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## The Acquisition of Natural Signed Languages: Lessons in the Nature of Human Language and Its Biological Foundations

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### THE OSTENSIBLE BIOLOGICAL FOUNDATIONS OF LANGUAGE

Prevailing views about the biological foundations of language assume that very early language acquisition is tied to speech. Universal regularities in the *timing* and *structure* of infants' vocal babbling and first words have been taken as evidence that the brain must be attuned specifically to perceiving and producing spoken language in early life. To be sure, a frequent answer to the question "how does early human language acquisition begin?" is that it is the result of the development of the neuroanatomical and neurophysiological mechanisms involved in the perception and the production of speech. An assumption that also underlies this view is that spoken languages are better suited to the brain's maturational needs in development. Put another way, the view of human biology at work here is that evolution has rendered the human brain neurologically "hardwired" for speech (Lieberman & Mattingly, 1985, 1989; Lieberman, 1984).

#### A Reasonable Doubt

As a young student and researcher, I had reason to doubt such views. While still a college undergraduate, I moved into a large mansion on the Hudson Palisades in New York City with an infant, West-African male chimpanzee, whom we named "Nim Chimpsky" (after, of course, Noam

Chomsky). This animal was part of a research project at Columbia University in which I attempted to raise the chimp like a child and to teach him signed language. Our research question concerned whether aspects of human language were species specific, or whether human language was entirely learnable (and teachable) from environmental input.

Although there is still much controversy surrounding the ape language research, what has remained surprisingly uncontroversial about all of the ape language studies to date is this: All chimpanzees fail to master key aspects of human language structure, even when you bypass their inability to produce speech by exposing them to other types of linguistic input, for example, natural signed languages. In other words, despite the chimpanzee's general communicative and cognitive abilities, their linguistic abilities do not equal what we humans do with language, be it signed or spoken. This fact raised the hypothesis to me that humans possessed *something* at birth *in addition to* the mechanisms for producing and perceiving speech sounds. Indeed, whatever this elusive "something" was, I knew that attempts to understand it would provide the key to what it was that distinguished human language from the communication of other animals.

### CRITICAL EVIDENCE REGARDING THE BIOLOGICAL FOUNDATIONS OF HUMAN LANGUAGE

As noted previously, most all contemporary thought about the biological foundations of language is based on the core assumption that language and speech are neurologically privileged from birth. There is, however, a flaw with this assumption: Given that only languages utilizing the speech modality are studied, it is, *a priori*, impossible to find data that would do anything but support this hypothesis. Only when a modality other than speech is analyzed can any generalization about the brain's predisposition for speech be evaluated.

Over the past 15 years, my research program has been directed at understanding the biological foundations of human language by examining both spoken and signed languages. The goal has been to discover the specific biological and environmental factors that together permit early language acquisition to begin in our species.

Studies of very early signed language acquisition offer an especially clear window into the biological foundations of all of human language. Spoken and signed languages utilize different perceptual modalities (sound vs. sight), and the motor control of the tongue and hands are subserved by different neural substrates in the brain. Comparative analyses of these languages, then, provide key insights into the specific neural architecture that determines early human language acquisition in our species. If, as has

been argued, very early human language acquisition is under the exclusive control of the maturation of the mechanisms for speech production and speech perception (Locke, 1983; Van der Stelt & Koopmans-van Bienum, 1986), then spoken and signed languages should be acquired in radically different ways. At the very least, fundamental differences in the *time course* and *structure* of spoken versus signed language acquisition would suggest that each may be processed and represented in different ways, presumably due to their use of different neural substrates in the human brain.

To investigate these issues, I conducted numerous comparative studies of children acquiring two spoken languages, English and French, and children acquiring two autonomous signed languages, American Sign Language (ASL) and Langue des Signes Québécoise (LSQ), from birth through the age of 48 months.

The empirical findings from these cross-linguistic and cross-modal studies are clear, involving surprising similarities in the overall time course and structure of early signed and spoken language acquisition.

### Timing Milestones in Signing and Speaking Children

Deaf children exposed to signed languages from birth acquire these languages on an identical maturational time course as hearing children acquire spoken languages. Deaf children acquiring signed languages do so without any modification, loss, or delay to the timing, content, and maturational course associated with reaching all linguistic milestones observed in spoken language (e.g., Charron & Petitto, 1987, 1991; Petitto, 1984, 1985, 1987a, 1988; Petitto & Bellugi, 1988; Petitto & Charron, 1988; Petitto & Marentette, 1990, 1991)—a finding that is also corroborated in the important findings of other researchers (e.g., Bellugi & Klima, 1982; Meier, 1991; Newport & Meier, 1985). Beginning at birth, and continuing through age 3 and beyond, speaking and signing children exhibit the identical stages of language acquisition. These include the (a) syllabic babbling stage (7–10 months) as well as other developments in babbling, including "variegated babbling," ages 10 to 12 months, and "jargon babbling," ages 12 months and beyond; (b) first word stage (11–14 months); (c) first two-word stage (16–22 months), and the grammatical and semantic developments beyond.

Surprising similarities are also observed in deaf and hearing children's timing onset and use of gestures (Petitto, 1992). Signing and speaking children produce strikingly similar prelinguistic (9–12 months) and postlinguistic communicative gestures (12–48 months). They do not produce more gestures, even though linguistic "signs" (identical to the "word") and communicative gestures reside in the same modality, and even though some signs and gestures are formationally and referentially similar. Instead,

deaf children consistently differentiate linguistic signs from communicative gestures throughout development, using each in the same ways observed in hearing children.

Throughout development, signing and speaking children also exhibit remarkably similar complexity in their utterances. For example, analyses of young ASL and LSQ children's social and conversational patterns of language use over time, as well as the types of things that they "talk" about over time (the semantic and conceptual content, categories, and referential scope), have demonstrated unequivocally that their language acquisition follows the identical path seen in age-matched hearing children acquiring spoken language (Charron & Petitto, 1987, 1991; Petitto, 1992; Petitto & Charron, 1988).

Recent work focuses on two very unusual populations, involving hearing children in bilingual, "bimodal" (signing-speaking) homes, as well as hearing children who are not being exposed to spoken language at all, only signed languages. The *hearing* children exposed to *both* signed and spoken languages from birth (e.g., one parent signs and the other parent speaks) demonstrate no preference for speech whatsoever, even though they can hear. Instead, they acquire both the signed and the spoken languages to which they are being exposed on an identical maturational timetable (Petitto, Costopoulos, & Stevens, in preparation). That is, the timing of the onset of all linguistic milestones occurs at the same time in both the signed and spoken modalities. For example, the bilingual, bimodal children acquiring French and LSQ produced their first word in French and their first sign in LSQ within hours of each other. Crucially, such children acquire the signed and spoken languages to which they are being exposed in the same manner that other children acquire two different spoken languages from birth in bilingual homes—for example, one with spoken Italian and French.

Most surprisingly, *hearing* children who are exposed *exclusively* to signed languages from birth through early childhood, with no spoken language input, achieve all milestones in signed language on the identical time course as seen in hearing children acquiring spoken language and deaf children acquiring signed languages (manual babbling, first signs, first two-signs, and beyond) (Petitto et al., in preparation). Thus, normal language acquisition occurred in these hearing children—albeit signed—*without* the use of auditory and speech perception mechanisms, and *without* the use of the motoric mechanisms for the production of speech.

Having established that the overall time courses of signed and spoken language acquisition are highly similar, questions remain about just how deep the similarities are in acquisition at the specific, structural level. I now review studies that address this issue in an attempt to shed new light on the mechanisms that underlie early language acquisition.

### Structural Homologies in Signing and Speaking Children

In trying to understand the biological roots of human language, researchers have naturally tried to find its "beginning." The regular onset of vocal babbling—the "bababa" and other repetitive, syllabic sounds that infants produce—led researchers to conclude that babbling represents the beginning of human language acquisition, albeit language production. Babbling—and thus early language acquisition in our species—is said to be *determined by the development of the anatomy of the vocal tract and the neuroanatomical and neurophysiological mechanisms subserving the motor control of speech production* (Locke, 1983; Van der Stelt & Koopmans-van Bienum, 1986). The behavior has been further used to argue that the human language capacity must be uniquely linked to innate mechanisms for producing speech in ontogeny (Lieberman & Mattingly, 1985, 1989). Crucially, it has also been used to argue that human language has been shaped by properties of speech in phylogeny (Lieberman, 1984).

In the course of conducting research on *deaf infants'* transition from *prelinguistic* gesturing to first signs, a class of *hand activity* containing linguistically relevant, "babbling-like" units that was different from all other hand activity during the "transition period" (9–12 months) became apparent (Petitto, 1984, 1987a, 1987b). These *deaf infants* appeared to be *babbling with their hands*. Additional studies were undertaken to understand the basis of this extraordinary behavior. The findings reported in Petitto & Marentette (1991) revealed unambiguously a discrete class of hand activity in deaf infants that was structurally identical to vocal babbling observed in hearing infants. Like vocal babbling, manual babbling was found to possess (i) a restricted set of phonetic units (unique to signed languages), (ii) syllabic organization, and it was (iii) used without meaning or reference. This hand activity was also wholly distinct from all infants' rhythmic hand activity, be they deaf or hearing. Even its structure was wholly distinct from all infants' communicative gestures.

The discovery of babbling in another modality confirmed the hypothesis that babbling represents a distinct and critical stage in the ontogeny of human language. However, it disconfirmed existing hypotheses about why babbling occurs: It disconfirmed the view that babbling is neurologically determined by the maturation of the speech-production mechanisms, *per se*. Specifically, it was thought that the *baba*, CV (consonant-vowel) alternation that infants produce is determined by the rhythmic opening and closing of the mandible (MacNeilage & Davis, 1990).

The Petitto and Marentette (1991) study also demonstrated the existence of "syllabic organization" in manual babbling. Like spoken language, the structural nucleus of the syllable in signed languages consists of the rhythmic opening and closing (or the rhythmic movement-hold) alternations of the hands/arms. Results indicated that the sign syllable alone

possesses a special rhythmic (or temporal) organization that is unlike all other hand activity observed in all infants. The convergence of similar structures unique to babbling, be it on the hands or on the tongue, suggested that something else was contributing to the appearance of babbling in ontogeny; something other than the mandible, per se, was guiding this convergence of structure on two radically different modalities.

I hypothesized that this "something else" is the existence of *supra-modal constraints*, with the rhythmic oscillations of babbling being key (Petitto, 1997). Both manual and vocal babbling alone are produced in rhythmic, temporally oscillating bundles, which I hypothesized may, in turn, be yoked to constraints on the infant's perceptual systems. The next challenge then was to figure out how to study it.

A new study of manual babbling uses innovative technology, called the "OPTOTRAK Computer Visual-Graphic Analysis System," in an attempt to understand the rhythmic nature of babbling (Petitto, Ostry, Sergio, & Levy, in preparation). The precise physical properties of infants' manual activity were measured by placing tiny infrared emitting diodes (IREDS) on infants' hands and feet. The IREDS transmitted light impulses to cameras that, in turn, sent signals into the OPTOTRAK system. This information was then fed into computer software that provided us with information analogous to the *spectrographic representation of speech*, but involved the *spectrographic representation of sign*. Thus, for the first time, we were able to obtain recordings of the timing, rate, path movement, velocity, and " $F_0$ "<sup>1</sup> for all infant hand activity, and to obtain sophisticated, 3-D graphic displays of each.

Preliminary results revealed the following: (a) Systematic *differences* exist between the rhythmic timing, velocity, and spectral frequencies of sign-exposed infants' manual babbling versus all infants' rhythmic hand activity (be they sign-exposed or not); (b) Systematic *similarities* exist in the timing contours of infants' manual and vocal babbling; (c) Converging structures observed in infant *and* adult-to-infant signing-speaking productions suggest that all humans at birth may possess peak sensitivity to a rudimentary "timing envelope"—a rhythmic timing bundle in natural language prosody of about 1.2 seconds—as well as a sensitivity to any maximally contrastive units that fall within this temporal period (e.g., a unit the size of the syllable).

Thus, homologous structural organization was observed in manual and vocal babbling, even though the neural substrates for manual articulation differ from the neural substrates for the articulation of speech.

<sup>1</sup>The fundamental frequency ( $F_0$ ) was calculated by decomposing the infants' 3-D movements into underlying spectral components (i.e., the different frequencies of movements that contributed to each hand, arm, and foot motion), and subsequently calculating these frequencies to their individual magnitude or power.

### Significance of Studies of Early Signed and Spoken Language Acquisition

Despite the modality differences, signed and spoken languages are acquired in virtually identical ways. The differences that are observed between children acquiring a signed language versus children acquiring a spoken language are no greater than the differences observed between hearing children learning one spoken language, say, Italian, versus another, say, Finnish.

Such findings cast serious doubt on the core hypothesis in very early spoken language acquisition: that the maturation of the mechanisms for the production and perception of speech exclusively determines the time course and structure of early human language acquisition. These findings further challenge the hypothesis that speech (and sound) is critical to normal language acquisition, and they challenge the related hypothesis that speech is uniquely suited to the brain's maturational needs in language ontogeny.

If speech alone were neurologically set or "privileged" in early brain development, then, for example, *hearing* infants exposed to both speech and sign from birth might be expected to attempt to glean every morsel of speech that they could get from their environment. Faced implicitly with a "choice" between speech and sign, the very young hearing infant in this context might be expected to turn away from the sign input, favoring instead the speech input, and thereby acquire signs differently (possibly later). Similarly, deaf *and* hearing infants exposed only to signed languages from birth should have demonstrated grossly abnormal patterns of language acquisition. None of this happened.

What is most remarkable about these findings is that the modality "switch" can be "thrown" *after* birth regarding whether a child acquires language on the hands or language on the tongue. We saw that children exposed to signed languages can acquire them just as easily as children exposed to spoken languages. Speech and sound are *not* critical to human language acquisition. Instead, there appears to be a stunning, biologically based *equipotentiality* of the modalities—be it spoken or signed—to receive and produce natural language in ontogeny. What, then, could this mean about the human brain at birth and how is language acquisition possible in our species?

### THE BIOLOGICAL FOUNDATIONS OF LANGUAGE

The key issue for students of early brain development is not the fact *that* signed and spoken languages are acquired similarly, but to determine *why* this is so. Given the different neural substrates, where does the capacity to produce common linguistic structures come from? How is it possible that the modality of language transmission and reception can be changed at birth—from speech to sign, or vice versa—without any delay or alteration to the time course and nature of human language acquisition? How can

the brain tolerate this radical change in the morphology of its expressive and receptive mechanisms for language, and what is the genetic basis for such stunning equipotentiality?

The present findings demonstrate that the brain at birth cannot be working under rigid genetic instruction to produce and receive language via the auditory-speech modality, per se. If this were the case, then both the maturational time course and the nature of signed and spoken language acquisition should be different. By contrast, using a wide variety of techniques and participant populations, I discovered that the acquisition of signed and spoken language is fundamentally similar.

What these findings do suggest is that the neural substrates that support the brain's capacity for language can be potentiated in multiple ways in the face of varying environmental pressures. The fact that the brain can tolerate variation in language transmission and reception, depending on different environmental inputs, and still achieve the target behavior provides support for there being a strong *amodal* genetic component underlying language acquisition, rather than the reverse. That is, the genetic foundations of language are not at the level of modality but at the level of abstract features of language structure such as its rhythmic and distributional patterning. Furthermore, there are multiple pathways by which language acquisition can occur. Thus, I suggest that a sensitivity to aspects of the specific distributional patterns found only in natural language is genetically determined and present at birth; this would constitute what is "rigid" or "fixed" about the brain in early language acquisition. At the same time, the language acquisition process is "flexible" in that language can be perceived and expressed via the hands or tongue.

In conclusion, the present findings led me to propose a new way to construe human language ontogeny. The only way that signed and spoken languages could be acquired with such startling similarity is if the brains of *all* newborns possess a mechanism that is sensitive to specific aspects of the distributional patterns and structural regularities of natural language, irrespective of the input modality. Rather than being exclusively hardwired for speech or sound, the young of our species are initially hardwired to detect aspects of the patterning of *language*—specifically, aspects of its rhythmic and distributional regularities—corresponding to the syllabic and prosodic levels of natural language organization. If the environmental input contains the requisite patterns unique to natural language, human infants will attempt to produce and acquire those patterns, irrespective of whether the input is on the hands or the tongue.

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## The Acquisition of First Signs: Place, Handshape, and Movement

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Since Stokoe's pioneering work on the structure of American Sign Language (ASL), signs have generally been described in terms of three major parameters: hand configuration, place of articulation, and movement (Stokoe, Casterline, & Croneberg, 1965). The psycholinguistic literature on ASL has since uncovered effects that differ strikingly by phonological parameter; this is true both of short-term memory for signs and of slips of the hand (Klima & Bellugi, 1979). The general result that, under the stresses of human performance, signs sometimes cleave along the lines of one or the other of these formational parameters supports the psychological reality of sublexical structure in ASL (Klima & Bellugi, 1979). The specific result that handshape is particularly susceptible to being slipped can be used to support the claim that handshape has a unique status within the phonology of ASL (e.g., on a separate tier as in Sandler, 1989). In the acquisition literature, one diary study found that place of articulation is much more accurately produced in children's early signs than is handshape or movement (Siedlecki & Bonvillian, 1993). Here, we revisit early phonological development in children acquiring ASL as a first language; we use videotaped data of spontaneous conversations between deaf children and their deaf parents to probe the relative difficulty of the three major parameters of sign formation.

Although the acquisition literature on ASL is large (see Meier, 1991; Meier & Newport, 1990; and Newport & Meier, 1985, for reviews), the literature on the form of early signs is surprisingly scant. Research on early sign development has been largely driven by such issues as whether first signs