THE CAMBRIDGE COMPANION TO

Chomsky

The Cambridge Companion to Chomsky

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I first met Noam Chomsky through a project that attempted to get the baby chimp Nim Chimpsky to "talk." At nineteen, with the certainty of youth, I knew that I would soon be "talking to the animals." Nim was the focus of our Columbia University research team's Grand Experiment: could we teach human language to other animals through environmental input alone with direct instruction and reinforcement principles? Or would there prove to be aspects of human language that resisted instruction, suggesting that language is a cognitive capacity that is uniquely human and likely under biological control? Nim was affectionately named "Chimpsky" because we were testing some of Chomsky's nativist views. To do so, we used natural sign language. Chimps cannot literally speak and cannot learn spoken language. But chimps have hands, arms, and faces and thus can, in principle, learn the silent language of Deaf people.

By the early 1970s, a surprising number of researchers had turned to learning about human language through the study of non-human apes. Noam Chomsky had stated the challenge: important parts of the grammar of human language are innate and specific to human beings alone. Key among these parts is the specific way that humans arrange words in a sentence (syntax), the ways that humans change the meanings of words by adding and taking away small meaningful parts to word stems (morphology), and the ways that a small set of meaningless sounds are arranged to produce all the words in an entire language (phonology). The human baby, Chomsky argued, is not born a "blank slate" with only the capacity to learn from direct instruction the sentences that its mother reinforces in the child's environment, as had been one of the prevailing tenets of a famous psychologist of the time, B. F. Skinner. Nor are babies born with innate knowledge of a specific language, which had been one caricature of Chomsky's innateness views of the time. What is innate in the baby, instead, is tacit knowledge of the finite set of possible grammars that world languages could assume (the finite set of units and the relations among them that make up a sentential string, and the finite ways that they move to form different arrangements in sentences). Innately equipped with this tacit knowledge of the finite set of possible language units and the rules for combining them, the baby listens to the patterns present in the specific language sample to which she is being exposed,

and "chooses" from her innate set of possible grammars the grammar she is hearing. Chomsky's brilliant theoretical proposals on these topics had so captured the imagination of the international public – and we were all so much in the thick of arguing for or against the innateness of language and other forms of higher human cognition – that history would soon come to call this period the "Chomskyan Revolution."

My departure from Project Nim Chimpsky in the mid 1970s to attend graduate school in theoretical linguistics at the University of California, San Diego, was bittersweet. It had become clear that while Nim had some impressive communicative and cognitive abilities, there was a fundamental divide between his knowledge and use of language and ours. No one can "talk to the animals" by sign or otherwise. Nim's data, along with our close analyses of data from all other chimp language projects, unequivocally demonstrated that Chomsky was correct: aspects of human language are innate and unique, requiring a human biological endowment.

Guided (and inspired) by Noam Chomsky's theoretical formulations of human syntax and morphology, we discovered that chimpanzee and human syntax are fundamentally different. While apes can string one or two "words" together in ways that seem patterned, they cannot construct patterned sequences of three, four, and beyond ("words" and "signs" are homologous). After producing a "matrix" two words, they then – choosing from only the top five or so most frequently used words that they can produce (all primary food or contact words, such as *eat* or *tickle*) – randomly construct a grocery list. There is no rhyme or reason to the list, only a word salad lacking internal organization. Remarkably, moreover, chimps never produce word morphology. They do not seem to have any understanding of a basic word stem, nor of modifying its meanings by adding small meaningful word parts ("morphemes") that we bind or "affix" in highly patterned ways to word stems. If they were to naturally acquire the word *fruit* (which they don't) they would not readily acquire *fruity*, *fruitful*, *unfruitful*, *fruitfulness* . . . Born with no capacity at all to make the stem/affix distinction, they never – unlike human children, who quite quickly develop the ability to understand and use affixed terms – develop it later.

Add to this picture the fact that the actual physical forms of chimp lexical productions vary from one time to another in very unsystematic ways. This is not a matter of chimps having bad or immature "pronunciation" of their lexicon, nor is it due to differences between the hands of chimps and humans. Instead, their lexical productions are not patterned and their production errors are random – not drawn from the finite set of units from which all of their words and sentences are built. This fact never changes over chimp development. In short, chimps lack sign phonology. It has always interested me that despite the controversial abilities attributed to chimpanzees in the "Ape-Language Wars" over the decades, no researcher has ever dared to claim that any chimp has

mastered the phonological aspect of human language organization. This deeply telling fact is returned to below.

Alas, the whole story is even worse than irregularities in chimpanzees' syntax, morphology, and phonology: the very *meanings* of their words were "off." For one thing, chimps cannot, without great difficulty, *acquire* the word *fruit*. While apes seem to have some capacity to associate words with concrete things and events in the world they inhabit, unlike humans, they seem to have little capacity to acquire and readily apply words with an *abstract* sense. Thus, while chimps can associate a small set of labels with concrete objects in the world (*apple* for apples, *orange* for oranges), they have enormous difficulty acquiring a word like *fruit*, which is a classification of both apples and oranges. There is no tangible item in the world that is literally fruit, only instances or examples of this abstract kind-concept that seems to exist only in human heads.

For another thing, chimps do not *use* words in the way we do at all. When we humans use the common noun *apple* in reference to that small round and juicy object in the world that we eat, we do not use it to index (pick out) only one object in the world (say, a specific red apple on a table), nor do we use it to refer to all things, locations, and actions globally associated with apples. Instead we use the label to "stand for" or *symbolize* the set of related objects in the world that are true of this particular kind-concept in our heads. Crucially, we also know the range or scope over which word kind-concepts may apply: for example, the label *apple* symbolizes a set of related *objects* and therefore this label is used only in reference to objects, not actions. (We further know how kind-concepts such as *apple* act in a sentence, i.e. what forms it can accept, like the noun plural marker *-s*, and what forms it cannot accept, like the verb present progressive marker *-ing*.) Although chimps can be experimentally trained to use a label across related items (such as the use of the sign *apple* while in front of a red apple or a green apple), children learn this effortlessly without explicit training, and chimps' spontaneous label-usage respects none of the above underlying constraints. Chimps, unlike humans, use such labels in a way that seems to rely heavily on some global notion of *association*. A chimp will use the same label *apple* to refer to the action of eating apples, the location where apples are kept, events and locations of objects other than apples that happened to be stored with an apple (the knife used to cut it), and so on and so forth – all simultaneously, and without apparent recognition of the relevant differences or the advantages of being able to distinguish among them. Even the first words of the young human baby are used in a kind-concept constrained way (a way that indicates that the child's usage adheres to "natural kind" boundaries – kinds of events, kinds of actions, kinds of objects, etc.). But the usage of chimps, even after years of training and communication with humans, never displays this sensitivity to differences among natural kinds. Surprisingly, then, chimps do not really have "names for things" at all. They have only a hodge-podge of loose associations

with no Chomsky-type internal constraints or categories and rules that govern them (Seidenberg & Petitto 1979, 1987; Terrace et al. 1979). In effect, they do not ever acquire the *human* word *apple*.

My disappointment with chimpanzee language was, however, balanced by the prospect of pursuing an intriguing hypothesis. Because humans can readily acquire both signed and spoken natural languages, they must, I reasoned, possess *something* at birth *in addition to* mechanisms for producing and perceiving speech sounds that makes this possible. I wanted to discover what this elusive "something" could be.

By the mid 1970s, linguistics and psychology (especially adult psycholinguistics and child developmental psycholinguistics) were abuzz with excitement over Chomsky's "language acquisition device" (LAD). As stated in general terms above, the LAD assumes innate knowledge of a set of universal and specifically linguistic elements and relations. Armed with such knowledge, the young child can (i) narrow the range of possible grammars consistent with a partial (and often defective) set of sentences (the "primary linguistic data") and (ii) fix on a theory (a grammar) for the specific native language to which it is exposed. My specific questions focused on mechanisms: if such a LAD exists, precisely how might the human brain embody it? How might innate, specifically linguistic knowledge of the set of basic elements and relations be encoded in neural tissue? I knew that attempts to understand this would provide a key to what *biologically* distinguishes human language (including human minds and brains) from the communication of other animals.

The biological foundations of human language

It is not surprising that most linguists, along with most of those who think about the biological foundations of language, closely associate language with speech. For most of us, speech comes early and remains the primary modality for linguistic expression. It is a mistake, however, to associate language and speech too closely. Natural languages must be defined more abstractly, and the science of language must be able to deal with evidence from other modalities. An excellent reason for thinking this is that signed languages are acquired at the same rate as verbally expressed ones. They also reflect the same universals ("principles"). So, language must be defined in a way that applies as easily to sign as it does to speech. To someone like me, who is interested in both the development of language and its neural embodiment, this fact raises intriguing questions.

A superficial reading of Chomsky's early and current work – both formal and informal – might give the impression that he, like many others, closely associates language and speech. In his formal work, for example, he calls one of the "interfaces" of the language faculty "phonetic form" (PF) [recently: PHON].

Informally, when arguing against philosophers who seem often to think of the words of languages as marks on a page, he points out that speech is certainly prior to marks on page or stone, and that words are sounds in the head. But a closer reading – confirmed by many inspiring discussions that I had with Chomsky beginning in the early 1980s when I was a doctoral student at Harvard – indicates that he has a much more abstract characterization of language and its acquisition in mind.

Chomsky is also famous for insisting that his formal view of linguistic computation is not a view of "real-time" neural processes. Moreover, he strongly resists the ideologues who want to tell us that mental processes are "nothing but" neural processes. So, those who study his work might get the impression that he dislikes neural and brain evidence. But this impression too is wrong. His basic view is that the neural investigation of language is still in its very early stages and at the moment the linguist is in a much better position to tell the neurophysiologist what to look for than the other way around. He welcomes good studies and evidence on the matter. One purpose of this chapter is to describe what is, I hope, some evidence of this sort.

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 versus 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, promise 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/or speech perception (Locke 2000; MacNeilage & Davis 2000), then spoken and signed languages should be acquired in radically different ways. At the very least, fundamental differences would be predicted in the maturational *time course* and *structure* of spoken versus signed language acquisition, presumably due to their use of different neural substrates in the human brain.

I have conducted comparative studies of monolingual hearing children (groups acquiring English, and others French) and monolingual deaf children (acquiring American Sign Language, ASL, or Langue des Signes Québécoise, LSQ) from ages birth through 48 months. I have also conducted studies of young bilinguals in "typical" contexts, such as babies acquiring French and English. These bilinguals were compared to two extraordinary cases of childhood bilingualism: bilingual hearing babies acquiring a signed and a spoken language from birth, as well as bilingual hearing babies acquiring two signed languages but no spoken language. Further, I have conducted comparative studies of how the human brain processes highly specific aspects of natural language structure in profoundly deaf adults processing signed language as compared to

hearing adults processing spoken language, using modern Positron Emission Tomography (PET) brain-scanning technology. The empirical findings from all of these studies are clear. They show surprising similarities in the overall time course and structure of early signed and spoken language acquisition as well as in their neural representation in the human brain. Below, I briefly summarize each set of key findings and offer a hypothesis about some of the neurological mechanisms that permit human language acquisition to begin. Then I suggest some implications for Chomsky's view of language.

Milestone data

Monolingual signing versus speaking babies

Deaf children exposed to signed languages from birth acquire these languages in the same stages and at the same times as hearing children who acquire spoken languages. The stages include the "syllabic babbling stage" (6–10 months) as well as other developments in babbling, including "variegated babbling" (ages 10–12 months), "jargon babbling" (ages 12 months and beyond), the "first word stage" (9–14 months), the "first two-word stage" (17–26 months), and the grammatical and semantic developments beyond.

Signing and speaking children also exhibit remarkably similar semantic, discourse, and pragmatic complexity in their development. For example, analyses of young ASL and LSQ children's social and conversational patterns of language use over time, as well as their expressions' conceptual content, categories, and referential scope, demonstrate unequivocally that their language acquisition follows the identical path seen in age-matched hearing children acquiring spoken language (Petitto 2000).

Bilingual hearing babies acquiring a signed and a spoken language

Recent work focuses on two very unusual populations that provide data rich with theoretical implications: hearing children in bilingual, "bimodal" (signing–speaking) homes, and hearing children who are not exposed to spoken language at all in early life, only to two signed languages. First, the bilingual *hearing* children exposed to *both* a signed and a spoken language from birth (e.g. one parent signs and the other parent speaks) demonstrate no preference whatsoever for speech, even though they can hear. For example, these speaking–signing bilingual children acquiring French and LSQ produced their first word in French and their first sign in LSQ at the same time. Indeed, each of these signing–speaking children's languages are acquired on an identical timetable, and this timetable is the same as for other bilingual children acquiring, for example, French and English from birth; it is even the same, remarkably, as the

timetable for monolingual children! And contrary to fears of confusing children by exposing them too early to two languages, bilingual children simultaneously exposed to two languages from birth achieve their linguistic milestones on the same timetable as monolinguals, revealing no language delay or confusion (Petitto et al. 2001; Charron & Petitto 1991; Holowka, Brosseau-Lapré & Petitto 2002; Kovelman & Petitto 2002, 2003; Petitto & Holowka 2002; Petitto & Kovelman 2003; Petitto, Kovelman, & Harasymowycz 2003). But the findings from the signing–speaking children provide us with data that have particularly clear theoretical implications. If speech *per se* were neurologically privileged at birth, then these children might have been expected to glean any morsel of sound that they could get, perhaps even turning from the visually signed input. Instead, they acquire both the signed and the spoken languages to which they are exposed on an identical maturational timetable.

Second, and perhaps even more surprising, are data from a study I was fortunate enough to undertake of an extraordinary group of bilingual children. Although these children could hear, their profoundly deaf parents had exposed them *exclusively* to two *signed* languages from birth through early childhood, with no spoken language input. For example, in one family, the deaf mother was from the United States and signed ASL and the deaf father was from Québec and signed LSQ. These children achieved all milestones in their two signed languages on the same timetable as each other and in the identical manner observed in all other bilingual and monolingual children (Petitto 2000). Moreover, this same pattern of development was also observed in yet another particularly interesting group of children – a group of hearing monolingual babies who were exposed exclusively to one signed language (no speech). Here, as above, these children achieved all of the classic language milestones in sign language on the same timetable as hearing babies acquiring speech, including babbling on their hands, but not vocally because they had never been exposed to speech (Petitto et al. 2001).

Summarizing so far, entirely normal language acquisition occurs in profoundly deaf children exposed only to signed languages, hearing bilingual babies acquiring a signed and a spoken language simultaneously, and, most remarkably, hearing children without any spoken language input whatsoever, only signed language input. These data clearly provide no support for the prevailing hypothesis that normal human language acquisition in all children is determined primarily by the maturation of the mechanisms to hear and produce speech. Interestingly, the hearing bilingual babies who were presented at birth with a tacit choice (speech versus sign) attended equally to these two input signals, showed no preference for speech whatsoever, and achieved every language milestone equally and on the same timetable as monolinguals. Moreover, the hearing babies exposed exclusively to signed language exhibited normal language acquisition (albeit in sign) and did so *without* the use of the brain's

auditory and speech perception mechanisms, and *without* the use of the motor mechanisms used for the production of speech.

Structural data

Homologies in signing and speaking babies

Researchers trying to understand the biological roots of human language have naturally tried to find its "beginning." The regular onset of vocal babbling – *bababa* and the other repetitive, syllabic sounds that infants produce – has led researchers to conclude that babbling represents the initial manifestation of human language acquisition, or, at least, of language production. Babbling – and, by extension, early language acquisition in our species – has been 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. In this view, baby babbling is at first a fundamentally motoric behavior, rather than a linguistic activity. Here, babies learn language by pairing these motoric forms – through learned associations – with meaningful words in the environment (e.g. MacNeilage & Davis 2000). The existence of babbling has been further used to argue that the human language capacity is exclusively linked *neurologically* at birth to innate mechanisms for producing speech in the development of language in a child, or ontogeny (Liberman & Mattingly 1989). It has also been presented as proof that human language evolved over the period of human phylogenetic development exclusively from our species' incremental motoric ability to control the mouth and the jaw muscles (Lieberman 2000).

In 1991, my graduate student Paula Marentette and I reported a surprising discovery, the existence of babbling on the hands of profoundly deaf babies (Petitto & Marentette 1991). Through intensive qualitative analyses of the hands of young deaf babies exposed to sign as compared to hearing babies exposed to speech (ages 10 to 14 months), we found a discrete class of hand activity in deaf babies that was structurally identical to vocal babbling observed in hearing babies. Like vocal babbling, manual babbling possesses (i) a restricted set of "phonetic" units (unique to signed languages) and (ii) syllabic organization. It is also (iii) used without meaning or reference. This babbling hand activity was also different from all babies' other hand activity, be they deaf or hearing. Its structure was particularly distinct from all babies' communicative gestures, or the deaf babies' attempts to produce real signs.

The discovery of babbling in the silent modality of the hands disconfirmed the view that babbling is neurologically determined wholly by the maturation of the ability to talk. Instead, it confirmed a claim central to Chomsky's theory: that early language acquisition is governed by tacit knowledge of the abstract

patterning of language that is biologically endowed in the species, and that this governance is so powerful that it will "out" itself by mapping onto the tongue if given the tongue, or the hands if given the hands – all the while preserving linguistic structures across the two modalities. The deep commonalities between the linguistic patterns expressed on the tongue in hearing children's vocal babbling and those seen on the hands of deaf children's silent babbling (independent of the tongue) teach us that Chomsky's prophetic emphasis on language's core underlying principles and patterns (not the peripheral ability to talk) are the organizing force behind our extraordinary capacity for language.

It is crucial that the Petitto & Marentette (1991) study discovered the existence of syllabic organization in the deaf babies' silent hand babbling. Like spoken language, the structural nucleus of the "sign" (identical to the "word") in signed languages is again the syllable. Although the precise quantitative properties of this rhythmic activity were not known at the time (see below), in signed languages, the sign-syllable consists of the rhythmic closing and opening (and/or the rhythmic hold–movement/movement–hold) alternations of the hands/arms. This sign-syllabic organization has been analyzed as being structurally homologous with the closing and opening of the mouth aperture in the production of consonant–vowel, CV (closed–open) mouth alternations in spoken language. The convergence of similar syllabic structures unique to babbling, be it on the hands or the tongue, suggested once again that something other than peripheral factors, such as the mouth and jaw, was driving this fundamentally linguistic behavior in young humans. Something else was guiding this powerful convergence of structure on two radically different modalities. Discovering what this was would bring us closer to discovering the underlying brain mechanisms (should they exist) that could make possible Chomsky's formal proposals about early language acquisition – his LAD.

A key clue about where to look emerged from the study of deaf babies' hand babbling. When they produced hand babbling, their hands seemed to move with a different rhythm than their other hand movements – those that all babies make. But was this difference real? Maybe babies exposed to signed languages simply used their hands more than babies exposed to speech. So my colleagues and I conducted a quantitative study of young baby hands using innovative technology, called "Optotrak"— optoelectronic position-tracking – in an attempt to identify the *quantitative rhythmic properties* that underlie all babies' hand activity. But to test the strength of our own views, we wanted to put them through the hardest possible test. So we examined the hands of typical young hearing babies acquiring spoken language and that rare group of babies mentioned above: hearing babies exposed only to signed languages from birth (no speech). Both groups of babies were equal in all respects, except for the modality of language input. If babbling (and, by extension, early language acquisition) is determined by the development of the control of the mouth alone,

then both groups of babies' hand activity should be the same. Alternatively, if babbling is a linguistic activity that reflects babies' sensitivity to specific patterns at the heart of human language and their capacity to use them, then the two groups of babies' hand activity should differ. Indeed, as Chomsky had argued in his LAD, if babies are born with tacit knowledge of the core patterns that are universal to all languages, even signed languages, then the linguistic hypothesis predicts that differences in the form of language input should yield differences in the hand activity of the two groups. In biological terms, tacit knowledge was construed as the baby's sensitivity to specific patterns at the heart of human language – in particular, the rhythmic patterns that bind syllables, the elementary units of language, into baby babbles, and then into words and sentences.

The precise physical properties of babies' hand activity were measured by placing tiny light-emitting diodes (LEDs) on their hands. The LEDs 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 the timing, rate, path movement, velocity, frequency, and sophisticated 3-D graphic displays of all baby hand activity. Optotrak computations were calculated "blind" to videotape reference to the babies' hands (we did not see the babies' hands in the first part of the study, only the lighted dots on the computer screen). Independently, on-line videotapes were made of all babies for post-Optotrak analyses. This method, then, provided the most accurate and rigorous quantitative analysis of moving hands to date, and an advance over previous subjective classification of baby hands from videotapes.

The quantitative Optotrak analyses revealed that hearing sign-exposed babies produced two types of hand activity, while the hearing speech-exposed babies only produced one. Sign-exposed babies produced a significantly different type of *low-frequency* rhythmical hand activity, with a frequency around *1 Hertz*, and another type of *high-frequency* rhythmical hand activity, with a frequency around *2.5–3 Hertz* – the type that the speech-exposed babies used nearly exclusively! Further, sign-exposed babies' low-frequency hand activity corresponded to the rhythmical patterning of adult sign-syllables and, after lifting the "blind," videotape data revealed that this hand activity alone exhibited the qualitative properties of silent linguistic hand babbling.[1]

Remarkably, a dramatic dissociation of two hand-movement types (linguistic vs. motoric) was carved onto a single manual modality differentiated by different rhythmical frequencies. This could only occur if babies find salient, and can make use of, the rhythmical patterning underlying human language. This evidence indicates that specific rhythmical patterns underlie baby babbling, and these reflect highly specific rhythmical sensitivities that babies must be born with. These sensitivities correspond to highly specific aspects of the patterning of natural language and almost certainly constitute one of the central biological

mechanisms by which babies discover the patterns of their native grammar in the linguistic stream around them (Petitto et al. 2001; Petitto et al. 2004).

In a new twist on a classic theme, we further wondered just how similar very early language *perception* is across sign and spoken languages. By around 4 months, all babies have the universal capacity to discriminate categorically all the phonetic-syllabic units found in the world's spoken languages (such as [ba] and [pa]), even those that they have never heard. But by around 14 months, most babies have lost this universal capacity and have instead gained an increased sensitivity to detect the phonetic contrasts in their native language. In order to test the neural basis of this capacity – is it a general acoustic or a specific linguistic capacity? – we built an infant-controlled Habituation Laboratory and showed hearing *monolingual* babies (never exposed to sign) moving images of hands. But these hands were phonetic-syllabic units in ASL (below). As with speech, we found that these babies demonstrated categorical discrimination of ASL hand phonetic-syllabic units at age 4 months, which they lost by 14 months (Baker, Isardi, Golinkoff & Petitto 2003; Baker, Sootsman, Golinkoff & Petitto 2003). Intriguing results were then seen in hearing *bilingual* babies (never exposed to sign) who looked like our young monolinguals at age 4 months. But at age 14 months they showed a linguistic "advantage": they demonstrated increased sensitivity to phonetic units over their monolingual peers, suggesting that experience with multiple languages can serve as a "perceptual wedge," keeping open longer the capacity to discriminate a wider range of phonetic units than their monolingual peers (Norton, Baker & Petitto 2003). Here, from the new perspective of infant language perception, these results provide compelling support that the sensitivity to phonetic-syllabic contrasts is a fundamentally linguistic (not general acoustic) process and part of the baby's biological endowment.

Before closing this line of studies, we decided to take one last look. This time we examined only the everyday hearing baby learning a spoken language. Again we asked, "is babbling a linguistic versus a motoric activity?" But now we also wanted to understand *when* the human language capacity emerges in early life and – crucially, for me, because of a research desire that was born after my work with Nim – to find *what* its neural basis is. Our challenge was answering these questions in a way that would not hurt or unsettle young babies.

To gain another perspective on these issues, we carried out another study. It is a notable fact that adults tend to talk out of the *right* side of their mouths. This seems to be due to the fact that our brain's *left* hemisphere is doing the lion's share of our language-processing. (We do not see this right mouth asymmetry when we speak to others because our brains correct the uneven image.) Intrigued by this fact of cerebral organization, we wondered whether baby babbling might be produced more out of the right side of infants' mouths, thereby reflecting the involvement of their left hemisphere's language-processing centers.

Encouraged by the availability of a non-invasive measure (below) to assess the laterality of mouth movements in adults, we applied it for the first time to baby mouths. This also gave us an opportunity to find out whether there was evidence of laterality in other forms of mouth activity. Specifically, would babies produce smiles out of the *left* sides of their mouths (reflecting the involvement of their *right* hemisphere's emotion-processing centers)? And would babies produce non-babbling vocalizations somewhere in between the left and right sides of their mouths?

Ten babies were studied at the onset of their babbling stage, five English babies and five French. This was an important study design consideration to ensure that no language-specific effects were being revealed on babies' mouths. The standard measure of mouth laterality – called the "Laterality Index" – was used, which has been used around the world in the study of adults, especially adults after suffering a neuropsychological trauma (e.g. from a stroke) to determine what brain tissue had been impaired and spared. We found that babies babbled out of the right side of their mouths, smiled out of the left, and produced non-babbling vocalizations somewhere in between. This study was the first to demonstrate left-hemisphere cerebral specialization for babies while babbling which, in turn, suggests that language functions in humans are lateralized from a very early point in development (Holowka & Petitto 2002).[2]

Summary: significance of studies of early signed and spoken language acquisition

Summarizing these studies of sign–speech homologies, it seems clear that despite modality differences, signed and spoken languages are acquired in virtually identical ways. The differences 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. These findings cast serious doubt on the core hypothesis in very early spoken language acquisition that the maturation of mechanisms for the production and/or perception of speech exclusively determine the time course and structure of early human language acquisition. They also challenge the hypothesis that speech (sound) is critical to normal language acquisition, and the related hypothesis that speech is uniquely suited to the brain's maturational needs in language ontogeny. What these data suggest, as Chomsky had hypothesized, is that language does indeed have innate computational systems. But here is the added observation that language will co-opt whatever provides it with an opportunity to develop in accordance with its innate agenda. This innate agenda seems perfectly happy to accept and use language on the hands (if presented with signed language) or the tongue (if the ambient language is a spoken one). That this should be true is stunning

testimony to the power of this innate agenda, that is, the brain's specified neural sensitivity to a core set of patterns underlying human language, and the corollary fact that an innate agenda must exist in the first place. But, again, where is this "patterning" taking place?

Testing hypotheses about the biological–neurological foundations of language with PET studies of signing and speaking adults

The left hemisphere of the human brain has for over one hundred years been understood to be the primary site of language processing (Wernicke 1874). As in early language acquisition, the fundamental explanation for this fact has been that language functions processed at specific left-hemisphere sites reflect its dedication to the motor articulation of speaking or the sensory processing of hearing speech and sound. Contemporary functional imaging studies of the brain have provided powerful support for this view, including those demonstrating increased regional cerebral blood flow (rCBF) in specific portions of the left hemisphere when searching, retrieving, and generating information about spoken words (specifically, in the left inferior frontal cortex, called the LIFC). This view is especially evident regarding the left Planum Temporale (PT), and to a lesser extent the right PT, which participates in the processing of the meaningless phonetic-syllabic units in all spoken language. The left PT forms part of the classically defined Wernicke's receptive language area, receiving projections from the primary auditory afferent system, and is considered to constitute a *unimodal* secondary auditory cortex (for a complete report of these issues and the present PET study under discussion, see Petitto et al. 2000). These data and studies do not, however, resolve the fundamental question of whether these brain sites involved in language processing are devoted to speaking and hearing, or whether they constitute tissue that is better thought of as dedicated to aspects of the patterning of natural language. For these data and studies do not exclude the possibility that areas of the brain thought to be "devoted" to speech perception and production are also those employed in human sign languages.

The existence of natural signed languages provides key insights into whether language processed at specific brain sites is due to the tissue's sensitivity to sound *per se*, or to the patterns encoded within it. In a study to test this, we measured rCBF while deaf signers underwent PET brain scans, which we co-registered with their MRI anatomical brain scans. Vital to this study's design was our examination of two highly specific levels of language organization in *signed languages*, including the generation of signs (lexical level) and phonetic-syllabic units (sublexical level; meaningless parts of signs). As I mentioned before, this level of language organization is found in all the world's languages (be they signed or spoken) and comprises the restricted set of meaningless

units from which a particular natural language is constructed.[3] If the brain sites underlying the processing of words and parts of words are specialized specifically for sound, then deaf people's processing of signs and parts of signs should engage cerebral tissue *different* from that classically linked to speech. Conversely, if the human brain possesses sensitivity to aspects of the patterning of natural language, then deaf signers processing these specific levels of language organization may engage tissue *similar* to that observed in hearing speakers.

We studied two entirely distinct cultural groups of deaf people who used two distinct natural signed languages. Five were native adult signers of American Sign Language (ASL; used in the United States and parts of Canada) and six were native adult signers of Langue des Signes Québécoise (LSQ; used in Québec and other parts of French Canada). ASL and LSQ are grammatically autonomous signed languages; our use of two distinct signed languages constitutes another significant design consideration, unique to the present research, introduced to provide independent, crosslinguistic replication of the findings within a single study. We further compared these eleven deaf people to ten English-speaking hearing adult controls who had no knowledge of signed languages.

Two main findings emerged from this Petitto et al. (2000) study. First, *both* the deaf people processing genuine signs and the hearing controls processing words exhibited clear cerebral blood flow increases within the identical brain region, the left inferior frontal cortex (LIFC). This finding demonstrated that one component of processing human language (something as abstract as lexical search and retrieval) was housed at a specific brain site. Because both language on the hands and language on the tongue were processed at the same brain site, it supported a surprising hypothesis: there exists tissue in the human brain dedicated to a *function* of human language *structure* independent of speech or sound.

The second major discovery involved tissue universally viewed as being literally tied to sound processing, again the Planum Temporale or PT, especially the processing of the small phonetic-syllabic units that make up a spoken word. Here we witnessed robust activation in the profoundly deaf people's PT while they were processing meaningless parts of signs (phonetic-syllabic or sublexical parts of a sign on the hands). This was the remarkable thing: how could there be activity in sound tissue in the brains of profoundly deaf people who never heard sound? The activity could not be due to processing based on any auditory representations as they are traditionally understood – the transduction of sound waves, and their pressure on the inner ear, into neural signals. In witnessing these specific results, we demonstrated neural activity in what has hitherto been thought to be exclusively auditory cortex by using purely visual stimuli – but, crucially, the visual stimuli were linguistic. Thus, rather than being dedicated exclusively to sound (as had been thought for generations) it must be that this

tissue is instead dedicated to linguistic *patterns* in the input – specifically to the patterns inherent in rhythmically contrasting phonetic-syllabic units – be they patterns on the hands or the tongue. In short. we found the biological instantiation of a key level of Chomsky's "hierarchical" levels of language organization: phonology.

Finally, we randomized the MRI anatomical brain scans of all of these deaf and hearing subjects, flipped the x-axis so that no one knew if they were looking at the subjects' left or right hemispheres, and then computed the gray- and white-matter tissue volumes in all of these brains' classic sound tissue (primary and secondary auditory cortices) – without ever knowing the hearing status of the brains being analyzed. In a nutshell. we found that there were no differences in the gray-matter volumes in the deaf and hearing peoples' sound tissue (meaning that there was no cell loss in the sound tissue of profoundly deaf people as compared to hearing people) and no differences in the white-matter volumes between the groups (meaning that there was no loss of neuronal input to this sound tissue). Surprisingly, like hearing people, there was a greater left-versus-right-hemisphere asymmetry in the sound tissue of the deaf people (for a full report of these findings see Penhune et al. 2003). How could this be? Why doesn't sound tissue shrivel up and die in deaf brains? Here, as above, it must be that such tissue is sensitive to specific linguistic patterns in natural language (not sound) and the on-going processing of sign language provides the tissue with just those linguistic patterns to keep it alive and kicking!

Together such facts demand that those who study language and its acquisition introduce hypotheses of the mind/brain that make sense of how this is possible.

Adaptive phonological differentiation

When examining the sublexical level of language organization of signed and spoken languages we find striking commonalities: both employ a highly restricted set of units organized into regular structured patterns – patterns that amount to rapid rhythmically alternating maximal contrasts. This suggests an hypothesis (albeit in a nascent form) that speaks to how visual images might activate auditory brain tissue. And it might at least focus further research efforts, for example, to explain what exactly it is about the neurons of the human PT and their connections to other systems in the head that gives the specific multimodal linguistic-pattern-responding character it has. The PT can be activated either by sight or sound because. I suggest, this tissue (or at least a part of it) has specific neurons or groups of neurons working in concert that, when activated by appropriate input patterns, responds selectively to specific distributions of complex, low-level units in rapid rhythmic alternation. These distributions are those that, informally, we think of as natural-language phonological structure. To be sure, PT tissue does also, in general, deal with sensory *sound* input – the

PT is typically employed in hearing humans in processing non-linguistic sound inputs, and its homologue in the brains of some apes apparently performs only this task. But, due to some yet unknown factor, PT tissue in humans has a sensitivity to certain specific patterns found only in natural languages. This actually may be one key neural difference between the chimpanzee and human brain and provides an intriguing experiment in nature regarding how far a creature could get in language without it: chimps can hear speech but have no brain power to find in the stream of sounds around them the finite set of units and their patterns that make up a language's phonological inventory. From this, we can predict just about how far they'd get without this capacity: no syntax, no morphology, and, of course, no phonology. But, with decent memory and association powers, they would be able to pick out or refer to things in their here and now with list-like global association. Voilà. This is just about what chimps do.

Crucially, the PT is apparently *not* neurally sensitive to any and all rhythmically alternating acoustic input containing contrasts. Music, for example, provides complex multifaceted rhythmical signals that engage brain tissue at multiple cerebral sites yet, in general, contemporary scientists agree that the PT (especially the left PT) is not the brain site for processing these different forms of rhythmically alternating contrasts (for a review see Zatorre & Binder 2000).[4] To summarize, the hypothesis is that the left PT site contains, in addition to other forms of specialization, specialization for highly specific, maximally contrasting rhythmical patterns in the input. These patterns are found exclusively in specific aspects of natural language – specifically, phonetic-syllabic units and their distributional patterning.

If this is correct, there is an initial *biologically guided* capacity (what I called the innate agenda, above) to find salient, and to attend to particular aspects of, input streams involving phonetic-syllabic contrasting units, which after several months of life can (given relevant input) become attuned to whatever sorts of sensory input are capable – consistent with the internal agenda – of activating it. Thus, experience with specific phonetic-syllabic units in the input stream provided by – in the case of humans – sound or vision to a young baby literally changes and "adapts" the baby's biological perceptual and attentional mechanisms to be sensitive to patterns in the given modality or modalities. This "guiding" capacity amounts to a neurally set agenda (a system that "looks for" certain patterns) and leads to the child's ability to discover, and to utilize, elementary units of language structure. Without such an internal agenda, the child's mind would not recognize the patterns needed for linguistic development. Nim's mind, lacking what Chomsky calls a "language faculty," would not and could not find that pattern in the input stream. It would never become salient. The PT neurally embodies a small part of the tacit knowledge of the set of basic elements and relations that Chomsky proposed must be contained in a child's LAD.

On the neural tissue underlying human language acquisition

Returning to the question with which I began my research – how does the brain permit the radical change in the morphology of its expressive and receptive mechanisms for language found in speech and sign, and what is the genetic basis for this stunning equipotentiality? – I think we have found at least some answers. The various studies discussed above 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 the nature of signed and spoken language acquisition – including the nature of the maturational time course and early language structures – as well as the cerebral organization of sign and speech in the adult brain should be different. Clearly, it is not. The fact that the brain can tolerate variation in language transmission and reception, despite different environmental inputs, and still achieve the target capacity (being a speaker of a natural language, perhaps several), provides support for a genetic component underlying language acquisition that is nevertheless biologically "flexible" (neurologically plastic). I hypothesized that PT tissue constitutes a key brain site that contributes to launching human language acquisition and have suggested that it gains its vital role in the establishment of nascent phonological representations in all humans through a process that I have termed "Adaptive Phonological Differentiation." This process "guides" the newborn's attention to find salient specific aspects of the input stream with specific rhythmical contrasts that correspond to key aspects of natural language structure: elementary phonetic-syllabic units and their sing-song distributional patterning (prosody). Drawing from the baby Optotrak findings mentioned above, I further suggest that this PT tissue tunes the infant's perceptual systems to find salient, and to attend to, (initially) maximally-contrasting, rhythmically-oscillating bundles of about 1.2–1.5 seconds. Armed with this honed sensitivity, the baby's mind can, in turn, begin to "select" the restricted set of elementary phonetic units and combinatorial regularities of their native language(s). The precise timing is unclear, but it is known that they begin the production of these elementary units at around six months (see also Jusczyk 1999).

The same processes must be at work when a baby is confronted at birth with two or more natural languages, whether spoken or signed. Here the newborn's sensitivity to specific rhythmical and distributing patterning must provide it with the means to detect two related but different rhythmically contrasting linguistic patterns. The development of this capacity surely serves as a basis upon which bilingual babies tacitly build up representations of their two distinct phonological systems. (Petitto et al. 2001; see also Holowka, Brosseau-Lapré & Petitto 2002; Petitto & Holowka 2002 for a discussion of the processes that make possible human bilingual acquisition). Again, exact timing in the case of multiple languages is unclear, but this process is certainly well underway by

age 6 months, exhibiting regular growth and expansion in the capacity to detect distinct forms of systematic rhythmical-temporal and distributional patterns over time. So, whether one language or many, a baby's innate mechanisms will – irrespective of whether the input is from eye or ear – guide it to find specific patterns in the input stream and, when its internal systems find them, they "instruct" motor systems to produce "output" informed by them.

Chomsky may not have encountered languages on the hands early in his life but, remarkably, his "abstract" theory of the LAD allowed for the flexibility in modality we have seen in this chapter. And while he assumed the LAD must be biologically instantiated in some way, he did not have any idea of how it is written into neural tissue. I think we now have some idea of how a small, but crucial, part of it is.