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CHAPTER 4

Cognitive development in deaf children: the interface of language and perception in neuropsychology

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Introduction

What does the sense of hearing contribute to human development? To answer the question, we must ask what the sense of hearing gives the child. Hearing gives the child the acoustic correlates of the physical world: approaching footsteps, dog barks, car horns, and the pitter-patter of rain. Hearing also allows the child to revel in the patterned complexity of a Beethoven symphony or a mother's lullaby. Children who are born deaf clearly miss a great deal. However, hearing conveys much more to the growing child than the acoustics of the physical world. Hearing is the sensory modality through which children perceive speech — the universe of talk that ties individuals, families and societies together. Children born with bilateral hearing losses that are severe (70–89 dB loss) or profound (>90 dB loss) are referred to as deaf. They cannot hear conversational speech (approximately 60 dB) and consequently do not spontaneously learn to talk. Indeed, not talking at the right age is one of the first signs that a child cannot hear.

The primary consequence of childhood deafness is that it blocks the development of spoken language — both the acts of speaking and comprehending. This fact leads us to ask what spoken language contributes to the child's cognitive development. Because deafness impedes the development of spoken language, we must ask whether complex and logical thought can develop in the absence of spoken language. Can the child develop 'inner thought' or working memory without the ability to hear? Consider sign language. Can sign language foster the same kinds of abstract mental development and complex thought as speech? Now consider an even more complex situation, namely, the cognitive development of children who grow up with little or no exposure to any language in any form, be it signed or spoken, as a simple consequence of being born deaf. What are the effects of such linguistic and social isolation on the child's development of a mental life?

Each of these questions has been asked about deaf children in one form or another since the beginning of philosophical inquiry (Lane, 1984). At first glance, the answers would seem to be straightforward and, historically, have been treated as such. However, as we shall see, the answers to these questions quickly become complex for several reasons. First, cognitive development entails more than maturation of the child's brain. Cognitive development is the product of the child's attempts to understand the family, neighborhood, school and the world at large during this period of rapid brain growth and learning. The effects of deafness on cognitive development are, therefore, quite diverse and complex due to the multitudinous ways in which families, societies, and cultures, react to and interact with children who are born deaf and hence do not spontaneously learn to talk and comprehend speech. Against this enor-

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mously varied backdrop, we explore here research on the cognitive development of deaf children.

We begin with the premise that cognition, or intelligence, is multi-faceted and reflected in the coordinated performance of numerous language and non-language tasks, including perception, memory, mental imagery, concept formation, problem solving, language learning, academic achievement, and navigating everyday life (Sternberg, 1989). Our focus here is on whether and how deafness affects the child's cognitive development across several domains that have been studied in some, but not equal, detail. The cognitive aspects we consider are the following: (1) Academic achievement; (2) reading development, (3) language development and the factors known to affect it; (4) performance on standardized intelligence tests; (5) visual–spatial and memory skills; (6) conceptual development, and (7) neuropsychological function. For each domain, we discuss the development of deaf children who use either signed or spoken language. However, because so little is known about them, we will only briefly discuss the cognitive development of deaf children who grow up with little or no exposure to conventional language (in any form, spoken or signed). We begin with academic achievement because it illustrates the unique developmental challenge congenital deafness poses for the young child.

Academic achievement

Population profiles

The Gallaudet Research Institute regularly collects and analyzes demographic data on the academic achievement of deaf children in the United States based on the Stanford Achievement Test (Allen, 1994). The median math computation skills of 15-year-old deaf children in the USA are at the 7th grade level. Age-matched hearing children perform at the 10th grade level (Allen, 1989). These statistics show that deafness, by itself, does not impede the child's ability to learn and manipulate abstract symbols and symbolic relations. By contrast, the median reading achievement of 17–21-year-old deaf students leaving American secondary schools is at the 4th grade level (Allen, 1994). This wide performance gap between language tasks as compared to non-language tasks is a common profile among deaf children worldwide (Conrad, 1979). These academic performance patterns illustrate the great difficulty experienced by deaf children perceiving and learning spoken language and visual representations of speech, namely written and read language. Indeed, the effects of deafness on spoken language development increase as degree of hearing loss increases. For example, students with mild to moderate hearing losses read at lower levels than do students with normal hearing. Furthermore, students with severe to profound hearing losses read more poorly than do students with moderate losses but on math computation they show equivalent achievement (Allen and Schoem, 1997).

The primary effect of degree of hearing loss on language development, in turn, interacts with factors extraneous to deafness, such as socioeconomic and ethnic status and additional handicaps. Deaf children from lower socioeconomic status homes perform less well than middle-class deaf children. For example, only 5% of Black and 6% of Hispanic deaf students (17–21 years old, severely to profoundly deaf) read at or above the 6th grade level whereas 15% of White deaf students read above this level (Allen, 1994). Deaf children who have motor or sensory impairments in addition to deafness, such as poor vision or cerebral palsy, perform less well as a group than deaf children without additional impairments (Allen, 1989). Together these data indicate that the academic achievement of deaf students is predicted to a large extent by the same factors that predict the academic achievement of normally hearing students in North America, that is, social class, ethnic and racial background, and other handicapping conditions. This means that deafness, by itself, does not determine academic success or failure but rather interacts with many other factors in complex ways.

Reading development

The median reading level of the deaf, high school population does not reach the level required for a person to be considered literate (i.e., the 6th to 8th grade level and beyond). Indeed, the median reading levels of the deaf student population have not changed much over the past century (Chamberlain and Mayberry, 2000). This discouraging, but often replicated, finding suggests that something about deafness creates a barrier to reading development. However, if the barrier were insurmountable, no deaf students would read proficiently. It is important to remember that these reading statistics are median reading levels. Half of deaf high school students read below the fourth grade level but half also read above this level.

Factors in reading development

Spoken language

Many deaf students read well. For example, in a study of 100 profoundly deaf 16–17-year-olds, Geers and Moog (1989) found 57% to read at or above the grade 7 level and 30% to read at the grade 10 level. The students shared several traits: above average performance on nonverbal IQ tests, parents who were college educated and professionally employed, and special education begun at or before preschool age. These facts mean that the students in this study all had access at an early age to high quality intervention services. In addition to high reading achievement, the students performed at high levels on a battery of spoken language tests.

Indeed, the spoken language development of deaf children, as measured by syntactic and vocabulary skills (independent of word decoding skills), has often been postulated to be a causal factor in reading development in the deaf population. Spoken language skills have been found to predict reading levels in deaf students, both those who use sign language ($r = +0.70$, Lichtenstein, 1983; Moores and Sweet, 1990) and those who use speech ($r = +0.83$, Geers and Moog, 1989). Sign language has historically been conceptualized as being unimportant or even detrimental to the reading development of deaf students, either because it has no sound patterning or because its grammatical structure is different from that of spoken language (Mayer and Wells, 1996; Moores and Sweet, 1990). In fact, whether sign language can provide the cognitive foundation that spoken language provides for reading development has been a matter of considerable debate for decades. Only recently has the question been investigated in a systematic fashion (Chamberlain and Mayberry, 2000). If sign language development interferes with reading development, then there should be a negative relation between deaf children's sign language skills and reading ability but recent research has found the opposite relation. Recent research shows a positive correlation between sign language skills and reading development.

Sign language

Mayberry and her colleagues (Mayberry, Chamberlain, Waters and Doehring, 2001) investigated the reading and sign skills of 48 severely and profoundly deaf students aged 7–15 years. They found 42% to read at the expected grade level and 67% to read above the fourth grade level. All the children were educated with sign language and spoken language (specifically 'Total Communication'). All the children additionally had average or above average performance on selected nonverbal IQ sub-tests and had begun to learn sign language through early intervention by age three. Unlike the orally trained children studied by Geers and Moog (1989), the reading levels of the children educated with total communication were predicted by their ability to comprehend sign language, not spoken language. (We define and discuss total communication below). These findings suggest that factors which promote the development of language comprehension in general, independent of sensory–motor modality, also promote reading development. In fact, the deaf children who showed the highest levels of reading and sign language comprehension tended to have parents who knew and used sign language with them from a very young age — 3 years or before. Parental use of sign language also meant that the deaf child was able to converse in signed language in nearly all domains of his or her life — both at home and school — which would mean that the child had abundant amounts of language input during childhood (Hoffmeister, 2000).

Other studies have also measured sign language skill in relation to reading development and found a positive relation between the two kinds of language. The sign language measures have included the following kinds of American Sign Language (ASL) knowledge: plural markers and synonyms/antonyms, ($r = +0.45$ to $+0.64$, Hoffmeister, 2000); comprehension of ASL classifiers, stories, and time markers (combined $r = +0.58$, Strong and Prinz, 2000); memory for ASL sentences, classifier production, and recognition of fingerspelling in ASL sentences ($r = +0.53$ to $+0.57$, Padden and Ramsey, 2000);

and comprehension of ASL stories and working memory for ASL sentences ($r = +0.49$ to 0.69 Chamberlain and Mayberry, 2000; Mayberry et al., 2001). One unique feature of these studies is that the high and positive correlation between sign language skill and English reading was found specifically for ASL, a natural sign language with a linguistic structure different from spoken English. These findings further show that the major impediment to deaf children's reading development is not simply an inability to speak English but rather impoverished language development, in any form, signed or spoken, as we discuss below.

Good and poor readers

The relation between ASL language ability and reading achievement was further investigated by Chamberlain (2001) who hypothesized that well developed reading skill is predicated on well developed language skill, even in sign language. To test the hypothesis, she measured the ASL and reading skills of a random sample of 35 deaf adults who reported using ASL as a primary language. Sign language skill was measured with two tasks, ASL grammatical judgement (Boudreault, 1998) and narrative comprehension in ASL and MCE, Manually Coded English described below (Mayberry et al., 2001). Reading skills were measured with two reading tests (the Gates–MacGinite and the Stanford). Performance distribution on the ASL and reading measures significantly overlapped. Half the adults performed at high levels on the sign language tasks, at near-native levels. These same individuals also could read well, reading at the 8th grade level or above. Most of the remaining participants performed at low levels on the sign language measures. These same individuals performed poorly on the reading tests, reading below grade 4 (Chamberlain, 2001) as Fig. 1 shows.

A few deaf adults read well but performed poorly on the sign language tasks. These individuals were, in actual fact, successful speakers of English. Although they considered sign language to be their primary mode of communication, they had successfully acquired spoken English in childhood and subsequently learned ASL as a second language in late adolescence. In other words, they had well-developed primary language skills. A few deaf adults performed at high levels on the sign language tasks but could not read well, constituting about 8.5% of the experimental sample. This figure is very similar to the proportion of the normally hearing population reported to have dyslexia, around 10%, that is, people who have good face-to-face language skills but cannot read (Chamberlain, 2001).

These results show that highly developed sign language skill is related to high levels of reading achievement in deaf individuals for whom sign language is a primary means of communication. Spoken language is not the only path to literacy development. These results also suggest that the low median reading levels of the deaf school-aged population are likely caused by low levels of primary language development, in sign language as well as in spoken language. Reading must be taught to deaf children, certainly. But in order to benefit from reading instruction, deaf children must have a well-developed primary language upon which to base the reading task.

Additional factors in reading achievement

Returning to the factor of socioeconomic status, Geers and Moog (1989) found in their sample of orally trained deaf students that those who achieved the highest reading levels were from middle class families. More specifically, they had parents who were college educated and professionally employed. They concluded that socioeconomic status predicts deaf children's reading achievement. This finding is supported by demographic data showing that Hispanic and Black deaf children show significantly lower levels of reading achievement than do White children (Allen, 1994). Socioeconomic status may have a greater impact on the academic attainment of deaf children than that of hearing children. This is because hearing children, no matter how poor, spontaneously acquire language by merely listening to family members who speak to them from infancy. By contrast, poor deaf children are at a high risk for not being exposed to accessible language at the right time in early childhood. This is because in most countries poverty translates into a lack of access to the educational and clinical services that expose deaf children to language at the appropriate age. These factors are early diagnosis of hearing loss, parent–infant and preschool programs, availability of hear-

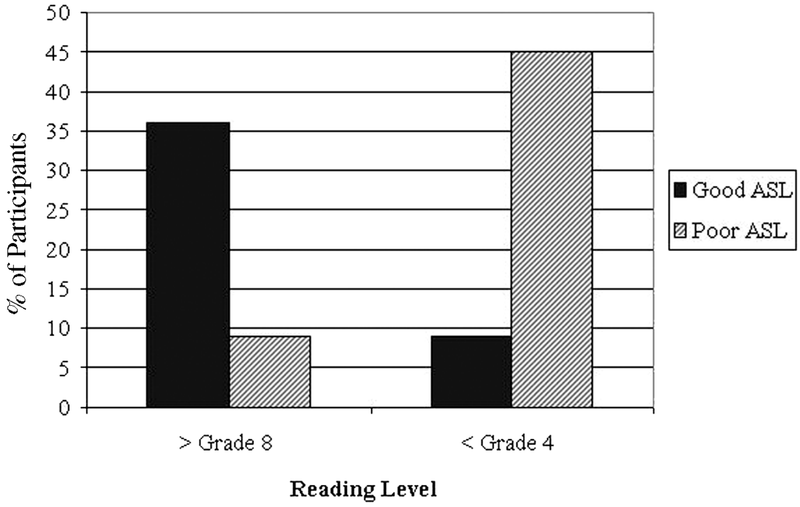

Fig. 1. The relation between English reading level and comprehension of American Sign Language (ASL) in a sample of 35 randomly selected deaf adults reporting ASL to be their primary language. *Good* ASL skills indicate nearly complete comprehension of ASL narratives and near-native control over ASL syntactic structures; *poor* ASL skills indicate minimal control of ASL syntactic structures and comprehension of less than half of an ASL narrative (extrapolated from Chamberlain, 2001).

ing aids, parent–infant programs that promote and teach sign language, parental sign language instruction, parent counseling, and so forth. This leads us directly to the question of why primary language skill is so difficult for deaf children to develop independent of socioeconomic status.

Language development

Because deaf children cannot hear the language spoken around them, they do not learn it spontaneously. In fact, one of the first signs that a child is deaf, aside from not responding to sound, is not beginning to talk at the expected age, 10–18 months (Meadow-Orlans, 1987). Making generalizations about the language development of deaf children is complex. This is due to the multiple sensory forms of linguistic input deaf children receive and the varying kinds and amounts of language input available to them during early childhood. For example, some deaf children receive no accessible language input of any kind (i.e., children who have severe to profound hearing losses that go undetected and thus receive no special intervention). Other deaf children receive incomplete spoken language input (incomplete because hearing aids and cochlear implants do not restore hearing to normal levels). Some other children receive sign language input in the form of MCE (Manually Coded English) or ASL. Signed language input is, in principle, fully accessible to deaf children due to its visual nature. Unfortunately, familial and educational circumstances often inadvertently conspire to yield both incomplete and reduced amounts of signed and spoken linguistic input throughout the deaf child's early life when normal language development occurs, as we discuss in detail below.

Speech

When considering deaf children's language development, it is important to distinguish the child's ability to speak from the child's ability to understand and produce language, that is, linguistic competence. The two factors of *speech* and *language* are clearly dissociable in deaf children's development. Indeed, intelligible speech is extremely difficult for deaf children to achieve. This is understandable for two reasons. First, deaf children either do not hear speech at all or hear it in a highly distorted fashion due to the sensori-neural nature of their hearing losses. Second, the visual facial movements people make when speaking provide only limited clues as to how speech is produced. Deaf children as a whole achieve low levels of speech intelligibility (for a review see

Seyfried and Kricos, 1989). Some proportion of deaf children learn to speak intelligibly. Such children typically have received special education at an early age (before preschool) with successful use of hearing aids, speech training, and very high levels of parental involvement in the child's speech and auditory development (Meadow-Orlans, 1987). Three other factors common to deaf children who successfully learn to speak are the following: (1) the ability to auditorily discriminate speech patterns, (2) higher than average nonverbal IQ, and (3) higher than average socioeconomic status (Geers and Moog, 1987).

Vocabulary

In a pioneering study of deaf children's cognitive development, Katheryn Meadow observed that, "The basic impoverishment of deafness is not lack of hearing, but lack of language. To illustrate this, we have only to compare the 4-year-old hearing child, with a working vocabulary of between two and three thousand words, to a child of the same age profoundly deaf since infancy, who may have only a few words at his command," (Meadow, 1968: 29).

The major developmental hurdle facing deaf children is not simply learning to speak intelligibly, but acquiring language — namely the lexicon, morphology, syntax, and semantics of language. Substantial delays in language development are the primary hallmark of childhood deafness without early and appropriate intervention. The reasons for this are simple. The average intensity of conversational speech by a male talker is around 60 dB. Even children with moderate hearing losses (i.e., 56–70 dB) show a 1-year delay in vocabulary development compared to age-matched children with no hearing loss. Children with severe hearing losses (71–90 dB) show a 3-year lag in vocabulary development (Davis, Elfenbein, Chum and Bentler, 1986). In turn, profound hearing loss (<91 dB) creates a significant delay in vocabulary development. One British study of 71 profoundly deaf children between the ages of 8 and 12 years showed their average comprehension of spoken vocabulary to be less than what would be expected of hearing 4-year-olds (Bishop, 1983). On a referential, mother–child communication task, a Canadian study found 8-year-old deaf children to show comprehension levels similar to 4-year-old hearing children (MacKay-Soroka, Trehub and Thorpe, 1988). Finally, an American study of 150 deaf children between the ages of 4 and 20 found severe delays in vocabulary comprehension. The deaf children tested showed little lexical development after 12–13 years (Moeller, Osberger and Eccarius, 1986), as shown in Fig. 2.

Delays in deaf children's vocabulary development are apparent from an early age. For example, one study reported that, during 15 months of intensive speech instruction, a 30 month old deaf child was able to learn *one* word a month (Lach, Ling and Ling, 1970). By contrast, hearing children spontaneously learn from 60–120 words a month between 30 and 48 months of age (Ingram, 1989). Lederberg and Everhart (1998) studied the early language of 20 deaf children and age-matched hearing children. They found that all the normally hearing children were producing two-word utterances at 22 months but half the deaf children were producing no language at this age. By 3 years of age, the normally hearing children were producing multi-word utterances but half the deaf children were producing only one-word utterances at an infrequent rate. This pattern of expressive language delay was constant across the different modes and types of early language intervention the deaf children received. This was true both in cases where the mothers and therapists used speech without sign and in cases where they used speech accompanied by sign (as in Total Communication, describe below). Despite their inability to hear their own voices and those of others, however, all the deaf children primarily used vocalizations to communicate with their hearing mothers. The mothers' use of signs did not prevent their deaf children from using speech (Lederberg and Everhart, 1998).

One accommodation the hearing mothers made to communicate with their deaf children was an increased use of body language and gesture between 22 months and 3 years (Lederberg and Everhart, 1998). This type of communicative accommodation was also observed in an earlier study. Hearing mothers of deaf infants between 12 and 18 months were observed to use similar amounts of vocalization and spoken language compared with mothers of age-matched hearing infants but they also used more gesture and tactile communication (Spencer, 1993).

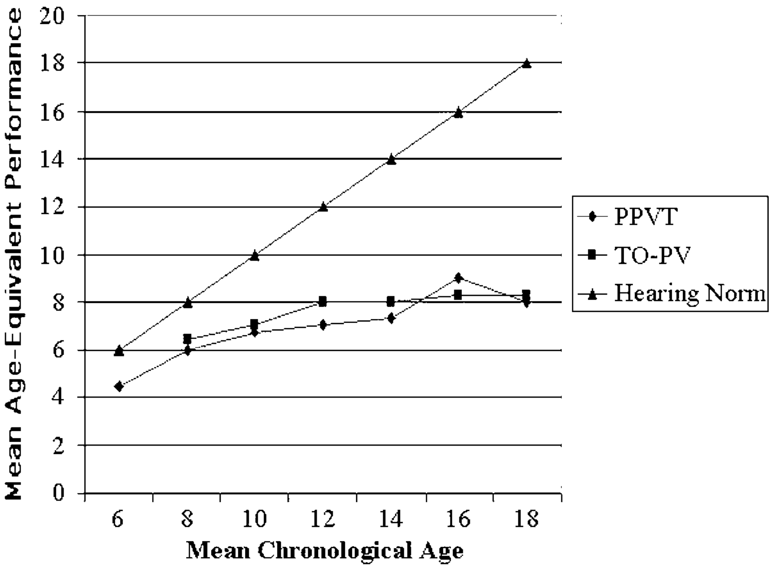

Fig. 2. The vocabulary comprehension test scores of 150 deaf children plotted as a function of expected performance for chronological age (with norms from hearing children added; redrawn from fig. 19, Moeller et al., 1986).

The striking delays in deaf children's vocabulary acquisition leads to the question of whether deafness affects the cognitive processes that underlie word learning. However, this appears not to be the case. Lederberg, Prezbindowski and Spencer (2000) found that overall vocabulary size, not age, predicted deaf children's word learning strategies. Young deaf children's ability to learn new words from context with minimal exposure was similar to that of hearing children, but only when vocabulary size was taken into account. This finding suggests that some kinds of language learning abilities emerge as a consequence of language development. Thus, deaf children whose language is very delayed may show learning patterns similar to younger hearing children, not due to deafness per se, but due instead to a significantly delayed rate of language growth. This is an important concept to which we return below.

Grammar

Given the highly delayed vocabulary acquisition of deaf children, it is not surprising to learn that their acquisition of syntax and grammatical morphology is also very delayed. In a study of orally-trained, 4–15-year-olds (75% of whom were 7 years and older), Geers and Moog (1978) found 50% of the children to have a level of expressive grammar lower than would be expected for hearing 3-year-olds (but with more mature content). In a study of 150 deaf children between the ages of 4 and 20, Moeller et al. (1986) found grammatical comprehension to be even more delayed than vocabulary comprehension. Few of the students tested achieved grammatical comprehension scores higher than would be expected for normally hearing 5–7-year-olds. Some researchers conclude that deaf children taught exclusively through spoken language appear to pass through the same general stages of language acquisition as their hearing peers but without reaching the same ultimate level of proficiency (Mogford, 1988).

Many similarities between deaf and hearing children's syntactic acquisition were documented in one of the most detailed investigations of deaf students' syntactic skills ever conducted. Quigley and his colleagues investigated the English syntactic skills of more than 400 deaf students on a variety of English grammatical structures including, for example, negation, conjunction, determiners, questions, pronominalization, relativization, and complementation, among others (for a review see Quigley and King, 1980). The research team first collected numerous samples of deaf children's writing to determine the most common types of grammatical errors they committed. In follow up studies, the team investigated the performance patterns of deaf students on a wide range of syntactic structures. The net result was both a screening test and a normed diagnostic test of grammatical skill, *Test of Syntactic Abilities* (Quigley, Steinkamp, Power and Jones, 1978).

These studies produced two main findings. First, deaf children's control of English syntax decreases with decreasing hearing levels. Second, the order of difficulty of English syntactic structures for deaf students, even those with profound hearing losses, is for the most part highly similar to those of English hearing students and second language learners of English (Quigley and King, 1980), as shown in Fig. 3. It is important to note, however, that this syntactic research was conducted solely through the modes of reading and writing. The extent to which these findings generalize to deaf children's face-to-face language in sign and/or speech is unclear. Nonetheless, these studies demonstrate the low level of control many deaf students have over English syntax when reading.

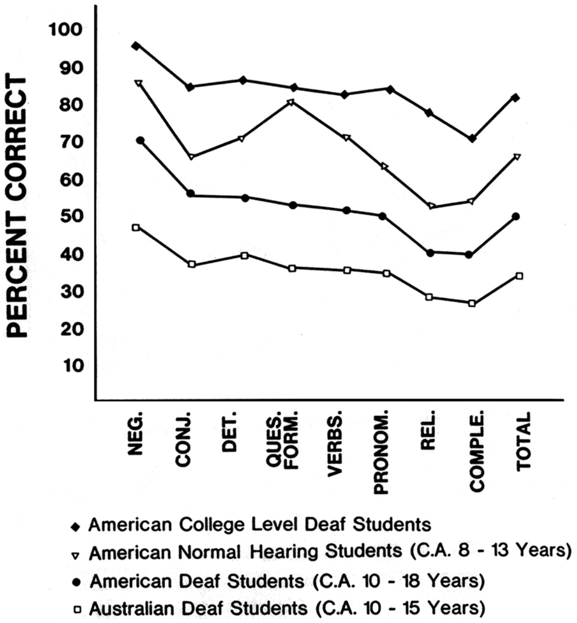

Fig. 3. Performance accuracy on selected English syntactic structures for 8–13-year-old hearing students, deaf students between the ages of 10–18 years in both the USA and Australia and deaf college students (fig. 7 from Quigley and King, 1980).

The achievement patterns deaf children show for spoken and written language indicate that they do not easily learn the grammar of a spoken language even in a visual form, i.e., reading and writing. Nearly a century of teaching and research with deaf children has also demonstrated that learning to read cannot serve as a primary language for deaf children for reasons we do not fully understand. Learning to read and learning a primary language are two different skills. We know now that learning to read is based upon the prior acquisition of a primary and dynamic 'face-to-face' language in either a signed or spoken form. Because primary language learning is often difficult and problematic for deaf children, educators have sought various means to facilitate language acquisition through the use of gesture and sign language. We now consider the gesture and sign language development of deaf children.

Gesture and homesign

Deaf children, who have not yet been exposed to sign language and have not yet acquired spoken language, often spontaneously create their own means of gesture communication for the purpose of self-expression. The phenomenon is known as *homesign*. 'Homesign' is an ASL term referring to the idiosyncratic gesture systems used by deaf individuals who were reared in isolation from other deaf signers. The phenomenon is that the deaf child makes statements and requests by combining points (to objects and people) with iconic gestures (called 'characterizing' gestures by Goldin-Meadow and Feldman, 1977) in an effort to communicate with hearing family members. For example, the child might point to an apple and then open and close his mouth around his fist to mean, "I eat an apple," (Goldin-Meadow, personal communication). All the young deaf children in hearing families observed by Goldin-Meadow and Mylander (1984) used gestures to communicate with their mothers with varying degrees of frequency.

In addition to creating a gesture lexicon, the deaf children combine their gestures into multi-gesture utterances in a rule-governed fashion. The children tend to gesture the patient (recipient of the action) followed by the action when the action is transitive (i.e., when the action acts on something as in 'eat, kick, twist,' etc.). However, when the action is intransitive (e.g., ‘think, sleep, walk,’ etc), the children tend to gesture the agent followed by the action (Goldin-Meadow and Feldman, 1977; Goldin-Meadow and Mylander, 1984).

In subsequent research these researchers found that the gesture lexicon and ordering rules of the gesture system originate from the deaf child and not their hearing parents. Indeed, the gestures of young deaf children differ from those of their hearing parents in frequency, complexity, and ordering patterns. The deaf child combines strings of gestures to convey ideas, or propositions (as the above example illustrates), similar to the way in which speakers combine strings of words to make statements. By contrast, the gestures produced by hearing people as they speak are much simpler. Speakers tend to produce only a single iconic gesture for each major idea they say (Mayberry and Nicholadis, 2000; McNeill, 1992). In homesign, gestures carry all of the meaning. In speech, spoken words carry all the meaning and gestures act as a supplement (McNeill, 1992). In young normally hearing children, gesture complexity increases with spoken language development from the earliest stages (Mayberry and Nicholadis, 2000). This means that gesture communication is linguistic for hearing children just as it is for deaf children.

The characteristics of homesign appear to be universal and transcend culture so far as is currently known. Goldin-Meadow and Mylander (1998) observed that Chinese deaf children produce homesign too. The homesign gestures and ordering patterns of the Chinese deaf children were very similar to those of American deaf children. Homesign may be a valuable diagnostic tool, although no research has yet documented the possibility. How often and how elaborately the young deaf child communicates via gesture prior to having learned any sign language or spoken language, or how frequently and complexly he or she gestures when speaking probably indicates increased symbolic sophistication (in either spoken or signed forms).

We now know that deaf children’s gesture communication can be elaborate and shows some basic properties shared by all languages. How is homesign related to sign language? We turn now to this question.

Sign language origins

A common misconception about the origins of sign languages is that they were invented by hearing teachers. However, documents from some of the earliest teachers in the late 18th century show that they intentionally borrowed the signs and gestures their deaf pupils used in the classroom to communicate with one another and used them for instructional purposes (Lane, 1984). 20th century research in Nicaragua demonstrates how quickly sign languages emerge among communities of individuals who are deaf from birth.

After the Sandinista revolution, literacy and education became a national priority in Nicaragua, including the education of deaf children (Morford and Kegl, 2000). Before the revolution, individuals who were deaf did not attend school. Instead, they lived with their hearing families in isolation from one another. Like deaf children everywhere who are unable to communicate with spoken language, these isolated deaf individuals developed idiosyncratic gesture systems, or homesign, to communicate with their families. Their homesign systems had many of the properties described above (Morford and Kegl, 2000).

When the first school for deaf students was established in Nicaragua, linguists who were present at the time observed that the older students, namely adolescents and young adults, communicated with one another using their various homesign systems (Kegl, personal communication; Morford and Kegl, 2000). Recall that homesign consists of combinations of iconic and point gestures to create simple utterances, as described above. When the youngest deaf children arrived at the school (e.g., ages 4–5), they were exposed to the homesign used by the older deaf students for communication. Surprisingly, however, the younger children did not copy the homesign systems of the older students. Instead, they were observed to use a sign language! The signing of the youngest deaf students was quick, limited to the hands (i.e., the children did not use pantomime), constrained in space, and consisted of signs with sub-lexical structure (i.e., meaningless phonetic units). They ordered their signs in relation to one another with syntax and grammatical morphemes. In other words, these young deaf children had created a sign language, or

Idioma de Señas de Nicaragua, from homesign input (Morford and Kegl, 2000; Senghas, 1995; Senghas, Kegl, Senghas and Coppola, 1994).

The phenomenon of children creating linguistic structure from fragmented language input is by no means unique to sign language. The phenomenon, known as creolization, has often been observed in situations of language contact where adults speak a pidgin (vocabulary words of a foreign language strung together with little or no syntax or morphology as means of communication between groups of adults speaking different languages). Young children exposed to pidgins creolize them, that is, they create new syntax and morphology to fill the existing gaps in the pidgin to which they have been exposed (Bickterton, 1990). Indeed, some of the first linguists to study ASL initially hypothesized that the sign languages used by Deaf communities worldwide were analogous to spoken Creoles (Fischer, 1978).

The sudden appearance of *Idioma de Señas de Nicaraga* provides insights into how sign languages evolve. There are at least two necessary stages of sign language evolution. First, from the sparse, but accessible (i.e., visible), gesture input they receive from speaking people who gesture as they talk, deaf children create gesture communication — homesign. This homesign shows rudiments of linguistic structure, namely a limited lexicon and ordering rules (Goldin-Meadow and Mylander, 1998). Second, young deaf children exposed to the homesign of older deaf children, in turn, fill the grammatical gaps in this rudimentary, quasi-language input to create a sign language (Morford and Kegl, 2000). Sign language is thus a remarkable human adaptation to childhood deafness. Language capacity is such an integral part of the human endowment that when language expression in the auditory–oral form is blocked by profound deafness, it reappears one generation later in a readily accessible and expressible form that circumvents the spoken language barrier of deafness.

American Sign Language

Most Deaf communities in North America use a sign language known as American Sign Language, or ASL. ASL is a natural language that has evolved among deaf people in North America, probably in the manner described above. Because ASL is perceived by the eyes and expressed with the hands and arms (in addition to the face and torso), its grammatical structure (phonology, lexicon, morphology, syntax, and semantics) is highly spatial (Emmorey, 2001). ASL is not a version of English on the hands. However, ASL has rarely been used in classrooms for deaf children. In fact, ASL has historically been actively banned from classrooms for deaf children because the goal of educators has always been to teach spoken language. Most educators have traditionally believed that ASL impedes this goal (Baynton, 1996; Lou, 1988). Nonetheless, ASL is the native language of many deaf people who were exposed to sign at a young age, especially those with deaf parents. ASL is also the primary language of many deaf people who do not acquire spoken language, even though they often learn ASL at very late ages, as described below.

ASL acquisition

Deaf children exposed to ASL from birth by their deaf parents spontaneously acquire it in a fashion comparable to that of hearing children who spontaneously acquire spoken language. Beginning with a sign-babbling stage, the child begins with a one-word stage, moves to a two-word stage, and then begins to acquire the complex morphological system of ASL (Marentette and Mayberry, 2000; Newport and Meier, 1985; Petitto and Marentette, 1991; Schick, 1990). The child does not fully master ASL grammar until around 5–6 years of age or later (for recent research on sign language acquisition, see Chamberlain, Morford and Mayberry, 2000). The ease with which deaf children spontaneously acquire ASL unequivocally demonstrates that congenital deafness does not alter the child's ability to acquire grammar. Rather, the major problem congenital deafness poses for the young deaf child is accessibility to sufficient language input at the right age (Morford and Mayberry, 2000).

The age of exposure problem

One rationale behind early speech intervention programs for deaf children (and bilingual education for hearing children) is the idea that languages are best learned early in life (Scovel, 1989). People generally believe that spoken languages can only be learned spontaneously and perfectly in early childhood. This concept is referred to as the *critical period* for language acquisition. Critical periods are common in the development of living things and are defined as a time-bounded period during development when the developing system, such as vision, is most sensitive to environmental input. A well-studied human example in is the development of binocular vision (Greenough and Black, 1992). Although most researchers think that spoken language acquisition is guided by critical period learning, sign languages have traditionally been excluded from this principle. The prevailing conviction among many educators has been that proficiency in sign language can be readily attained by anyone at any age. However, recent research shows that the age constraints that guide the outcome of second language acquisition also apply to the ultimate outcome of sign language acquisition (Emmorey, Bellugi, Frederici and Horn, 1995; Newport, 1988).

In a series of studies, Mayberry and her colleagues (Mayberry, 1994; Mayberry and Eichen, 1991; Mayberry and Fischer, 1989) found numerous effects associated with age of sign language exposure. For example, overall accuracy decreased with later age of sign language acquisition. This was true for memory and comprehension of ASL sentences and stories as well as for sentences in a version of Pidgin Sign English (PSE), a simplified form of ASL with some English elements used between deaf and hearing people. Deaf participants who were not exposed to sign until late childhood and early adolescence, around 9–13 years, showed significant deficits in ASL comprehension, despite the fact that ASL was their primary means of communication and they had used ASL for all of their adult lives. Indeed, the performance of the deaf individuals who first learned ASL in adolescence was worse than what would be expected from second-language learners of a spoken language. Why might this be so?

Recall that the major consequence of childhood deafness is a significant delay in the development of spoken language. This means that when deaf adolescents are first exposed to sign language, it is often because they acquired insufficient spoken language to enable them to cope with everyday life. In other words, many deaf children are only allowed to use sign language after they prove that they are unable to acquire spoken language. For these deaf adolescents, then, sign language exposure occurs at an age well beyond early childhood. Importantly, these deaf students have often acquired very little functional spoken language prior to learning to sign. This situation is *not* second-language learning. This situation is akin to *first* language acquisition begun in adolescence. The important question then becomes whether these deaf students ever catch up with respect to their sign language skills. Do they ultimately use sign language as proficiently as second-language or native-language (i.e., acquired from birth) learners of ASL?

This question was investigated in another study (Mayberry, 1993). The ASL sentence comprehension skills of deaf adults with contrasting early language backgrounds were compared. One experimental group consisted of congenitally deaf adults who began to learn sign language between the ages of 9 and 13. They were exposed to sign language at this late age because their spoken language skills were not functional. Thus, their ASL acquisition was analogous to first-language learning. The comparison group consisted of deaf adults who were born with normal hearing which they suddenly lost between the ages of 9 and 11 due to various viral infections. After becoming deaf, these individuals were enrolled in schools for deaf children where sign language was used. Thus, one group acquired spoken English in early childhood (because they could hear) so ASL was clearly a *second* language for them. By contrast, the other group had acquired little language prior to learning ASL at the *same* older ages. The critical question was whether the two groups would show comparable ASL comprehension. The answer was no. The ASL skills of the two groups were very different. The second-language learners performed at near-native levels. By contrast, the late, first-language learners showed significant ASL comprehension deficits despite the fact that it was their primary language and they had been using it for many years (Mayberry, 1993), as Fig. 4 shows. Importantly, the late-language learners were as intelligent as the other groups in terms of non-verbal intelligence, as we discuss in detail below.

Thus, the postponement of first-language acquisition to ages beyond early childhood has permanent, deleterious effects on language comprehen-

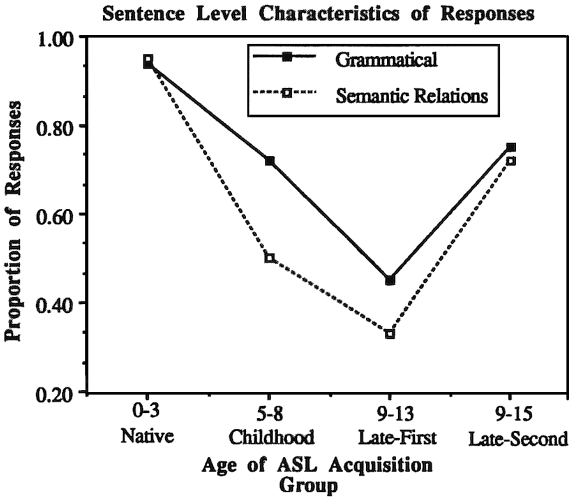

Fig. 4. ASL sentence comprehension and memory performance of deaf adults as a function of the age at which they were first began to learn ASL and whether it was their first or second language (fig. 4 from Mayberry, 1993).

sion in later adulthood. This finding was replicated and extended in another study. Mayberry and Lock (2001) compared the English grammatical skills of two groups of second-language learners, one deaf and one hearing, to a group of late, first-language learners who were deaf. The deaf second-language learners of English acquired ASL from their deaf parents; they began to learn English as a second language in school between the ages of 5 and 7. The hearing second-language learners had a variety of native languages (Urdu, Italian, German, and French) and began to learn English as a second-language in school between the ages of 5 and 9. By contrast, the late first-language learners began to learn sign language and English at the same time between the ages of 5 and 9 when they enrolled in a school that used sign language; they had not acquired any language in early childhood. As predicted by previous research, there were no performance differences on the English syntax task for the two groups of second-language learners of English. The deaf, second-language learners and the hearing second-language learners performed similarly across all the English syntactic structures. However, the late-first language learners performed at low levels on all the English syntactic structures and tasks (Mayberry and Lock, 2001).

Together the results of these studies demonstrate that language exposure in early childhood is *necessary* for language to develop fully in any language, be it a first or second language. Deaf children exposed to accessible language in early life show second-language grammatical and reading skills comparable to hearing children, even though their first language was in sign rather than in speech. Thus, the unique risk congenital deafness poses for infants and children is that it prevents them from getting accessible language input at the right developmental stage. Deaf people who, for whatever reasons, are not exposed to accessible language during early childhood (in any form, spoken or signed), consequently suffer from two permanent handicaps: they cannot hear sound and they do not readily comprehend any language in any mode, be it in sign, speech, or writing. This second handicap, incomplete language comprehension, is completely preventable.

Educators have attempted to ameliorate the language problems common to deaf children through a variety of approaches. One commonly used educational method that combines the use of signs and speech is called Total Communication. We now turn to this means of classroom communication.

Total Communication

Two factors prompted a majority of American schools for deaf children to supplement a strictly vocal mode of instruction (‘oralism’) with signs. One factor was the dawning realization by linguists that the sign languages used by Deaf Communities worldwide were natural languages, such as American Sign Language, ASL, in North America (e.g., Klima and Bellugi, 1979; Stokoe, Casterline and Cronebeg, 1965). The second factor was widespread dissatisfaction with the academic achievement of deaf children taught exclusively through speech (Lou, 1988). The objective behind this philosophical change of heart, known as Total Communication, or TC, was to make the structure of spoken language visually accessible to deaf children. The hope was that deaf children would spontaneously acquire the grammar of spoken language by watching ‘English in the air’ in much the same fashion as hearing children acquire the grammar of spoken language by simply listening to 'English in the air' (Moores, 1982).[1]

Manually coded english

To implement TC, teachers and parents accompany their speech with a simultaneous rendition in sign. The sign portion is accomplished by borrowing vocabulary words/signs from ASL, signing them in English word order, and then using invented signs to represent grammatical English morphemes, such as determiners, plural and tense markers, and so forth. Several groups of educators began the task of inventing signed English morphology at the same time. Their various results are collectively known as Manually Coded English, or MCE (for a description, see Lou, 1988; Schick and Moeller, 1992; Wilbur, 1987).

Allen (1989) observed that, between 1974 and 1983, American deaf students showed gains in mean reading and mathematics achievement, especially at younger ages. Whether these gains were due to the widespread adoption of TC, the greater availability of services for families with deaf infants, or some combination of factors is, of course, impossible to say. The hope that TC would lead to vastly improved facility in English grammar for the majority of deaf children has not been fully realized, unfortunately. This is because 'mode' of communication is not the only factor that predicts deaf children's English learning and academic success, as we describe below.

Geers, Moog and Schick (1984) examined the ability of 327 profoundly deaf 5–8-year-olds to produce English sentences containing a variety of early developing grammatical structures. Half the children were orally trained and half were TC trained, i.e. speech plus MCE — manually coded English. Although there was considerable variation, the TC children as a group developed English grammar at a slower rate compared to the orally trained children. However, it is important to remember that orally trained children, as a group, are more likely to be privileged than TC children, especially with respect to hearing level and socioeconomic status, as described above. Leakey (1991) observed in one sample of TC trained children that they were correct less than half the time in their production of signed English grammatical morphemes, such as articles, prepositions, and auxiliary verbs and tense markers. These results seem to indicate that English grammar cannot be learned through a combined speech and sign mode. Factors other than communication mode may contribute to poorer than expected English language outcome, however. These factors constitute problems with respect to linguistic input and learnability. We consider these factors below.

The input problem

Even when English grammar is made visually accessible in classrooms through the use of simultaneous English and MCE, it is still often inaccessible to many deaf children for large portions of the day, especially at home. This is the situation for deaf children in day classes or schools when their hearing families make little effort to sign. For example, Mayberry et al. (2001) interviewed 24 severely and profoundly deaf 7–15-year-olds with hearing parents who attended TC day classes in a large city. One-third of the children reported that they could communicate with no one in their families because no family member knew or used any kind of signs or sign language with them. Another third reported that they could communicate with only one person in their family, typically the mother. Less than one-third of the children reported that they could communicate with family members through sign. These interview data suggest that the linguistic input many TC children receive, although visually accessible, is often restricted to class time in contrast to the speech overheard throughout the waking hours by hearing children.

Considerable success in learning English has been reported for TC educated children when their schools and families have made a concerted effort to provide consistent MCE input for the children in all aspects of their lives. Schick and Moeller (1992) investigated the English and reading skills of 13 profoundly deaf

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[1] The signing used in Total Communication, commonly referred to as Manually Coded English (MCE), uses a grammar that is unlike ASL, the natural sign language used by deaf people in the United States and most of Canada. The grammar of ASL is dissimilar from English because it evolved independent of spoken English. ASL has evolved through generations of deaf children's minds. By contrast, MCE was invented by committees of educators to specifically mirror English grammar in sign. For a more detailed description of MCE, see Wilbur (1987).

children between the ages of 7 and 14. Unlike previous reports, all these deaf children read at levels within normal limits for hearing children. In addition, they performed at superior levels on a test of English grammar in comparison to norms based on orally trained deaf children (see Geers et al., 1984). Detailed analyses of the children's expressive English showed it to be very similar to that of matched normally hearing children in terms of complexity and grammatical intactness. There was a tendency for the deaf children to delete some types of grammatical morphology from their English expression, most notably those English morphemes that require a separate sign in MCE but are fused to the root word in spoken English (Schick and Moeller, 1992).[2] These findings show that the use of MCE can lead to high levels of functional language acquisition in a signed version of a spoken language, English in this case, and to literacy levels typical for hearing children. The key factor appears to be ensuring that the frequency and consistency of the child's signed language input is comparable in many ways to that of hearing children's spoken language input.

Other research shows that restricted language input may retard the development of signed language comprehension. Mayberry et al. (2001) studied 48 severely and profoundly deaf 7–15-year-olds. The children whose sign input was limited to classroom hours (that is, TC children with hearing, non-signing parents) understood stories given in sign language (both MCE and ASL) less well than children whose sign input was unlimited. The latter children had parents who signed with them at home, both deaf and hearing parents. The comprehension gap between the two groups, those with *limited* versus *abundant* sign input, became more marked with age (specifically, at 13–15 years as compared to 7–9 years). These findings suggest that the effects of restricted linguistic input on language development may be cumulative and hence not readily apparent in the young deaf child.

The facilitative effects of abundant sign input on language development via MCE were also found by Geers and Schick (1988). They compared the ability of two groups of TC children to produce a variety of early developing grammatical structures in English. One group of 50 profoundly deaf 5–8-year-olds had deaf parents who had used sign language with them from birth. The other group (matched for age, hearing level, and nonverbal IQ) had hearing parents whose sign skill varied considerably. The group with *abundant* sign input significantly outperformed the group with *limited* sign input on a test of English grammatical skill (given in simultaneously presented MCE and spoken English). Again, the differences between the two input groups with respect to production of English grammar became more marked with age. Indeed, the TC children who had received abundant sign input from birth produced English grammatical structures (in MCE with speech) at a level commensurate with a group of orally trained deaf children who were previously tested by the researchers (Geers and Schick, 1988).

To summarize, research results suggest that the crucial factor in deaf children's language development is not the sensory modality through which they perceive and produce language (i.e., speech without sign, speech with sign, or sign without speech). Instead, the abundance and richness of consistent linguistic input, accessible and available to the deaf child throughout early life and later schooling is a key factor in the child's cognitive outcome, both in terms of language development and educational achievement.

The learnability problem

Some researchers pose yet another version of the input problem, which we call the 'learnability problem.' Many linguists and educators criticize the use of MCE as the mode of instruction for deaf children because it is artificial, i.e., not a real language (Johnson, 1990; Johnson, Liddell and Erting, 1989). There are at least three linguistic and psychological consequences of this artificiality. By artificiality

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[2] When using MCE, for example, the child would be likely to accompany both the morphemes of the verb, 'going' with two signs because each morpheme, 'go' and '-ing' are stressed syllables in speech. However, the same child would be less likely to accompany both the morphemes in the verb 'goes' with two signs because the English verb phrase is one syllable in speech. The verb 'goes' requires two signs, however, one sign for the root 'go' and another sign to mark the third-person singular, '-es'. Thus it should be clear that this type of sign morphological deletion in children's and adult's production of MCE is an adaptation to signing and speaking simultaneously when the syllabic and stress patterns of two modalities are in conflict with respect to stress patterns.

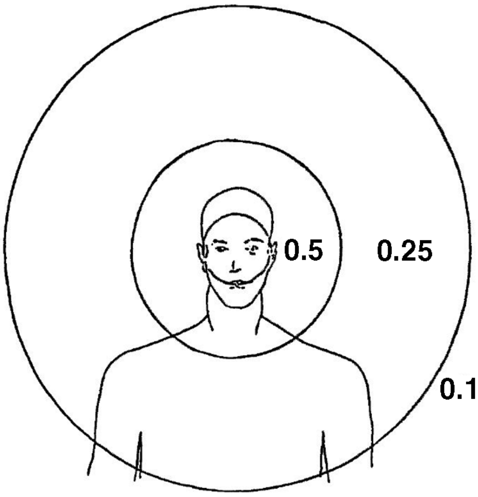

Fig. 5. Visual acuity is greatest at the face where signers focus during sign language perception. Visual acuity decreases sharply as a function of number of degrees from the focus point, ranging from 0.50 just beside the face to only 0.10 at the shoulder and chest. Areas of low visual acuity in the signer's visual focus rely on peripheral vision; peripheral vision, although poor in visual acuity, is dept at perception of movement trajectory and velocity (fig. 2 from Siple, 1978).

we mean using communication that has not evolved naturally through the minds of generations of young children, as have all natural languages, including signed languages.

The first consequences of using an artificial communication system are perceptual and phonological. Linguists now know that the signs of natural languages have sublexical structure, which means that all signs are constructed from a finite set of meaningless articulatory, or phonetic, units. One property of ASL phonological structure is that it evolved to fit the constraints of the human visual system. Siple (1978) first observed that ASL signers focus on one another's faces (and not on the hands and arms). This means that signs made around the face fall into the foveal area of the visual field, or central vision, as shown in Fig. 5. Central visual processes perceives form and shape. In fact, ASL signs made around the face use contrasts of small changes in handshape and location. Signs made away from the face fall into peripheral vision. Peripheral vision perceives the trajectory and velocity of movement. In fact, ASL signs made away from the face use contrasts of movement patterns.

Many of the invented MCE signs for English grammatical morphology violate the perceptual fit between central and peripheral visual processes and the articulatory structure of ASL signs. The poor fit between the visual processing and many MCE signs makes it impossible for the signer to see the form of many invented signs. For example, in some MCE systems the various forms of English verb auxiliary 'have, has, had' are created with handshape changes consisting of *V*, *S*, and *D* (finger spelled handshapes) made inward to the chest with two hands as a derivation of the root verb root 'have' in ASL. However, when looking at a signer's face, as all signers do, these handshape changes are invisible; only the movement and location of three invented signs can be detected, yielding only one sign rather than the three invented English grammatical auxiliary verbs. This observation was predicted by studies of sign identification in peripheral vision. Swisher, 1993 (Swisher, Christie and Miller, 1989) found that the handshapes of unfamiliar signs could not be recognized in peripheral vision. Supalla (1991) noted that the deaf children he observed who were educated with MCE tended to replace the invented pronouns of the MCE system they used with modifications to the movements of the signs, reminiscent of ASL grammatical inflections that indicate person, even though the children had never seen ASL.

The second and third consequences of the linguistic artificiality of MCE systems are morphological and prosodic. Linguists now know that sign languages have a strong tendency to produce grammatical morphology within various changes to movement trajectories through space; these grammatical morphemes are produced simultaneously with the sign root rather than through a sequence of signs. This creates visual intonation patterns through the air in which grammatical roots and morphemes are simultaneously combined. The linear, sign for morpheme, speech/sign expression of MCE systems destroys this visual intonation and significantly slows the pace of sign. In fact, many deaf adults remark that they cannot parse and grasp MCE signing.[3] Hearing adults do not have this problem because they listen to

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[3] Patrick Boudreault, Pamela Witcher and Patricia Viens, personal communication.

the speech portion of MCE and thus are not required to perceive MCE solely through vision.

Summary

In asking how hearing affects the child's cognitive development, we have found that the primary deficit posed by deafness is a high risk for impoverished language acquisition in any form. We have seen that deaf children, as a group, show heterogeneous levels of language development related to both the developmental timing and accessibility of their language exposure. Some deaf children show high levels of language development (in signed or spoken language) commensurate with those of hearing peers but other deaf children show significantly delayed and depressed levels of language (in signed or spoken language). This state of affairs leads to two important questions. First, what are the consequences of this wide variation in language development (in signed or spoken language) for cognitive development? Second, does the sensory modality of the child's primary language (i.e., signed versus spoken language) have any specific effects on cognitive development? We begin our inquiry with a summary of IQ test performance followed by a look at memory, symbolic play, and conceptual development.

IQ test performance

Intelligence tests were originally devised to predict academic performance (Sternberg, 1989). Thus, one important question is whether the lower than average academic achievement of the deaf population (relative to the hearing population) is due to a lower than average IQ. Two issues related to the question have been studied in some detail. One question is how the nonverbal IQ performance of deaf students compares to the general population. Another issue is whether deaf children show unique performance patterns, that is, cognitive strengths or weaknesses that are atypical of normally hearing children. Our discussion of these issues will be facilitated if we first note which IQ tests are commonly administered to deaf students.

Mean nonverbal IQ

The office of Demographic Studies at Gallaudet University gathered IQ data on 41,000 deaf students enrolled in special education in the United States. 15,000 students had been given the performance scale of the WISC, the Leiter, and the Hiskey–Nebraska; the remaining students had been administered a variety of other nonverbal tests (Schildroth, 1976). Average performance IQ for the general hearing population is 100. Mean nonverbal IQ for deaf children with *no* additional handicap was 100.1. Deaf children with *one* additional handicap showed a lower mean nonverbal IQ of 86.5 (Schildroth, 1976).

Braden (1992) replicated these findings with a meta-analysis of 285 studies that together tested 171,517 deaf students from 1900–1988. Mean nonverbal performance IQ across the studies was 97.4 with a SD of 15.33. Braden discovered that mean nonverbal IQ increased as the study publication date increased. This improvement in IQ test scores may be due to better societal awareness of the special needs of deaf children in recent years. In addition, Braden (1992) noted that methods of IQ test administration have changed radically over the years. Studies that reported using a strictly oral means of test administration reported lower mean nonverbal IQ scores than those that used a combination of speech and signs. The finding is logical; children perform better on tests when they understand the directions.

On the performance scale of the WISC-R, deaf boys tend to perform at somewhat higher levels than deaf girls on subtests that are highly visual and spatial in nature (specifically, block design, object assembly, and picture completion). Deaf girls tend to outperform deaf boys on the coding subtest. Some psychologists think that the coding subtest, although nonverbal in nature, is related to language ability. Both the direction and magnitude of the reported sex differences among deaf students are identical to those reported for the general population, accounting for less than 1% of the variance (Phelps and Ensor, 1987).

Hearing preschoolers are often tested with The McCarthy Scales. Deaf preschoolers (2–5 years with no additional handicaps) perform similarly to hearing preschoolers on the McCarthy subtests that require *no* language, namely, block building, puzzle solving, and draw-a-design. The performance of deaf preschoolers on these nonverbal subtests is unrelated to the severity of their hearing loss, within a range of 65–110 dB (Bond, 1987).

Although the mean nonverbal IQ of the deaf population approximates that of the hearing population, some research suggests that the strengths and weakness of performance IQ in the deaf population are not identical to those of the normally hearing population. Such a finding would not be surprising, given the fact that deaf children must rely on vision to figure out the world to a much greater extent than do hearing children. As expected, then, analyses of performance IQ test items reveal that deaf children do not show the same hierarchy of item difficulty across various subtests as compared with hearing children (Maller, 1997; Zwiebel and Mertens, 1985).

Common IQ tests

The most frequently used test in North America is the Wechsler Intelligence Scale for Children (WISC). Typically the performance scale is administered; the verbal scale is infrequently administered (McQuaid and Alovisetti, 1981). In a review of 285 studies reporting measures of deaf children's IQ, Braden (1992) found that 14 different nonverbal tests have been used. Of these nonverbal IQ tests, five tests have norms for deaf children. Watson and Goldgar (1985) compared deaf children's performance on two of the tests, the WISC-R performance scale and the Hiskey–Nebraska Test of Learning Aptitude (H-NTLA). They found performance on the two tests to be highly correlated ($r = +0.85$). However, they also found that the H-NTLA showed greater kurtosis, that is, a distribution of scores in comparison to the WISC-R yielding many extreme scores, namely, scores < 70 and > 119, where 100 represents average performance. Braden (1992) found no significant differences for reported nonverbal IQ scores across studies that used norms for deaf children compared with studies that used norms developed for hearing children. This important comparison demonstrates, again, that the nonverbal IQ of deaf children does not differ from that of hearing children, as Table 1 shows. Indeed, this is a robust finding, as we discuss below.

Unique performance patterns

Verbal IQ

Verbal (i.e., language) tests or subtests are infrequently used to estimate the IQ of deaf children due to their pervasive language delay, as described in detail above. For example, Geers and Moog (1988) administered both the verbal and performance scales of ?#1 the WISC-R to a group of profoundly deaf students who were educated orally. Despite their excellent spoken language skills however, the deaf students scored 22 points lower on the WISC-R verbal scale (with a mean of 89) than on the performance scale (with a mean of 111).

The verbal scale of the WISC-R has been administered experimentally in sign language (in several dialects) to deaf students. Mean verbal score in sign language was 96.3 when the digit span subtest was included in the overall score and 97.8 when it was excluded (Miller, 1985). Deaf students often show a reduced *sequential* short-term-memory span in comparison to hearing students for word lists (including digits) even when the stimuli are signs rather than written or spoken words, which we discuss in detail below (Hanson, 1982; Mayberry and Waters, 1991). Another study failed to replicate the finding of a normal verbal scale score and reported lower than average verbal scale scores on the WISC-R for a group of 27 deaf children when test administration was in various kinds of sign language (Chovan, James and Benfield, 1994). These conflicting results probably reflect real differences in the sign language skills of the deaf students tested in the two studies. Level of sign language development, and hence level of sign language comprehension and production, is heterogeneous in the deaf population and thus needs to be controlled in such studies, as explained above. Maller (2001) administered both the performance and verbal scales of the WISC-III to 110 deaf children ranging in age from 8–16 using "Pidgin Sign English that was mostly ASL" (Maller, 2001: 5). The deaf children with deaf parents significantly outperformed the deaf children with hearing parents on the verbal scale of the WISC-III with mean scores of 86.48 and 77.19 respectively. Note that the verbal scale performance of these deaf signing children was comparable to that of the orally educated deaf children discussed above reported by Geers and Moog (1988). ?#2

For the hearing population, verbal and performance scale scores on the WISC-R are correlated ($r = +0.50$). Verbal and performance IQ are also correlated for deaf students ($r = +0.45$, Craig and Gordon, 1988; Watson, Sullivan, Moeller and Jensen,

TABLE 1

Intelligence tests used to assess deaf and hard-of-hearing people[a]

Name of test	*N* studies	Mean IQ
Performance tests		
Chicago Non-Verbal Examination	5	97.25
Grace–Arthur Performance Scale	16	96.02
Hiskey–Nebraska Test of Learning Aptitude	17	97.53
Kaufman–Assessment Battery for Children	6	96.86
Leiter International Performance Scale	12	87.19
Ontario School Ability Examination	6	98.44
Snijers–Oomen Nonverbal Tests	5	96.71
WAIS-R Performance Scale	9	102.84
Wechsler–Bellevue Performance Scale	11	107.32
WISC Performance Scale	38	101.22
WISC-R Performance Scale	44	100.81
Motor-free nonverbal tests		
Draw-a-Man/Person	13	91.72
Pintner Non-Language Test	13	91.87
Ravens Progressive Matrices	17	97.56
Verbal tests		
WAIS-R Verbal Scale	5	84–36

[a] Published reports of IQ tests used during the past 50 years, table 1 from Braden, 1992.

1982). Performance on both the WISC-R and WAIS-R performance scales are also correlated with academic performance (Paal, Skinner and Reddig, 1988; Watson et al., 1982). Indeed, the correlation is impressive given the depressed language skills of most deaf students.

Uneducated deaf children

The assumption underlying the large-scale studies of IQ discussed above is that the deaf children under study are, or have been, enrolled in an educational program appropriate for deaf children at from age 5 or 6 onwards as would be the case for normally developing hearing children. The expectation of normal, nonverbal IQ test performance clearly cannot be applied to deaf children who are educationally deprived. This is shown by case studies of deaf children who immigrated with their families to North America in late childhood or adolescence after having attended *no* school in their home country or a school for hearing children with no accommodations or interventions for their deafness. For example, Grimshaw and her colleagues (Grimshaw, Adelstein, Bryden and MacKinnon, 1998) investigated the development of a deaf boy raised in Mexico where he did never attended school. His WISC-R and WAIS-R performance levels were 85 with above average performance on the Object Assembly subtest and very low performance on the Coding and Picture Arrangement subtests (specific scores were not given). Another case study of a 16-year-old deaf girl raised in Guatemala where she never attended school reported a nonverbal IQ level of “8 years” based on performance on the Leiter and unspecified subtests of the WAIS (Emmorey, Grant and Ewan, 1994). Morford (2001) reported the performance by two additional deaf students. One 13-year-old girl performed at the 5th percentile on the Ravens after having attended school for only 3 months. After 32 months of educational experience, she performed at the 50th percentile on the Ravens. Finally, a 12-year-old boy, who had attended a school for hearing children in his home country (but without any special consideration of his deafness), received a nonverbal IQ of 71 on the WISC-R after 19 months of being enrolled in a North American school for deaf children. After 31 months of special schooling he received a nonverbal IQ of 85 on the same test.

Together these case studies show that the average nonverbal IQ performance reported for the deaf school-aged population is a consequence of appropriate educational experiences at the appropriate young ages despite often severe language delay. Deaf children who suffer from educational deprivation do not show normal nonverbal IQ performance.

Higher than average nonverbal intelligence

Several investigators have observed that a subset of the deaf population shows higher than average performance on nonverbal IQ tests. In a study of more than 1000 deaf students, Sisco and Anderson (1980) observed that deaf students who had deaf parents outperformed their deaf peers who had hearing parents on every subtest of the WISC-R performance scale (with an overall mean performance IQ of 107 as compared to 96). Moreover, the deaf students raised in deaf families performed at higher mean levels compared to the hearing population mean on every subtest of the WISC-R performance scale (with a mean score of 107 as compared to 100).

Several explanations have been proposed to account for the higher than average nonverbal IQ shown by deaf children raised in deaf families. One hypothesis is that the performance difference reflects the fact that intelligence is, in part, inherited. This account, which we call the *genetic* hypothesis, argues that, because at least half of intelligence is inherited, deaf children who have deaf parents perform higher than average on nonverbal IQ tests because they have inherited genes for superior intelligence (for example, see Kusche, Greenberg and Garfield, 1983). Underlying this proposal is the idea that the deaf individuals who have been the most successful at reproducing over multiple generations are also the most intelligent.

The second explanation, which we call the *early learning* hypothesis, emphasizes the impact of the child's early environment on cognitive development. Some researchers speculate that early *language* exposure facilitates intellectual development in general (e.g., Vernon, 1968). Another version of this hypothesis is that deaf parents are better prepared than hearing parents to meet the early learning needs of the deaf child (e.g., Schlesinger and Meadow, 1972; Sisco and Anderson, 1980). Underlying both explanations is the premise that deaf children with deaf parents perform higher than average on nonverbal IQ tests because they have acquired language on schedule (in early childhood). In a third version of the hypothesis, other researchers propose that the effect relates to the physical form of the language being learned in early childhood. They posit that learning a visuospatial, or three-dimensional grammar, such as in ASL, boosts the child's visual and spatial abilities to higher than average levels (Bellugi et al., 1990).

The available data do not clearly adjudicate between the *genetic* and *early experience* hypotheses, although recent research has shed light on the question. As previously noted, Sisco and Anderson (1980) found that genetically deaf children (those with deaf parents) performed at *higher* mean levels on the WISC-R performance scale than the general population. However, Conrad and Weiskrantz (1981) only partially replicated the finding. They compared the performance of two groups of British deaf children whose deafness was genetic (those with deaf parents and those with hearing parents but deaf siblings) using norms from the British Ability Scales. Both deaf groups performed at higher than average levels than British hearing children. This finding is similar to the American results. Next they compared the performance of the two groups of deaf children with an age-matched group of hearing children from a private school. The performance of two deaf groups was indistinguishable from that of the hearing group on the Ravens' Progressive Matrices (a test of visual reasoning), Block Design, and a test of visual design recall (Conrad and Weiskrantz, 1981). However, Paquin (1992) argued that the hearing control group used by Conrad and Weiskrantz (1981) was not representative of the hearing British school-aged population but rather was a select sample from a small private school that probably selected students for above-average intelligence.

In a subsequent study, Kusche et al. (1983) replicated the original American findings (Sisco and Anderson, 1980). They compared the WISC-R performance scores of two groups of genetically deaf children (those with deaf parents and those with hearing parents but deaf siblings) to two matched groups of *nongenetically* deaf children (those with hearing parents and hearing siblings). The groups were matched on a number of factors including sex, age, hearing level, grade, and mother's educational level. The two groups of genetically deaf children had higher mean performance scores on the WISC-R than the hearing population mean (112 as compared to 100). The two genetically deaf groups also showed higher mean performance compared with the two *nongenetically* deaf groups (112 as compared to 101). These findings were partially replicated in another study (Craig and Gordon, 1988).

The higher than average performance IQ of the genetically deaf groups studied by Kusche et al. (1983) cannot be attributed to knowledge of sign language, because all the deaf groups, genetically deaf or not, knew and used sign language. This suggests that some portion of the higher than average nonverbal IQ of genetically deaf children may be inherited or that nongentic deafness can be associated with cognitive problems of some sort related to the cause of deafness. One way to test this hypothesis would be to test the performance IQ of the deaf children's parents and siblings.

Paquin (Paquin, 1992) investigated the genetic hypothesis by testing the nonverbal IQ of 31 families in which both the parents and the children were deaf. He obtained nonverbal IQ scores for both parents in 18 families, one parent in 13 families and 50 deaf children of the 31 families. He used either the WISC-R or the WAIS-R nonverbal performance scales. Performance on the two scales has been found to produce the same score (Braden and Paquin, 1985). Paquin found mean nonverbal performance to be 114.5 for the deaf parents and 114.0 for the deaf children. Replicating the previous American studies, the performance of the deaf parents and their deaf children was significantly above the mean of the hearing population (Paquin, 1992).

As Paquin (1992) notes, there are two possible mechanisms of genetic transmission of genes for deafness and nonverbal IQ; these mechanisms are assortative mating and pleiotropism. Assortative mating would produce higher nonverbal IQ among genetically deaf individuals if brighter deaf people have tended to marry other bright deaf people across generations. Pleiotropism would produce higher IQ among genetically deaf people if genes for both deafness and intelligence actually became linked over time and were expressed together. Such genetic linkage would predict that genetically deaf children would show higher than average nonverbal IQ but that their hearing siblings would not because the two genes are fused in expression (Paquin, 1992); this latter prediction has not been tested.

A major problem for the genetic explanation of the higher than average nonverbal IQ of deaf individuals with deaf parents, however, is that there over 100 different kinds of genetic deafness, both dominant and recessive (Boughman and Shaver, 1982). It is improbable that all genetic deafness is associated with higher than average performance IQ. However, this does not rule out the possibility that some types of genetic deafness may be linked with some types of intelligence.

Another possible explanation for the higher than average nonverbal IQ of genetically deaf individuals was investigated by Braden (1987). He tested both the manual reaction time and manual movement time of three groups of adolescents, genetically deaf, nongenetically deaf, and normally hearing; he also tested the groups' performance on the Ravens Progressive Matrices. The reaction time measure required participants to lift a finger in response to a given light; the movement time measure required participants to push a button below a given light. The deaf adolescents with deaf parents outperformed the other two groups on the reaction time measure. In addition, both deaf groups outperformed the normally hearing students on the movement time measure. The performance of the genetically deaf and hearing groups did not differ on the Ravens Progressive Matrices but the nongenetically deaf group performed at a lower level.

Factors related to language and early environment rather than to genetic background can explain these findings. First, it is important to know that the Ravens Progressive Matrices is an untimed reasoning test that has been found to be related to some aspects of language skill. In a study of 468 deaf students between the ages of 15 and 16, Conrad (1979) found that performance on the Ravens was highly correlated to measures of phonological decoding in memory for written words, i.e., to mental representations for vocabulary. Other research has found that performance on the Ravens is highly related to working memory (Carpenter, Just and Shell, 1990). Together these findings explain why the deaf children from deaf families performed similarly to the hearing group on the Ravens test. The deaf children from deaf families likely had a native sign language and hence developed mental language representations in addition to working memory (as we discuss in detail below). This would also explain why the deaf children from hearing families performed more poorly than the other two groups on the Ravens; they were likely to have experienced late and/or incomplete language exposure in sign or spoken language and thus have underdeveloped mental language representations and working memory. The finding that both the deaf groups outperformed the hearing group on the manual reaction time could be due to the fact that both groups used sign language as a primary language. They were highly practiced at moving their hands quickly. Finally, the finding that the deaf students from deaf families outperformed those from hearing families on reaction time to a visual stimulus could be due to the effects of exposure to a visual language in early childhood, something the deaf group from hearing families lacked. Research has found that exposure to sign in early life enhances some aspects of visual processing, as we discuss below.

Visuospatial skills and memory

Supernormal visual skills

Research investigating the visuospatial skills of deaf and hearing individuals has uncovered numerous positive effects of using sign language. For example, Bettger, Emmorey and Bellugi (1997) found that individuals who used ASL, native deaf signers, native hearing signers, and non-native deaf signers, all performed more accurately on the Benton Test of Facial Recognition than did hearing non-signers. The advantage was especially apparent on ‘shadowed’ faces, that is, stimuli that were harder to perceive. Other research has found that deaf children who know no sign language do not show performance advantages on the Benton Test of Facial Recognition (Parasnis, Samar, Bettger and Sathe, 1996). The positive effects of using sign language on face recognition are not limited to native signers. Non-native deaf signers and non-native hearing signers (teachers) were observed to require fewer trials to complete a face matching task compared with hearing non-signers (Arnold and Murray, 1998). As few as 2 years of sign language learning produced increased accuracy of facial expression identification in hearing individuals, especially of facial expressions that signal emotions of sadness and disgust. These facial expressions are harder for general population to identify (Goldstein and Feldman, 1995).

Learning and using sign language has also been found to sharpen the visuospatial abilities of recognizing movement patterns and generating and rotating mental images. For example, Chinese deaf children who use sign language were found to perform at higher mean levels than age-matched Chinese hearing children on memory for the movements of Chinese characters drawn in the air (Fok, Bellugi, Van Hoek and Klima, 1988). Both deaf and hearing native signers were found to generate and rotate visual images more quickly than hearing non-signers (Emmorey, Kosslyn and Bellugi, 1993). Moreover, deaf individuals who do not know sign language do not show these effects (Chamberlain and Mayberry, 1994). The degree to which these effects are contingent upon early sign exposure has not yet been fully explored (Emmorey, 1998). Also, it is important to note that the degree to which these effects interact with the well-documented, but small, differences in spatial processing between males and females has not been adequately investigated. In some studies, the differences between the experimental groups of hearing and deaf participants are more apparent for males than for females. Thus, future research needs to control for both age of sign language acquisition and sex. We discuss the brain correlates of these findings below after turning to memory skills.

Short-term memory

As early as 1917, Pintner and his associates found a considerable discrepancy between the digit spans of deaf and hearing children. The oldest deaf subjects in their studies had a mean digit span three digits less than the youngest hearing subjects. (For a review see Chamberlain and Mayberry, 2000). He concluded that deafness causes a delay in development which he called “mental retardation” (Pintner, 1928). Hoemann (1991) noted that more than four decades of research was required to refute this erroneous claim.

Recent investigations into the memory processes of deaf individuals explain Pintner’s early findings, which have been consistently replicated. The digit span of hearing subjects typically exceeds the digit span of deaf subjects, even when the digits are given in a written or signed presentation. Research has found that auditory experience does influence STM span but indirectly, not directly. Audition affects STM span because it plays a major role in spoken language acquisition. Deaf children vary widely in their level of language development (spoken or signed), familiarity with written words, and in whether and how they use mental rehearsal as a strategy to facilitate recall.

Language development (or more simply, familiarity) determines how well words from a given language can be recalled. Individuals can recall more frequently occurring words than infrequent ones; individuals who speak two or more languages can recall more words from their native language than their second, or weaker, languages. Deaf children often show reduced STM spans for written words in comparison to age-matched hearing children simply because they are less familiar with English words. The STM spans of congenitally deaf children for written words are thus predicted by the dual factors of degree of hearing loss and degree of language development (Conrad, 1970, 1979; Hamilton and Holtzman, 1989; Novack and Bonvillian, 1996). When the linguistic element is removed from the STM task, and deaf children are asked to recall nonsense figures, their performance is equivalent to age-matched hearing children (Furth, 1966). When deaf children's visual strengths are tapped by asking them to recall the spatial array of a set of items, they often show equivalent (Logan, Mayberry and Fletcher, 1996) or superior performance in comparison to age-matched hearing children (Belmont and Karchmer, 1978). On spatial memory tasks, such as Corsi blocks, deaf children raised in deaf families have been found to outperform those from hearing families (Wilson, Bettger, Niculae and Klima, 1997).

Whether deaf children use rehearsal (mental repetition of the items to be recalled) as a strategy in memory processing is another important factor that explains observed STM span differences between deaf and hearing children. Bebko (1984) found that both orally and TC trained deaf children lagged several years behind hearing children in their development and use of spontaneous rehearsal strategies in serial STM tasks. Rehearsal development, in turn, was predicted by the child's language history. The probability that a deaf signing child would rehearse items during a STM task was thus related to the number of years he or she had used sign language (Bebko and McKinnon, 1990).

Even at the post-secondary level, STM discrepancies persist (Bellugi, Klima and Siple, 1975; Bonvillian, Rea, Orlansky and Slade, 1987) but the exact cause of these discrepancies is unclear. For example, deaf and hearing college students show similar STM spans when recall is free, or unordered (Hanson, 1982). When recall is serial, or ordered, the spans of deaf students are often, but not always, reduced with respect to hearing subjects (Hanson, 1990; Krakow and Hanson, 1985). This pattern has been reported several times in the literature (e.g., O'Connor and Hermelin, 1978) and has prompted some researchers to speculate that auditory experience is essential for temporal, or sequenced, processing. However, deaf and hearing adults show similar performance on temporal processing tasks when language is not involved, e.g., detection of flicker frequency (Poizner and Tallal, 1987). The most parsimonious explanation currently available, then, is that discrepancies between deaf and hearing students' STM spans for written words are related to real differences in cumulative linguistic experience.

Similar factors may account for the finding that deaf children's STM spans for signs and fingerspelling are also reduced in comparison to age-matched hearing children's span for spoken words. Deaf children vary widely in their developmental experience with sign language, which affects development of STM processes in at least three ways. Children who begin language acquisition at older ages and/or have limited language input during early childhood have underdeveloped sign language skill, which, in turn, affects their STM development (Mayberry and Waters, 1991). In addition, deaf children who are delayed in language acquisition are less likely to rehearse during STM tasks (Bebko and McKinnon, 1990). Finally, articulation differences between sign language and speech are also a factor. For example, sign duration as measured by the length of a given sign's movement trajectory has been found to influence STM span for signs in deaf signers (Wilson and Emmorey, 1998). This is analogous to the word length effect in memory for spoken words (Baddeley, Thomson and Buchanan, 1975) and has been found for fingerspelling memory in deaf children also (Mayberry and Waters, 1991).

Conceptual development

In asking how deafness affect the child's development, we have seen that, despite heterogeneity in primary language development and levels of reading and academic achievement, deaf children show normal performance levels on nonverbal IQ tests and above average performance on several types of visuospatial tasks. How might this pattern of cognitive strengths and weaknesses relate to the development of reasoning skills? Does childhood deafness impede the development of abstract and logical thought? The framework for this question has changed over time reflecting the theoretical shift that has occurred in developmental research with hearing children (Wellman and Gelman, 1992). Earlier research with deaf children investigated the question from the standpoint of general stages of cognitive development using Piaget's theory as a basis. Recent research has focused instead on domains of knowledge, such as the deaf child's understanding of people and the physical and biological worlds.

Symbolic play

In Piaget's theory of intellectual development, the child's early reasoning develops in stages through interactions with the physical world so that language is not initially essential to conceptual development. Children's play with objects and toys becomes increasingly complex and coincides with the onset of language in normally hearing children (McCune-Nicholich, 1981). Both early play and language are hypothesized to emerge from a unitary symbolic capacity (Bates, Benigni, Bretherton et al., 1979). One question with respect to deaf children has been whether their pervasive language delay affects their early play with objects. Another related question has been whether the disruption that deafness can pose for mother–child interactions impedes the deaf child's development of symbolic play. These questions have been addressed in some studies with conflicting results.

Spencer (1996) studied the play sophistication of 30 2-year-olds in three groups, deaf children with deaf mothers, deaf children with hearing mothers, and hearing children with hearing mothers. In addition to observing and coding the children's play, Spencer classified all the children as having one of three levels of language development, pre-word combinations, beginning word combinations, and frequent word combinations. She found that the frequency and duration of the children's abstract play, as well as ordered sequences, varied as a function of language development. A similar pattern held when she analyzed the play behavior of only the deaf children with hearing mothers; language development coincided with the frequency and duration of ordered play (Spencer, 1996).

In a follow-up study, Spencer and Meadow-Orlans (1996) found no play differences at 9 months of age across the same varying child–mother dyads, namely, deaf children with deaf mothers (13 pairs), deaf children with hearing mothers (15 pairs), and hearing children with hearing mothers (15 pairs). By 12 months of age, more of the hearing children showed sequenced play than did the deaf children; some of the deaf children showed developmental delays. At 18 months, all of the hearing children and all of the deaf children with deaf mothers showed pre-planned representational play but only half of the deaf children with hearing mothers did so. However, language development did not always coincide with the emergence of play. Some children at 12 months showed no language but nonetheless engaged in representational play. By 18 months, even the children with the lowest language levels showed some pre-planned representational play (Spencer and Meadow-Orlans, 1996). These results suggest that, although language and play may both emerge from the same symbolic capacity in young children, deafness primarily affects the emergence of the language portion of this capacity.

A large-scale study by Bornstein and his colleagues (Bornstein, Selmi, Haynes et al., 1999) found a complex relation between language development and the emergence of play. They assessed the language and play sophistication of 89 child/mother dyads of 4 contrasting types, hearing children with hearing mothers, hearing children with deaf mothers, deaf children with deaf mothers, and deaf children of hearing mothers. Few differences in the play sophistication between the hearing and deaf children were observed even though the hearing children, regardless of whether their mothers were hearing or deaf, had many more words than the deaf children. Independent of the hearing status of the child or mother, language and play was correlated for children younger than 22 months but not for children older than 22 months. Bornstein et al. (1999) interpreted these findings to mean that play and language constitute a unitary symbolic ability in the earliest stages of development that then bifurcates into two separate abilities with age.

Concept attainment

The ability of deaf children to form concepts despite delayed language was well illustrated in a study by Friedman (1987). She compared the performance of three groups of children on an object sorting task, (1) normally hearing children with normal language acquisition, (2) normally hearing children with specific language impairment, and (3) orally trained deaf children. In comparison to the hearing groups, the orally trained deaf children had delayed language acquisition and did not know the names of the categories they were being asked to classify. Nevertheless, the deaf children were able to sort objects by categories (such as tools and furniture) nearly as well as the hearing children with normal language acquisition. By contrast, the language disordered children, who could name all the objects and categories, had difficulty with all the sorting tasks.

Does deafness affect conceptual development beyond the child's early symbolic representations in play and object understanding? Using a Piagetian framework, Furth (Furth, 1966) and his colleagues studied the reasoning skills of deaf children in a large series of studies. Recall that in Piaget's theory, the child's early reasoning develops in stages through interactions with the physical world so that language is not initially essential to conceptual development. In his studies, Furth repeatedly found that deaf children, as a group, appear to follow the same stages of early conceptual development as their hearing peers despite pervasive language delay (Furth, 1991). For example, deaf children develop the concepts of sameness, symmetry, and part–whole relationships on schedule, but are slower to develop the concept of opposition (Furth, 1961, 1963). Opposition may be more difficult for deaf children with delayed language to understand simply because it is linguistically coded. Hearing children often acquire the vocabulary for opposites in tandem, as in 'hot/cold, little/big, dark/light,' and so forth (Ingram, 1989). It is important to note that the language skills (in sign or speech) of the children in these studies were not measured. Furth and his colleagues believed at the time that they were investigating cognitive development in children bereft of language. For this reason his book was titled, *Thinking Without Language*. However, it is important to remember that when these studies were conducted, next to nothing was known about sign language and it was not considered to be a language. Hence it was not acknowledged as such.

Reasoning ability

Reasoning skills in general

Studies of deaf children's more advanced conceptual and reasoning abilities are less common. This may be due in large part to the difficulty in studying the thought and reasoning processes of individuals who may not understand task instructions (and researchers who may not understand the individuals they test). For example, in a study of deaf children's development of the concept of conservation (of weight and liquid), French deaf children were found to lag behind hearing children by 4–8 years (Oleron and Herren, 1961). In a replication study, Furth (1966) noted that American deaf children used labels in the experimental tasks in what appeared to be an opposite fashion compared to hearing children. The deaf children consistently signed the word 'more' over the container that had least liquid in response to the question, "Are these the same?" He surmised that what the deaf children actually meant was that the container with the least amount of liquid required *more* liquid in order to be equivalent with the other container, not that they lacked the ability to discern equivalence, or conserve (Furth, 1966). After training on the task, the deaf children tested showed the ability to conserve at about a 2-year lag with respect to hearing children.

The ability of deaf children and adults to discover and use abstract symbols and follow rules of logic shows some lag in development but no atypical patterns. For example, Youniss, Furth and Ross (1971) studied the ability of high and low achieving deaf and hearing adolescents to acquire and use logic symbols. After 1 week of training, most of the hearing participants could perform the task but few of the deaf participants could. With additional training, most of the deaf participants performed as well as the hearing participants. Like minority or educationally underachieving groups, the deaf participants required more training than did the hearing participants. The analogy was demonstrated by Furth (1964) who found that deaf and hearing adult participants showed comparable performance on a logic task when they were matched on the basis of academic achievement and socioeconomic status. Note that academic achievement would likely reflect language skills of the deaf participants as well.

Theory of mind

We turn now from general stages of cognitive development to the deaf child's acquisition of knowledge in specific cognitive domains. Does deafness affect the child's ability to learn about the worlds of objects, biology, and people? The cognitive domain that has received the most attention is deaf children's understanding of other peoples' behavior, the concept referred to as 'theory of mind.' In order to achieve this understanding, the child needs to learn that other people have desires and beliefs that are different from her or his own and that these desires and beliefs can explain the behavior of others (Wellman and Gelman, 1992). Understanding the mental states of other people is rooted in the infant's recognition of the facial expression and later identification of emotional states in others. Theory of mind also arises from young child's understanding that ideas about objects and actions are not the same as real objects and actions. The question for deaf children has been whether the fact that they have fewer interactions with other people during early life and/or delayed language development affects this important cognitive achievement.

In a series of studies, Peterson and Siegal (1995, 1997, 1999) investigated the performance of deaf children on theory of mind tasks. In the first study, they tested the performance of 26 Australian deaf children with hearing parents between the ages of 8 and 13 on a false-belief task. In this task, the child is shown a story enacted by two puppets. One puppet, Sally Ann, hides a marble in a basket and leaves. A second puppet appears and then moves the marble to a covered box and leaves. When the first puppet returns, the child is asked where Sally Ann will look for the marble. This question is followed by control questions, namely, where is the marble actually located and where did Sally Ann put the marble in the first place? Previous research has found that 4-year-old normally developing, hearing children can perform this task. However, Peterson and Siegal (1995) found that only 35% of the deaf children they tested could perform the task. Success on the task was unrelated to the deaf children's age or nonverbal IQ (Draw-a-Man or Ravens).

Peterson and Siegal (1995) next compared the performance of the deaf children to published data available from 14 children with Downs' syndrome and 20 children with autism (Baron-Cohen, Leslie and Frith, 1985). The performance of the deaf children was below that of the children with Downs' syndrome but comparable to that of the autistic children. These results suggest that language development is a key factor in theory of mind development, although the deaf children's language skill was not measured in this study.

In a second study, Peterson and Siegal (1997) replicated and extended their findings. They tested 4 groups of children: deaf children with deaf parents (native signers who were 9 years old), deaf children between the ages of 4 and 13 with hearing parents, autistic children between the ages of 4 and 14, and hearing, normally developing 4-year-olds. The children were asked to perform false-belief tasks, as described above. In addition, the children performed tasks requiring biological knowledge, such as whether a baby cat adopted by a family of giraffes would grow up to be a giraffe or a cat, and object knowledge, such as whether a photograph and drawing of a object represented the same thing. On the false-belief tasks, the deaf children with deaf parents (native signers) performed as well as the hearing preschoolers. By contrast, the deaf children with hearing parents and the autistic children performed at similar and lower levels. These findings were further replicated in a third study assessing performance on false-belief tasks with the addition of an orally trained deaf group. The orally trained deaf children performed at similar levels to the deaf children with deaf parents. It is important to note that the orally trained children had better hearing than both the other deaf groups (deaf of deaf and deaf of hearing, Peterson and Siegal, 1999). The net results of these studies suggest that language development plays a key role in children's ability to understand the behavior of others. Language appears to be less important to the development of other core domains of knowledge, as shown by the fact that the hearing and deaf groups did not differ on tests of object and biological knowledge.

What is it about language development that fosters the conceptual development known as 'theory of mind?' Peterson and Siegal surmised that the important factor was the number of conversations children are able to have with proficient language users. Two subsequent studies suggest that not only are conversations important, but that overall level of language development is key as well. Courtin and Melot (1998) replicated these findings and added important controls to their investigation of theory of mind in deaf children. First, they eliminated any deaf child who could not follow the instructions. Second, they tested only children with profound hearing losses. Next, they tested five groups of French children. Two groups were hearing children, 4-year-olds and 5-year-olds. Three groups were deaf: one group were 5-year-olds with deaf parents, and two groups were both 7-year-old with hearing parents; one group used sign language and the other was orally trained. The 5-year-old deaf children with deaf parents passed more false-belief tasks than did either the 4- or 5-year-old hearing children or the two groups of deaf children with hearing parents. In turn, the 5-year-old hearing children passed more false-belief tasks children than did the 7-year-old deaf children with hearing parents.

Similar results were found in a large-scale study of deaf children where, unlike the previous studies, their language skills were tested in detail (deVilliers, deVilliers, Hoffmeister and Schick, 2000). Measures of vocabulary and complex grammatical structures in either ASL or spoken English, such as complements and relative clauses, correlated with the deaf children's ability to perform false-belief tasks. This finding suggests that both the ability to name others' motivations via language, which requires a well-developed vocabulary, and the ability to express one's thoughts about others' motivations, which requires complex sentence structure, or syntax, enable children to understand and predict the behavior of others. Deaf children whose language is impoverished show clear and substantial delays in the development of this conceptual domain. The key factor is clearly not deafness. The key factor is well-developed language.

We have seen that childhood deafness has diverse effects on children's cognitive development as a function of early access to language and family and educational environments. Significant numbers of deaf children show very delayed and depressed language development but other deaf children do not. Some deaf children show supernormal visuospatial skills, apparently due to using sign language, but other children do not. How are these diverse patterns of cognitive development related to brain development? Does childhood deafness affect how the brain organizes itself to perform language and non-language cognitive tasks? Researchers have investigated three versions of this question. One line of research asks if there are brain correlates of auditory deprivation and/or sensory compensation. A related line of inquiry asks what regions of the brain process sign language and whether these are the same as those that process spoken language. A third, but little investigated, line of research asks whether and how impoverished language skills affect overall brain organization.

Neuropsychological function

Sensory compensation

A common belief about people who are blind or deaf is that they develop 'extra' perceptual skill in the intact sense to compensate for the impaired sense. In other words, blind people are thought to 'hear' better than sighted people and deaf people are thought to 'see' better than hearing people (Niemeyer and Starlinger, 1981). Recent research has found some evidence in support of this folk wisdom from the standpoint of childhood deafness.

In a series of studies, Neville and her colleagues asked groups of deaf and hearing adults to perform an experimental task requiring detection of movement presented to peripheral vision. They found that congenitally deaf adults who used sign language showed ERPs (event-related brain potentials) that were 5–6 times larger than those of hearing adults over both the left and right occipital regions. These brain regions are normally responsible for visual analysis (Neville and Lawson, 1987a,b,c). In addition, when performing the movement detection task, the deaf adults showed ERPs 2–3 times larger than those of hearing participants over the left temporal and parietal regions (typically responsible for linguistic processing). The greater and more widespread brain activity in response to visual stimuli by the deaf adults as compared to the hearing adults was also apparent behaviorally. The deaf adults were faster and more accurate at detecting movements in peripheral vision than were the hearing adults (Neville and Lawson, 1987a).

In subsequent experiments, Neville and Lawson (Neville and Lawson, 1987b) found that the heightened cortical response to visual stimuli shown by congenitally deaf adults is due in part to knowing and using sign language and not solely due to deafness. They compared the ERPs and behavioral responses of three groups of participants: congenitally deaf adults who used ASL, hearing adults who acquired ASL as a native language from deaf parents, and hearing adults who were unfamiliar with sign language. The three groups responded differently to the movement detection task in the following fashion.

Hearing adults unfamiliar with ASL responded as expected; they showed larger ERPs over the right hemisphere (both the temporal and parietal regions) than the left hemisphere. The right hemisphere is typically involved in spatial processing. By contrast, both the deaf and hearing groups who used ASL showed larger ERPs over the *left* than right hemisphere (Neville and Lawson, 1987a). For people who sign, movement is linguistically salient; ASL grammatical morphemes are made with varying movement trajectories; also signers signal in peripheral vision when they wish to take conversational turns (Swisher, 1993). Because movement patterns are grammatical and pragmatic for people who sign, their brains responded appropriately, i.e., with the language left-hemisphere. Finally, there were also differences in cortical processing between the hearing and deaf groups who used ASL that could then be interpreted as effects specifically related to childhood deafness. The congenitally deaf adults who knew sign language showed larger ERPs over the occipital regions than did the hearing adults who knew sign language (Neville and Lawson, 1987a).

Bosworth and Dobbins (1999) replicated these results by finding strong right-visual field effects (i.e., left hemisphere) for deaf adult signers (who learned by age 6) in a motion detection task when the stimuli were presented to peripheral vision. By contrast, hearing adults unfamiliar with ASL showed strong left-visual effects (right hemisphere). In another study, Bavelier, Corina and Neville (1998) asked deaf native ASL signers and hearing adults unfamiliar with ASL to monitor changes in the luminance of displays of moving dots presented to either central or peripheral vision. Using fMRI (functional magnetic resonance imaging), they found that the deaf native ASL signers showed greater neural responses to motion in peripheral vision than did hearing adults who were non-signers. The greater responses of the deaf native signers were in the motion analysis area of the occipital lobe, namely the MT/MST pathway at the temporal-occipital junction near the anterior and lateral occipital sulci.

What do these findings reveal about the effects of childhood deafness on brain organization? Neville (1993) has interpreted these results to mean that there are separate neurocortical effects for (1) sensory compensation and (2) acquiring a spatial grammar. Childhood deafness produces visual (sensory) compensation in regions of the cortex normally responsible for the visual processing of motion. These cortical areas of the brain respond with significantly more vigor in deaf adults who use ASL than in hearing adults (regardless of whether the hearing adults know sign language or not). In addition, learning and using a spatial grammar and relying on visual pragmatics both prompt the left (language) hemisphere to respond to visual motion patterns, independent of hearing ability. Because the left hemisphere processes language, it treats movement patterns as linguistic stimuli in people who sign. This theoretical interpretation has been supported by the results of two other lines of research, as we described below.

Cortical correlates of sign language processing

Studies of sign language processing allow us to ask the critical question as to whether the language centers of the left hemisphere are specifically specialized for the auditory and oral aspects of language. The alternative possibility is that the left hemisphere language centers of the brain are abstractly specialized for language, independent of sensory–motor modality. One way to answer this question is to investigate individual cases of left- and right-hemisphere brain damage in adult deaf signers. A second way to answer the question is to neuroimage the sign language processing of deaf and hearing signers. Recent research has used both approaches.

Using case studies of brain damage, researchers have asked whether the spatial grammar of ASL is processed by the left hemisphere language centers or by the space/form, motion, and face processing centers of the right hemisphere (for a review see Corina, 1998). Like hearing speakers, deaf signers who suffer lesions to the left posterior temporal region show serious ASL expressive language deficits (Corina, Kritchevsky and Bellugi, 1996). Also comparable to hearing speakers, left anterior temporal lesions in deaf signers result in ASL articulation deficits (Poizner, Klima and Bellugi, 1987). At the same time, these left-hemisphere lesions do not produce visuospatial deficits. In other words, deaf signers show difficulty expressing and articulating ASL as a consequence of left-hemisphere damage but do not show difficulties in recognizing pictures or performing block design or face recognition tasks. By contrast, subsequent to right-hemisphere lesions, deaf signers show marked deficits performing visuospatial tasks, such as picture and face recognition and block design, but no or few deficits in ASL expression and articulation (Corina, 1998; Corina et al., 1996; Poizner et al., 1987). Together these case studies demonstrate a marked dissociation between language and non-language processes in terms of left and right hemisphere function. This is so despite the commonality in visuospatial surface forms for both sign language and non-language tasks such as block design or picture identification. This means that the brain organizes its work by abstract cognitive function and not surface sensory form.

Neuroimaging studies have both corroborated and complicated the overall picture presented by case studies of brain damage in deaf signers. Although case studies find ASL expressive and articulation deficits subsequent to left- but not right-hemisphere lesions, neuroimaging studies conducted to date show both left- and right-hemisphere activation in sign language processing. Some of the conflicting results between these two research paradigms may be due in part to confounding factors related to experimental design, language tasks, and participant controls. However, it is important to know that a similar situation of conflicting results characterizes neuroimaging studies of spoken language (Poeppel, 1996).

In a fMRI study using ASL and English sentences, Neville and her colleagues (Neville, Bavelier, Corina et al., 1998) found that deaf and hearing native ASL signers showed activation in the classic language areas of the left hemisphere, Broca's and Wernicke's areas, when processing ASL sentences. Hearing, native English speakers unfamiliar with ASL showed similar activation patterns in the left-hemisphere when reading English sentences. However, in the ASL task, both the deaf and hearing native ASL signers showed additional activation in the right hemisphere in the areas of superior temporal lobe, the angular region, and the inferior prefontal cortex. When reading English sentences, the deaf ASL natives showed right hemisphere activation, as did the hearing ASL natives but to a lesser extent. The hearing, native English speakers unfamiliar with ASL did not show this pattern of right-hemisphere activation when reading the English sentences.

Right hemisphere activation for sign tasks was also found in a rCBF (regional cerebral blood flow) study by Rönneberg, Söderfeldt and Risberg (1998). Using semantic classification and episodic memory tasks, they found deaf signers to show activation in the right visual association areas, i.e., temporal–occipital. However, the hearing speakers showed activation in the left temporal area when performing the task in speech. Unfortunately, the sign language acquisition histories of the deaf adults were not described in this study, nor were any measures taken of the deaf adults' sign language proficiency. It is thus unclear whether the deaf participants in this study were 'native' or non-native learners of sign.

As previously described, non-native learning of ASL produces substantial differences in ASL comprehension in comparison to native learning (Mayberry and Eichen, 1991; Mayberry and Lock, 2001). It is not clear what activation patterns should be expected for second- versus first-language ASL learners. For example, some PET studies using various tasks requiring lexical search have found identical activation patterns for the first and second spoken language (Klein, Milner, Zatorrre et al., 1995, 1999). By contrast, one ERP study examining the processing of closed class (grammatical) words showed different activation patterns for first as compared to second-languages as a function of age of second-language acquisition (Weber-Fox and Neville, 1996).

Finallly, Petitto and her colleagues (Petitto, Zatorre, Guana et al., 2000) conducted a PET study of hearing adult speakers and adult deaf signers. The deaf adults were native or early learners of either ASL or LSQ (Langue des signes québeçoise, the sign language used among culturally French deaf people in Québec and Ontario). The deaf participants watched either ASL or LSQ syllables, watched ASL or LSQ signs, copied ASL or LSQ signs, and generated ASL or LSQ verbs in response to signed nouns. The hearing adults were native speakers of English and watched the same signed syllables and signed words as the deaf participants; the hearing participants additionally read English nouns and spoke verbs in response. On the verb generation task both the deaf and hearing participants showed activation in the left inferior frontal cortex. When watching the signed syllables and single signs, the deaf participants showed bilateral activation of the superior temporal gyrus but the hearing non-signers did not because the sign stimuli was not linguistic for them.

To summarize, the neuroimaging studies of sign language conducted to date have all found left hemisphere activation in the classical Wernicke and Broca's areas for a variety of sign language tasks in deaf and hearing native signers. As such, the findings corroborate the available case studies of brain damage in deaf signers. Left hemisphere lesions lead to ASL deficits, as has been found to be the case for hearing people who use spoken languages. However, some neuroimaging studies have found varying degrees of right hemisphere activation associated with sign language processing for which no satisfactory explanation has been offered to date. These conflicting results could be due to a variety of factors including different imaging methods and linguistic tasks in addition to possible differences in the early language histories of the participants. Also, it is important to note that the case studies of left- and right-hemisphere lesions are primarily studies of ASL expression whereas the neuroimaging studies are mostly studies of ASL comprehension. Considerably more research is required to determine what the right hemisphere contributes to sign language processing (and/or reading) and how a late age of acquisition affects this pattern. This will be a complex endeavor because, on the one hand, the right hemisphere processes aspects of language in hearing people including features of prosody and discourse. In addition, the right hemisphere also processes non-language, visuospatial information as in recognizing objects and faces in hearing and deaf people.

Although significant progress has been made in understanding the neurocortical correlates of auditory deprivation and sign language processing, we still know very little about how the severe language delay and deprivation that can accompany childhood deafness affects cortical organization. We now turn to this question.

Congenital deafness and hemispheric dominance

Using EEG patterns to create topographical maps of cortical function, Wolff and Thatcher (1990) studied 79 deaf children and a matched group of hearing children 6–16-years-old. Half the deaf children were genetically deaf and the other half were exogenously deaf (whom the researchers classified as 'neurologically at risk'). Based on the assumptions of their EEG coherence model, both deaf groups showed more neuronal differentiation (maturation) over the occipital (visual) regions than did the hearing children. The deaf groups also showed greater differentiation over the right hemisphere than the hearing children. These findings corroborate Neville's research showing that childhood deafness produces sensory compensation, or enhancement, in the areas of the cortex normally responsible for visual and spatial processing, described above.

Wolff and Thatcher (1990) observed another difference between the deaf and hearing children.

Again, based on the assumptions of their EEG model, the deaf children showed less neuronal differentiation (maturation) over the left and right frontal lobes than the hearing children. Reduced frontal lobe differentiation was also related to the groups' behavior. Both the genetically and exogenously deaf children scored one standard deviation higher than the matched group of hearing children on a hyperactivity measure. Finally, they observed that both deaf groups showed less neuronal differentiation (maturation) over the left (language) hemisphere than did the hearing children. They reported that this finding was consistent with several previous studies reporting reduced left-hemisphere dominance for language among deaf children as compared to hearing children (see for example, Ashton and Beasley, 1982; Gibson and Bryden, 1984; Marcotte and LaBarba, 1985, 1987). The repeated finding that, as a group, deaf children show reduced left-hemisphere dominance for language is likely due to their delayed and fragmentary exposure to language in early childhood. The sign language skills of the deaf children who participated in these studies were not tested, however. Another of Wolf and Thatcher's (1990) findings supports this interpretation. They found that the deaf children with deaf parents, i.e., native ASL signers, showed greater differentiation (maturation) over the left hemisphere than did the deaf children with hearing parents (both genetically and exogenously deaf). Clearly, future research investigating the effects of childhood deafness on cortical organization with other neuroimaging paradigms is required and must carefully measure and describe the sign language skills of the participants under study.

Other research has reported a higher incidence of left-handedness among deaf children. This may be related to the reduced left-hemispheric dominance for linguistic processing among deaf children, as a group, as a consequence of their pervasive language delay and deprivation. For example, in a study of 226 deaf high school and college students and 226 hearing students, Bonvillian, Orlansky and Garfield (1982) found 15% of the deaf students to be left-handed but only 10% of the hearing students to be left-handed. Approximately 10% of the hearing population is left-handed. Conrad (1979) reported a similar incidence of sinistrality among deaf British high schoolers — 17%. A higher incidence of sinistrality for deaf as compared to hearing children has also been found for deaf children in India (Ittyerah and Sharma, 1997). Bonvillian et al. (1982) noted that over 85% of the deaf left-handers in their study first learned to sign at 8 years of age or later. They speculated that delayed language acquisition contributes to left-handedness. In a study of children acquiring ASL from their deaf parents, Bonvillian, Richards and Dooley (1997) observed that the 24 preschoolers showed a marked right-hand preference when signing as compared to when they were performing non-language tasks. They further found that hand dominance among the ASL learning children was related to measures of motor development rather than language acquisition. Finally, there are other possible explanations for the higher incidence of left-handedness in the deaf school-aged population. For example, the left-handers identified in the Bonvillian et al. study also had a greater incidence of exogenous deafness than the right handers. This factor is important because the incidence of left-handedness is greater for brain-damaged individuals than for the general population. In addition, these deaf children may have experienced less pressure to be right-handed than is typical for hearing children.

In sum, we know little about the effects delayed and impoverished language acquisition on brain organization, although it is common phenomenon among children born deaf. Much more research is required to tease apart the cortical correlates of sensory compensation, sign language acquisition and use, and language deprivation in early life.

Summary

Now we return to the question with which we started. What does hearing contribute to the child's cognitive development? We have seen that children who are born deaf frequently experience severely delayed and impoverished language development regardless of mode of expression, that is, spoken language or sign language. The delayed and depressed language development of deaf children, as a group, is not caused by, and does not cause, general intellectual deficiencies in cognitive domains that function independent of language. This fact demonstrates that language and non-language cognitive development is dissociable to a large degree. Deaf children show normal early play behavior and conceptual development in comparison to hearing children. Deaf children also show normal performance on nonverbal IQ tests. Deaf children and adults who use sign language often show above average performance on several kinds of visuospatial tasks, including face recognition, block design, movement detection, and spatial memory, although the degree to which these effects are dependent upon age of sign language acquisition is currently unknown.

The language difficulties endemic to the population of children who are born deaf are completely preventable and caused by a lack of exposure to accessible linguistic input at the right time in human development, namely infancy and early childhood. The language difficulties caused by postponing exposure to accessible language until late childhood and adolescence are permanent and not ameliorated by substituting sign language for spoken language at an older age. Deaf children's significantly delayed language development, in sign or speech, leads to poor reading achievement; on average it is lower than literate levels. However, many deaf children read as well as their normally hearing peers; successful reading achievement can be based on either successful spoken language development or successful sign language development. Deaf children's incomplete language development also delays their ability to understand the motivations and actions of other people. The possible negative ramifications of the all too common language problems of deaf children on complex cognitive action in adulthood are unknown. However, it is clear that deaf people as a group are remarkably adept and clever at leading independent lives despite stupendous obstacles, more so than most other disadvantaged groups (Jacobs, 1989; Schein and Delk, 1974).

The study of deaf children has given us numerous insights into the nature of neurocognitive development of all children. Deaf children have shown us that the human mind is characterized by enormous linguistic creativity. When language is unavailable, the child's mind invents one (home sign). When groups of people are cut off from auditory language, they spontaneously use a visual one (sign language). Deaf children have also shown us that the human brain is remarkably flexible and not fooled by superficial differences in sensory form. The brain allocates labor by abstract function, not sensory perception. Whether the left or right hemisphere processes spatial information depends upon whether the information serves a linguistic function or not. The left hemisphere processes language even when it is visual and spatial. Finally, the young brain is very plastic and works to capacity. When auditory information is unavailable, the brain allocates more of its resources to the processing of peripheral visual information.

Although deaf children have taught us a great deal, numerous questions remain. Little is known about the neurocognitive development of deaf children who mature in linguistic and/or social isolation. Little is known about how deaf children learn to read. Little is known about how poverty affects the development of deaf children. Little is known about the emotional development of deaf children in relation to their language development or lack thereof. How does congenital deafness affect human development? Both profoundly and not at all.

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?#1: Geers and Moog (1988) not in the reference list. (page 87)
?#2: Geers and Moog (1988) not in the reference list. (page 87)
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1 2002 Elsevier Science B.V. All rights reserved Handbook of Neuropsychology, 2nd Edition, Vol. 8, Part II S.J. Segalowitz and I. Rapin (Eds) CHAPTER 4 Cognitive development in deaf children: the interface of language and perception in neuropsychology Rachel I. Mayberry * School of Communication Sciences and Disorders, McGill University, 1266 Pine Avenue West, Montreal, PQ H3G.Â Cognitive development is the product of the child s attempts to understand the family, neighborhood, school and the world at large during this period of rapid brain growth and learning.Â By contrast, poor deaf children are at a high risk for not being exposed to accessible language at the right time in early childhood.