On The Biological Foundations of Human Language

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Introduction: With Thanks to Ursula and Edward

Fall in New York City never looked so beautiful to me as it did on that second day of September, 1976, the day that I had to leave it for Kennedy Airport's last flight to San Diego. That evening, I left for graduate study in Theoretical Linguistics at the University of California San Diego and to meet the woman who was to be my graduate advisor and research director, Ursula Bellugi. She had a lab down the road at The Salk Institute for Biological Studies. But earlier that day, I did not want to go. Nim Chimpsky did not want me to go either, and he showed me so by subjecting me to the single most ferocious attack that I had experienced in my many years of living and working with him.

Nim Chimpsky, the west African male chimpanzee who had been my charge since infancy, was part of a grand experiment at Columbia University, called "Project Nim," led by Herbert Terrace and Tom Bever. Though only a college undergraduate, I moved into a large mansion on the Hudson Palisades in New York City with this wild animal and attempted to raise him like a child while exposing him American Sign Language (ASL). Our question concerned whether aspects of human language were species-specific, or whether human language was wholly learnable from environmental input. As I left Project Nim for Ursula Bellugi's California laboratory, Nim's successes and failures with this marvel that we call "Language," had already given me insight into where the answer to this profound question would lie.

Although there is still much controversy surrounding the ape language studies, one enduring finding has remained surprisingly uncontroversial. All chimpanzees fail to master key aspects of human language structure, even when you give them a way to bypass their inability to speak--for example, by exposing them to other types of linguistic input such as natural signed languages. This fact raised the hypothesis to me that humans possessed something at birth in addition to the mechanisms for producing and perceiving speech sounds that aided them in acquiring natural language. Indeed, whatever this elusive "something" was, I knew that attempts to understand it first required a solid grasp of the biological foundations of human language. This, in turn, I thought would provide the key basis from which to discover the essential features that distinguished human language from the communication of all other animals. And, from all that I had heard from Terrace and Bever about "Ursie" and her "brilliant research," there was no other place in the world to study the biological foundations of language than in her laboratory at The Salk Institute.

What a world it was! I was right to feel initial butterflies about going to the place, and about Ursula. With Nim's teeth marks still pressed into my torn skin, I walked into her laboratory to find, at once, the most thrilling and intimidating intellectual climate that I had ever known. I had never met anyone like Ursula. With break-neck speed, language streamed from her mouth and hands. Ideas. She had so many. She exuded them, most times whole and, at times, in tantalizing parts. Like the ring at the carousel, we would grasp at those parts, because we knew that when Ursula said something it was important. She had little patience for people who couldn't get to the point. We lived for those moments when she looked at us with clear, open eyes (meaning that she approved of an idea) and wanted to jump off the Torrey Pines cliffs when she gazed at us with the dreaded squinted eyes (the sure sign that she was bored, or, worse, thought what was being said was off the mark).

Both then and now, Ursula was masterful at listening and at pulling out "the question." She was equally masterful at knowing just what types of ingredients would ultimately constitute "the answer," just what paths to take. Then, after assessing our strengths and weaknesses, she would plonk us down on a path and make us go. Ursula also had a unique gift for knowing how to bring the right people together, how to create the right chemistry within which the intellectual explosion would occur--something that has remained one of the hallmarks of her laboratory to this day.

It was in this context that I first met Edward Klima and was fortunate to come to know his brilliance. Ed had an uncanny ability to surmise exactly what one wanted to say no matter how garbled it came out. He especially knew what one was trying to say in writing. He had (and still has) a stunning command of the word, which he demonstrated repeatedly by dragging our fragments of sentences up from the ditches and turning them into elegant prose. But more than this, I learned from Ed how to hold an idea in the palm of my hand, how to exam it, turn it about, and, how to use it like bricks to build the strongest possible logical structure.

No doubt, Ursie and Ed have given all of us who have been lucky enough to meet and know them some of the same things, and a little something different. For me, in addition to everything else, they gave me the gift that comes from sharing one's intellectual passions with others. They propelled forward my passion for sign language, for Language, for child language and, most of all, my passion for the magnificent universe within the human body that runs the show, the human brain.

In this chapter, I want to honor Ursula Bellugi and Edward Klima by outlining the nature of the discoveries that I have made in my own laboratory over the past 15 years since completing my doctoral dissertation under both Ursie's guidance at Salk and Roger Bown's at Harvard University (where life's twists and turns eventually settled me). But it is I whom am honored to have worked with Ursie and Ed and, through them, to have been fortunate enough to know and work with the other extraordinary scientists who grace the pages of this book. My science and my life have been touched by Ursie, by Ed, and by them all.[1]

Research on Biological Foundations of Human Language

Over the past 15 years, my research program at McGill University has been directed at understanding the specific biological and environmental factors that together permit early language acquisition to begin in our species. Prevailing views about the biological foundations of language assume that very early language acquisition is tied to speech. Universal regularities in the maturational timing and structure of infants' vocal babbling and first words have been taken as evidence that the brain must be attuned to perceiving and producing spoken language in early life. Without a doubt, 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 (Liberman & Mattingly, 1985, 1989; Lieberman, 1984).

My work with Nim Chimpsky first caused me to be suspicious of this view. As noted above, Nim did not fail to acquire human language merely because he could not speak. But my studies of very early signed language acquisition offered me the clearest window by far into why the above account was wholly incomplete. 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 very different ways. At the very least, fundamental differences in the timing and structure of early spoken versus signed language acquisition may be observed, presumably due to their use of different neural substrates in the human brain.

To investigate these issues, I have conducted many 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 ages birth through 48 months. The empirical findings from these cross-linguistic and cross-modal studies are clear, involving surprising similarities in the overall timing and structure of early signed and spoken language acquisition.

Similar Timing Milestones in Signing and Speaking Infants

Deaf children exposed to signed languages from birth, acquire these languages on an identical maturational time table 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 & Charron, 1988; Petitto & Marentette, 1990, 1991); this finding has also been corroborated by the important discoveries of other researchers (e.g., Bellugi & Klima, 1982; Newport & Meier, 1985; Meier, 1991). 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 (7-11 months) as well as other developments in babbling, including "variegated babbling," ages 10-12 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 as well (Petitto, 1992; see also the important work by Abrahamsen and Volterra, and others, in this volume). Signing and speaking children produce strikingly similar pre-linguistic (9-12 months) and post-linguistic 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 (its semantic and conceptual content, categories, and referential scope), have demonstrated that their language acquisition follows the same path seen in age-matched hearing children acquiring spoken language (Charron & Petitto, 1987, 1991; Holowka, Brosseau-Lapré & Petitto, submitted; Petitto, 1992; Petitto & Charron, 1988). As many others in this volume have first discovered, signing infants also exhibit the classic grammatical errors that are universally seen in speaking children despite the iconic nature of some signs. To name just a few, these include phonological substitutions, "over-regularizations," principled question-formation and negation errors, anaphoric referencing confusions, and even systematic pronoun reversal errors. Here, for example, an 18 month old child will treat an indexical point directed at a person in the second-person addressee role ("YOU") as if it signified a first-person pronoun ("ME"), a surprising error for at least two reasons: The linguistic symbol to convey this information is the non-arbitrary point, and during this same period children continue to use the point as a communicative gesture in rich ways (e.g., pointing to an adult's blouse to indicate a missing button; e.g., Petitto, 1984, 1987a; Meier, 1991).

Recent research in my laboratory focuses on two very unusual populations. One population involves hearing infants in bilingual-"bimodal" homes (for example, one parent signs and the other speaks). The second population involves hearing infants who are being exposed only to signed languages from birth, with no systematic exposure to spoken language whatsoever. In the first group of hearing bimodal babies, we have found that they demonstrate no preference for speech even though they can hear. If speech were neurologically privileged at birth, these babies might be expected to glean any morsel of sound and speech that they encounter, perhaps even turning away from the signed input; the prediction here is that these babies might achieve the early linguistic milestones in each modality on a different maturational time course. Instead, they acquire both the signed and the spoken languages to which they are being exposed on an identical maturational timetable (Petitto, Katerlos et al., in press). That is, the onset of all early linguistic milestones in both the signed and the spoken modalities occurs at the time. For example, the hearing bilingual-bimodal babies acquiring LSQ and French, as well as those acquiring ASL and English, begin babbling in each modality in a time-locked manner and exhibit parallel stages of babbling over time in each modality. One intriguing observation here that is presently under intensive study is that these babies' manual and vocal babbling appear to be produced simultaneously more frequently than not. So, for example, an 11 month-old baby who is producing canonical vocal babbling in his crib is highly likely also to be observed producing canonical manual babbling, even though the phonetic and syllabic formational properties of each type of babbling is produced quite differently. In babies acquiring two spoken languages from birth, such as Italian and French, this particular situation would not be possible given the obvious constraint of having only one mouth. Moreover, these hearing bimodal babies produce their first sign in LSQ or ASL and their first word in French or English within hours of each other, respectively. We have also found that these babies' early lexicons in each modality can be "mutually exclusive" (for example, a baby's first ASL sign is DOG and first English word is "more"), or overlapping (for example, a baby's first LSQ sign is CHAPEAU, hat, and first French word is "chapeau"); some babies exhibit both "mutually exclusive" and overlapping lexical items in each modality at the same time. Crucially, this is precisely what we have found in our hearing bilingual controls, those babies acquiring French and English from birth (Petitto, Katerlos et al., in press; Petitto, Costopoulos & Stevens, in preparation). To be sure, the findings from our studies have found that hearing babies acquiring signed and spoken languages from birth do so in the same manner observed in other babies acquiring two different spoken languages from birth in bilingual homes.

The findings from the hearing babies with no systematic spoken language input are especially compelling. These babies can hear, but they are receiving no systematic speech stimulation from the moment of birth through around 30 months. Instead, they receive only signed language input from their profoundly Deaf parents as well as their extended Deaf families living in distinct communities outside of Montréal. Two types of families were studied, monolingual and bilingual. In the monolingual families, one group of hearing infants were being exposed only to LSQ from their LSQ Deaf parents and relatives, and another group of hearing infants were being exposed only to ASL from their ASL Deaf parents and relatives. In the bilingual families, one of the parents (originally from the United States) signed only ASL to their babies and the other parent (originally from Québec) signed only LSQ to their babies; hence, the hearing babies being raised by these sets of parents received bilingual language exposure--but only in signed language!

All of these particular families were further unique in the following way: By choice, all of these parents had made the decision to expose their infants exclusively to their native signed languages, and, thus, these hearing infants received no <u>systematic</u> spoken language input in early life; note that a firm commitment to one's native language is entirely commensurate with the accepted practices in contemporary Québec society.[2] The construct of "systematic input" is key here. While it is likely that these infants may have occasionally overheard the speech of others in the supermarket, and the like, children in such contexts generally do not acquire knowledge of a language from such unsystematic fragments of overheard (non child-directed) speech. As further corroboration of this fact, the babies' productive and receptive vocabulary skills in both spoken French and English were tested at regular intervals and, crucially, prior to their entry into systematic spoken language exposure, and it was demonstrated to be either non-existent (that is, they had no spoken words in production and comprehension), or restricted to knowledge of a one or two highly ritualized social greeting words such as "bye-bye" when leaving a room.

Our intensive study of these hearing babies acquiring only signed languages in early life have surprised us. These babies achieve all linguistic milestones on a normal maturational time table. If early human language acquisition were wholly determined neurologically by the mechanisms for speech production and reception, then these hearing babies raised without systematic spoken language stimulation should show a-typical patterns of language acquisition. Instead, all of these groups of hearing babies produced manual babbling, first signs, first two-signs, and other milestones, at the same time as is seen in all other children, be they hearing acquiring speech or Deaf acquiring sign. Further, the bilingual group here (those hearing babies receiving early exposure to both ASL and LSQ, but not speech) demonstrated highly similar patterns of bilingual language acquisition observed in our hearing controls acquiring French and English, and the bilingual-bimodal hearing infants acquiring one signed and one spoken language (Petitto, Katerlos et al., in press; Petitto, Costopoulos & Stevens, in preparation). Thus, entirely normal language acquisition occurs in these hearing babies--albeit, signed--<u>without</u> the use of auditory and speech perception mechanisms, and <u>without</u> the use of the motoric mechanisms for the production of speech.

Having established that the overall time course 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 may underlie early language acquisition.

<u>Structural Homologies in Signing and Speaking Infants:</u>
<u>The Discovery of Manual Babbling</u>

In trying to understand the biological roots of human language, researchers have naturally tried to find its "beginning." The regular onset timing and structure of vocal babbling--the “bababa” and other repetitive, syllabic sounds that babies produce--have 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 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 (Liberman & Mattingly, 1985, 1989). It has also been used to argue that human language has been shaped by properties of speech in evolution (Lieberman, 1984).

In the course of conducting research on Deaf infants' transition from pre-linguistic gesturing to first signs, I noticed a class of hand activity that contained linguistically relevant units that was different from all other hand activity during the "Transition Period" (9-12 months; Petitto, 1984, 1987 a & b). Deaf babies appeared to be "babbling," albeit with their hands (see Petitto, 1987a, page 18, section 4.1.2). An additional study was undertaken to understand the basis of this extraordinary behavior. This time, however, a key control group was added: Hearing babies who were acquiring spoken language with no exposure to signed language. In Petitto & Marentette (1991), we analyzed all of the hand activity produced in our sample of Deaf and hearing babies. Once again, the findings revealed unambiguously a discrete class of hand activity in Deaf babies only that was virtually identical to characterizations of vocal babbling observed in hearing babies. Further, critical analyses of the structure and use of manual babbling revealed that it was fundamentally distinct from all babies' communicative gestures. It was distinct from Deaf babies' attempts to produce real first signs (including immature phonetic approximations to adult signs, baby signs, and the like). It was further distinct from what I have called "excitatory motor hand activity" that all Deaf and hearing babies make during this developmental period: for example, the excitatory opening and closing hand and arm movements that infants produce upon being presented with a new object (or some abrupt change in the external stimulation); such "excitatory motor hand activity" would constitute instances of the class of rhythmic "motor stereotypes" that Ester Thelan and other scientists have observed in all young babies (Thelan, 1991). Indeed, only one class of hand activity exhibited all of the key defining features of human infant babbling and it was only observed in sign-exposed Deaf babies as opposed to the hearing controls; hence, the discovery of "manual babbling" in profoundly Deaf babies exposed to natural signed languages.

In studies of hearing babies' vocalizations, a composite of several key defining features is used to distinguish vocal babbling from all other vocal activity. At least 5 general features have been used by scientists to help in the identification of genuine instances of vocal babbling, with the first three being most widely accepted for several decades based on a vocalization's (1) phonetic and syllabic structure, (2) manner of use, and (3) stages of development throughout early language acquisition. Marilyn Vihman and others have further identified that there is (4) a continuity of phonetic form and syllable type within an individual baby's vocal babbling and first words (Vihman et al., 1985). An additional feature that helps to pin down one particularly crucial babbling stage has been offered by Oller and Eilers (1988), and others, and is called the (5) syllabic ratio. Beginning roughly around ages 7 to 11 months, babies begin producing what Kim Oller first coined syllabic or "canonical" babbling. This involves the production of well-formed consonant-vowel (CV) clusters produced with repetitive, multi-cycle reduplications (such as "bababa") and in a rhythmic manner that reflects the prosody (timing, stress) of natural language. Oller and Eilers found that once babies begin producing such well-formed CV babbling syllables they generally comprise about 20% or more of the infants' total vocal activity; hence, the 20% ratio (percent of syllabic to total vocal utterances) was offered as a yardstick to aid in the classification of infants' vocal activity as being in the syllabic (canonical) vocal babbling stage of language acquisition. More recently, other researchers have added to the above list of criteria by analyzing the specific physical properties of babbling, especially manual babbling, as a way to identify and harness this fascinating phenomenon in all children (e.g., involving analyses of the behavior's temporal duration, velocity, path trajectories, and movement cycles-per-second that are discussed below in this Petitto chapter; see also Meier, this volume).

Remarkably, the manual babbling that Petitto and Marentette found in sign-exposed Deaf babies was fundamentally similar to hearing babies' vocal babbling in precisely the ways noted above. (i) Phonetic and syllabic structure: Like vocal babbling, by 10 months the Deaf babies began producing a restricted set of sign phonetic units in sign syllables (more below) with distinct repetitive, multi-cycle hand and arm movements, which were temporally constrained. This particular behavior constituted an especially important finding, and I later returned to study its specific properties (discussed below).

(ii) Manner of use: Like vocal babbling, the Deaf babies used manual babbling as if the forms had no meaning, with no apparent intent to signify or represent external objects in the world or internal states and intentions; like hearing babies, they instead used communicative gestures during this developmental period for such purposes, such as the point. Crucially, however, there was a decidedly deliberate manner in which the Deaf babies used manual babbling that was fundamentally unlike the way that they used all other hand activity, especially other excitatory motor hand activity during this period (more below). Like hearing babies, the Deaf babies appeared to understand that this specific activity was something that adults valued and something that is used between one person to another; without wanting to attribute too much to children, it was almost as if they understood that this activity had some role in "communication." For example, one enduring finding from my lab has been that all babies (be they hearing or Deaf) will produce rich babbling protocol if they are in the presence of two adults having a conversation, but one where they (the babies) are personally excluded: that is, one where the two adults do not address any of their conversation to the baby. Under such circumstances, most all babies will begin producing a surprisingly high degree of babbling. For the Deaf baby, this is quite dramatic, as they will actually raise their hands(s) and arm(s) into the mother's "site-line" and begin producing meaningless babbling units, often giggling out loud in apparent delight when mother finally turns her head to acknowledge this behavior.

Interestingly, our analyses of Deaf mothers' (and Deaf adults') "motherese" during this developmental period have demonstrated that adults consistently respond differently to their babies' manual babbling as compared to all other hand activity, even the excitatory motor hand activity that occurs during this period whose rhythmic, multi-cylce form shares some resemblance with manual babbling (more below; Petitto, Holowka, Ostry et al., submitted). Deaf adults respond to a babies' manual babbling with language, pure and simple. Here, adults either expand upon the babies' fragmentary syllabic units and turn them into real signs that they then sign back to the baby, or they simply "play with" the infants' linguistic morsels by producing the very fragments back to the child; frequently, they query the infant, asking the equivalent of "What are you trying to say to mommy?" Conversely, adults respond both to an infant's manual gestures and to an infant's excitatory motor hand activity during this period with actions. Alas, this appears to be yet another of those behaviors in child language that scientists have excitedly "discovered" in the laboratory, yet mothers (in this case Deaf mothers and adults) appear to have tacitly known about this phenomenon for a long time.

To be sure, we have consistently observed that the way in which Deaf babies use their manual babbling is fundamentally different from the way that they use other hand activity, especially other excitatory motor hand activity that occurs during this period. Finally, Deaf babies often look at their own hands when manually babbling in the same way that hearing babies appear to be attending to the sounds in their own vocal babbles, for example, as has been observed in their solitary "crib speech." Deaf babies do not look at their own hands when producing other excitatory motor hand activity. Such fundamental differences in the manner of use between Deaf babies manual babbling versus their other excitatory motor hand activity during this period is important and has significance for the additional studies of manual babbling discussed below.

(iii) Stages of development throughout early language acquisition: Manual babbling emerged on the same maturational time table as vocal babbling and exhibited the identical "stages" of babbling. For example, hearing babies begin consonant-vowel (CV) productions from around 4 to 6 months, but some time between 7 to 11 months most babies enter the syllabic or canonical babbling stage that was discussed above. By around 10 to 12 months "variegated babbling" is produced, whereby different CV units are strung together, as in "gabada." Beginning around 12 months and continuing well into children's production of early words and sentences, "jargon babbling" is produced; here, children produce strings of word-like CV units that exhibit the prosodic organization of a simple sentence, albeit meaningless. The Deaf babies in our study exhibited structurally similar stages in manual babbling, and did so on the same timetable as hearing babies' vocal babbling.

(iv) and (v) Continuity in structure with first words and the syllabic ratio: As in vocal babbling, the sign phonetic units that were most predominant in the Deaf babies' manual babbling were later observed to be those units that were most predominant in their first signs (Petitto & Marentette, 1991).

Moreover, the Deaf babies met and surpassed Oller & Eilers (1988) syllabic ration in their manual babbling. Manual babbling constituted 32% to 71% of the manual activity in Deaf infants. Whereas, instances of what Petitto and Marentette also called "manual babbling" in the hearing controls, constituted a mere 4% to 15% of their manual activity--a nonetheless intriguing phenomenon that I will now examine.

What further interested me about the findings first reported in Petitto and Marentette (1991) is that the hearing babies also produced a behavior that superficially looked like "manual babbling." Like the Deaf babies in this study, the hearing babies with no exposure to signed languages produced repetitive, multi-cycle hand and arm movements from around ages 7 to 12 months. Recall that the attribution of true "babbling," be it vocal or manual, is not made based on the presence of one or two features, but involves a composite of key defining features that we found to be absent in the hearing infants' manual productions. The physical form of the hearing babies' manual babbling--or, the extent to which it could be said to possess sign phonetic and sign syllabic structure--was less complex than the manual babbling of Deaf babies; it contained far fewer hand shapes, movements, orientations, and locations. For example, hearing babies' manual babbling contained only 3 hand shapes that resembled sign-phonetic units, as compared with the Deaf babies' 13, and they produced only one movement as compared with Deaf babies' 13. The hearing babies' hand shapes were also organized into far fewer syllable types. They produced only 1 unit that resembled a sign syllable as compared to the Deaf babies' 4. The manner of use differed in the important ways discussed above including the fact that the hearing babies did not produce their manual babbling in an apparently deliberate (yet meaningless) and communicatively appropriate manner. Nor did they look at their own hands when they produced these forms, and the like. There were no stages of development evidenced, as the forms did not increase in complexity over time. For obvious reasons, there was no continuity between these hand forms and first signs (recall these hearing babies were acquiring only spoken languages). Finally, as noted above, the hearing infants' manual babbling violated Oller & Eilers' "syllabic ratio." Thus, we concluded that the hearing babies' manual babbling was really fundamentally similar to the excitatory motor hand activity observed in all young babies, especially to the motor-stereotypes described by Ester Thelan (1991) and others (Petitto & Marentette, 1991).

Our initial finding of manual babbling in the hearing babies nonetheless compelled our attention. How could this rather remarkable hand activity in hearing babies be possible? Why was similar excitatory motor hand activity also present in the Deaf babies at the same time as their manual babbling? Might the occurrence and developmental timing of this behavior in all infants suggest something about the "ready-state" nature of the human body to express language from multiple pathways? In Petitto and Marentette, I argued just that: The presence of so-called manual babbling in the hearing babies who had no sign input suggested that there is a biological "equipotentiality" of the spoken and signed modalities to receive and produce natural language. My earlier studies had already taught me that both the signed and the spoken modalities were recruited with equal ease in development depending upon the modality of the input language (and, of course, hearing status). The remaining puzzle was this: How could such seemingly effortless and instantaneous transfer from one modality to the next exist if all of acquisition was exclusively determined by the maturation of the mechanisms for producing and receiving speech? I therefore reasoned that an additional mechanism had to be contributing to the human language acquisition process--one that existed in addition to important motor and perceptual constraints. I hypothesized that accidental evolutionary processes must have provided humans with a mechanism that is sensitive to elementary aspects of the temporal and distributional patterning of natural language <u>structure</u> independent of modality; I thought of this as the sort of biologically plausible mechanism that later "grammatical knowledge" could build itself up from. I further argued that this mechanism must be neurologically yoked to motor production and perceptual constraints, but it must be nonetheless engaged in discrete processing of low-level aspects of natural language patterning. Although at the time, I was not sure about the specific temporal properties of this mechanism, the fact that units of about the same size and duration were being pushed out onto the hands and tongue in very early signed and spoken language acquisition, led me to conclude that some sort of dedicated temporal sensitivity was contributing to the human acquisition process and was very the mechanism that apes lacked! Based on the manual babbling findings, I hypothesized that babies may be born with a mechanism that is first sensitive to a brief temporal window and especially to units with rapid alternations (hence, the infants' ability to attend to, perceive, and ultimately produce, maximally contrasting phonetic units within a basic syllable); I was to return to this idea in next study. What seemed clear at the time, however, was that this mechanism could develop equally well in ontogeny with either the hands or tongue, thereby explaining why all infants could attend to and, crucially, produce units of about the same size and organization, and on the same maturational time table, across such radically different modalities; this was the biological mechanism that was driving the identical timing milestones and this was the mechanism that explained the clear "equipoteniality" of signed and spoken languages in acquisition. One very surprising implication of this view is that the human language modality is neurologically set after birth depending upon the modality of language input, which, in the end, I believe will be found to be correct (Petitto & Marentette, 1991; Petitto, 1994; for a more detailed discussion of the properties of this hypothesized mechanism see also Petitto, 1997).

Because we have a mechanism that is going to become neurological wed to a modality in the first year of life, and because, I hypothesized, both the tongue and hands at birth are equipotential language articulators, the prediction is that we will see language-like articulations spill out into the "unused" modality, albeit in unsystematic ways. Having received no systematic signed language input, a hearing baby's hands will nonetheless approximate syllabic-like manual units, though in unsystematic ways. Further, they will occasionally hit upon real hand shapes and movements that happen to exist in natural signed languages due to specific physical affordances of the human body (in this case the hands) that all natural language phonologies exploit to a greater or lesser extent. In order for the equipotentiality argument to hold, the identical phenomenon should also be seen in profoundly Deaf infants--and it is. Having received no systematic spoken language input, this Deaf infant will occasionally produce a well-formed CV vocal syllable in unsystematic ways. Here, aspects of the human oral-facial cavity make possible this profoundly Deaf infant's ability to hit upon a real CV vocal unit (such as "ba"), albeit unsystematically, even though they have never heard this syllable.[3]

The hearing infants' ostensible "manual babbling" and Deaf infants' ostensible "vocal babbling" can be further witnessed within this developmental period (6 to 12 months) due to another developmental factor: Development of the primary and secondary motor cortices is occurring during this time and is evidenced by characteristic changes in infant motor behavior--whose movements change from rhythmically-oscillating bursts (for example, rhythmic flexing of the hands and feet when excited) to more coordinated body and limb control. The proclivity toward rhythmic body movements during this period, in combination with particular affordances provided by the human body's hands and oral-facial cavity, can further account for the appearance of the accidental manual babbling forms in hearing babies and vocal babbling forms in Deaf babies. However, the significantly reduced frequency and complexity of these ostensible babbling forms in the hearing and Deaf babies, as compared with the frequency and complexity of the babbling forms in each group's respective primary language modality, again, caused me to argue that the former constituted a class of fundamentally non-linguistic motor hand activity, while the later was fundamentally linguistic (Petitto & Marentette, 1991).

As is often the case, the discovery of babbling in another modality answered some questions but raised many more. The discovery of manual babbling 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 exclusively determined by the neurological maturation of the speech-production mechanisms. For example, it has been rigorously argued that the “baba,” CV alternation that infants produce results from the rhythmic opening and closing of the jaw (MacNeilage & Davis, 1990). But the study raised important questions about the phenomenon as well. The Deaf babies' syllabic (or canonical) manual babbling (ages 7-11 months) was especially compelling because it was produced with distinct, repetitive, multi-cycle hand and arm movements; it further appeared to possess strikingly different temporal organization as compared with other hand activity, though the physical properties of its temporal organization were not fully understood. But other hand activity in the Deaf babies, as well as in the hearing babies, contained repetitive, multi-cycle movements. Was this important behavior that we identified as being "syllabic manual babbling" a fundamentally linguistic or motor activity? (How similar was its physical properties to hearing infants' vocal babbling at this time)? Were the manual babbles observed in Deaf infants and the manual babbles in hearing infants fundamentally similar or different? Crucially, was the manual babbling observed in Deaf and hearing babies fundamentally similar or dissimilar to the rhythmic excitatory motor hand activity that all infants make? Said another way, was all infants' manual babbling fundamentally similar to the motor stereotypes seen in young infants by Ester Thelan and others (e.g., Meier et al., 1998)? Answers to these questions would prove to be essential in understanding whether the human brain possesses a discrete mechanism dedicated to aspects of natural language patterning that aids language acquisition, or whether the early seemingly linguistic activity in babies is fundamentally determined by general motor constraints.

It struck me that the key to answering these questions would entail a deeper understanding of the physical properties that constrain a baby's production of the basic manual babbling unit, with an understanding of its temporal oscillations being crucial. The Petittto and Marentette (1991) study had already reported that the basic manual babbling unit contained "syllabic organization." Drawing from existing linguistic descriptions of the sign syllable, Petitto and Marentette identified the syllable in signed languages to consist of a restricted set of sign phonetic units whose structural nucleus contained movement: described in physical terms as a rhythmic *opening and closing* (or the rhythmic hold-movement alternations) of the hands and arms (e.g., Liddell & Johnson, 1989; Perlmutter, 1991). Though healthy controversy has continued to thrive among Theoretical Linguists concerning the definition of the sign syllable (Brentari, 1999; Liddell & Johnson, 1989; Perlmutter, 1991), this working definition succeeded in differentiating classes of manual activity across all of our young Deaf and hearing babies. To test this further, we applied all existing linguistic definitions of the sign syllable to our data, and all existing definitions resulted in a differentiation of the classes of manual activity that we had identified. In particular, none failed to identify Deaf babies' manual babbling as being a distinct class of manual activity. Note that similar lively debates about the definition of the syllable in spoken languages have gone on for decades. Nonetheless, an equally long history of psychological research--and now Cognitive Neuroscience studies of language processing and cerebral activation--have established that the syllable is a "real" perceptual and production unit in natural language processing. Thus, my goal (both then and now) has been to discover the systematic physical properties of infant hand activity, irrespective of contemporary controversy over its abstract formalization.

Though syllabic organization was indeed observed in the Petitto and Marentette study, nothing was understood about its *temporal* organization, which I found distinctive. When Deaf babies manually babbled, I noticed that the reduplicated *temporal* patterning of these opening and closing (hold-movement) hand and arm movements appeared to be different from the temporal patterning of their gestures, attempts to sign, or simply the movements of their hands when excited. In other words, it is not just the presence or absence of syllabic organization that distinguishes among the classes of infant manual activity, but the presence of this organization in conjunction with a highly specific temporal patterning that appears to be key. However, it is simply not possible to measure such temporal oscillations through mere videotape inspection (qualitative analyses) and can only be studied with methods that permit precise quantification. But how was I to do this?

To study the temporal patterning of infant hand activity, I have conducted a series of studies with my colleague, David Ostry, and students Lauren Sergio and Bronna Levy, using our “OPTOTRAK Visual-Graphic Analysis System" (see Petitto, 1993, 1997; Petitto, Holowka, Ostry et al., submitted). The same Deaf and hearing infants were studied at ages 6, 10, & 12 months (cross-sectional and longitudinal design), while participating in a series of tasks that were designed to elicit manual activity, including manual babbling. The precise physical properties of all manual activity produced by all infants were measured by placing tiny Light-Emitting Diodes (LEDs) on their hands, arms, shoulders, and feet. The LEDs transmitted light impulses to cameras that, in turn, fed signals into computer software that extracted information analogous to the spectrographic representation of speech, but adapted for the spectrographic representation of sign. Specifically, we were able to record the timing, rate, path movement, velocity, and "f_0" (fundamental frequency) for all infant hand activity, and to obtain 3-D graphic displays.

We were first interested in whether distinct classes of manual activity would "fall out" of the OPTOTRAK data based exclusively on their quantitative physical properties; in this case, we could not see the actual manual form the baby produced, we only had access to its physical features, such as its temporal duration, velocity, trajectory path through space, number of movement cycles per second, and the like. We were then interested in whether manual activity specifically identified as "syllabic (or canonical) manual babbling" (ages 7-11 months, based on all existing qualitative criteria) was physically distinct from or similar to other classes of manual activity, such as the (a) rhythmic excitatory motor hand and leg activity that all young infants make to novel objects (e.g., Thelen, 1991), (b) communicative gestures, (c) attempts to sign, and the like. Many analyses were conducted, but several key ones included a comparison of the physical properties of Deaf babies' syllabic manual babbling with their own excitatory motor hand and leg movements; then we compared the Deaf babies' excitatory motor hand and leg movements with this same class in hearing babies. We also examined the physical properties of the hearing infants' instances of "manual babbling" with all of the above activity, and so forth.

Briefly, we found that distinct classes of manual activity "fell out" of the data based on their physical properties. Systematic differences existed between the rhythmic timing, velocity, and spectral frequencies of Deaf infants' syllabic manual babbling versus all infants' rhythmic excitatory motor hand activity, communicative gestures, and so forth, during this identical time period (7-11 months). Hearing infants' "manual babbling" possessed physical features more closely related to all infants' class of excitatory motor hand activity. Syllabic manual babbling units in Deaf infants alone were produced in a tightly constrained space and were typically produced exclusively with hand and upper arm movements, with no accompanying leg movements. Crucially, syllabic manual babbling in Deaf babies only was produced with a slower velocity and rate as compared with all other hand activity. Here, an average of 1 to 2 manual babbling movement units were completed within repetitive temporal bursts of approximately 1.2 seconds. By contrast, other rhythmic excitatory motor hand activity was faster in both the Deaf and hearing infants; here, an average of 3 to 4 completed movement units were produced within 1.2 seconds, and, crucially, such hand activity was always accompanied by leg movements. This whole-body involvement when infants (Deaf and hearing) produced excitatory motor manual activity was very striking. When Deaf babies were manually babbling only the top half of their body was involved. By contrast, when all children produced other rhythmic motor hand activity, the lower part of their body became involved as well. Further analyses reveal that the temporal patterning of syllabic manual babbling in Deaf babies is similar to the temporal patterning of early vocal babbling in hearing babies, range 6-10 months, and present analyses are exploring how close this relationship is and how it changes over time.

Once again, the findings suggest some answers, and raise more questions. Manual babbling is a robust phenomenon in sign-exposed babies. Moving away from videotape analyses, innovative technology informs us that manual babbling is physically distinct from other types of other rhythmic excitatory motor hand activity (motor-stereotypes) in principled ways, and it is distinct from hearing babies' less frequent and less complex instances of ostensible "manual babbling." Remarkably, a common temporal constraint may be operating, even though the neural substrates for sign and speech are distinct. How is this possible?

Testing Hypotheses about the Biological Foundations of Language:
Insights from PET studies of adult signing and speaking adults

In Petitto, 1997, I proposed an hypothesis as to how it is possible for signed and spoken languages to be acquired so similarly. The hypothesis has several components, some of which I summarized above. In addition to suggesting that the same dedicated brain mechanism underlies both signed and spoken language acquisition, I went one step further and I hypothesized that the same brain tissue is subserving the acquisition of both. I further specified that this brain tissue constitutes a mechanism that has peaked sensitivity to maximally-contrasting, temporally-oscillating bundles of about 1.2 seconds that initially permits all infants to discover sub-lexical and prosodic patterning in the input (be it signed or spoken) and soon after to produce them. If correct, this theory further predicts that adult signed and spoken languages should utilize the same sites in the human brain. Ursula, Ed and colleagues including Howard Poizner, and others, had already conducted their pioneering studies of brain-damaged Deaf adults showing that Deaf signers suffer the classic Broca's and Wernicke's aphasias in sign language following left-hemisphere lesions as has been observed in speech (see also others in this volume, such as David Corina, Antonio Damasio, Hanna Damasio, Karen Emmorey, and Judy Kegl). Yet I wondered just how specific this was: Was the identical brain tissue involved in the processing of indentical linguistic functions across sign and speech?

Recently, I, Robert Zatorre, and our colleagues, conducted a series of studies of cerebral blood flow (rCBF) in profoundly Deaf signing adults and hearing people with no knowledge of signed language using Positron Emission Tomography (PET) technology in combination with Magnetic Resonance Imaging (MRI) (Petitto, Zatorre et al., in press). Many intriguing findings were observed, but one of particular relevance here involves activation that we observed within one highly specialized brain site, the Planum Temporale, a major site within the Wernicke's receptive language area which receives auditory projections from the auditory afferent system (e.g., Binder et al., 1996; Galaburda & Sanides, 1980) and which is widely considered to have a unimodal auditory processing function. We observed the expected activation in the Planum Temporale when hearing people processed highly specific phonetic-syllabic units auditorially. Remarkably, however, we observed entirely unexpected activation in the Planum Temporale of Deaf people when they processed the identical level of language organization visually--that is, phonetic-syllabic units on the hands. The discovery of common brain activation sites in languages with and without sound, provides powerful corroborating evidence with the acquisition findings that the brain may possess mechanisms dedicated to processing specific patterns unique to natural language--and not sound or speech.

Taken together, both the acquisition and the adult processing findings have intriguing implications regarding the evolution of the linguistic capacity in our species, as they support the idea that aspects of the abstract grammatical patterning of natural language may be a product of evolutionary processes (e.g., Donald, 1993; Pinker & Bloom, 1990; see also Woll, 1996, for a lovely discussion of the evolutionary implications of signed languages and language evolution). A by-product of the existence of evolved mechanisms that are sensitive to the abstract patterning of human language, per se, would be that humans could generate multiple pathways for perceiving and producing language. Quite powerfully, this is precisely what the very existence of natural signed languages has taught us.

On The Biological Foundations of Human 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? 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 suggest that the brain at birth cannot be working under rigid genetic instruction to produce and receive language via the auditory-speech modality. 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 subject populations, I and others have discovered that the acquisition of signed and spoken language is fundamentally similar.

What the present 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 upon different environmental inputs, and still achieve the target behavior, provides support for there being a strong genetic component underlying language acquisition, possibly involving the type of mechanisms that I have suggested here: specifically, those sensitive to aspects of the abstract patterning of natural language structure. At the same time, the language acquisition process is biologically "flexible" (neurologically plastic) in that language can be perceived and expressed via the hands or tongue.

In conclusion, the present findings have led me to propose a new way to construe human language ontogeny. 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 . I have suggested here that this initial sensitivity is to aspects of its temporal and distributional regularities initially 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 to acquire those patterns, irrespective of whether the input is on the hands or the tongue.

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As always, the studies above answer some questions and raise many others--especially regarding the specific nature of the "temporal and distributional sensitivities" that I and others have hypothesized to exist in the newborn brain (e.g., Marcus et al., 1999; Newport, this volume; Saffran et al., 1996). Of course, I will continue to pursue these questions. Because, like Ursula and Ed, I cannot stop myself. Because when I passed through Ursula's laboratory many years ago, this is one of the enduring gifts that they gave me: the courage, strength, and sheer stamina to follow one's passion to know.

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FOOTNOTES

1. I am indeed grateful to Ursie and Ed for all of the remarkable people that I came to know through them. On the afternoon that I arrived in Ursie's lab, she put me in an office with a desk jutting out between Ted Supalla on one side and Ella Mae Lentz and Carlene Pederson on the other "because," she said, "you know sign language." These three extraordinary individuals promptly took me apart and, over the course my time there, were kind enough to put me back together, being stronger and wiser! I also am especially fortunate that I came to know Benjamin Bahan and Richard Meier, as well as Carol Padden and Sam Supalla. My discussions with many others in and around Ursie's laboratory greatly influenced me, including the many scientists who visited it: Tane Akamatsu, Elizabeth Bates, Robbin Battison, Collin Blakemore, Penny Boyes-Braem, Bernard Bragg, Benidite de Boysson-Bardies, David Corina, Francis Crick, Karen Emmorey, Lou Fant, Susan Fischer, Angela Fok, Nancy Frishberg, Victoria Fromkin, Vicki Hanson, Judy Kegl, Harlan Lane, Scott Liddell, Diane Lillo-Martin, Ruth Loew, Marina McIntyre, Madeline Maxwell, Helen Neville, Don Newkirk, Elissa Newport, Lucinda O'Grady, Frank Paul, Elena Pizzuto, Howard Poizner, Judy Reilly, Patricia Siple, Ovid Tzeng, Virginia Volterra, Ronnie Wilbur. What an amazing group of scientists and friends!

2. The primary reason that these parents' commitment to their children's exclusive exposure to a native sign language was eventually abandoned by around 30 months is because, in all cases, the parent at home wanted to return to work. Thus, for pragmatic reasons only, the children were placed in either state-run day care centres or with neighbors (hearing or deaf) who took in other children (typically hearing).

3. Contrary to Lenneberg's (1967) provocative claims, both my own research and the research of others (e.g., Oller, 1986) have demonstrated clearly that a profoundly Deaf infant with no auditory augmentation and no auditory training does <u>not</u> spontaneously produce systematic canonical CV babbling on the same time course and with the same complexity as is observed in hearing infants.

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