

GROWTH OF LANGUAGE NETWORKS

Nearly all children acquire one or more languages, reaching essentially adult competence in the first five to seven years of life. What is most striking about language learning is not so much the speed at which it happens—a developmental process that takes several years to complete is not exactly fast—but the fact that it requires little adult supervision, let alone explicit instruction, and that the progression from no language to a language is not quite linear and incremental. In children’s productive language, some error patterns may disappear while others emerge—for example, irregular verbs may be overregularized, as *breaked* for *broken*.¹ Some abilities may even develop abruptly—for example, the use of function words, such as articles or pronouns, which transform speech from telegraphic to structured.² Yet language learning follows a path that is largely similar across children and languages,

as reflected in the developmental milestones familiar to many new parents.³

Research in psycholinguistics indicates that the child is never a blank slate prior to exposure to a language and that the process of language acquisition is not just a matter of brute-force learning from data. If the first thesis was true, we would see much variation among children in how they acquire language, in particular in what skills emerge when. Instead, one finds characteristic developmental trajectories, which suggests that maturation of brain systems determines what aspects of language infants or children can learn and when that can happen. If the second thesis was true—that language acquisition reduces to learning from data—then we would see largely linear growth curves, as if knowledge was stockpiled incrementally and monotonically, much like adding coins to a coin collection. Instead, we find U-shaped turns (correct-incorrect-correct patterns of use over time) and S-shaped transitions (rapid changes from incorrect to correct patterns of use) in development. This points to some discontinuous internal reorganization, where the acquisition of new knowledge may have an impact on how previously learned information is represented and used.

The idea reviewed in this chapter is that infants and young children are able to acquire specific aspects of language only in specific stages of cognitive development. The clock that sets the pace of this process is not an external

one (linguistic input is there all the time, even before birth) but an internal one—the process of brain maturation and growth. This process is genetically constrained (details in chapter 9) and therefore largely the same for all children. Some believe that language is innately specified. Yet the idea that knowledge of grammar may be encoded in the human genome is biologically implausible. Others would soft-pedal the innateness thesis by saying that the human brain is “language ready.” That is closer to truth but is not quite it. If we could upload a complete language system to a newborn’s brain, we would certainly not magically create a competent, fluent speaker of that language.⁴ The reason is intuitively clear: the hardware (an immature brain) would not be ready to run that software (a full-fledged language system). In the case of language acquisition, the software must be programmed in gradually, largely as a function of the stage of growth and organization of the hardware.⁵

The Quiet Phase: Cracking the Speech Code

When does language learning start, and how? The answer may surprise you: it begins as soon as the fetus can hear, several weeks before birth at term, however limited the sounds perceived in utero might be. Prenatal exposure to speech may give the baby clues about specific temporal characteristics of spoken language—properties that do

not change much when distorted, as they may be in the womb. It is, however, postnatal experience—in particular, exposure to speech sounds, usually in a social context—that lets the baby “crack the speech code.”⁶ The capacity to detect and process rhythm and prosody in speech emerges in the first weeks of life, followed by the ability to categorize (that is, form increasingly abstract representations of) phonemes. During the first months, infants become sensitive first to vowels in the language they are exposed to (or what will be their first language, their L1), then to consonants, and eventually to combinations of consonants and vowels (syllables).⁷ These emerging phonological representations are the result of the child’s ability to detect patterns in adult speech by tracking statistical regularities, including co-occurrence frequencies and transition probabilities between input sounds, such as individual phonemes or syllables, and later between words or groups of words. Infants are capable statistical learners: this allows them to discover meaningful building blocks of language—morphemes and words—in an initially opaque speech stream.

The fact that advanced auditory processing can start so early, even before birth, and then at full speed in the first weeks of life, indicates that the baby’s auditory system and probably neighboring regions of the superior temporal lobe are developing rapidly around the perinatal period. Indeed, the maturation of neural auditory circuits,

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together with other sensory systems in the brain (vision, touch, and so on), takes off quickly. But processing speech is more than just hearing speech. Nonauditory speech processing areas of the bilateral superior temporal cortex mature in the first three years of life, during which they become increasingly attuned to the native speech sounds the child is exposed to. There is no evidence for the initial speech specificity of the human auditory network, which is largely shared with our nearest evolutionary neighbors (chapter 10).⁸

An important index of structural brain maturation is synaptogenesis: the process of temporary overproduction of synapses (the junctions between two neurons), followed by pruning to reach adult levels. Synaptogenesis peaks at around 6 months of age in many sensory areas, including auditory cortex, and at around 9 months in receptive speech areas. There is a window of opportunity in the first year of life for acquiring correct receptive representations of all the basic speech sounds of one's first language. During this period, the brain commits to (at least) one particular language phonologically, which, on the one hand, renders it easier to then learn the words (vocabulary) of that language but, on the other hand, may interfere with the acquisition of additional languages, especially those with a different phonology.⁹

The first year, give or take a few months, may well be called the quiet phase of language acquisition. During

this period, production of spoken language sounds is limited to babbling. The average infant may be silent (that is what the Latin word *infans* means), but she is not at all idle. Finding words in the speech stream is one task she is facing in her waking hours. Another is to begin to attach meaning to the words she is extracting from the input. Recent work shows that as early as 6 to 9 months, infants “know” the meanings of many concrete nouns (e.g., *apple*, *shoe*). Moreover, at about the same age, they can relate words semantically (e.g., *milk* and *bottle* vs. *milk* and *ball*).¹⁰ Their internal vocabulary is forming, supported by maturation of parietal and temporal cortical networks for semantic processing.¹¹

First Words and Utterances: Learning to Speak

Let us go back for a moment to the dual-stream model of speech and language by Hickok and Poeppel (chapter 4). The model assumes a ventral stream that interfaces sound and meaning, engaging primarily structures of the temporal lobe bilaterally, and a dorsal stream, mapping phonological to motor representations of speech, in temporal and frontal cortices of the left hemisphere. As suggested by the results discussed, ventral stream function, such as learning to decode speech sounds and associate them with new meanings, begins to develop during the first 6

to 9 months of age and is soon followed by development of dorsal stream function.

Learning to speak is partly a motor learning task, but it is one that crucially builds on previously acquired sensory representations of speech sounds. Already in the babbling phase and later, the infant can use those representations to correct and fine-tune her productions, so that the sounds she tries to articulate will resemble more and more those she hears from others. The dorsal stream uses what the ventral stream has learned (how phonemes and words sound and what they mean) to learn something new (how phonemes and words should be pronounced). This model is consistent with much neurodevelopmental data, suggesting that brain maturation occurs earlier in sensory systems (in occipital-temporal regions, for instance) than in motor or control systems (the frontal cortex, for instance). Before information can be used by higher-order integrative systems, like the dorsal stream in the model by Hickok and Poeppel, it must first be encoded and organized within sensory and perceptual systems.¹²

When do children begin to produce their first words and utterances? Babbling develops around 9 months of age, when motor and adjacent prefrontal cortices begin to effectively connect with auditory and speech perception regions of the temporal lobes. Children produce their first words at around 10 to 12 months of age and two-word utterances toward the end of the second year of

life. As with other aspects of language acquisition, there is some variability as to when individual children attain these skills. Productive child language exhibits little grammatical organization before that age, with the exception of basic word order and morphology in some languages. Between ages 12 and 18 months, children's utterances are typically short, and about half of all their utterances are nouns. The remaining half includes other single words, such as verbs and the first two-word utterances. Between 18 and 24 months of age, two-word utterances become much more frequent, and the total share of nouns now drops to around one-third of all utterances. Data from the Wordbank Project indicate that, at around 16 months of age, only about 25 percent of all children are reported by their parents to be combining words.¹³ This fraction grows to about 50 percent by 20 months of age and to around 75 percent by 24 months, similarly across languages.

Syntax and Semantics: Toward Adult Competence

At the end of the second year of life, around age 18 to 24 months, most children can produce two-word utterances and can communicate effectively with adults using words, gestures (pointing and beyond), and other expressions. At this stage, a child's productive grammar is still rudimentary. For example, even such a basic set of syntactic

properties of languages as word order (e.g., whether adjectives follow or precede the nouns they modify; whether verbs follow or precede their objects) is acquired relatively late, around 19 months according to one study.¹⁴ Recent work has shown that even young infants track statistical patterns in speech that correlate with syntactic structure, such as cues to the placement of function words (determiners and pronouns, for example, which are often shorter and more frequent than most content or lexical words).¹⁵ Statistical learning may indeed lead to discovery of syntactic properties of words, but that is an extended process that involves syntactic abstraction, whereby each individual word is represented as a member of one or more grammatical classes: noun, verb, adjective, and so on. Syntactic processing cannot happen unless words are categorized, and most categories take time to emerge. The first to appear is that of nouns, starting at 12 months, while most functional categories emerge only later, beginning at 14 to 16 months.¹⁶ One-year-old infants are still figuring out the basic syntactic categories of their language.

Here is a puzzle: How do young children understand and produce multiword utterances (never mind how many and how long and complex) when their mental grammar is only beginning to take shape? Linguist Ray Jackendoff has coined the term *asynthetic integration* to denote the kinds of processes that may be at work here. In short, the child's brain can put together word meanings even if not all words

are labeled syntactically or if knowledge of syntactic rules of meaning composition has not yet been acquired.¹⁷ ERP studies, reporting modulations of the N400 effect in infants, support this view. Children can relate or integrate semantic information from coincident or overlapping sensory stimuli across modalities (an auditory word and a picture, for example) by 6 months of age. The ability to relate or integrate meaning over time within and across modalities arises at 9 months. The capacity to relate or integrate the meaning of spoken words in sequences or sentences appears at 18 months at the latest.¹⁸ Behavioral and EEG studies show instead that grammatical processing skills, precisely of the sort required for syntax-driven composition of word meaning in phrases and sentences, develop later, between 18 and 32 months. Nonsyntactic meaning-building operations are available to children prior to the acquisition of a complete grammar.

From the second half of the third year of life, thanks to the emergence of syntactic and pragmatic skills and to significant vocabulary expansion, children's receptive and productive language begins to gradually converge toward adult competence. Utterances are longer and syntactically more complex and organized. Sentences containing more than two words are not uncommon even at 3 years of age, and most 4-year-olds frequently ask and answer questions. Note that the correct syntactic structure of questions is far from trivial in many languages. At this age, children begin

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to recount events and personal experiences (in the past) and to express clearly their desires, intentions, and goals (about the future). The ability to understand the intentions of others allows infants to read social cues from very early on. But from age 5, most children are able to actively exploit this information in communication: they will understand that what is said is not always what is meant. As any parent or older sibling knows well, a 5-year-old can be a delightful conversation partner, fully able to take turns appropriately and to contribute to the conversation informatively, often even creatively. None of this would be possible without the maturation of areas of prefrontal and parietal cortex subserving aspects of social cognition and abstract representations of properties of entities or events (such as numerosity, space, and time) and without functional integration of these regions with core perisylvian language networks. Throughout school age, the child needs only to fine-tune a system that is essentially in place, looking similar to adult language. But as we will find out in the next two chapters, additional language learning and acquisition of reading and writing skills can spice up things a little.

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