on non-language cognitive tests. The SES of the deaf group with no early language was likely higher than the group with early sign language. Finally, aside from the native English controls who were first exposed to English at birth, the three remaining groups were exposed to accessible English at school at similar ages and had used it for a similar length of time.

2.3. Experimental tasks

2.3.1. Grammatical judgement

A grammatical judgement task was used to assess knowledge of selected English structures. The grammatical judgement task is commonly used to assess the language ability of monolingual, bilingual, and brain damaged populations (Linebarger, Schwartz, & Saffran, 1983). English grammatical and ungrammatical stimuli were presented in print, one at a time, on a computer screen. The participant indicated with a button press whether the given stimulus was grammatical or not. The computer measured both response accuracy and latency. Response accuracy reflected sensitivity to syntactic structures and response latency reflected the time required to identify these structures.

2.3.2. Sentence to picture matching

In order to assess comprehension of the same selected English grammatical structures, participants were given a second task, sentence to picture matching. Sentence to picture matching is commonly used to assess comprehension of selected grammatical rules in a particular language. The participant was shown a printed sentence and asked to select the one picture from among three alternatives that best depicted the stimulus sentence meaning.

2.4. English grammatical structures

Five English grammatical structures were selected to represent a continuum of complexity from simple to complex and were as follows: simple, dative, conjoined, passive, and relative clause sentences. Previous research has found that these structures represent a sequence of early to later acquired in the English acquisition of both normally hearing (Ingram, 1989) and deaf children (Quigley & King, 1980). Because the performance of the deaf school-aged population on these structures has been investigated in detail, we used them in the present study to determine the extent to which early language experience, or a lack thereof, may be a contributing factor in deaf individuals' often poor performance on these structures. More specifically, previous research has found that 18 year olds who were born deaf show difficulty with syntactic structures involving multiple clauses, as in relative clause sentences, and non-canonical word order, as in passive sentences (Quigley & King, 1980). These particular syntactic structures have not been proposed as being especially difficult for hearing L2 English learners.

2.4.1. Stimulus controls

To ensure that grammatical structure was the primary factor that varied across the stimuli, all sentences were to seven to ten words in length. The vocabulary was at an approximate grade one reading level to ensure that lexical knowledge was not confounded with grammatical processing and comprehension. For the grammatical judgement task, 24 stimuli were created for each grammatical structure. The 12 grammatical stimuli for each grammatical structure were made ungrammatical by the application of a single deviation that rendered it ungrammatical; the same deviation was then applied to all 12 examples of the grammatical structure. When a word was removed from a grammatical example to make it ungrammatical, a simple adjective was added to the ungrammatical counterpart to ensure that the word length of each stimulus pair, grammatical and ungrammatical, was identical. The adjectives added were the words "big, old, " and "red."

2.5. Stimuli

Stimuli for the grammatical judgement task were 120 in total, 24 stimuli for each of the five English grammatical structures, 12 grammatical sentences and 12 ungrammatical counterparts. The target grammatical structures are described below and shown in Table 2.

Stimuli for the sentence to picture matching task were 25 in total with five example sentences of each of the five target grammatical structures that appeared in the grammatical judgement task and were taken from the Rhode Island Test of Language Structure, RITLS (Engen & Engen, 1983).

2.5.1. Simple sentences

The simple sentences consisted of a subject and verb followed by a prepositional phrase as in, "The girl is playing in the water." The present progressive verb tense was used throughout. The grammatical stimuli were made ungrammatical by exchanging the auxiliary verb "be" with the auxiliary verb "have," as in, "The girl have playing in the water." Previous research has found this to be a common error made by deaf children (Quigley, Montanelli, & Wilbur, 1976).

2.5.2. Dative sentences

The dative sentences consisted of a subject, verb, and an indirect object as in, "The boy is giving the girl a cookie." The grammatical stimuli were made ungrammatical with a word order violation by moving the indirect object in front of the verb as in, "The boy a cookie is giving the girl." Deaf children have been found to have problems interpreting word order (Quigley & Power, 1972).

2.5.3. Conjoined sentences

The conjoined sentences consisted of two clauses joined by a temporal conjunction as in, "The girl is eating while the man is sleeping." The grammatical stimuli were made ungrammatical with a word order violation by moving the conjunction to the end of the sentence as in, "The girl is eating the man is sleeping while." As previously explained, deaf children often have problems interpreting English word order (Engen & Engen, 1983).

2.5.4. Passive sentences

The passive structures were non-reversible, full passives as in, "The boy was hit by the red ball." The grammatical sentences were made ungrammatical by deleting the marker "by," as in "The boy was hit the big red ball." Previous research has shown the passive structure to be

Table 2
Examples of the English syntactic structures and rule violations tested

Syntactic structure	Rule violation	Example
Simple	Auxiliary changed from "be" to "have"	The girl is playing in the water *The girl have playing in the water
Dative	Indirect object placed before the verb	The father is giving the girl an apple *The father an apple is giving the girl
Conjoined clauses	Conjunction placed at end of sentence	The girl is eating while the man is sleeping *The girl is eating the man is sleeping while
Non-reversible passive	Deletion of passive marker "by"	The girl was hit by the ball *The girl was hit the ball
Subject–subject relative clause	Incorrect relative clause marker	The boy who is chasing the girl is happy *The boy whose is chasing the girl is happy

very difficult for deaf children (Engen & Engen, 1983; Power & Quigley, 1973).

2.5.5. Relative clause sentences

The relative clause sentences contained a medial relative clause. The subject of the main clause was modified by the relative clause and served as the subject of the relative clause (subject–subject relatives) as in, "The boy who is chasing the girl is happy." The grammatical sentences were made ungrammatical by substituting the incorrect relative marker "whose" for "who" as in, "The boy whose is chasing the girl is happy." Previous research has found relative clauses to be difficult for deaf children (Engen & Engen, 1983; Quigley, Smith, & Wilbur, 1974).

2.6. Procedures

2.6.1. Grammatical judgement materials

The grammatical judgement task was presented on an Apple G3 PowerBook laptop computer with an attached game pad with two buttons, green and red. The green button signified a "yes" response and the red button signified a "no" response. The grammatical judgement task was created with PowerLaboratory 1.0.3 experimental software (Chute & Daniel, 1996). The 120 stimuli were presented in a fixed random order to each participant. The computer recorded the participant's response accuracy and latency. Response latency was recorded in milliseconds from the onset of the stimulus to the participant's button press. Each stimulus presentation was preceded by a focus signal ('+') of 500 ms duration to alert the participant that the stimulus would appear shortly on the monitor. The stimulus remained on the screen until the subject responded.

2.6.2. Sentence to picture matching materials

The sentence to picture matching task was presented on paper in a binder format. The printed stimulus sentence was centred at the top of the page and the three alternative pictures were given below on the bottom. The stimulus sentences and pictures were taken from the RITLS (Engen & Engen, 1983). The pictures showed three possible grammatical interpretations of the stimulus sentence rather than lexical or morphological contrasts. For example, the stimulus sentence, "The woman who is holding the baby has a hat on," was accompanied by three pictures each depicting two women with one holding a baby; in one foil the woman not holding the baby wears a hat and in the other foil there is no hat. There were 25 stimuli, five examples of each of the five selected grammatical structures. The 25 stimuli were presented in a fixed random order.

2.6.3. Participant testing

Each participant was tested individually in a single session. The nature of the tasks, stimuli, and informed consent were explained in English to the hearing participants and in ASL to the deaf participants. The grammatical judgement task was administered first followed by the sentence to picture matching task.

The participant was shown how to perform the grammatical judgement task using three practice trials. The participant performed the practice trails by reading the stimulus on the computer screen and then pressing the green button on the game pad if he or she judged the stimulus to be grammatical or the red button if the participant judged it to be ungrammatical. 'Yes' responses were always made with the dominant hand; left-handed participants made 'yes' responses with the left hand. Participants were told that the computer recorded accuracy and latency and instructed to be careful but not to pause unnecessarily.

After completion of the grammatical judgement task, the sentence to picture matching task was explained in English to the hearing participants and in ASL to the deaf participants. Participants were instructed to read the stimulus sentence at the top of the page and then to point to one of the three pictures that best depicted the sentence meaning. Participants were given three practice trials. Responses were recorded by an examiner on a score report form. Participants had unlimited time to respond.

3. Results

The groups' performance on the grammatical judgement task was analyzed for response accuracy and latency and A' as described below. For the sentence to picture matching task, response accuracy was analyzed. Further analyses were conducted to compare the performance of participants within the groups who were first exposed to accessible English at earlier (6–8 years) versus older (9–13 years) ages.

3.1. Grammatical judgement task

3.1.1. Response accuracy

The participants' response accuracy on the grammatical judgement task was analyzed with two, $4 \times 5 \times 2$ repeated measures analyses of variance for subjects and items. These analyses revealed whether the effects held across both the participants and the stimuli and further determined whether grammaticality was a performance factor. The between-subjects factor was early language experience with four levels of group, NC, Early-Sign, Early-Spkn, and No-Early Lang. The within-subjects factors were: (1) syntactic structure with five levels of type (simple, dative, conjoined, passive, and relative clause) and (2) grammaticality with two levels, grammatical and ungrammatical.

The results showed a significant main effect for early language experience ($F_{\text{Subjects}}[3, 50] = 18.58$, $p < .0001$;

$F_{\text{Items}}[3, 165] = 405.88,\ p < .0001$). Mean error rate was 5% for the NC, 14% for the Early-Sign, 14% for the Early-Spkn, and 34% for the No-Early Lang group. There was a significant main effect for grammatical structure that interacted in a two-way interaction with early language experience ($F_{\text{Subjects}}[12, 200] = 2.910$, $p < .001$; $F_{\text{Items}}[12, 165] = 8.127$, $p < .001$) and in a three-way interaction with grammaticality ($F_{\text{Subjects}}[4, 200] = 14.010$, $p < .001$; $F_{\text{Items}}[4, 55] = 7.826$, $p < .001$). There was no main effect for grammaticality, however. The nature of the three-way interaction was such that the performance of the No-Early Lang group on the ungrammatical examples of the simple, passive, and relative clause structures was significantly lower than their performance on the grammatical counterparts of these structures. In addition, their accuracy on the ungrammatical examples of the simple, passive, and relative clause structures was significantly less than that of the other three groups. The performance of the early language groups, NC, Early-Sign Lang, and Early-Spkn Lang, was not significantly different from one another independent of grammatical structure or grammaticality, with one exception. The Early-Spkn Lang group was significantly less accurate on the grammatical examples of the dative structure compared with the performance of the NC and Early-Sign Lang groups on these stimuli (Student–Newmann–Keuls, $p < .05$ for each comparison with a harmonic mean for group *n*).

3.1.2. Response A'

To determine the extent to which the above results were biased by guessing behavior, we further analyzed the groups' performance by calculating an A' score for each participant for each of the five grammatical structures. The formula we used was: $0.5 + [(y + x)(1 + y - x)]/4y(1 - x)$ (Linebarger et al., 1983). A' is a form of signal detection that factors guessing behavior into performance by comparing the ratio of hits ($x =$ correct judgements of ungrammatical stimuli) and false alarms ($y =$ incorrect judgements of grammatical stimuli) as a function of chance. A' scores range from 0.5 suggesting no rule sensitivity to 1.0 showing high rule sensitivity.

We analyzed the A' scores with a 4×5 analysis of variance for subjects only. The between-subjects factor was early language experience with four levels of group. The within-subjects factor was grammatical structure with five levels of rule type. Grammaticality was not a factor because it was incorporated into the A formula in the form of 'hits' and 'misses' as explained above. The results showed that guessing behavior was not a biasing factor in the relative performance patterns of the groups across the syntactic structures. First, there was a significant main effect for early language experience ($F[3, 50] = 18.881$, $p < .001$). The mean A' scores were .93 for NC, .83 for the Early-Sign Lang, .82 for the Early-Spkn Lang, and .68 for the No-Early Lang group. There was also a significant main effect for type of grammatical structure ($F[4, 200] = 18.945$, $p < .001$) that interacted with early language experience ($F[12, 200] = 2.897$, $p < .001$), as shown in Fig. 1. The nature of the interaction was such that the No-Early Lang group obtained A' scores that were significantly lower on the simple, passive, and relative clause structures than those of the three groups who had early language experience. In addition, the No-Early Lang group obtained A' scores on the conjoined structure that were significantly lower than those of the NC but not the Early-Sign Lang and Early Spkn-Lang groups. Finally, the Early-Spkn Lang group obtained A' scores on the dative structure that were significantly lower than those

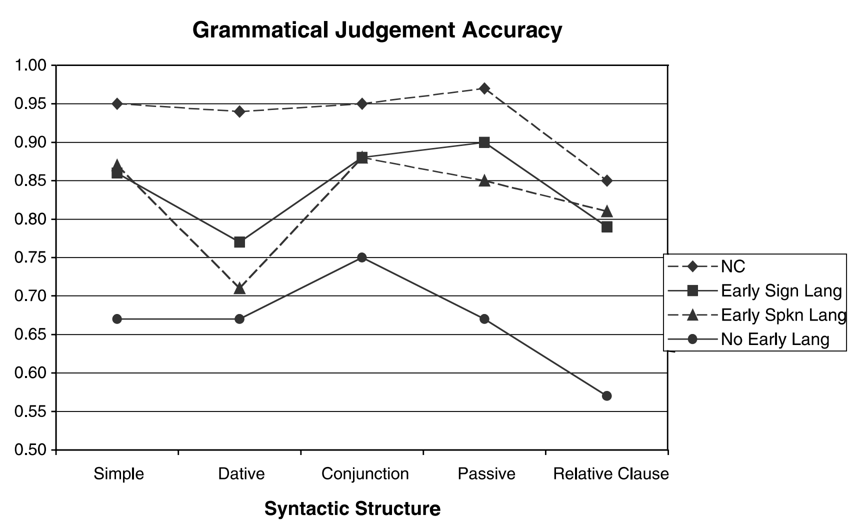

Fig. 1. Performance accuracy on a grammatical judgement task expressed as mean A' score (that takes guessing into account) as a function of English syntactic structure and early language experience, native English control (NC), early sign language learners, early spoken language learners, and no early language learners. Chance performance would be at 0.50 as indicated by the minimum on the Y-axis.

of the NC group but not the Early-Sign Lang and No-Early Lang groups (Student–Newmann–Keuls, $p < .05$ for each comparison with a harmonic mean for group n).

3.1.3. Response latency

Response latencies for correct grammatical judgements were analyzed with two, $4 \times 5 \times 2$ repeated measures analyses of variance for subjects and items in order to determine whether grammatical processing rate is also affected by the onset of accessible language experience. The between-subjects factor was early language experience with four levels of group. The within-subjects factors were: (1) grammatical structure, with five levels of type and (2) grammaticality with two levels, grammatical and ungrammatical.

The results showed a significant main effect for early language experience ($F_{\text{Subjects}}[3, 50] = 13.622$, $p < .001$; $F_{\text{Items}}[3, 165] = 134.671$, $p < .001$). There was also a main effect for grammatical structure that was significant in the subject analysis ($F_{\text{Subjects}}[4, 200] = 5.086$, $p < .001$) but not in the item analysis. There were no significant interactions between early language experience and grammatical structure and no significant main or interaction effects for grammaticality in either the subject or item analyses.

The effect of early language experience on grammatical judgement response latency was such that each group's response latency was significantly different from the other's, as shown in Table 3. The NC group responded more quickly than the three other groups. The No-Early Lang group responded more slowly than the three other groups. Of the two early language groups, the Early-Sign Lang participants responded more quickly than did the Early-Spkn Lang participants (Student–Newmann–Keuls, $p < .05$ for each comparison with a harmonic mean for group n).

Table 3
Grammatical judgement response latency in milliseconds as a function of early language experience (for correct responses only)

Group	Mean	*SD*
Native control	3880	1570
Early-Sign Lang	4778	2171
Early-Spkn Lang	6325	4594
No-Early Lang	8492	4377

3.2. Sentence to picture matching task

The participants' scores on the sentence to picture matching task were analyzed with two 4×5 repeated measures analyses of variance for subjects and items. The between-subjects factor was early language experience with four levels of group; the within-subjects factor was grammatical structure with five levels of rule type. The results showed a significant main effect for early language experience ($F_{\text{Subjects}}[3, 30] = 24.06$, $p < .0001$; $F_{\text{Items}}[3, 60] = 26.225$, $p < .001$). Mean comprehension accuracy was 97% for the NC, 94% for the Early Sign Lang group, 95% for the Early-Spkn Lang group, and 74% for the No-Early Lang group. The results also showed a significant main effect for grammatical structure ($F_{\text{Subjects}}[4, 200] = 20.39$, $p < .0001$; $F_{\text{Items}}[4, 20] = 5.308$, $p < .0001$) that further interacted with early language experience ($F_{\text{Subjects}}[12, 200] = 11.88$, $p < .0001$; $F_{\text{Items}}[12, 60] = 4.688$, $p < .0001$), as Fig. 2 shows. The nature of the interaction was such that the

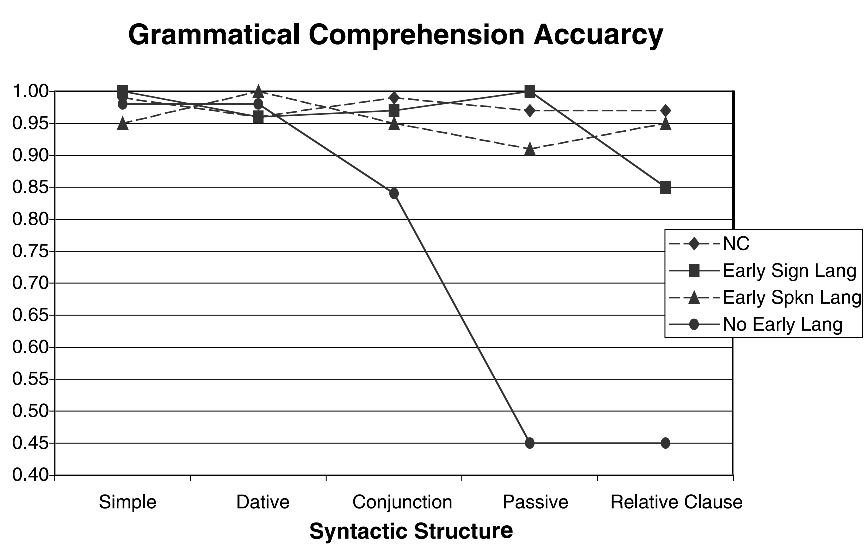

Fig. 2. Mean performance accuracy on a sentence to picture matching task expressed as proportion correct as a function of English syntactic structure and early language experience, native English control (NC), early sign language learners, early spoken language learners, and no early language learners. Chance performance would be 0.33.

groups' comprehension accuracy did not differ significantly across the simple, dative and conjoined structures. However, the No-Early Lang group was significantly less accurate than the three other groups on the passive and relative clause structures, performing at near chance levels (Student–Newmann–Keuls, $p < .05$ for each comparison with a harmonic mean for group n).

3.3. Subgroup analyses

To determine whether non-verbal cognitive skills were a biasing factor in the results for the groups who were born deaf, we compared the performance of the participants in each group who received non-verbal IQ testing with those who did not. The results showed no difference within groups related to non-verbal IQ performance (Early-Sign, $t = 1.144$, $df = 12$, *ns*; No-Early Lang, $t = -1.78$, $df = 11$, *ns*).

To determine next whether age of exposure to accessible English within the groups may have biased the pattern of results, we sorted the Early-Spkn Lang and No-Early Lang groups into subgroups of younger (6-8 years) versus older (9–13 years) ages of exposure to accessible English and reanalyzed the grammatical judgement and comprehension data. We included the subgroup of Early-Sign Lang participants whose age of first exposure to accessible English (4–7 years) was comparable, although not identical, to the younger age subgrouping of the other two groups.

3.3.1. Grammatical judgement accuracy

We analyzed the adjusted grammatical judgement performance (A' scores described above) with one-way analyses of variance separately for each syntactic structure. All subgroups who had early language experience significantly outperformed those who did not, regardless of whether their first accessible English exposure occurred at younger ages (6–8 years) or older (9–13 years) ages on the simple ($F[4, 28] = 7.02$, $p < .001$), passive ($F[4, 28] = 9.21$, $p < .001$) and relative clause ($F[4, 28] = 5.78$, $p < .001$) structures (Fischer's PLSD for each comparison, $p < .01$). In addition, there were no performance differences among the younger and older age subgroups who experienced language in early life, as shown in Table 4.

3.3.2. Grammatical judgement response latency

We analyzed the mean grammatical judgement response latency with one-way analysis of variance for the five subgroups without the factors of syntactic structure and grammaticality because the main analysis showed no significant effects for these factors. The subgroups who had early language responded significantly more quickly than the subgroups with no early language, except for the one subgroup who first learned English at older (9–13 years) ages ($F[4.28] = 3.66$, $p < .02$; Fischer's PLSD for each comparison, $p < .05$). There were no differences within each group, Early-Spkn Lang and No Early Lang, as a function of subgrouping.

3.3.3. Grammatical comprehension

Finally, we analyzed the sentence to picture matching performance of the five subgroups with one-way analyses of variance separately for each syntactic structure. All the subgroups who had early language experience significantly outperformed those who did not, regardless of whether their first exposure to English was at younger (6–8 years) or older (9–13 years) ages, on the passive ($F[4, 28] = 26.29$, $p < .001$) and relative clause ($F[4, 28] = 19.64$, $p < .001$) structures (Fischer's PLSD for each comparison, $p < .01$). Finally, there were no performance differences among the younger and older subgroups who experienced language in early life, as shown in Table 5.

Table 4
Adjusted mean grammatical judgement accuracy of the Early-Sign Lang, Early-Spkn Lang and No-Early Lang participants subgrouped by age of exposure to accessible English

Subgroup	Syntactic structure				
	Simple, mean (*SD*)	Dative, mean (*SD*)	Conjoined, mean (*SD*)	Passive, mean (*SD*)	Relative clause, mean (*SD*)
Early-Sign Lang					
4–7 years ($n = 7$)	0.87 (0.14)	0.79 (0.15)	0.88 (0.09)	0.95 (0.05)	0.79 (0.17)
Early-Spkn Lang					
6–8 years ($n = 7$)	0.95 (0.06)	0.68 (0.10)	0.85 (0.06)	0.93 (0.11)	0.83 (0.13)
9–13 years ($n = 6$)	0.88 (0.17)	0.72 (0.20)	0.94 (0.05)	0.84 (0.16)	0.86 (0.21)
No-Early Lang					
6–8 years ($n = 8$)	0.69 (0.05)*	0.67 (0.10)	0.74 (0.17)	0.69 (0.15)*	0.57 (0.13)*
9–13 years ($n = 5$)	0.63 (0.04)*	0.66 (0.15)	0.75 (0.09)	0.63 (0.04)*	0.54 (0.04)*

* $p < .01$.

Table 5
Mean grammatical comprehension accuracy of the Early-Sign and Spkn-Lang and No-Early Lang participants subgrouped by age of accessible English exposure

Subgroup	Syntactic structure				
	Simple, mean (*SD*)	Dative, mean (*SD*)	Conjoined, mean (*SD*)	Passive, mean (*SD*)	Relative clause, mean (*SD*)
Early-Sign Lang					
4–7 years ($n = 7$)	1.00 (0)	0.96 (0.08)	1.00 (0)	1.00 (0)	0.90 (0.16)
Early-Spkn Lang					
6–8 years ($n = 7$)	1.00 (0)	1.00 (0)	0.94 (0.09)	0.96 (0.07)	1.00 (0)
9–13 years ($n = 6$)	0.92 (0.10)	1.00 (0)	0.96 (0.08)	0.80 (0.44)	0.84 (0.16)
No-Early Lang					
6–8 years ($n = 8$)	1.00 (0)	0.96 (0.07)	0.82 (0.18)	0.62 (0.33)*	0.42 (0.08)*
9–13 years ($n = 5$)	0.96 (0.08)	1.00 (0)	0.88 (0.10)	0.08 (0.10)*	0.36 (0.08)*

* $p < .01$.

4. Discussion

The results address a fundamental question about the nature of language acquisition and the postulated critical period for language. Does age equally constrain the outcome of all language acquisition regardless of whether the language is a first or second one? To answer the question, we investigated the English syntactic abilities of deaf and hearing adults who either did or did not have linguistic experience (spoken or signed) during early childhood with two tasks, timed grammatical judgement and untimed sentence to picture matching. On the grammatical judgement task, adults who had early language experience performed at near-native levels on a subsequently learned language, regardless of whether the early language was spoken or signed. By contrast, adults who had little or no early language experience performed poorly on several syntactic structures, namely, simple, passive and relative clause sentences. On the sentence to picture matching task, adults who had early language again performed at near-native levels regardless of whether their early language was signed or spoken. Again by contrast, adults who had no early language experience performed at near-chance levels on the complex structures of passive and relative clause sentences. These findings held when the groups were subdivided into earlier ages of exposure to accessible English (6–8 years) versus older ages (9–13 years). Finally, the age of first-language experience also affected grammatical judgement response latency. Adults who had early language experience and began to learn English before age 9 recognized English syntactic structures more quickly than those who had no early language, although more slowly than native English learners, independent of syntactic structure and regardless of whether the early language experience was signed or spoken.

The results replicate and extend our previous findings both cross-modally and cross-linguistically (Mayberry, 1993). Early experience with a spoken language led to near-native performance on a task involving complex ASL structures whereas a lack of such experience did not. Together the results of our previous and present studies suggest that language experience during human development dramatically alters the capacity to learn language throughout life and that these effects are supramodal with respect to both the first and second language (Mayberry, Lock, & Kazmi, 2002).

The contrastive grammatical judgement and comprehension patterns of the groups with and without early language provide clues about the nature of this critical period phenomenon. First, the syntactic processing patterns of the two groups who had early language experience were remarkably similar across tasks. The similarities were striking given that one group first learned a signed language and the other a variety of spoken languages and that one group was born profoundly deaf and the other normally hearing. Nonetheless, the grammatical judgement performance of both groups with early language was similar to that of the native controls with one exception. Both groups were less accurate on the dative sentences compared to the native controls. In creating these stimuli, we made ungrammatical stimuli that would have been grammatical if translated into some of these participants' native languages, spoken or signed, by placing the indirect object in front of the verb, as in, "The boy a cookie is giving the girl." Many Early-Spkn and Early-Sign Lang participants accepted these stimuli as grammatical. This suggests that early language acquisition leads to the development of both general and specific syntactic representations that organize and subserve subsequent language learning. By syntactic representations we mean mental representations of syntactic categories organized in a hierarchical fashion (Jackendoff, 1993).

The early-language groups showed high levels of accuracy on both tasks across the syntactic structures indicating that their syntactic representations for English grammar were robust. The additional finding that the early language groups were somewhat slower in accessing these syntactic representations in comparison to the native controls suggests either that their syntactic representations of English grammar are not identical to those of native English learners or, alternatively, that their processing of English grammar is not as fully automatized as that of native learners. The question is whether these effects arise from syntactic competence or performance factors. However, this somewhat slower rate of grammatical processing cannot be due to the fact that the early language groups knew and used two languages because all but one of the native controls also knew more than one language. Rather, slower, but accurate, grammatical processing latencies may reflect successive language acquisition in childhood, a second language acquired after a native one. Response latency decrements of a similar magnitude for grammatical judgements have been reported by White and Genesee (1996) as a function of second-language proficiency.

The grammatical processing patterns of the group with scant early language experience were strikingly different from those of the groups who had early language. These differences were clearly due to a paucity of accessible and detailed linguistic input in early life and not deafness. This is shown by the high performance level of the early language group who was also born profoundly deaf but who experienced accessible language early; their performance was at near-native levels, like their hearing peers who also experienced language early. It is important to note that this was also true of the deaf participants in the Early-Sign Lang group who were first exposed to signed language by age 3. This suggests that early childhood is a period of robust sensitivity to accessible linguistic input. The grammatical processing deficits associated with a lack of early language were not due to factors such as non-verbal IQ, SES, access to preschool education, method of English instruction in schools where sign was used, or highest level of education attained because these factors did not differ between the groups who were born deaf. The primary contrast was that one group experienced accessible language from birth, or shortly thereafter, while the other did not. The finding that the group with no early language was unable to acquire English grammar well after many years of daily usage means that these effects are long lasting.

The question arises as to whether these effects are pedagogic in nature and not due a critical period for language, that the child who begins his or her educational experience with little or no language is unable to comprehend the language of instruction. This is most certainly the case for all children learning languages in immersion situations but unlikely the cause of the present findings. In previous research we discovered that increasing delay in accessible first-language exposure produces decrementally poorer language performance (Boudreault, 1999; Mayberry, 1993, 1994; Mayberry & Eichen, 1991; Mayberry & Fischer, 1989). Current research in our laboratory finds that even longer delays in accessible first-language exposure, i.e., age 13 or older, produces even lower levels of grammatical ability than those reported here (Gates, 2002). If the present and previous effects were simply pedagogic in origin, they would not be expected to show such consistent, lifelong, and linear decrements in relation to the duration of language deprivation in early life.

The low levels of grammatical judgement accuracy shown by the group with no early language suggests that they have incomplete or missing representations of English syntax for both simple and complex structures. Unlike the groups who had early language experience, they did not perform the same across the tasks. Only linguistic information was available for the grammatical judgement task but extra-linguistic information was additionally available for the sentence to picture matching task. Exact representations of the English auxiliary system, word order, and subordination, for example, were required to perform well on the grammatical judgement task. This may not have been the case for the picture to sentence matching task where correct guesses could have been made via an alternative strategy such as identifying the meaning of some words without the organizing benefit of syntax. A strategy based on isolated word meaning coupled with guessing would likely have led to wrong responses for the complex passive and relative clause sentences on the sentence to picture matching task, however. More than two agents were illustrated in the alternative pictures for the relative clause sentences, and multiple actions/relations were illustrated for the passive sentences. The only route to correct responses for such sentences was through identification of syntax. In addition, the finding that the mean response latencies of the group with no early language was slower than that of the groups who had early language and learned English by age 9, independent of syntactic structure, coupled with their low accuracy levels, provides support for this interpretation.

A lack of accessible language experience in early life appears to impede development of syntactic representations in any subsequently learned language, independent of sensory-motor modality. This is demonstrated by the present results, where English was the target language and by our previous findings where ASL was the target language. Children who are born deaf and have no accessible early language have been found to show gesture ordering patterns that are similar across cultures and suggestive of syntactic categories organized hierarchically (Goldin-Meadow & Mylander, 1998). However, this expressive gesture, known as homesign, does not appear to provide sufficient linguistic experience for the capacity to learn language to develop completely. The present participants who were born deaf and had no early language presumably used gesture as young children to communicate with their hearing families yet, as described above, as adults they show attenuated levels of syntactic development in any language, spoken or signed. More research is required to tease apart the complex relations among the onset of language acquisition, the nature of the linguistic input, and the development of syntactic representation. Whether early language experience affects the development of other linguistic representations, including phonological and lexical ones, is an important question we are currently investigating in our laboratory.

Much previous research has found that the acquisition of English grammar is problematic for students who are born severely and profoundly deaf (Engen & Engen, 1983; Quigley & King, 1980, among many others). For example, Quigley et al. (1974) reported that 18 year olds who were deaf performed with 56% accuracy on relative pronouns and 59% on relative clauses on a task requiring detection of grammatical errors in written sentences. This syntactic performance is remarkably consistent with the present findings, where mean accuracy on the grammatical judgement task for the group with no early language was 54% for relative clause sentences and 45% on the comprehension task. These similarities are not a coincidence but likely reflect the limited access to language in early life commonly experienced by children who are born deaf. Evidence is accumulating that the deleterious linguistic effects arising from a lack of early language is a contributing factor to the low levels of reading achievement endemic to the deaf population as well (Chamberlain, 2002; Chamberlain & Mayberry, 2000).

Our present and previous findings are also consistent with what is known about the dramatic effects of early experience on the development of other biological systems (Changeux, 1985). Language may be a genetically specified ability but our previous and present results suggest that the development of language capacity may be an epigenetic process whereby environmental experience during early life drives and organizes the growth of this complex behavioral and neurocortical system. For example, complete development of the neurocortical architecture of the visual system crucially depends on the onset and type of visual stimulation experienced during early life. Visual deprivation in early childhood profoundly alters lifelong visual abilities in animals (Wiesel, 1982) and humans (Goldberg, Maurer, Lewis, & Brent, 2001). Our findings suggest that the human language system may develop in much the same fashion, as first proposed by Snow (1987).

Experiments investigating the effects of enriched versus impoverished environments on the brain development of rats during early life elucidate the complex interactions between early experience and neurocortical growth that are also apparent at a behavioral level in at least two ways. First, animals raised in complex environments show increased dendritic branching during the exuberant phase of neural development in comparison to those raised in impoverished environments (Kolb, Forgie, Gibb, Gorny, & Rowntree, 1998). Animals raised in complex environments also maintain more synaptic connections during the pruning phase of neurophysiological development in contrast to those raised in impoverished environments (Greenough & Black, 1992). Thus, complex environmental stimulation during both the phases of neuronal exuberant growth and pruning (Huttenlocher, 1990) produces more complex neurophysiological development and concomitantly more complex behavior in comparison to a lack of such stimulation from the environment. If the same kind of reciprocal interaction occurs in early human life between linguistic stimulation from the environment and development of the neurocortical systems that subserve language, this would mean that the common interpretation of the critical period for language needs to be reformulated. Instead of being a phenomenon of diminishing ability to learn language caused by increasing brain growth, the critical period for language would instead be a time-delimited window in early life where the degree and complexity of neurocortical development underlying the language system is governed, in part, by linguistic stimulation from the environment which together with neurocortical development creates the capacity to learn language. The present findings better fit the latter explanation than the former.

To summarize, we have found evidence that age constraints on the outcome of first-language acquisition are quite different from those for second languages. These findings illuminate the postulated critical period for language by suggesting that early language experience helps create the ability to learn language throughout life, independent of sensory-motor modality. Conversely, a lack of language experience in early life seriously compromises development of the ability to learn any language throughout life. These findings mean that timely first-language acquisition is necessary, but not sufficient, for the successful outcome of second language learning.

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