*Signed and Spoken Language: A Unique Underlying System?**

SHARON PEPERKAMP and JACQUES MEHLER

EHESS—CNRS, Paris

ABSTRACT

Sign language has only recently become a topic of investigation in cognitive neuroscience and psycholinguistics. In this paper, we review research from these two fields; in particular, we compare spoken and signed language by looking at data concerning either cortical representations or early acquisition.

As to cognitive neuroscience, we show that clinical neuropsychological data regarding sign language is partially inconsistent with imaging data. Indeed, whereas both clinical neuropsychology and imagery show the involvement of the left hemisphere in sign language processing, only the latter highlights the importance of the right hemisphere. We discuss several possible interpretations of these contrasting findings.

As to psycholinguistics, we survey research on the earliest stages of the acquisition of spoken language, and consider these stages in the acquisition of sign language. We conjecture that under favorable circumstances, deaf children exploit sign input to gain entry into the language system with the same facility as hearing children do with spoken input.

More data, however, are needed in order to gain a fuller understanding of the relation of different kinds of natural languages to both the underlying anatomical representations and their early acquisition.

INTRODUCTION

All biological phenomena are assumed to have an evolutionary history by which their structure is determined. Therefore, understanding the biology of language requires, among other things, an account of the evolutionary history that resulted in the unique grammatical ability of the human species. In his book *The Language Instinct*, Steven Pinker writes:

> Newborn babies, like other mammals, have a larynx that can rise up and engage the rear opening of the nasal cavity, allowing air to pass from nose to lungs avoiding the mouth and throat. …This gives the tongue the space to move both up and down and back and forth, changing the shape of two resonant cavities and defining a large number of possible vowels. But it comes at a price. In *The Origin of Species* Darwin noted "the strange fact that every particle of food and drink which we swallow has to pass over the orifice of the

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trachea, with some risk of falling into the lungs" …The positioning of the larynx deep in the throat, and the tongue far enough low and back to articulate a range of vowels, also compromised breathing and chewing. Presumably the communicative benefits outweighed the physiological costs.   (Pinker, 1994, p. 354)

This suggests that spoken languages have a communicative benefit over gestural systems. For instance, spoken language allows communication in which the speaker uses his hands for other purposes and the addressee does not see the speaker. The question, then, is to what extent the structure of language reflects the requirements of the auditory and vocal modalities as instantiated in spoken language. A comparison between the biology of sign language and that of spoken language can shed light on this question. Specifically, if the cortical substrates of spoken and signed languages coincide, one might conjecture that those languages are mediated by the same "language organ" (cf. Chomsky, 1980). Likewise, if spoken and signed languages are acquired in the same way, one might argue that the "language organ" of the hearing and that of the deaf are triggered by the same abstract properties.

Research on the biological foundations of language has mainly focused on spoken language; this state of affairs is not surprising, given the dominant position of spoken languages. The recent (psycho)linguistic interest in sign language was rekindled by the seminal work of Klima and Bellugi (1979). In this paper, we review research that focuses on two aspects of the comparison between signed and spoken language: cortical representation and early stages of acquisition.

THE CORTICAL REPRESENTATION OF LANGUAGE

Classical neuropsychology has taught us that language is, by and large, mediated by the left hemisphere (LH) (Geschwind & Galaburda, 1985; Geschwind & Levitsky, 1968). The asymmetry of the Planum Temporale (PT) in humans, according to which the left hemisphere's PT is larger than the right one, has often been viewed as part of the cause for the association of language with human brains (Geschwind & Galaburda, 1985). Recently, however, it was shown that in the chimpanzee *Pan troglodytes*, a not so distant cousin of man, the PT is as asymmetrical as in humans (Gannon, Holloway, Broadfield, & Braun, 1998). Therefore, although the asymmetry of the PT might be a necessary condition for the emergence of language, it is not a sufficient condition.

The LH involvement with language seems, however, well grounded within the clinical neuropsychological literature. In particular, lesions of the LH all too often result in aphasia; aphasia following lesions of the right hemisphere (RH), by contrast, is a rare phenomenon (cf. Gazzaniga, 1989; Geschwind, 1979; Lecours, Lhermitte, & Bryans, 1983). These observations are corroborated by cortical activation studies using brain imaging (Dronkers, 1996; Mazoyer, Dehaene, Tzourio, Frak, Murayama, Cohen, Levrier, Salamon, Syrota, & Mehler, 1993). There is still debate, however, as to whether the observed lateralization is the consequence of language acquisition, or whether, conversely, it enables language acquisition to begin with. Lenneberg (1967) argued that the brain is initially equipotential, since children recover from aphasia more frequently than adults. Equipotentiality, however, is not the only possible explanation for the recovery from aphasia. Rather, this fact might just attest to the greater plasticity of younger brains (Witelson, 1987), an alternative that goes well

with the finding that functional asymmetries are already present in neonates (Bertoncini, Morais, Bijeljac-Babic, McAdams, Peretz, & Mehler, 1989; Best, 1988).

Lesion studies have ceased to be the only window to the biological basis of language. Nowadays, the cortical activity in healthy volunteers producing or perceiving utterances can be studied by means of modern brain-imaging technology. In this section, we present results obtained with these new methods regarding spoken and signed languages, respectively. In particular, we show that whereas there is strong evidence that spoken languages are processed mainly in the LH, research concerning sign language suggests that the RH might be equally involved in language processing.

The cortical representation of spoken language

The advent of brain imaging is opening new vistas and providing new data, thus improving our understanding of the biological basis of language (Frackowiak & Friston, 1994). Crucially, it allows us to study how language is represented in the brain of healthy volunteers. A number of brain imaging procedures have become available, which can be classified into two broad families. The first involves methods that measure the electric activity of neuron populations. The best known methods are Event Related Potentials (ERP) and Magnetic Encephalography (MEG), which have an excellent temporal resolution but a less accurate spatial resolution. The second class of procedures measures regional cerebral blood flow changes associated with neuronal activity. It includes Positron Emission Tomography scan (PET) and functional Magnetic Resonance Imaging (fMRI). These methods have great spatial precision, but their temporal resolution needs to be improved.

The first imaging studies of language were mostly carried out while volunteers read words or short sentences (Peterson, Fox, Snyder, & Raichle, 1990; Posner & Raichle, 1994). Mazoyer et al. (1993) were among the first to explore brain activation of volunteers who listen to spoken sentences. They carried out a study using Positron Emission Tomography (henceforth: PET), in which volunteers listened to short stories in French, their native language, or Tamil, a language with which they were unacquainted. When listening to French, the volunteers showed increased activity in many sites of the LH and a modest increase in activation over restricted areas of the RH. The former, by and large, coincide with the classical language areas established in clinical neuropsychology. When the volunteers listened to Tamil, by contrast, a limited symmetrical cortical activation was observed.

Mazoyer et al.'s study did not investigate whether the LH was activated because French was the volunteers' native language (L1) or just because the volunteers understood the stories in French. In order to explore this issue, other brain imaging studies were carried out, comparing the representation of native and non-native languages. First of all, Perani, Paulesu, Sebastian-Galles, Dupoux, Dehaene, Bettinardi, Cappa, Fazio, & Mehler (1996) used PET to study volunteers who were listening to stories in their native language (L1), that is, Italian; to a second language (L2) acquired after the age of seven, that is, English; and an unknown language, that is, Japanese. Although the volunteers had reached only a moderate mastery of English, they had no difficulty understanding the stories in English. Perani et al. found that L1 activated the classical LH language areas, while L2 and the unknown language gave rise to much more reduced activation; in particular, fewer areas in both the LH and the RH reached significant activation. The authors speculated that whereas L1 yields roughly

the same pattern of cortical activity across volunteers, L2 has a representation that is quite varied from one person to the next.

Second, in order to investigate whether the conjecture of Perani et al. (1996) is pertinent, Dehaene, Dupoux, Mehler, Cohen, Paulesu, Perani, Moortele, Lehiricy, & Bihan (1997) explored the representation of L1 (French) and L2 (English) in bilinguals[1] whose proficiency in English is comparable to that of those who participated in the Perani study. Dehaene et al. used Functional Magnetic Resonance Imaging (henceforth: fMRI), a method that is more suited to studying the cortical activity in individuals. They confirmed that while L1 is similarly represented in all volunteers, the cortical activation of L2 varies considerably from one person to the next. Moreover, there appeared to be no region that showed an increase of activity in all volunteers in response to L2. By contrast, L1 yielded an increase of activity in the classic language areas of the LH, including the superior and midtemporal gyri as well as the superior temporal sulcus. Analogously to the volunteers in the Perani study, Dehaene et al.'s volunteers had acquired L2 after the age of seven.

Third, Perani, Paulesu, Sabastian-Galles, Dupoux, Dehaene, Bettinardi, Cappa, Fazio, & Mehler (1998) studied the cortical representation of L1 and L2 in highly proficient bilinguals. Their aim was to evaluate whether the representations of L1 and L2 are affected by age of acquisition in people who have attained a very high level of proficiency. They thus studied both early and late high-proficiency bilinguals. Early bilinguals were Spaniards living in Barcelona who had learned Spanish and Catalan before the age of four. They had continued to use both Spanish and Catalan in a very balanced fashion throughout life until they were tested. Late bilinguals were Italians who had learned English after the age of ten but who had mastered it so well that they were capable of working as interpreters (which some of them actually did for a living). Early and late bilinguals were studied with PET scan while they listened to stories in L1 and L2. Rather similar cortical representations of L1 and L2 were observed in both groups. Perani et al. (1998) concluded that the differing cortical activation observed for L1 and L2 in the 1996 study were due to the low level of proficiency of L2 rather than to the advanced age of acquisition of L2.

Finally, Kim, Relkin, Kyoung-Min, and Hirsch (1997) obtained results that are compatible with the observation that the cortical representations of L1 and L2 overlap more as the proficiency in L2 increases. In this functional fMRI study, volunteers with different first and second languages were asked to generate silent speech in either L1 or L2. Kim et al. found that the cortical representations of L1 and L2 were indistinguishable in volunteers who have acquired L2 early in life. Late bilinguals, by contrast, had spatially separated representations for L1 and L2 in Broca's area but similar representations in Wernicke's area. The latter result contrasts with that of Dehaene et al. (1997), who found separate representations for L1 and L2 in Wernicke's area for low proficiency bilinguals. It should be noted that the results of Kim et al. cannot be directly compared with those of Perani et al. (1998). Whereas the volunteers in Perani et al.'s study listened to stories, those in Kim et al.'s study produced silent speech. Speech production tasks are usually associated with activity over Broca's area, the language production center. The differences found in this area by Kim et al., therefore, do not conflict with the fact that Perani et al. observed

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[1] Bilingualism is not an all or none concept. In this paper, we distinguish between low-proficiency bilinguals, who have moderate mastery of a second language, and high-proficiency bilinguals, whose mastery of the second language is virtually as good as that of their native language.

similar cortical representations for spoken language processing.

In summary, the results of Kim et al. (1997) and Perani et al. (1998) indicate that the language centers of the left hemisphere participate in the processing of spoken L1 and L2 in people who have attained a high degree of proficiency in L2. In other words, all spoken languages appear to rest on tissue that spans designated areas of the LH. In all of the perception experiments, however, significant activations were also found in the RH temporal lobe, although these activations were much less extensive than those in the LH.

We can now inquire whether sign language is represented as any other natural language or whether the modality of expression of a language plays a critical role in the cortical representation observed in imaging studies; if the latter is true, one expects to observe a different pattern for sign language. Below, we turn to studies that have tried to determine the cortical representation of sign language.

The cortical representation of sign language

We will first review studies of deaf patients who have suffered brain damage, suggesting that sign languages, much like spoken languages, are basically processed by the LH. We then focus on investigations that have tried to determine the representation of sign language processing by healthy volunteers using brain imaging methods.

Poizner, Klima, and Bellugi (1987) studied aphasia in six ASL patients, only four of whom were native signers. Hickok, Bellugi, and Klima (1996) carried out a similar study on 23 right-handed ASL signers with unilateral brain lesions. Of these, 13 had a LH lesion and 10 had a RL lesion. In both groups, four patients were native signers of ASL. All others had learned ASL before the age of 13. The outcome of this study is that only patients with an injured left hemisphere become severely aphasic, supporting the view that sign languages rely on similar cortical structures as spoken languages. Independent evidence in favor of this hypothesis is provided by Hickok, Kritchevsky, Bellugi, and Klima (1996), who studied a congenitally deaf patient with severe expressive aphasia. Crucially, this patient was shown to have a LH lesion involving parts of the insula, a finding that parallels results obtained with hearing aphasics. Indeed, Dronkers (1996) reports that all hearing patients with speech production difficulty following trauma have brain damage that includes parts of the LH's insula. If the insula is spared, by contrast, similar lesions to the LH do not give rise to production difficulties. Granted, a single case cannot be taken as definitive evidence that the language production areas are identical in speakers of spoken and signed languages. The correspondence, however, is quite striking, and we tentatively conjecture that the production of both spoken and signed languages relies upon the left insula.

Finally, Damasio, Bellugi, Poizner, and Gilder (1986) studied a 27 year old hearing sign language interpreter who had learned ASL at age 18, before and after a right temporal lobectomy was performed. Prior to the operation, an anesthetic was injected into the patient's LH. This produced a transient aphasia for both languages, English and ASL, suggesting a similar involvement of the LH with spoken and signed languages. Due to medical circumstances, no injection could be applied to the right side. After the partial removal of the right temporal lobe, the patient's language ability was intact. Indeed, neither her English nor her ASL performance was reduced. Again, although this single case study is insufficient to draw definitive conclusions, it suggests that the LH is involved with the processing of natural

languages regardless of the modality with which they are perceived or produced. This suggestion can now be evaluated in greater detail with the help of brain imaging methods.

In the past few years, in fact, the cortical representation of sign language has been compared to that of spoken language in healthy volunteers. For instance, Soderfeldt, Ronnberg, and Risberg (1994) studied Regional Cerebral Blood Flow in nine Swedish people who had normal hearing but were born to deaf parents. They were asked to comprehend passages of a novel presented in signed or spoken language. The authors found that the posterior temporal lobe was bilaterally activated by language, irrespective of modality. Similar results were found in a more recent study (Soderfeldt, Ingvar, Ronnberg, Eriksson, Serrander, & Stone-Elanger, 1997), which relied on PET. In particular, the authors reported bilateral activation for both spoken and signed language in the perisylvian cortex, which includes the posterior temporal lobe.

The studies by Soderfeldt et al. are a challenge to the long held claim that language is more associated with the LH than with the RH. That is, they clearly suggest that the LH and the RH become equally active in response to language in the brains of bilinguals with a spoken and a signed language, regardless of the modality used. This is a surprising result that was not obtained in the PET studies on the representation of spoken languages, as discussed above. Recall, in fact, that the latter found only a limited amount of RH activity in response to utterances; the activity in the LH was much more important. Soderfeldt et al.'s data concerning the RH involvement when volunteers process sign language is equally interesting and hard to explain. Fortunately, this result can be compared to other recent imagery studies, to which we turn now.

Neville, Coffey, Lawson, Fischer, Emmorey, & Bellugi (1997) carried out an Event Related Potentials study (ERP) with three groups of volunteers. One group consisted of congenitally deaf native signers of ASL. Another group was composed of hearing people born to deaf parents who learned ASL and English at the same time during their earliest infancy. Finally, the third group consisted of speakers of English who either had learned ASL late in life or were unacquainted with ASL altogether. All groups were presented with sentences in either ASL or English. ASL sentences were presented on a video screen, while English sentences were presented word by word on a computer screen. Neville et al. (1997) reported that, independently of modality, very similar neural systems are involved, although early sensory deprivation obliges the congenitally deaf to depend more on posterior temporal and occipital areas of the cortex. Crucially, as in the study by Soderfeldt et al., Neville et al. (1997) found that early acquisition of ASL results in bilateral representation of speech, regardless of whether the speakers are hearing or deaf.

Although ERP is an excellent tool to evaluate the temporal unfolding of processing, it cannot be used as reliably to determine the spatial layout of the sites that participate in these processes. Therefore, studies using methods with better spatial resolution, such as fMRI or PET, are desirable to further investigate the cortical representation of ASL. Neville, Bavelier, Corina, Rauschecker, Karni, Llalwani, Braun, Clark, Jezzard, & Turner (1998) thus used fMRI to compare the processing of ASL and English. As in the ERP-study, English sentences were presented word by word on a computer screen, and ASL sentences were presented on a video screen. Baseline conditions were defined by the processing of "sentences" consisting of consonant strings or nonsigns, respectively. Three groups of volunteers participated in this study. The first group included hearing native speakers of

English who were unacquainted with ASL. The other two groups consisted of deaf and hearing native signers of ASL, respectively. Of these, only the latter had attained native-like English. These people, in fact, had been born to deaf parents and had been raised in a family of ASL signers. Given that they had also interacted in English since very early childhood, they became ASL-English bilinguals with equally high levels of proficiency in both languages. Volunteers in all three groups appeared to process their native language in the classical LH language areas found in so many other studies (cf. Geschwind, 1970; Mazoyer et al., 1993). Furthermore, when processing ASL, both hearing and deaf native signers showed an increase in activity in sites of the RH that are homologous to the LH language areas. In the hearing native signers of ASL, English activated the LH only; ASL, by contrast, activated equally both hemispheres. Thus, in highly proficient English-ASL bilinguals, English is associated with the LH, while ASL is associated with both the RH and the LH. This last result contrasts remarkably with the findings of Kim et al. (1997) and Perani et al. (1998), concerning highly proficient bilinguals with two spoken languages. Recall that the latter studies reported very similar representations of L1 and L2, mostly confined to the LH. In other words, it appears that the languages of bilinguals with two spoken languages are represented in overlapping sites of the LH, whereas the languages of bilinguals with a spoken and a signed language exploit the same LH resources but diverge in how much they exploit the RH; crucially, the RH is mostly related to ASL processing.

Neville et al's. (1997, 1998) results should be compared to two more studies. First, McGuire, Robertson, Thacker, David, Kitson, Frackowiak, & Frith (1997) used PET to study profoundly deaf volunteers who produced "inner signing" of sentences. The activated region, in the left inferior frontal cortex, corresponded to the one that was engaged during the silent articulation of sentences in hearing subjects. This suggests that "inner signing" and "inner speech" are mediated by similar regions. Second, at the 1998 Society of Neuroscience, Petitto and Marentette at McGill University reported results of a study involving the perception of single words or signs, as well as the generation of verbs in response to nouns. They found that the same sites, engaging mostly the classical LH language areas, mediate language processing, irrespective of modality. Thus, the results of McGuire et al. and Petitto et al. suggest, contrary to Neville et al., that classical LH areas are devoted to the processing of abstract linguistic properties found in all natural languages, such as distributional and temporal patterns, rather than to the processing of speech or sign per se. Note, however, a salient difference between the Neville et al. study and the other two studies: Neville and her colleagues explored sentence perception, whereas McGuire et al. and Pettito et al. used language production or single word processing. This difference might be responsible for the contrasting results and hence, no definitive conclusion regarding the function of the activated sites in the brain can be drawn.

The findings reported so far have two possible interpretations: Either brain imaging methods are still not good tools to discover which areas of the brain are associated with what abilities, or, alternatively, spoken and signed languages partially rely on different cortical circuitry. The first option, that is, brain imaging is not an optimal tool to explore the association of cognitive abilities with the brain, cannot be rashly dismissed. In fact, it might be unwarranted to infer from the increase of cortical activity in a certain site that this site participates actively in the performance of the task. Indeed, the site could be accidentally associated with the performance of the task without actually participating in the computations necessary to

accomplish it. We would thus need to explore whether the neutralization of a site leaves the behavior unaltered or knocks it out. Unfortunately, we presently lack this kind of data.[2] The second option, that is, spoken and signed languages use partially different cortical circuitry, raises the issue of the interpretation of clinical neuropsychological data. It would thus remain to be explained how to reconcile neuropsychological data with imaging data.

Much more research is needed before we can gain a better understanding of the biological basis of spoken and signed languages. However, the reader may well appreciate that the new brain imaging methods we have illustrated have already sharpened the issues.

LANGUAGE ACQUISITION IN PREVERBAL INFANTS

In order to understand the biological underpinnings of language, one has to gain a better understanding of the species' endowment for acquiring language. In particular, does the infant look for language structures in any input that is compatible with universal rhythmical properties, or is one of the modalities more prominent? That is, does the child turn to the visual modality only in the absence of auditory input?

Whereas psycholinguists have carried out many studies to understand spoken language acquisition in preverbal infants, they have devoted a relatively modest effort in exploring the very first stages of sign language acquisition. In this section, we will first present an overview of data regarding spoken language acquisition, and then turn to sign language acquisition in preverbal infants.

The acquisition of spoken language

Spoken language acquisition in preverbal infants has been described in great detail in Jusczyk (1996) and Mehler and Dupoux (1994). These studies show that human infants are born with the competence to discriminate and classify all the phonetic contrasts that occur in natural languages (Eimas, 1974, 1975; Eimas, Siqueland, Jusczyk, & Vigorito, 1971). Moreover, infants are born with an exquisite sensitivity for rhythmic and other prosodic properties of natural languages. For instance, at birth, they notice when a speaker changes from one language to another. This ability persists when the stimuli are highly filtered, such that most segmental information is missing, leaving only prosodic properties as good candidates for cues that infants may rely on (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, & Amiel-Tison, 1988).

During the first year of life, infants acquire many phonological properties of their native language and lose their sensitivity to phonological contrasts that are not pertinent. For instance, at six months, they have acquired the prototypical vowels of their language (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992) and start to lose their sensitivity for non-native vowel contrasts (Polka & Werker, 1994). Similarly, at eleven months, they know the consonants of their language and no longer discriminate non-native consonantal contrasts

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2 Recently, Cohen et al. (1997) used transcortical magnetic stimulation to investigate whether the visual cortex of congenitally blind volunteers participates in the discrimination of somatosensory inputs. One would hope that similar experiments will soon be carried out in order to explore the role of the RH in native signers of ASL.

(Werker & Tees, 1984). Furthermore, at seven months, infants begin to segment continuous speech into separate words (Jusczyk & Aislin, 1995). Finally, at nine months, infants are sensitive to lexical statistics and phonotactic properties pertaining to their language. That is, Jusczyk, Cutler, and Redantz (1993) found that English-acquiring infants of this age prefer to listen to disyllables with the metrical pattern that is predominant in English, that is, with stress on the first rather than on the second syllable. Jusczyk, Luce, and Charles-Luce (1994) found that, similarly, infants prefer to listen to monosyllables with phonetic patterns that occur frequently in English, rather than to those with infrequent phonetic patterns.

The most detailed proposals regarding language acquisition are based upon the assumption that all natural languages are instances of Universal Grammar, which consists of a set of innate principles and parameters. All the child has to do in order to acquire language, then, is determine the parameter settings that hold in the language s/he is exposed to (Chomsky, 1981). Although much progress has been made within this framework (cf. Roeper & Williams, 1987; Wanner & Gleitman, 1982; Wexler & Culicover, 1980), some paradoxes and difficulties have been observed. In particular, as pointed out by Mazuka (1996), it is still unclear how infants set their first, basic, parameters. An important question thus concerns the bootstrapping of language acquisition: what allows infants to begin to learn words and set grammatical parameters? According to the phonological bootstrapping hypothesis, infants start acquiring the lexicon and the syntax of their native language by relying on phonological cues present in the speech signal they are exposed to (cf. Morgan & Demuth, 1996).

As to lexical acquisition, a necessary condition for infants to use prosodic cues to begin to segment speech and, hence, learn words during the first year of life is that they perceive these cues. Christophe, Dupoux, Bertoncini, and Mehler (1994) thus tested the sensitivity of newborns to word boundaries. They found that three-day-old infants can indeed discriminate between disyllabic stimuli that contain or do not contain a word boundary. Saffran, Aslin, and Newport (1996) showed that eight-month-old infants can segment speech on the basis of statistical cues only, relying on the fact that transitional probabilities from one phoneme to another are generally higher if the phonemes are part of the same word than if a word boundary occurs between them. Thus, access to prosodic cues is not a necessary condition for the onset of speech segmentation.

As to the bootstrapping of syntactic acquisition, both Mazuka (1996) and Nespor, Guasti, and Christophe (1996) propose that infants make use of prosodic correlates to set the value of a syntactic parameter, that is, the head direction parameter, which specifies whether heads precede or follow their complements. Specifically, Nespor et al. base their proposal on the fact that in right-recursive languages, that is, languages with heads that precede their complements, the most prominent word in the phonological phrase is always the rightmost one; and contrarily, in left-recursive languages, that is, languages with heads that follow their complements, the most prominent word in the phonological phrase is always the leftmost one (Nespor & Vogel, 1986). Therefore, in order to set the head direction parameter, infants only need to establish whether the prominence is at the beginning or at the end of phonological phrases. Preverbal infants, then, should be sensitive to phonological phrase boundaries as well as to the relative prominence relation within phonological phrases. This hypothesis is currently being tested experimentally by Christophe et al. (pers. comm.), and the initial results are encouraging.

No experimental research concerning the phonological bootstrapping hypothesis has yet been carried out with regard to sign language acquisition. Several other findings concerning the earliest stages of sign language acquisition, though, have been reported. The remaining part of this section is dedicated to these findings.

The acquisition of sign language

In two studies on ASL by Carroll and Gibson (1986) and Schley (1991), it is shown that at four months, hearing infants possess certain prerequisite perceptual abilities that are necessary to acquire a sign language. Carroll and Gibson tested infants by means of a habituation-recovery method on near minimal pairs of signs. Infants discriminated between certain signs that differ only in a single underlying movement dimension. In particular, they discriminated between LEFT and LIBRARY. These signs both consist of a single, nonrepeated movement, but whereas the movement in LEFT is nonrotating, the one in LIBARY is rotating. However, infants failed to discriminate between WHERE and SCOLD, which differ in the plane in which the movement is made. In the former, this is parallel to the frontal plane of the signer's body, while in the latter, it is perpendicular to that plane.

Similarly, Schley (1991) investigated the ability of four-month-old hearing infants to discriminate and classify movement contrasts that are used to mark inflectional categories in ASL. During the habituation phase, infants saw three different forms of the verb LOOK-AT, marked for temporal aspect, for instance "to look at something *for a long time*," or "to look at something *over and over again*." After reaching the habituation criterion, two new inflected forms of LOOK-AT were shown. One of these novel signs belonged to the same class as those in the habituation set, hence, it was marked for temporal aspect. The other one, by contrast, was marked for distributional aspect, for instance "to look at a group *as a whole*" or "to look at *individuals within* a group." In ASL, temporal aspect is marked by a movement that repeats a cycle articulated in the median plane, whereas distributional aspect is marked by a movement consisting of one cycle with internal iterations, articulated in either the frontal or the horizontal plane. Hence, signs from the temporal aspect class and those from the distributional aspect class differ in their movement. Crucially, the infants looked longer at a sign from a novel inflectional class than to a new sign drawn from the old class. Thus, by the age of four months, even without any exposure to sign language, infants have the ability to perceive an invariant in movement in signs drawn from ASL, hence to classify movement contrasts. Interestingly, this result parallels findings in developmental psycholinguistics for spoken language reported above, which showed the capacity of infants to discriminate any phonetic contrast that occurs in spoken language.

Several studies address the issue of babbling. For instance, Petitto and Marentette (1991) show that deaf children, like hearing children, go through a babbling stage: While hearing infants babble by making sounds with their vocal apparatus, deaf children babble with their hands. These preliminary results suggest that prosody and rhythm may play a similar role in the acquisition of signed and spoken languages. Deaf infants typically also show a limited amount of vocal babbles, which are characterized by less variation in form and a more reduced set of phonemes with respect to the vocal babbles of hearing children (Oller & Eilers, 1988). Petitto and Marentette report that hearing children produce instances of manual babbling though not as frequently as deaf infants. Moreover they use fewer phonetic units than do deaf infants. Meier and Willerman (1995), by contrast, collected data

suggesting that the manual babbling of hearing children who have no sign input is relatively frequent. They relate this possible asymmetry between deaf and hearing infants to, among other things, the fact that hearing children without sign input receive visual feedback from their own babbles, whereas deaf children lack auditory feedback from their vocal babbles.

Although large-scale studies concerning children's acquisition of signed languages are missing, there is evidence suggesting that the acquisition of signed languages is equally fast and follows the same developmental path as that of spoken languages. In particular, the timing of milestones for signed languages largely coincides with that for spoken languages (Meier & Newport, 1990; Newport & Meier, 1985). One possible exception to this generalization concerns the earliest milestones; that is, signing children appear to produce their first lexical item and reach a ten-word vocabulary almost two months earlier than speaking children (Bonvillian, Orlansky, & Novack, 1983; Folven & Bonvillian, 1991; Orlansky & Bonvillian, 1984, 1985). Given that the data is gathered with only two small groups of subjects, involving nine and 13 children respectively, more research concerning the one-word stage of signing children would be welcome in order to evaluate the reported findings. While iconicity of signs is not believed to explain an early advantage, several other factors have been suggested in order to account for it (Newport & Meier, 1985; Orlansky & Bonvillian, 1985). First, signs might be easier to perceive than spoken words, due to earlier maturation of the visual cortex than of the auditory cortex. Second, signs might be easier to produce, if motor control of the hands matures earlier than that of the vocal apparatus. Third, the finding might be an artifact, reflecting that first signs are easier to recognize than first words by the adult observer.

CONCLUSION

Cognitive neuroscientists and psycholinguists have only recently begun to compare and contrast spoken and signed languages. As to the psycholinguistic findings regarding language acquisition by preverbal infants, we mentioned that the data on the earliest stages of sign language acquisition are particularly scarce. We tentatively conjecture, however, that under favorable circumstances, deaf children attain the grammar from signed input with the same facility as hearing children do from spoken input. As to the findings in cognitive neuroscience, we showed that clinical neuropsychological data regarding sign language is partially inconsistent with imaging data. Indeed, whereas both clinical neuropsychology and imagery show the involvement of the LH in sign language processing, only some imaging studies highlight the importance of the RH. There are at least two possible interpretations of this discrepancy, which are open for future research.

First, signed language might rely more than spoken language on bilateral cortical representation. This would mean that the involvement of the RH in sign language processing has been neglected in clinical neuropsychology studies. Second, signed and spoken languages might share the same basic network of areas in the LH. This would leave unexplained why some imaging studies have found such massive involvement of the RH in sign language perception. One direction for future research would therefore be to explore how task related variables could affect the involvement of the RH. In particular, we share the concern that experimentalists have to always find the optimal baseline comparison task. An imaging study carried out with deaf and hearing native signers with backwards signing

and backwards speech as baseline conditions might provide valuable data concerning this issue.

As the reader can readily grasp, the options are quite open, and the alternatives we sketched here are highly speculative. More data is needed in order to gain a fuller understanding of the acquisition of natural languages and the relation of different kinds of natural languages to the underlying anatomical representations. Therefore, we hope that the present paper will encourage colleagues to carry out more comparative research.

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