CHAPTER 8

Language Development

BRIAN MacWHINNEY

OVERVIEW

One of the best ways to learn about children is to talk and interact with them. Even before children produce their first words, we can learn about their ideas and wishes by following their gazes, gestures, and vocalizations. The more language they learn, the more we can understand and appreciate their minds and personalities. By studying children's names for animals and foods, we can learn how they think about the biological world. By studying their babbling, we can understand how the brain comes to control the vocal apparatus. By observing how children learn two or more languages and cultures, we can come to understand how the mind controls ambiguity, contrast, and competition. By studying how children learn to read, follow maps, and perform experiments, we can track the details of scientific learning, and eventually problem solving in activities such as chess, architecture, medicine, and law. In these and many other ways, we can use language as a window onto the developing mind and brain.

Apart from its role in child development, language is also a window onto human society and social relations. Each day, we spend an enormous amount of time engaged in linguistic interactions. Because we spend so much time talking, it should come as no surprise that the language we end up acquiring is full of great complexity and detail. On the one hand, much of language is rule governed. We consistently form plurals in English by adding the suffix *-s*. However, not all plurals are formed by adding *-s*. There are exceptions for words like *leaves*, *fish*, *oxen*, and *children*. Language is also rich in fixed syntactic expressions (Sidtis, 2011). We use phrases such as *how about your car?* and *what about your car?* happily enough, but would never dream of using *when about your car?* or *how under your car?*. When we ask sarcastically, *what is this fly doing in my soup*? we do not expect a literal answer such as *the backstroke* (Kay & Fillmore, 1999). Instead, we are using this unique and rather limited construction to express a very specific type of meaning appropriate in a very narrow context. The rule for forming double-object constructions such as *Pat gave John the ball* or *Sarah mailed her Mom the chocolates* seems quite general, but we find it strange to say *Tom delivered the fraternity the pizza* or *He recommended me his book*.

Orthography is also rich with exceptions. We pronounce the "ough" in *plough, tough*, and *slough* in three totally different ways, despite their similar orthography. Dialect variation adds still more irregularity and inconsistency. When we are in Boston, we expect to hear *car* pronounced without the final /r/; when we are in Pittsburgh, we expect to hear *oil* pronounced as *earl*. We know that we should not say *good night* to someone until we leave, even if it is late at night, whereas we have no problem using *good morning* and *good evening* as greetings on arrival.

In the face of all this irregularity, it is easy to conclude that "all rules leak." But this does not mean that language is totally random. On the contrary, there are patterns and subregularities everywhere. We consistently place the English adjective before the noun. We consistently place the English auxiliary before the subject in questions such as *are you happy?* Language is continually affected by this ongoing competition between patterns (or "rules") and episodes (or "rote") (MacWhinney, 1975b). Rote forms are the stored episodic encoding of particular real life experiences linked to verbal forms. This storage relies on the hippocampal-temporal system for episodic encoding (McClelland, McNaughton, & O'Reilly, 1995). Rules are patterns that have been extracted by generalization across a collection of episodes. This competition between rote and rules is a driving force underlying all aspects of language development. In this chapter, we will explore how this fundamental process interacts with all the many additional neural, social, cultural, and personal complexities of children's lives.

Our exploration of language development includes four major sections. We begin with consideration of the contrast between the two major modern approaches to language learning: Universal Grammar and Emergentism. Next, we examine in detail the course of development across the seven basic language systems: auditory development, articulatory development, lexical development, syntactic development, morphological development, mental model development, and conversation development. In the third section, we examine the neurodevelopmental bases of language disorders; and the final section examines multilingual development.

UNIVERSAL GRAMMAR

The modern study of child language development is influenced by two very different conceptual frameworks: Universal Grammar and Emergentism. To understand the nature of this contrast, let us examine these two approaches in detail. The theory of Universal Grammar and its application to child language learning have been developed by Noam Chomsky and colleagues across the last half century (Chomsky, 1957, 2010). Chomsky considers language to be a universal ability found in all humans at birth. Specifically, he maintains (1980, pp. 134–135) that "There are certain processes that one thinks of in connection with learning: association, induction, conditioning, hypothesis-formation and confirmation, abstract and generalization, and so on. It is not clear that these processes play a significant role in the acquisition of language. Therefore, if learning is characterized in terms of its distinctive processes, it may well be that language is not learned." The claim is that, although languages appear to differ, they are all basically the same, except perhaps for a small set of parameters that can be set to the right value by listening to a few crucial sentences. The view of language as a Special Universal Gift is often further connected to the idea that it must have arisen from a small set of evolutionary events (Bickerton, 1990). Frequently, it is then further linked to the idea that the language faculty is a unique property of the human mind represented neurologically in a distinct cognitive module (Fodor, 1983). Studies of language learning stimulated by this perspective have tended to focus on a small set of syntactic structures that are thought to constitute the core of Universal Grammar or UG (Chomsky, 1981). According to this Principles and Parameters model of language structure (Hyams & Wexler, 1993), the learning of particular languages occurs through the process of parameter setting. During parameter setting, children identify the exact shape of their mother tongue by choosing the proper settings on a small set of binary oppositions. For example, a positive setting on the "head-final" parameter will select for languages like Japanese that place the verb after the direct object as in *he bananas eats*, as opposed to languages like English that place the verb before the direct object as in *he eats bananas*. The idea is that the position of the direct object in these languages is also aligned with the position of the adjective or the relative clause before or after the noun and other structural facts. However, few languages divide cleanly along these parameters. For example, German and Hungarian allow for placing the direct object sometimes before the verb and sometimes after the verb. Also, if English were to follow a head-initial pattern strictly, the adjective would be placed after the noun, as it is in Spanish.

Chomsky and colleagues (Hauser, Chomsky, & Fitch, 2002) have emphasized the fact that no other animal species has ever developed a system of communication as rich and complex as human language. Unlike the communication systems of other species, language allows humans to create complete and open-ended descriptions of all manner of objects and activities outside of the here and now. This marked contrast between our species and our nearest primate relatives suggests that, over the 6-million-year course of human evolution, there must have been important genetic changes that allowed humans to develop this particular species-specific ability. Further proof of this genetic basis comes from the fact that children learn their first language easily, whereas learning of a second language is often slow and incomplete. The idea is that, after some critical period, the species-specific gift for language learning expires, thereby making second language learning difficult or even impossible.

What might be at the core of this uniquely human ability? Hauser, Chomsky, and Fitch (2002) speculated that what makes human language unique is its capacity for recursion. Since its introduction (Chomsky, 1957), generative grammar has emphasized the ways in which linguistic productivity is based on recursion in general (Tomalin, 2007) and the recursive embedding of sentences inside other sentences in particular. For example, Miller (1965) noted that structures like relative clauses can be added at will to sentences, making the number of possible sentences in a language uncountably large. Perhaps there was some simple genetic change that occurred in recent human evolutionary history that led to the introduction of this remarkable ability.

The idea that there might be a gene for recursion is attractive, because it offers the possibility of linking together facts from linguistics, cultural anthropology, neurology, genetics, and evolution. Evidence indicating that the FOXP2 gene has undergone rapid change in the past 200,000 years further supports this possibility (Enard, 2011). However, the claim that recursion is linked to some recent genetic innovation generates predictions that are problematic. One prediction is that all human languages should display recursion. In fact, many languages make far less use of sentential recursion through relative or complement clauses than we do in English. Languages of North America, such as Navajo or Mohawk, will break a sentence such as *The boy who shot the arrow dropped the stone,* into components like *That boy, he shot the arrow,* and *That one, he dropped the stone*. In such sequences, cognitive embedding is reflected through pronominal linkage, rather than sentential recursion. In his account of his work with the isolated Pirahã of the Amazon, Everett (2007) explains how this group communicates effectively without relying on sentential recursion at all. In their world, what is important is an accurate description of events, rather than the recursive linkage of events into bigger discourse structures. However, the fact that a given culture makes no use of sentential recursion may tell us very little about the role of recursion on a deeper cognitive level. In cognitive terms, recursion is based on processes that were already available to nonhuman primates (Arbib, 2010). The evolution of formal written expression in complex cultures has demonstrably amplified the linguistic devices for marking recursion (Donald, 1998; MacWhinney, 2009). It is not that recursion leads to the evolution of language, but that the evolution of language leads to a fuller use of recursion.

The view of language as a species-specific ability linked to a critical period is also problematic. Studies of the neural basis of communication in organisms such as crickets (Wyttenback, May, & Hoy, 1996), quail, and song birds (Marler, 1991) have emphasized the extent to which species-specific communication patterns are stored in highly localized hardwired neurologic structures. However, in many bird species, the consolidation of the song pattern emerges gradually over the first weeks and remains plastic or mutable for several more weeks (Konishi, 1995). When we look at human language learning, we see even more evidence for plasticity and gradual emergence, rather than strong initial canalization. There is little evidence that child language development follows a tight biological timetable of the type that we see in the development of communication systems in other organisms. In fact, children can learn language even when they have received no input up to the age of 6 (Davis, 1947).

The nativist account of language acquisition emphasizes the idea that language is not really learned at all, because it is already innate. In truth, even with consistent and massive input, children struggle for 3 full years to acquire the core aspects of articulation, lexicon, and syntax in their native language. Children learn language gradually and inductively across a period of many years, rather than abruptly and deductively through the setting of a few simple parameters. No one has ever detected a discrete moment at which a child sets some crucial linguistic parameter. Moreover, it is difficult to use standard experimental methods to prove that children have acquired some of the abstract categories and structures required by Universal Grammar, such as argument chains, empty categories, landing sites, or dominance relations (van der Lely, 1994).

A final problem with the UG approach to language development is that it expects that language development should be essentially complete by Age 4. In fact, a great deal of language development occurs after Age 4 and continues throughout our lives. If we focus only on those aspects of language that are solidified by Age 4, then we will need other accounts to deal with language development in later childhood and across the life span.

EMERGENTISM

For an alternative understanding of language development, we can turn to the theory of Emergentism (MacWhinney, 1999; Overton, 2006). The general principle underlying emergentism (Lewes, 1874) is that patterns in one domain emerge from patterns in a separate domain that then become subjected to constraints of the new domain. The classic example of this is the emergence of the properties of water on the molecular level. On the atomic level, the water molecule is a simple combination of two hydrogen atoms and one oxygen atom. However, the unique properties of water such as surface tension or its solvent properties only appear as a result of forces operating on the level of the molecule and cannot be predicted directly from the atomic level.

Emergence operates in social structures as much as in physical structures. Consider the forces that determine the length of checkout lines at a supermarket. Over time, you will find that the number of people queued up in each line stays roughly the same. There are rarely six people in one line and two in the next, unless there is a line with special rules. There is no socially articulated rule governing this pattern. Instead, the uniformity of this simple social structure emerges from other basic facts about the goals and behavior of shoppers and supermarket managers.

Honeybees are certainly no smarter than shoppers. However, working together, bees are able to construct an even more complex structure. When a bee returns to the hive after collecting pollen, she deposits a drop of wax-coated honey. Each of these honey balls has approximately the same globular shape and size. As these balls get packed together, they take on the familiar hexagonal shape that we see in the honeycomb. There is no gene in the bee that codes for hexagonality in the honeycomb, nor any overt communication regarding the shaping of the cells of the honeycomb. Rather, this hexagonal form emerges from the application of packing rules to a collection of honey balls of roughly the same size.

Nature abounds with such examples of emergence. The shapes of crystals emerge from the ways in which atoms can pack into sheets. Crystalline lattice structures (cubic, hexagonal, monoclinic, orthorhombic) emerge as packing solutions based on the relative size of the atoms in ionic compounds. The outlines of beaches emerge from interactions between coastal geology and ocean currents. Consider the shape of Cape Cod near Provincetown, where the northeasterly drift of the Gulf Stream works to push the outline of the cape toward the mainland. Weather patterns like the Jet Stream or El Niño emerge from interactions between the rotation of the Earth, solar radiation, and the shapes of the ocean bodies. Biological patterns emerge in similar ways. For example, the shapes of the spots on a leopard or the stripes on a tiger emerge from the timing of the expression of a pair of competing genes expressing color as they set up standing waves governed by B-Z equilibria across the developing leopard or tiger embryo (Murray, 1988). No single gene directly controls these patterns. Rather, the stripes emerge from the interactions of the genes on the physical surface of the embryo. The shape of the brain is very much the same. For example, Miller, Keller, and Stryker (1989) have shown how the ocular dominance columns described by Hubel and Weisel (1963) emerge from the competition between projections from the two optic areas during synaptogenesis in striate cortex.

Emergentist thinking is basic to the natural sciences. However, it applies equally well to the social, neural, and behavioral sciences. The application of emergentism to the study of language and language development has proved to be particularly rewarding. Emergentism agrees with Universal Grammar (UG) on one core issue: human language is uniquely well adapted to human nature (Christiansen & Chater, 2008). The fact that all people succeed in learning to use language, whereas not all people learn to swim or do calculus, demonstrates how fully language conforms to our human nature. Languages avoid sounds that people cannot produce, words they cannot learn, or sentence patterns they cannot parse. Emergentism differs from UG in that it attributes this match to general versus specific mechanisms. In the UG account, specific genetic mechanisms arose over recent evolutionary history to support this uniquely human ability. In the emergentist account, language depends on a set of domain-general mechanisms that ground language on the shape of the human body, brain, and society. This is the core difference between UG and emergentism.

Our examination of emergentist theory involves four steps. First, we consider the basic Darwinian concept of development through proliferation, competition, and selection. Second, we discuss how this overall vision is realized through specific competitive mechanisms in the body, brain, and society. Third, we examine how emergence works across structural levels with an emphasis on the seven levels of language structure. In a later section dealing with neurolinguistic processes, we examine the ways in which these mechanisms mesh across divergent timeframes.

Competition

The most fundamental emergentist mechanism is competition. This is the mechanism at the core of the Darwinian approach to evolution. Biological evolution is driven by the processes of proliferation, competition, and selection. In the biological world, proliferation of variant genetic patterns arises from mutations to the DNA, as well as independent assortment and recombination in sexual reproduction. Competition involves the attempt of the organism to survive and procreate. Selection involves the imposition of constraints to determine the winners in the battle for survival and procreation. In language, proliferation arises during exposure to alternative ways of saying similar things. In fact, every time we hear a word like *dog*, it is produced slightly differently, as we hear it produced by speakers with different vocal tracts, and dialects, and in different sentential and conversational contexts. Competition then processes these forms in ways that solidifies the strongest patterns as generalizations. Generalization involves treating forms that are slightly different as if they were equivalent. In this sense, it transforms competition into cooperation. As we will see, proliferation, competition, and cooperation are implemented through specific mechanisms on the bodily, neuronal, and social levels.

Mechanisms Based on the Body

Language production is supported by the vocal apparatus and language perception is supported by the auditory system. Vocalization depends on precise coordination of the actions of dozens of muscles in the jaw, face, larynx, tongue, palate, lips, and lungs. Hearing relies on the motions of small hair cells in the cochlea as well as external neural pathways that achieve a great deal of auditory processing even before signals reach the cortex. Although the brain is responsible for control and integration of these two systems, the physical properties of these organs determine the possible ways in which language can be structured. The possible shapes of tones and pitch contours are limited by what the vocal cords can produce. The shape of syllables is determined by the way in which the jaw and articulators can move, and the speed of language production is limited by the ability of these various articulators to move together.

In 1794, Huygens demonstrated that two pendulums moving at different periods would couple together to find a single periodicity, if they are attached to a single board with springs. Because of this coupling, one pendulum serves as the strong attractor that entrains the other pendulum to its periodicity. Such resonant coupling also occurs within language. For example, studies of the mechanics of infant babbling have demonstrated that there is an early period when the child moves the jaw with a consistent rhythm (MacNeilage, 1998b). During babbling, the periodicity of this movement then serves to entrain a similar periodicity in the opening and closing of the glottis. The result of this coupling is the emergence of canonical babbling (Vihman, 1996).

Neural Mechanisms

The proliferation of linguistic episodes in the language heard by the child triggers a series of emergent processes in the brain. These processes reflect core concepts in general systems theory (von Bertalanffy, 1968). Some of the most important of these are:

- *Episodic encoding*. As we noted earlier, the child's encoding of the language heard during specific experiences is the source of all further learning.
- *Pattern extraction*. Like cognition more generally, language learning is dependent on the extraction of patterns by generalization across episodic forms (Rumelhart, McClelland, & the PDP Research Group,1986). Generalization detects commonalities between forms in terms of their ability to predict structures on other levels. For example, it would look at commonalities between various productions of the sound /p/ in terms of their involvement in words like *pill*, *pie*, or *pet*.
- *Homeorrhesis*. We can define homeorrhesis as the maintenance of a consistent structure during processes of change. Neurons continually die, regenerate, and change. However, when a neuron dies, regulatory processes in the DNA that are sensitive to the overall brain architecture can assure that the new cells replace the dead cells into terms of both structure and function.
- *Control*. Systems such as the basal ganglia (striatum, thalamus, cortex, globus pallidus, and substantia nigra) provide multiple loop-back levels for attentional control, proceduralization, and error-based learning.
- *Topological organization*. The brain depends on a system for connecting areas through topological (tonotopic, somatotopic, retinotopic, etc.) organization that emerges during embryogenesis. This system works to place things that are nearby in space, tone, or taste into nearby areas of the cortex (Huth, Nishimoto, Vu, & Gallant, 2012). The functioning of this process can be modeled using self-organizing feature maps (Kohonen, 2001) and topological sheets (Shrager & Johnson, 1995).
- *Redundancy*. The brain supports multiple systems for redundancy to provide plasticity and recovery from injury. For example, the brain can compensate for damage to left hemisphere language areas in children with early focal lesions through reorganization to the right hemisphere (Booth et al., 1999; MacWhinney, Feldman, Sacco, & Valdes-Perez, 2000).
- *Resonance*. Neurons fire when the multiple inputs arriving from other cells are strong enough in combination to polarize the cell membrane. This spread of firing across groups of interconnected neurons supports the general computational pattern of spreading activation that allows one idea to activate another. This system of connectivity provides support for Hebbian learning that holds that "neurons that fire together wire together." This type of coactivation is fundamental, for example, to achieving fluent multilingualism.

Social Mechanisms

Along with mechanisms grounded in the body and the brain, language is shaped by basic social mechanisms, including:

- *Imitation and mimesis*. Children are driven by a fundamental urge to sound like those around them (Meltzoff & Decety, 2003). The first target of imitation is usually the mother, and sometimes a nursemaid. Later, children will imitate siblings, peers, and the wider society. Once social groups form, the processes of imitation lead to the diffusion of new accents, expressions, and words through the process of mimesis that underlies the spread of trends, fads, and other new social forms. Like genetics, memetics is grounded on the basic Darwinian principles of proliferation, competition, and selection (Mesoudi, Whiten, & Laland, 2006).
- *Reinforcement*. Children are also highly sensitive to positive and negative feedback (Sokolov, 1993). Corrective feedback (*that's not a kitty, it's a tiger*) tends to focus mostly on meaning, whereas correction of grammatical errors relies primarily on sequences in which the child makes an error, such as *he eated it* and the parent then recasts the sentence by saying *yes, he ate it* (Bohannon, MacWhinney, & Snow, 1990).
- *Social referencing*. Children also learn by watching other people's actions and reactions. For example, they can learn to act with hostility by watching a video displaying hostility (Bandura, Ross, & Ross, 1963) or they can learn fear of insects by watching people express this fear (LoBue, Rakison, & DeLoache, 2010). This type of learning involves both imitation and appreciation of people's reactions.
- *Common ground*. Language learning is further supported by the construction of common ground between

interlocutors, using shared mental models. Once established, common ground can support scaffolding (Bruner, 1987) and the learning of conversational structure (E. Clark, in press).

Levels and Emergence

In order to understand the emergence of patterns between levels of linguistic structure, it is helpful to review the ways in which structure emerges in physical and biological systems. Consider, first, how water derives its unique properties. The combination of two hydrogen atoms with one oxygen atom produces a water molecule. Because the two hydrogens give over their lone electron to covalent bonds with the oxygen, they become positive and the oxygen becomes negative. All the basic properties of water emerge from this polarity. First, polarity leads each water molecule to form four water dimer hydrogen bonds with other water molecules. In the liquid state, these bonds can be easily broken, allowing movement between molecules, although the bonds are tight enough to produce surface tension. When energy is removed by cooling, the bonds can no longer be broken and water forms a crystalline lattice as the bonds tighten and expand. The solvent properties of water also derive from the role of hydrogen bonds. Although these properties of water can be explained through physical laws, these properties only display themselves once atoms combine into molecules. At that point, a new structural level emerges that is governed by new constraints.

Protein folding provides a more extensive example involving four structural levels. The primary structure level of a protein is determined by its sequence of amino acids, which is, in turn, a function of the order of base pairs in a codon of DNA that is then transcribed to RNA and translated by the ribosome. The proteins emerging from the ribosomes then take on a secondary structure of coils, folds, and pleats arising from the formation of hydrogen bonds between CO and NH groups along the polypeptide backbone. Tertiary structure derives from hydrophobic interactions and disulfide bridges that produce bonding between side chains. Quaternary structure emerges from the aggregation of polypeptide subunits, as in the combination of four subunits in hemoglobin. Altogether, “the specific function of a protein is an emergent property that arises from the architecture of the molecule” (Campbell, Reece, & Mitchell, 1999, p. 74).

Language involves the coordination of emergent structures across the seven levels we will review in this chapter. The processes on these seven levels are far more complex than those involved in protein folding, but the role of emergent processes constrained by forces unique to each level is similar. Traditionally, linguistics has recognized the six structural levels of auditory phonology, articulatory phonology, lexicon, morphology, syntax, and pragmatics. However, a fuller analysis requires that we differentiate pragmatic processes into those that construct mental models and those that govern patterns in conversation (Pickering & Garrod, 2004). Research in cognitive neurolinguistics (MacWhinney & Li, 2008) provides further support for this seven-component analysis.

Let us begin with a quick glance over each of these seven components. First, consider the relation between auditory and articulatory learning. Auditory development involves learning how to distinguish the basic sounds of the language and using them to segment the flow of speech into words. This learning involves the receptive or perceptual side of language use. Children’s articulatory development, in contrast, involves learning to control the mouth, tongue, and larynx to produce sounds that imitate those produced by adults. This learning involves the productive or expressive use of language. Auditory learning and articulatory learning are the two sides of phonological development. Clearly, we cannot acquire conventional control over articulation until we have learned the target auditory contrasts. Thus, audition logically precedes articulation.

The third dimension of language development is lexical development, or the learning of words. To serve as a means of communication between people, words must have a shared or conventional meaning. Picking out the correct meaning for each new word is a major learning task for the child. But it is not enough for children to just recognize words produced by their parents. To express their own intentions, they have to be able to recall the names for things on their own and convert these forms into actual articulations. Thus, lexical development, like phonological development, includes both receptive and expressive components.

Having acquired a collection of words, children can then put them together in combinations. Some of these combinations involve forms that can appear by themselves; others involve forms that only appear in combination. When forms are combined, the components may change their phonological shape. This produces a fourth level of emergent structure called morphophonology.

The fifth level of emergent structure also arises from the combination of words, but it involves not the phonological form of words, but their sequential patterning. This is the system of syntax—the patterns by which words and phrases are arranged to make meaningful statements and to mark the roles of individual words in the overall utterance.

The sixth linguistic component that a child must learn to master is the system of mental models that relate syntactic patterns to meaningful interpretations. During production, this system takes meanings and prepares them into a form that Slobin (1996) has called "thinking for speaking." During comprehension, this system takes sentences and derives embodied mental models for the meanings underlying these sentences.

The seventh component that the child must acquire encodes the social and pragmatic principles of conversation. This is the system of patterns that determines how we can use language in particular social settings for particular communicative purposes. Because pragmatics refers primarily to the skills needed to maintain conversation and communication, child language researchers find it easiest to refer to pragmatic development as the acquisition of communicative competence and conversational competence (Ochs & Schieffelin, 1983). A major component of communicative competence involves knowing that conversations customarily begin with a greeting, require turn-taking, and revolve about a shared topic. Children must also learn that they need to adjust the content of their communications to match their listener's interests, knowledge, and language ability.

The task facing the child is to learn all the relevant patterns of the target language across these seven levels. On each level, learning is facilitated and constrained by general-purpose mechanisms (episodic encoding, generalization, competition, imitation, etc.) that interact in different ways with each type of structure. Learning is further constrained and facilitated by the fact that it occurs in tandem across all seven levels. These mutual constraints across levels make learning easier for the child, but they also make the task of scientific analysis far more challenging (Simon, 1962).

AUDITORY DEVELOPMENT

William James (1890) described the world of the newborn as a "blooming, buzzing confusion." However, we now know that, at the auditory level at least, the newborn's world is remarkably organized. The cochlea and auditory nerve provide extensive preprocessing of signals for frequency and intensity. By the time the signal reaches the auditory cortex, it is fairly well structured.

Distributional Learning

In the 1970s, researchers (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) discovered that human infants were specifically adapted at birth to perceive phonemic contrasts such as the one between /p/ in *pit* and /b/ in *bit*. Soon, it also became apparent that even chinchillas were capable of making this distinction (Kuhl & Miller, 1978). This suggests that much of the basic structure of the infant's auditory world might be attributed to fundamental processes in the mammalian ear and cochlear nucleus, rather than some specifically human adaptation.

Although infants have access to a wide palette of auditory contrasts from birth, they soon begin to lose the ability to distinguish contrasts not represented in their native language (Kuhl, 2010; Werker, 1995). Infants that grow up in a bilingual world can maintain flexibility regarding contrasts that differ between the languages they are learning (Sebastián-Galles & Bosch, 2005). However, if the infant is growing up monolingual, flexibility in processing is gradually traded off for quickness and automaticity (Kilborn & Cooreman, 1987). The drop in ability to perceive certain nonnative contrasts is particularly marked between 6 months and 2 years, after which much of this ability returns, perhaps as the result of a reduction in the need to focus attention on native language contrasts (Werker, 1995).

Infants appear to be engaged in pattern extraction even before birth. DeCasper and Fifer (1980) tape-recorded mothers reading a Dr. Seuss book, and then played back these tapes to newborns before they were 3 days old. Making the playback of the tapes contingent on the sucking of a pacifier, they found that babies sucked harder for recordings from their own mothers than for those from other mothers. Moreover, newborns preferred stories their mothers had read out loud even before they were born over stories that were new (DeCasper, Lecanuet, & Busnel, 1994). Thus, it appears that their prenatal auditory experience shaped their postnatal preference. These learned preferences are not specific to just the mother, but eventually generalize to other speakers of the language. Thus, at 3 months, a French infant will prefer to listen to French, whereas a Polish infant will prefer to listen to Polish (Jusczyk, 1997).

The tuning of the auditory system for detection of native language phonemic contrasts depends on the same processes of episodic encoding and subsequent generalization that are found on all levels of language learning. As children begin to learn words spoken in variant ways by different speakers, they are forced to treat ostensibly different auditory forms as equivalent in lexical terms. Occasionally, this can lead them to treat sounds that are really different as equivalent (Stager & Werker, 1997). However, they can rely on distributional learning across their episodic inventory of word forms and sounds to eventually sort out these patterns of variation and equivalence (Thiessen, 2007; Thiessen & Yee, 2010)

Sequential Learning

Children learn both sequential and distributional patterns (Thiessen & Erickson, in press) in sounds and words. Sequential patterns predict which words can precede or follow a given word or syllable. For example, there is a high transitional probability that *ty* will follow *pret*, as in *pretty*, whereas the probability of *ba* following *ty* is much lower, only occurring in sequences such as *pretty baby*. By tracking such statistics, children can make guesses regarding sequences that are likely to be candidate words. To do this, the infant must have something akin to a tape recorder in the auditory cortex that records input sounds, replays them, and accustoms the ear to their sequential and distributional patterns, well before learning the actual meanings of these words. This notion of an auditory recorder fits in well with the idea that language learning is grounded on episodic recordings that are then further processed for pattern extraction.

One experimental method (Aslin, Saffran, & Newport, 1999) for studying early sequential learning relies on the fact that babies tend to habituate to repeated stimuli from the same perceptual class. If the perceptual class of the stimulus suddenly changes, the baby will brighten up and turn to look at the new stimulus. To take advantage of this, experimenters can play back auditory stimuli through speakers placed either to the left or right of the baby. If the experimenter constructs a set of words that share a certain property and then shifts to words that have a different property, the infant may demonstrate awareness of the distinction by turning away from the old stimulus and orienting to the more interesting, new stimulus. For example, if the 6-month-old hears a sequence such as *badigudibagadigudigagidu* repeated many times, the parts that are repeated will stand out and affect later listening. In this example, the repeated string is *digudi*. If infants are trained on these strings, they will grow tired of this sound and will come to prefer to listen to new sound strings, rather than one with the old *digudi* string. This habituation effect is strongest for stressed syllables and syllables immediately following stressed syllables (Jusczyk, 1997).

Words as Cues to Segmentation

Distributional and sequential information can help the infant segment out potential candidate words from the speech stream. However, an even more powerful method for segmentation relies on word learning itself. Recent models (Monaghan & Christiansen, 2010) have shown that the ability to detect known words within new sequences is a crucial key to effective segmentation. Moreover, we know that parents provide children with powerful assistance in this process. Based on corpora in the Child Language Data Exchange System (CHILDES, http://childes.talkbank.org) database (MacWhinney, 1995), Brent and Siskind (2001) and MacWhinney (in press) found that nearly a quarter of the utterances presented to young children involve single words. Words that are produced in isolation can be acquired without segmentation. Thus, if the mother points to a dog and says *doggie*, the child can acquire this sound as a new word. Then, when the child hears the combination *nice doggie*, the familiar form *doggie* can be segmented out from the unfamiliar form *nice*. This is what MacWhinney (1978) called the “segmentation of the known from the unknown.” The further task that then faces the child is to link the unknown form *nice* to a specific candidate meaning.

ARTICULATORY DEVELOPMENT

The first directly observable evidence of language-like behaviors occurs when the child vocalizes. At birth, the child is already capable of four distinct types of cries (Wäsz-Hockert, Lind, Vuorenkoski, Partanen, & Valanne, 1968): the birth cry, the pain cry, the hunger cry, and the pleasure cry. The birth cry occurs only at birth and involves the infant trying to clear out the embryonic fluid that has accumulated in the lungs and trachea. The pain cry can be elicited by pricking the baby with a pin. The hunger cry is a reliable indicator of the infant’s need to be fed. The pleasure cry, which is softer and not too frequent at first, seems to be closer to the forms of later language. Using spectrographic analysis, one can study these early cries to identify children with genetic abnormalities such as *cri du chat* or Lesch–Nyan syndrome.

Fixed Action Patterns

Infant cry patterns can be understood from the framework of the study of animal behavior or ethology (Tinbergen, 1951). In that framework, animals are viewed as capable of producing certain fixed action patterns. For example, bucks have fixed action patterns for locking horns in combat. Birds have fixed action patterns for seed pecking and flying. In humans, fixed action patterns include sucking, crying, eye fixation, and crawling. These various fixed action patterns are typically elicited by what ethologists call *innate releasing mechanisms*. For example, the sight of the nipple of the mother's breast elicits sucking. Mothers respond to an infant's hunger cry by lactating. A pinprick on a baby's foot elicits the pain cry, and parents respond to this cry by picking up and cuddling the child. In this regard, we can think of the origins of language as phylogenetically ancient and stable.

During the first 3 months, a baby's vocalizations involve nothing more than cries and vegetative adaptations, such as sucking, chewing, and coughing. However, around 3 months (Lewis, 1936; McCarthy, 1954), at the time of the first social smile, babies begin to make delightful little sounds called "cooing." These sounds have no particular linguistic structure, but their well-integrated intonation makes them sure parent pleasers. During this time, the number and variety of vowel-like sounds the infant produces shows a marked increase. Unlike the vowels of crying, these vowels are produced from pleasure. Irwin (1936) noted that, up to 6 months, the infant's sounds are 90% back consonants like /*g*/ and /*k*/ and midvowels like /ɐ/ and /ə/.

Babbling and Cortical Control

At around 6 months of age, vocalizations shift from back consonants to front consonants. This shift may be a result of the shift from the dominance of spinal control over grosser synergisms like swallowing to cortical control over finer movements (Berry & Eisenson, 1956; Tucker, 2002). This shift to cortical control allows the baby to produce structured vocalizations, including a larger diversity of individual vowels and consonants, mostly in the shape of the consonant-vowel (CV) syllables like /*ta*/ or /*pe*/. As the frequency of these structured syllable-like vocalizations increases, we begin to say that the infant is babbling. Neural control of early babbling is built on top of patterns of noisy lip smacking that are present in many primates (MacNeilage, 1998a). These CV vocal gestures (Hoyer & Hoyer, 1924) include some form of vocal closure followed by a release with vocalic resonance.

Until the sixth month, deaf infants babble much like hearing children (Oller & Eilers, 1988). However, well before 9 months, deaf infants lose their interest in babbling, diverging more and more from the normal pathway (Mavilya, 1972). This suggests that their earlier babbling is sustained through proprioceptive and somaesthetic feedback, as the babies explore the various ways in which they can play with their mouth. After 6 months, babbling relies increasingly on auditory feedback. During this period, the infant tries to produce specific sounds to match up with specific auditory impressions. It is at this point that the deaf child no longer finds babbling entertaining, because it is not linked to auditory feedback.

Unlike the vegetative sounds of the first three months, the sounds of both early and later babbling show evidence of learning. Like other forms of learning, articulatory learning involves an interplay between episodic recording of templates and generalization of patterns from these episodes. During the early period, episodes are recorded as specific movements leading to particular proprioceptive results. Through this activity, the child develops some control over both the articulators and the production of sound in the larynx (Oller, 2000). In later babbling, episodes involve a linkage of a specific articulatory gesture with a specific auditory outcome. For example, a child may record exactly what was needed to produce a /pa/ and then string these together to produce /papapapa/.

Linkage of production to audition takes the child to a higher level of generalization or pattern extraction. Although vowels can be acquired directly as complete stable units in production, consonants can be articulated only in combination with vowels, as pieces of whole syllables. The information regarding the place of articulation for most consonants is concentrated in the sound changes that occur before and after the steady state of the vowel (Cole & Scott, 1974). In CV syllables like /*pa*/ or /*ko*/, each different consonant will be marked by different patterns of transitions before and after different vowels. Thus, in /*di*/, the second formant rises in frequency before the steady state of the vowel, whereas in /*du*/, the second formant falls before the vowel. Massaro (1975) argued that this blending makes the syllable the natural unit of perception, as well as the likely initial unit of acquisition. By learning syllables as complete episodic packages, the child avoids the problem of finding acoustic invariance for specific phonemes. If the syllable is, in fact, the basic unit of perception, we would expect to find that auditory storage would last at least 200 ms, or about as long as the syllable. It appears that there is a form of auditory storage that lasts about 250 ms (Massaro, 1975), indicating that storage may indeed be adapted to the encoding and processing of syllables.

Infants commonly produce syllables sounding like /*ba*/ and /*di*/, but are relatively less likely to produce /*bi*/, probably because making a /*b*/ results in a tongue position well suited to a following /*a*/ but not a following /*i*/ (MacNeilage, Davis, Kinney, & Matyear, 2000). Vihman (1996) studied infants and toddlers learning Japanese, French, Swedish, and English. A very small number of syllables accounted for half of those produced in all the groups, and the two most frequent syllables, /*da*/ and /*ba*/, were used by all language groups. This restriction in repertoire supports the idea that infants are using a basic motor template to produce syllables. These same constraints also affect the composition of the first words (Oller, 2000).

In the heyday of behaviorism, researchers viewed the development of babbling in terms of reinforcement theory. For example, Mowrer (1960) thought that babbling was driven by the infant's attempt to create sounds like those made by their mothers. In behaviorist terms, this involves secondary goal reinforcement. Other behaviorists thought that parents would differentially reinforce or shape babbling through smiles or other rewards. They thought that these reinforcements would lead a Chinese baby to babble the sounds of Chinese, whereas a Quechua baby would babble the sounds of Quechua. This was the theory of "babbling drift." However, closer observation has indicated that this drift toward the native language does not occur clearly until after 10 months (Boysson-Bardies & Vihman, 1991). After 12 months, we see a strong drift in the direction of the native language as the infant begins to acquire the first words. Opponents of behaviorism (Jakobson, 1968) stressed the universal nature of babbling, suggesting that all children engage in babbling all the sounds of all the world's languages. However, this position also seems to be too strong. It is true that some English-learning infants will occasionally produce Bantu clicks and Quechua implosives, but it is not true that children produce all or even many of these exotic sounds (Cruttenden, 1970).

Circular Reactions

Piaget's (1952) theory of sensorimotor learning provides an interesting account of many of these developments. Piaget viewed much of early learning as based on circular reactions in which the child learned to coordinate the movements of one process or schema with another. In the case of babbling, the child is coordinating the movements of the mouth with their proprioceptive and auditory effects. In these circular reactions, the child functions as a "little scientist" who is observing and retracing the relations between one schema and another. For example, in the first month, the newborn will assimilate the schema of hand motion to the sucking schema. In babbling, the child assimilates the schema of mouth motions to the perceptual schema of audition, proprioception, and oral somaesthesia. This occurs most clearly during the period of late babbling when the child is experimenting with sounds that are found in other languages. Also, the fact that deaf babies continue to babble normally until about 6 months indicates that early babbling is largely a coordination between articulation and proprioception. This type of schema coordination further demonstrates the linkage between episodic encoding and generalization. During babbling, the child can encode each sensorimotor event in great detail, create a variant of that event, and then generalize over the variant forms to extract motoric principles regarding articulatory targets and their modifications.

Phonotactic Processes

The child's first words can be viewed as renditions of adult forms that have gone through a series of simplifications and transformations. Some of these simplifications lead to the dropping of difficult sounds. For example, the word *stone* is produced as *tone*. In other cases, the simplifications involve making one sound similar to those around it. For example, *top* may be produced as *pop* through regressive assimilation. Assimilation is a process that results in the features of one sound being adapted or assimilated to resemble those of another sound. In this case, the labial quality of the final /*p*/ is assimilated backward to the initial /*t*/, replacing its dental articulation with a labial articulation. These processes (Donegan, in press) are all grounded on a principle of "least effort" that holds that vocal gestures that involve the fewest movements or changes in movements of the articulators are favored (Ohala, 1974).

The child's problems with phonological form are very much focused on production, rather than perception. An illustration of this comes from the anecdote in which a father and his son are watching boats in the harbor. The child says, *Look at the big sip*. Echoing his son's pronunciation, the father says, *Yes, it's quite a big sip*. To this, the child protests, saying, *No, Daddy, say 'sip' not 'sip.'* Such anecdotes underscore the extent to which the child's auditory forms for words line up with the adult standard, even if their actual productions are far from perfect.

Detailed observations of the course of phonologic development have shown that the development of individual word forms does not follow a simple course toward the correct adult standard. Sometimes there are detours and regressions from the standard. For example, a child may start by producing *step* accurately. Later, under the influence of pressures for simplification of the initial consonant cluster, the child will regress to production of *step* as *tep*. Finally, *step* will reassert itself. This pattern of good performance, followed by poorer performance, and then finally good performance again is known as "U-shaped learning," because a graph of changes in accuracy across time resembles the letter U. The same forces that induce U-shaped learning can also lead to patterns in which a word is systematically pronounced incorrectly, even though the child is capable of the correct pronunciation. For example, Smith (1973) reported that his son systematically produced the word *puddle* as *puggle*. However, he showed that he was able to produce *puddle* as an incorrect attempt at *puzzle*. One possible interpretation of this pattern is that the child produces *puggle* in an attempt to distinguish it from *puddle* as the incorrect pronunciation of *puzzle*. Here, as elsewhere in language development, the child's desire to mark clear linguistic contrasts may occasionally lead to errors.

WORD LEARNING

The third level of linguistic structure is that of the word. Linguists refer to the system of word forms as the mental lexicon. The learning of the first word is based on three earlier developments. The first is the infant's growing ability to record the sounds of words, as discussed in the previous section on auditory development. The second is the development of an ability to control vocal productions, as discussed in the previous section on articulatory development. The third is the general growth of the symbolic function (Callaghan & Corbit, Chapter 7, this *Handbook,* this volume), as represented in play, imitation, gesture (Zlatev, in press), and object manipulation. Piaget (1954) characterized the early cognitive development in terms of the growth of representation or the object concept. In the first 6 months of life, the child is unable to think about objects that are not physically present. However, a 12-month-old will see a dog's tail sticking out from behind a chair and realize that the rest of the dog is hiding behind the chair. This understanding of how parts relate to wholes supports the child's first major use of the symbolic function. When playing with toys, the 12-month-old will begin to produce sounds such as *vroom* or *bam-bam* that represent properties of these toys and actions. Often, these phonologically consistent forms appear before the first real words. Because they have no clear conventional status, parents may tend to ignore these first symbolic attempts as nothing more than spurious productions or babbling.

Even before producing the first conventional word, the 12-month-old has already acquired an ability to comprehend perhaps a dozen conventional forms. By 11 months, children show differential ERP brain reactions to known and unknown words (Thierry, Vihman, & Roberts, 2003). During this period, parents may realize that the prelinguistic infants are beginning to understand what they say without being able to provide convincing evidence of this ability. Researchers deal with this problem by bringing infants into the laboratory, placing them in comfortable highchairs, and asking them to look at pictures, using the technique of visually reinforced preferential looking. A word such as *dog* is broadcast across loudspeakers. Pictures of two objects are then displayed. In this case, a dog may be on the screen to the right of the baby and a car may be on the screen to the left. If the child looks at the picture that matches the word, a toy bunny pops up and does an amusing drum roll. This convinces babies that they have chosen correctly and they then continue looking at the named picture on each trial. Some children get fussy after only a few trials, but others last for 10 trials or more at one sitting and provide reliable evidence that they know a few words. Many children demonstrate this level of understanding by the 10th month—2 or 3 months before they have produced their first recognizable word (Oviatt, 1980).

Given the fact that the 10-month-old is already able to comprehend several words, why is the first recognizable conventional word not produced until several months later? Undoubtedly, many of the child's first attempts to match an articulation with an auditory target fall on deaf ears. Many are so far away from the correct target that even the most supportive parent cannot divine the relation. Eventually, the child produces a clear articulation that makes sense in context. The parent is amazed and smiles. The child is reinforced and the first word is officially christened. But all is still not smooth sailing. The challenges of word production discussed earlier make early words difficult to recognize. Rather than having to go through sessions of repeated noncomprehension, children may spend a month or two consolidating their conceptual and phonological systems in preparation for an attack on the adult target. However, most children do not go through this silent period. Instead, late babbling tends to coexist with the first words (Oller, 2000).

Infants are willing to learn all sorts of meaningful relations between signs and the objects that they represent.

For example, Namy and Waxman (1998) found that normal 18-month-olds are happy to learn gestures as object labels. Similarly, Woodward and Hoyne (1999) found that 13-month-olds are happy to respond to the sound produced by an object as if it were its name. This ecumenical approach to learning emerges from the fact that learning is based on encoding of individual episodes within which natural sounds, pictures, vocalizations, gestures, and objects are all on an equal footing. Later, processes of generalization operate on these episodes, leading the child to treat vocalizations as better candidate words than gestures, pictures, or natural sounds.

Discovering Meanings

From Plato to Quine, philosophers have treated the task of figuring out word meaning as a major intellectual challenge. They argue that, if the child were to allow for the possibility that word meanings might include disjunctive Boolean predicates (Hunt, 1962), then it might be the case that a novel word like *grue* could have the meaning *green before the year 2000 and blue thereafter*. Similarly, it might be the case that the name for any object would refer not to the object itself, but to its various undetached parts. When one thinks about word learning in this abstract way, it appears to be impossibly hard.

Quine (1960) illustrated the problem by imagining a scenario in which a hunter is out on safari with a native guide. Suddenly, the guide shouts *Gavagai* and the hunter, who does not know the native language, has to quickly infer the meaning of the word. Does it mean *shoot now*, or *there's a rhino*, or perhaps even *it got away*? If the word refers to the rhino, does it point to the horn, the hooves, the skin, or the whole animal? Worse still, the word could refer to the horn of a rhino if it is before noon and the tail of a jackal after noon. Without some additional cues regarding the likely meaning of the word, how can the poor hunter figure this out?

Fortunately, the toddler has more cues to rely on than the hunter. The first person to recognize the extensive nature of these cues was Augustine, the great Church father, who wrote this in his *Confessions* (1952, p. 8, original 397 A.D.):

> This I remember; and have since observed how I learned to speak. It was not that my elders taught me words (as, soon after, other learning) in any set method; but I, longing by cries and broken accents and various motions of my limbs to express my thoughts, that so I might have my will, and yet unable to express all I willed or to whom I willed, did myself, by the understanding which Thou, my God, gavest me, practice the sounds in my memory. When they named anything, and as they spoke turned towards it, I saw and remembered that they called what they would point out by the name they uttered. And that they meant this thing, and no other, was plain from the motion of their body, the natural language, as it were, of all nations, expressed by the countenance, glances of the eye, gestures of the limbs, and tones of the voice, indicating the affections of the mind as it pursues, possesses, rejects, or shuns. And thus by constantly hearing words, as they occurred in various sentences, I collected gradually for what they stood; and, having broken in my mouth to these signs, I thereby gave utterance to my will. Thus I exchanged with those about me these current signs of our wills, and so launched deeper into the stormy intercourse of human life, yet depending on parental authority and the beck of elders.

Augustine's reflections are remarkable for several reasons. First, he emphasizes the natural, situated, and emergent nature of word learning. Second, he understood the importance of a preliminary period of auditory learning, followed then by an arduous process of articulatory control. Third, he focused on the learning of words in the direct presence of the referent (Cartwright & Brent, 1997; Huttenlocher, 1974). Fourth, to further confirm common ground and shared attention on a candidate referent, he made use of a variety of gestural and postural cues from his elders.

Recent research has supported and elaborated Augustine's intuitions. The ability to follow eye gaze appears to rely on fundamental developments in the visual system that emerge in the first 4 months of life (M. Johnson, 1992). These developmental changes involve the linkage of basic phylogenetic abilities to ongoing epigenesis. Similar changes arise in the tracking of postural cues and pointing. By the time the child comes to learn the first words, these cues are generally accessible. Baldwin (1991) has shown that children try to acquire names for the objects that adults are attending to. Similarly, Akhtar, Carpenter, and Tomasello (1996) and Tomasello and Akhtar (1995) have emphasized the crucial role of mutual gaze between mother and child in the support of early word learning. Bates, Benigni, Bretherton, Camaioni, and Volterra (1979) showed how 10-month-olds would reliably follow eye gazes, pointing, and gesturing. Gogate, Bahrick, and Watson (2000) showed that, when mothers teach infants a name for a novel toy, they tend to move the toy as they name it, much as Augustine suggested.

One hardly needs to conduct studies to demonstrate the role of gaze, intonation, and pointing, because these cues are so obvious to all of us. However, a second aspect of Augustine's analysis is subtler and less fully appreciated. This is the extent to which children seek to divine the intention of the adult as a way of understanding a word's meaning. They want to make sure that the adult is directly attending to an object, before they decide to learn a new word (Baldwin et al., 1996). If the adult is speaking from behind a screen, children are uncertain about the adult's intentions and fail to learn the new word. Tomasello and Ahktar (1995) illustrated this by teaching 2-year-olds a new verb such as *hoisting*. In some of the trials, the toy character would inadvertently swing away and the experimenter would say *whoops*. In those trials, the children would not associate *hoisting* with the failed demonstration. Generalizing from these studies, Tomasello (2003) and Bloom (2000) have argued that word learning depends primarily on the child's ability to decode the parent's intentions. Callaghan and Corbit (Chapter 7, this *Handbook*, this volume) provide a further review of the many recent studies emphasizing the role of perceived intentionality in the learning of words and other symbols. Further support for this view comes from the fact that autistic children have problems picking up on both gestural and intentional cues, possibly because of the fact that they have incompletely constructed models of the goals and intentions of other people (Baron-Cohen, Baldwin, & Crowson, 1997; Frith & Frith, 1999)

Initial Episodic Mapping

Laboratory studies of word learning typically rely on a process of fast initial episodic mapping of a new word to a new meaning. This is the type of learning that occurs when a child encounters a new word for the first time. The initial mapping process involves the association of auditory units to conceptual units (Naigles & Gelman, 1995). For example, the 14-month-old can be brought into the laboratory (Schafer & Plunkett, 1998) and shown a picture of an animal called a *tiv*. The child will then demonstrate understanding of the new word by turning to a picture of the new animal, rather than a picture of a dog, when hearing the word *tiv*. In these laboratory experiments, children are learning a new concept in parallel with a new word. They are also learning this word in the specific episodic context of a series of pictures displayed in a psychology laboratory. Thus, generalization and recall of these new forms may be minimal. In the real world, children often have developed a clear idea about a concept well before they have learned the word for that concept. The child comes to the task of word learning already possessing a fairly well structured coding of the basic objects in the immediate environment (Sugarman, 1982). Children treat objects such as dogs, plates, chairs, cars, baby food, water, balls, and shoes as fully structured, separate categories (Mervis, 1984). They also show good awareness of the nature of particular activities such as falling, bathing, eating, kissing, and sleeping. This means that, in reality, conceptual organization typically precedes lexical mapping. Thus, word learning is usually not the mapping of a new word to a new meaning, but the mapping of a new word to an old meaning. Moreover, in some cases, the sound of the word may already be a bit familiar and the learning really involves the mapping of an old form to an old meaning. Because natural learning is difficult to control, there have been relatively few studies of this more natural process (MacWhinney, 2005a).

Undergeneralization, Generalization, and Overgeneralization

Early word uses are often highly *undergeneralized* (Dromi, 1987). For example, a child may think that *dog* is the name for the family pet or that *car* refers only to vehicles parked at a specific point outside a particular balcony (Anglin, 1970). Undergeneralization arises from the fact that language learning begins with the accumulation of episodic associations. It is sometimes difficult to detect undergeneralization, because it never leads to errors. Instead, it simply leads to a pattern of idiosyncratic limitations on word usage. Early undergeneralizations are gradually corrected as the child generalizes meanings by hearing words used in a variety of contexts. During the generalization process, each new context is compared with the current meaning. Those features that match are strengthened (MacWhinney, 1989) and those that do not match are weakened. When a feature becomes sufficiently weak, it drops out altogether.

This process of generalization is guided by the same cues that led to initial attention to the word. For example, it could be the case that every time the child hears the word *apple,* some light is on in the room. However, in none of these cases do the adults focus their attention on the light. Thus, the presence or absence of a light is not a criterial feature of *apple*. The child may also occasionally hear the word *apple* used even when the object is not present. If, at that time, attention is focused on some other object that was accidentally associated with *apple,* the process of generalization could derail. However, cases of this type are rare. The more common case involves use of *apple* in a context that totally mismatches the earlier uses. In that case, the child simply assumes nothing and ignores the new exemplar (Stager & Werker, 1997).

Gradually, the process of generalization leads to a freeing of the word from irrelevant aspects of the context. Over time, words develop a separation between a "confirmed core" (MacWhinney, 1989) and a peripheral area of potential generalization. As the confirmed core of the meaning of a word widens and as irrelevant contextual features are pruned out, the word begins to take on a radial or prototype form (Lakoff, 1987). In the center of the category, we find the best instances that display the maximum category match. At the periphery of the category, we find instances whose category membership is unclear and which compete with neighboring categories (MacWhinney, 1989).

According to this core-periphery model of lexical structure, overgeneralizations arise from the pressures that force the child to communicate about objects that are not inside any confirmed core. Frequently enough, children's overgeneralizations are corrected when the parent provides the correct name for the object (Brown & Hanlon, 1970). The fact that feedback is so consistently available for word learning increases our willingness to believe that the major determinants of word learning are social feedback, rather than innate constraints on word learning. Although there are occasional confusions along the path, children can use the many cues to word meaning identified by Augustine and modern research studies, as well as the basic ability to work with a confirmed episodic core to implement powerful practical solutions to Quine's Gavagai problem.

The process of initial episodic encoding and cautious generalization is the primary stream of semantic development. However, often children need to throw caution to the winds in order to find ways of expressing meanings that they do not yet fully control. When they do this, they produce *overgeneralizations*. For example, children may overgeneralize (and alarm their parents) by referring to tigers as *kitties*. Although overgeneralizations are not as frequent as undergeneralizations, they are easier to spot because they always produce errors. Overgeneralization errors arise because they have not yet learned the words they need to express their intentions. It is not that the child actually thinks that the tiger is a kitty. It is just that the child has not yet learned the word *tiger* and would still like to be able to draw the parent's attention to this interesting catlike animal.

The smaller the child's vocabulary, the more impressionistic and global will be the nature of these overgeneralizations. For example, Ament (1899) reported that his son learned the word *duck* when seeing some birds on a lake. Later, he used the word to refer to other ponds and streams, other birds, and coins with birds on them. Bowerman (1978b) reports that her daughter Eve used *moon* to talk about a lemon slice, the moon, the dial of a dishwasher, pieces of toenail on a rug, and a bright street light. But this does not necessarily mean that the child actually thinks that *duck* refers to both lakes and birds or that *moon* refers to both lemon slices and hangnails. Rather, the child is using one of the few words available to describe features of new objects. As the child's vocabulary grows in size, overgeneralization patterns of this type disappear, although more restricted forms of overgeneralization continue throughout childhood.

This model of overgeneralization assumes that the child understands the difference between a *confirmed core* of features for a word and the area of potential further generalization. The confirmed core extends to referents that have been repeatedly named with the relevant word. The area of extension is an area outside this core where no other word directly competes and where extension is at least a possibility. Overgeneralizations should not lead to changes in the confirmed core of a word meaning, unless some misunderstanding arises between parent and child.

Flexible Learning

As the child begins to learn new words, the process of learning itself produces new generalizations (L. Smith, 1999). For example, children soon come to realize that new words almost always refer to whole objects. This learning is based on the earlier realization that objects typically function as perceptual wholes. However, a cautious child learner may realize that this assumption can sometimes be wrong. For example, one evening, I was sitting on a Victorian couch in our living room with my son Ross, aged 2;0, when he pointed to the arm of the couch, and asked, *couch?* He then pointed at the back and then the legs, again asking if they were also *couch*. Each time, I assured him that the part to which he was attending was, indeed, a part of a couch. After verifying each component, he seemed satisfied. In retrospect, it is possible that he was asking me to provide names for the subparts of the couch. However, like most parents, I tried to focus his attention on the whole object, rather than the parts. Perhaps, I should have first taught him that all of the parts were pieces of couch and then gone on to provide additional names for the subparts, such as *arm, seat, back,* and *edge,* ending with a reaffirmation of the fact that all of these parts composed a *couch*.

Learning to learn can also induce the child to treat early word meanings in terms of common object functions. For example, Brown (1958) noted that parents typically label objects at the level of their most common function. Thus, parents will refer to *chairs*, but avoid *furniture* or *stool*, because *chair* best captures the level of prototypical usage of a class of objects. As a result, children also come to realize that the names for artificial objects refer to their functions and not to their shape, texture, or size.

Children are also quick to pick up on a variety of other obvious correlations. They learn that the color of artificial objects such as cars and dresses can vary widely, but that animals like zebras or cardinals have unique colorings and patterns. They learn that any new word for an object can also refer to a toy characterizing that object or a picture of the object. They learn that people can have multiple names, including titles and nicknames. They learn that actions like climbing or pulling are best understood by mapping onto their own human perspective (MacWhinney, 2008), and that the meanings of adjectives are modulated by the baseline properties of the object modified (*red tomato* vs. *red cheeks*). Generally speaking, children must adopt a highly flexible, bottom-up approach to the learning of word meanings (Maratsos & Déak, 1995), attending to all available cues, because words themselves are such flexible things.

This flexibility also shows up in the child's handling of cues to object word naming. Because shape is a powerful defining characteristic for so many objects, children learn to attend closely to this attribute (Colunga & Smith, 2008). However, children can easily be induced to attend instead to substance, size, or texture, rather than shape. For example, Smith (1999) was able to show how children could be induced, through repeated experiences with substance, to classify new words not in terms of their shape but in terms of their substance.

Children's Agenda

The view of the child as a flexible word learner has to be balanced against the view of the child as having a definite personal agenda. Like Augustine, children often see language as a way of expressing their own desires, interests, and opinions. In some extreme cases, children may adopt the position espoused by Humpty Dumpty, when he chastises Alice for failing to take charge over the meanings of words. As Humpty Dumpty puts it, "When I use a word, it means just what I choose it to mean—neither more nor less."

Fortunately, the agenda that children seek to express through early words match up closely with what their parents expect them to express. During the months before the first words, the child may use certain gestures and intonational patterns to express intentions such as desires, questions, and attention focusing (Callaghan & Corbit, Chapter 7, this *Handbook*, this volume; Halliday, 1975). Later, children seem to seek out words for talking about fingers, hands, balls, animals, bottles, parents, siblings, and food. Much of this early agenda appears to focus initially on the learning of nouns, rather than verbs or other parts of speech. Gentner (2005) argues that this is because it is easier to map a noun to a constant referent. A variant of Gentner's position holds that nouns are learned more readily because it is easier for children to figure out what people are talking about when they use nouns than when they use verbs. Moreover, nouns tend to be used in the same categorical and taxonomic ways (Sandhofer, Smith, & Luo, 2000), whereas verbs refer to a wider range of conceptual structures, including wishes, movements, states, transitions, and beliefs.

Input factors play a role as well. Studies of languages other than English show that sometimes children do not produce more nouns than verbs. For example, children learning Korean (Gopnik & Choi, 1995) and Mandarin Chinese (Tardif, 1996) may produce more verbs than nouns under certain conditions of elicitation. Two plausible explanations for this phenomenon have been offered. First, in both Korean and Mandarin, verbs are much more likely to appear at the ends of utterances than in English, where the last word in input sentences tends to be a noun (Nicoladis, 2001). Perceptual studies (Jusczyk, 1997) have shown that it is easier for children to recognize familiar words at the ends of sentences, suggesting that this structural feature of languages influences rates of word learning as well. Second, Korean and Mandarin mothers tend to talk about actions more than do English mothers, who tend to focus on labeling things. Goldfield (1993) showed that American mothers who used more nouns tended to have infants with a higher proportion of nouns in their vocabularies.

Whorf Versus Humpty Dumpty

As learning progresses, the child's agenda become less important than the shape of the resources provided by the language. For example, languages like Salish or Navajo expect the child to learn verbs instead of nouns. Moreover, Navajo verbs focus more on position, shape, and containment than do verbs in English. For example, the verb *ahéénı́shtiih* in Navajo refers to "carrying around in a circle any long straight object such as a gun." The presence of obligatory grammatical markings in languages for concepts such as tense, aspect, number, gender, and definiteness can orient the child's thinking in certain paths at the expense of others. Whorf (1967) suggested that the forms of language might end up shaping the structure of thought. Such effects are directly opposed to the Humpty Dumpty agenda-based approach to language. In practice, there is a dynamic interaction between Whorf and Humpty-Dumpty. Important though language-specific effects may be, children end up being able to express basic ideas equally well, no matter what language they learn.

Learning From Syntactic Contexts

Shared reference is not the only cue toddlers can use to delineate the meanings of words. They can also use the form of utterances to pick out the correct referents for new words. Consider these contexts:

- Here is a pum. —count noun
- Here is Pum. —proper noun
- I am pumming. —intransitive verb
- I pummed the duck. —transitive (causative) verb
- I need some pum. —mass noun
- This is the pum one. —adjective

Each of these sentential contexts provides clear evidence that *pum* is a particular part of speech. Other sentential frames can give an even more precise meaning. If the child hears, "This is not green, it is pum," it is clear that *pum* is a color. If the child hears, "Please don't cover it, just pum it lightly," then the child knows that *pum* is a verb of the same general class as *cover*. The use of cues of this type leads to a fast, but shallow, mapping of new words to new meanings. Learning of this type was first identified in 3-year-olds by Brown (1973) and later in children younger than 2;0 by Katz, Baker, and Macnamara (1974).

Words as Invitations to Learning

Words function as invitations for new learning, because they point to a set of related objects or events that share discoverable similarities. The more words the child learns, the clearer this effect becomes. New words for animals, like *hedgehog* and *dolphin* invite an exploration of the habits, shapes, colors, and activities of that animal. New words for physical actions, like *gallop* and *knit,* invite an exploration of the ways in which the body can use these motions to act on other objects. Research has shown that the mere presence of a word can induce sharper and more consistent concept formation. For example, Waxman and Kosowski (1990) gave children two stories. In the first story, they used the word *dobutsu* as a label, saying, "There's a being from another planet who wants some dobutsus. I don't know what dobutsus means, but he likes things like a dog, a duck, or a horse. Can you find him something he wants?" In the second story, they provided no label, saying, "This puppet only likes things like dogs, ducks, and horses. Can you find him something he likes?" Children were much more likely to point to another animal when the label *dobutsu* was used than when no label was provided. This effect has also been demonstrated for infants (Waxman & Markow, 1995) and echoed in several further studies, all of which emphasize the role that words play as invitations to categorization and cognition (Gentner, 2005).

Competition and Mutual Exclusivity

Even the most complete set of syntactic cues and the fullest level of shared attention cannot prevent an occasional confusion about word meanings. Some of the most difficult conflicts between words involve the use of multiple words for the same object. For example, a child may know the word *hippo* and hear a hippo toy referred to as a *toy*. But this does not lead the child to stop calling the toy a *hippo* and start calling it a *toy*. Markman (1990) has suggested that children are prevented from making this type of error by the presence of a universal constraint called Mutual Exclusivity that holds that each object can have only one name. According to this constraint, if a child hears a second name for the old object, they should either reject the new name as wrong or else find some distinction that disambiguates the new name from the old. If mutual exclusivity were an important constraint on word meaning, we would expect children to show a strong tendency toward the first solution—rejection. However, few children illustrate such a preference. The fact is that objects almost always have more than one name. For example, a *fork* is also *silverware* and a *dog* is also an *animal*. Linguistic structures expressing a wide variety of taxonomic and metonymic relations represent a fundamental and principled violation of the proposed mutual exclusivity constraint. The most consistent violations occur for bilingual children who learn that everything in their world must, by necessity, have at least two names. Mutual exclusivity is clearly not a basic property of natural language.

One reason why researchers have devoted so much attention to mutual exclusivity stems from the shape of the laboratory situation in which word learning is studied. The child is presented with a series of objects, some old and some new, given a word that is either old or new, and then asked to match up the word with an object. For example, the child may be given a teacup, a glass, and a demitasse. She already knows the words *cup* and *glass*. The experimenter asks her, "Give me the demitasse." She will then correctly infer that *demitasse* refers to the object for which she does not have a well-established name. In this context, it makes sense to use the new name as the label for some new object. When an adult presents the child with a novel name in the context of a new object and an old object, the child assumes that the adult is being cooperative and reasonable and is using the new name for the new object (Golinkoff, Hirsh-Pasek, & Hollich, 1999).

In the real world, competition (Merriman, 1999) forces the child to move meanings around so that they occupy the correct semantic niche. When the parent calls the toy hippo a *toy,* the child searches for something to disambiguate the two words. For example, the parent may say, "Can you give me another toy?" or even "Please clean up your toys." In each case, *toy* refers not just to the hippo, but also potentially to many other toys. This allows the child to shift perspective and to understand the word *toy* in the framework of the shifted perspective. Consider the case of a rocking horse. This object may be called *toy, horsey,* or even *chair,* depending on how it is being used at the moment (E. Clark, 1997). This flexible use of labeling is an important ingredient in language learning. By learning how to shift perspectives, children develop powerful tools for dealing with the competitions between words. In this way, conflicts between meanings create complex structures and cognitive flexibility.

Building Theories

As children learn more and more words, they begin to develop clearer ideas about the ways in which words can refer to objects, properties, and events. The meanings of organized groups of words come to represent many aspects of the cognitive structure of the child's world. Children begin to realize that certain properties of objects are more fundamental and inherent than others. For example, Keil and Batterman (1984) talked to children about a cat that had been given a skunk's tail, nose, and fur. Before the age of 5, children believed that this animal would now actually be a skunk. After age 5, children began to realize that mere addition of these features would not change the fact that the animal was still inherently a cat. In effect, children are beginning to develop belief in a scientific theory that holds that animals cannot change their ontological status through simple transformations. Theories also provide children with conceptual structures they can use to infer the properties of new words. For example, if children are told that a *dobro* is a fish, then they can also infer that the *dobro* swims and has gills (Gelman, 1998). It appears that schooling supports this shift toward ontological essentialism (Astuti, Solomon, & Carey, 2004).

Milestones in Vocabulary Growth

Typically, the child demonstrates new language abilities first in comprehension and then only later in production. For example, children comprehend their first words by 9 months or even earlier, but produce the first word only after 12 months. Children are able to comprehend 50 words by about 15 months but do not produce 50 words in their own speech until about 20 months. More generally, children acquire words into their receptive vocabulary more than twice as fast as into their productive vocabulary.

Children tend to produce their first words sometime between 9 and 12 months (Templin, 1957). One-year-olds have about 5 words in their vocabulary, on average, although individual children may have none or as many as 30; by 2 years, average vocabulary size is more than 150 words, with a range among individual children from as few as 10 to as many as 450 words. Children possess a vocabulary of about 14,000 words by 6 years of age; adults have an estimated average of 40,000 words in their working vocabulary at Age 40 (McCarthy, 1954). To achieve such a vocabulary, a child must learn to say at least three new words each day from birth.

The growth of children's vocabulary is heavily dependent on specific conversational input. The more input the child receives, the larger the vocabulary (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Children from higher socioeconomic status groups tend to have more input and a more advanced vocabulary (Arriaga, Fenson, Cronan, & Pethick, 1998; Dickinson & Moreton, 1991). Within the middle class, children with verbally responsive mothers achieve the vocabulary spurt and combine words into simple sentences sooner than do children with less verbally responsive mothers (Tamis-LeMonda & Bornstein, 2002). These facts have led educators to suspect that basic and pervasive differences in the level of social support for language learning lie at the root of many learning problems in the later school years. However, the lack of publicly available data recorded from lower-class families makes the exact nature of input differences difficult to assess.

Models of Word Learning

Earlier, we discussed computational models of auditory development (McCandliss, Fiez, Protopapas, Conway, & McClelland, 2002), articulatory development (Guenter & Perkell, 2003), and speech segmentation (Blanchard, Heinz, & Golinkoff, 2010), each as separate developmental processes. The DevLex Model of Li, Zhao, and MacWhinney (2007) brings together auditory, articulatory, and lexical learning in a single framework. The input to the DevLex model includes compressed representations of actual sentences spoken to children as taken from the Child Language Data Exchange System (CHILDES) database (http://childes.psy.cmu.edu). This information characterizes each word in terms of the company it keeps. For example, the words *car*, *bus*, and *bicycle* can all appear in the context such as *he rides a ___ to school*. However, only *car* and *bus* can appear in the context *he drives a __ to school*. In addition to information about co-occurrence frames, words are coded in terms of semantic features extracted from WordNet (G. Miller, Beckwith, Fellbaum, Gross, & Miller, 1990). Such features can help disambiguate words that occur in very similar sentential frames. After some 500 cycles of training on this input, newly learned words organize themselves into groups in the lexical map. This emergent topological organization accords well with traditional part-of-speech analysis. The ability of the lexicon to sort out and encode parts of speech through self-organization provides an important basis for learning syntax, which is the next linguistic level we discuss.

The DevLex auditory map is encoded as a series of phonemes organized into syllables (Jusczyk, Jusczyk, Kennedy, Schomberg, & Koenig, 1995), using a slot-and-frame feature notation from MacWhinney, Leinbach, Taraban, and McDonald (1989). This notation allows for up to five syllables. Within each syllable, there are slots for up to three initial consonants, two vowels, and three final consonants. The fillers of each slot are coded in terms of auditory-articulatory features (Ladefoged, 1980) such as [+labial] or [-voiced]. The articulatory map combines this representation with a sequence-encoding mechanism that treats words as an “avalanche” of syllables (Grossberg, 1978; Gupta & MacWhinney, 1997).

Learning in this model relies on the self-organizing feature map (SOFM) architecture developed by Kohonen (2001). SOFM networks model word learning by creating patterns of organization in cortical maps. Within each part of speech area, words are located in neighborhoods next to other semantically similar words. For example, one neighborhood in the lexical map would include *fork*, *knife*, and *plate* and another would include *jump*, *hop*, and *stumble*. In the auditory map, a neighborhood might include *pin*, *tin*, and *bin*. In the articulatory map, neighbors all share the same initial segments, as in *pin*, *pill*, and *pillow*. Emergent self-organization on each of these three maps uses the same learning algorithm. However, the learning of connections between the three maps depends on associative Hebbian learning (Hebb, 1949; Kandel & Hawkins, 1992). What makes this mapping process self-organizing is the fact that there is no preestablished pattern for these mappings, no error correcting feedback, and no preordained relation between particular nodes and particular feature patterns.

SYNTAX

The transition from the first words to the first sentences is nearly imperceptible. After learning the first words, children begin to produce more and more single-word utterances. As their vocabulary grows, children begin saying words in closer proximity (Branigan, 1979). For example, they may say *wanna,* followed by a short pause and then *cookie*. If the intonational contour of *wanna* is not closely integrated with that of *cookie,* adults tend to perceive this as two successive single-word utterances. However, the child may already have in mind a clear syntactic relation between the two words.

As the clarity of the relations between single words strengthens, the temporal gap between the words decreases. However, the transition from successive single-word utterances to true word combinations requires more than just faster timing. Two other achievements must occur. First, the child has to figure out how to join words together into a single intonational package or breath group. Second, the child has to figure out which words can be meaningfully combined and in what order.

The level of successive single-word utterances is one that chimpanzees can reach when they learn signed language. Domesticated chimps like Sarah, Washoe, or Kanzi can learn about a hundred conventional signs or tokens. They can then combine these words in strings to produce meaningful communication. However, the combinations that chimpanzees produce never really get beyond the stage of successive single-word utterances. For example, the chimpanzee Washoe, who was raised by the Gardners (Allen & Gardner, 1969), produced strings such as *open now me now open door please open please me* to express the request to have a door opened. In a sequence like this, the chimp uses every word that might apply to the current scene without paying much attention to how these words combine (Terrace, Petitto, Sanders, & Bever, 1980).

Item-Based Patterns

Unlike chimpanzees, children are quick to adopt a systematic approach to the process of combining words. The description of the growth of this process is the task of the theory of syntactic development. In the early days of psycholinguistic theory, Braine (1963, 1971) explored ways of applying learning theory to the study of syntactic development. The formulation he devised focused on the idea that function words tend to appear in fixed positions vis-à-vis content words. For example, *the* appears before nouns, and the suffix *-ing* appears after verbs. Many of these positional patterns involved combinations of predicates such as *want, more,* or *go* with arguments such as *cookie* or *flower*. Braine found that a small set of semantic combination types could be used to account for nearly all of the sentences in the small corpora that he studied. In some cases, the positional occurrence of the words involved was quite fixed. For example, children always said *my* + *X* and never *X* + *my* to express the possession relation. However, in other cases, the order was more variable. Like Harris (1951) or Tesniére (1959), Braine analyzed these constituent structures in terms of slots that could be filled by items of a certain class. Formulating a set of 12 such positional patterns for a small corpus of child utterances, he referred to his account as a "pivot-open" grammar, because it specified the position of pivot words vis-à-vis the open class. Bloom (1971) criticized this model for overgenerating and failing to pay adequate attention to semantic patterning. In response, Braine (1976) revised his account, emphasizing the role of "groping patterns" that established links based not on lexical class, but semantic relations (Schlesinger, 1974).

Instead of turning to a formulation based on high-level semantic patterns, MacWhinney (1975a) emphasized the highly episodic nature of early combinations. He introduced the term "item-based pattern (IBP)" to describe these limited scope combination types. Rather than viewing the combination of *more* and *milk* as expressing a pattern such as *recurrence* + *object* from the beginning, MacWhinney interpreted the combination as evidence of the more concrete IBP *more* + *X,* where the word *more* refers to a particular lexical item and not some general concept. This analysis stresses the extent to which the IBP first emerges as a highly limited construction based on the single lexical item *more*.

In this account, the grammar of the child's first word combinations is extremely episodic and concrete. The child learns that each predicate should appear in a constant position with respect to the arguments it requires. For example, in English, the word *more* appears before the noun it modifies and the verb *run* appears after the subject with which it combines. The combination is based on a slot-filler relation. Consider the combination *more milk,* which is generated from the IBP *more* + *X*. In this combination, *milk* is a filler for the slot that is represented by the X.

MacWhinney (1975a) examined the word order of 11,077 utterances produced by two Hungarian children between the ages of 17 and 29 months. He found that between 85% and 100% of the utterances in these samples could be generated by a set of 42 IBPs. Some examples of these patterns in English translation are*: X* + *too, no* + *X, where* + *X, dirty* + *X, and see* + *X*. The IBP model is able to achieve a remarkably close match to the child's output because it postulates an extremely concrete set of abilities that are directly evidenced in the child's output.

MacWhinney made no general claims about a pivot or open class, focusing instead on the idea that the first syntactic patterns involve links between individual lexical items and other words with which they are prone to combine. An example of an IBP is the structure *the* + *X*. This pattern states that the word *the* occurs before another word with which it is semantically related. In addition to these positional facts, the IBP encodes the shape of the words that can occupy the slot determined by X and the nature of the semantic relation between *the* and *X*. This is to say that an IBP is a predicate-argument relation that encodes:

- The lexical identity of the predicate
- The lexical category of the argument(s)
- The sequential position of the predicate vis-à-vis its argument(s)
- The semantic relation between the predicate and its argument(s)

The predicates of IPBs can specify one, two, or even three arguments. A word such as *want* needs to be completed with two other words to form a complete, meaningful predication. First, there must be a nominal that serves as a direct object, as in *want cookie*. Second, there must be a nominal that serves as the subject, as in *I want cookie*. Because *want* expects these two additional words, we call it a two-argument predicate. Other predicates, such as *under* or *my,* take only one argument, and a few such as *give* take three (*John gave Bill a dollar*.). We can refer to this argument structure as the valency of the predicate (Herbst, 2007), much as atoms have a valency structure in chemistry. Nouns that are derived from verbs, such as *destruction* or *remission* can take optional arguments *(the destruction of the city* or *a decline in the dollar)* to form complex noun phrases. Basic nouns such as *chair* and *goat* do not have these expectations. However, in English, nouns require modification with a determiner such as *the* or *this*. Thus, in the phrase *the dog,* there is a covalent relation, because the determiner requires the noun for completion and the noun requires the determiner.

Learning Item-Based Patterns

Children learn IBPs by listening to sentences. For example, if the child's older sister says *my dolly*, the child may recognize the word *dolly* from previous experience and then further notice the presence of *my* in front of *dolly*. At this point, the child can compare the phrase *my dolly* with the single word *dolly,* noticing the differences (MacWhinney, 1978). The first difference is the presence of *my* before *dolly*. From this evidence, the child can extract the IBP *my* + *X*. In this case, the child is learning the word *my* at the same time as the IBP. Possibly, the older sister may be asserting her control over the doll and wrestling it from the younger sister's possession. Thus, the younger child can pick up not only the meaning of *my* and the IBP, but also the concept of the relation of possession between the two words. Thus, it is more accurate to speak of this IBP as combining *my* + *object possessed,* rather than just *my* + *X*. By specifying a particular semantic role for the filler, we are emphasizing the fact that the pattern encodes both syntax and semantics.

Initially, this IBP is restricted to the words *my* and *dolly,* and the relation of possession that occurs between them. However, if the older sister then says *and this is my horsey*, the child can begin to realize that the open slot for the pattern based on the item *my* refers potentially to any manner of *toy*. Subsequent input will teach the child that any object can fill the slot opened up by the operator *my*. Each IBP goes through this same course of generalization. The movement from the initial fully episodic combination *my* + *dolly* to the more general *my* + *X* is yet another example of the fundamental movement in language learning from episodic encoding toward generalization.

Evidence for Item-Based Patterns

We can also demonstrate the productivity of IBPs by teaching children novel words that serve as slot fillers. For example, we can show a child a picture of a birdlike creature that we call *a wug*. The positioning of the nonce word *wug* after the indefinite article induces the child to treat the word as a common noun. We can then show the child two pictures of the strange creature and ask her, *what are these?* By responding with the answer *wugs,* children show productivity of the IBP based on the plural suffix /s/. Also, we can set up a game in which each person names toys in terms of who owns them. This can lead the child to produce the combination *my wug,* thereby showing the productivity of the pattern *my* + *object possessed*. Similarly, a German-speaking child can be taught the nonce name *der Gann* (nominative, masculine, singular) for a toy. The experimenter can then pick up the toy and ask the child what he is holding. By the age of 3, children will correctly produce the accusative form *den Gann* (accusative, masculine, singular).

Although it is easy to convince children to accept new content words, such as nouns or verbs, it is far more difficult to teach them to accept new function words, such as determiners (*each*, *some*), prepositions (*in*, *under*), or auxiliaries (*have*, *been*). This is because function words must establish their own new IBPs. As a result, it is difficult to convince children to use novel verbs in a fully productive fashion. Instead, children tend to be conservative and unsure about how to use verbs productively until about Age 5 (Tomasello, 2000). By then, they start to show productive use of constructions such as the double object, the passive, or the causative (Bowerman, 1988). For example, an experimenter can introduce a new verb such as *griff* in the frame *Tim griffed the ball to Frank,* and the child will productively generalize to *Tim griffed Frank the ball*.

The productivity of IBPs can also be illustrated by errors in word combination. Early child syntax is replete with examples of errors produced by the simple application of IBPs (Brown, Cazden, & Bellugi, 1969; Klima & Bellugi, 1966; Menyuk, 1969). Examples include *where Mama boot, who that, what train, no Rusty hat,* and *that no fish school*. These combinations arise from the application of IBPs such as: *where* + *object located,* or *no* + *object denied*. In these patterns, the open slot can hold single nouns, noun phrases, or simple sentences. The fact that slot fillers can themselves be formed from IBPs allows for recursive rule application that we will call *clustering*. How clustering can be implemented on the neuronal level is discussed later in this chapter.

Over time children will learn to correct these errors by adding additional IBPs. For example, they will learn to use *where's,* rather than *where* for interrogatives, producing correct combinations, such as *where's the wheel?* Some children form an overgeneralized *no* + *X* negation pattern in which X is not restricted to an object. Errors illustrating this incorrect overextension include: **no do this,* **no wipe finger,* **no sit there,* **no play that,* **he no bite you,* and **I no taste them*. These are corrected by learning to use *don't* instead of *no* in this environment. It will take still more extensive learning to correct interrogative combination errors such as **where go,* **what happen,* **where put him on a chair,* **what happen me,* and **why need them more*. Some errors are due to missing auxiliaries, as in **what they are doing* and **where he's going* are extremely common. There are also errors, such as **where the wheel do go* and **what you did eat,* in which the auxiliary is misplaced after the subject. These errors are further evidence for basic patterns such as *where* + *S*. Later on, children replace *where* + *S* with *where* + *tense*. However, they fail to restrict the *where* + *tense* pattern to exclude main verbs. Overgeneralization errors attesting to the productivity of this later pattern include: **where goes the wheel,* **where could be the shopping place,* or **where's going to be the school?* After the first few months of word combination, there are no reports of errors that go against the basic item-based interrogative patterns. For example, there are no reports of errors such as *he can't do it why* (Labov & Labov, 1978).

The fact that grammatical patterns are often acquired word by word provides further evidence for the operation of IBPs. For example, Kuczaj and Brannick (1979) showed that children are quicker to show placement of the tensed auxiliary after the interrogatives *what* and *where* than after *how long* or *when*. Thus, children will produce *what is he doing?* at the same time they produce **when he coming*? Similarly, Bowerman (1978a) noted that, at 17 months, her daughter Eva used the patterns *want* + *X* and *more* + *X* productively. However, these patterns did not generalize to other words like *open, close, bite, no more,* or *all gone*.

One could argue that sentences of the type we have discussed are produced not through word combination, but through analogy. Accounts based on analogy can be used to account for virtually any particular form. However, accounts based on analogy can also predict error types that never occur. For example, Kuczaj and Brannick (1979) noted that questions like *gonna he go?* have never been reported, although children say *he's gonna go, he will go,* and *will he go?* If analogy were operating here, we would expect to find *gonna he go?* on analogy with *will he go*? On the other hand, the theory of IBPs provides a satisfactory account for the absence of these error types. According to this account, the auxiliary *will* is combined with *he go* using the IBP *will* + *action*. This pattern does not generalize to *gonna,* because, by definition, the IBP *will* + *action* is restricted to the auxiliary *will*. Thus, the learning of IBPs is conservative in a way that correctly predicts nonoccurring overgeneralizations.

Consider another example of how lexical classes help the child avoid overgeneralization. Children may notice that both *big* and *red* pattern together in forms such as *big barn* and *red barn*. This might induce them to produce forms such as **I painted the barn big* on analogy with *I painted the barn red*. However, a more conservative learner would stick close to facts about the verb *paint* and the arguments that it permits. If the child has heard a form like *I painted the barn white,* it would make sense to extend this frame slightly to include the resultative predicate *red*. However, to extend from the word *white* to semantically unrelated words like *big* or *difficult* would be to go far beyond the attested construction. As a result, this type of category-leaping overgeneralization is extremely infrequent. Just as a focus on a confirmed core can help the child avoid overgeneralizations during word learning, focus on a confirmed combinatorial core can help the child avoid syntactic overgeneralization.

Feature-Based Patterns

Although IBPs can be used to generate nearly all word combinations, children soon generalize beyond IBPs to formulate more general combinatorial rules or constructions. The modern theory of usage-based learning (Ambridge & Lieven, in press; Goldberg, 2006; Tomasello, 2003) places a strong emphasis on the role of constructions in language processing, structure, development, and change. At the core of this theory is the basic idea that constructions are learned as generalizations across IBPs. Consider the learning of the pattern that places the adjective before the noun in English. At first, children pick up a few IBPs such as *nice* + *object, good* + *object,* and *pretty* + *object*. They acquire these patterns during the learning of new adjectives from the input. For example, children may hear the form *nice kitty,* from which they create the pattern *nice* + *X*. At first, the slot filler is limited to the original noun *kitty,* but it is then quickly generalized to all possible objects. When the child then begins to learn the parallel patterns for *good* and *pretty,* the process of slot generalization becomes quicker, as the child begins to realize that words like *nice, good,* and *pretty* that describe characteristics of objects all accept a related object in the following syntactic position. This linking of IBPs then creates a feature-based pattern

(FBP) that specifies the combination *modifier* + *object described* for English. Other early FBPs include *possessor* + *possession (John's computer)* and *locative* + *location (behind the tree)*. Once children have learned these more general patterns, they can apply them immediately to newly learned words.

FBPs can also apply to the positioning of nouns as topics in languages like Hungarian or Chinese. These languages encourage the formation of sentences that place nominal topics in initial position, according to the FBP *topic* + *comment*. At first, children may pick this up as an IBP. For example, they might hear a Hungarian sentence of the shape *the glass # empty* with the # sign indicating an intonational break between the topic and the comment. They first encode this as a pattern linked to *glass*. However, after hearing a few more parallel patterns for other nouns, they then extract a general FBP, just as they do for the *modifier* + *object described* pattern for adjectives. Studies by MacWhinney (1975a) and T. H. Lee (1999) have demonstrated that children use *topic* + *comment* patterns productively by Age 2.

Competition and the LPLA

Paralleling Quine's formulation of the Gavagai problem for word learning, Chomsky (Piattelli-Palmarini, 1980) has formulated the Logical Problem of Language Acquisition or LPLA for syntactic learning. The LPLA is presented as evidence for the importance of Universal Grammar, because without guidance from innate universal principles, language would presumably not be learnable. MacWhinney (2004, 2005b) shows that the solution to both the Gavagai problem and the LPLA relies on viewing language through the Darwinian lens of proliferation, competition, and selection. For both word learning and syntactic learning, children initially pick up forms through episodic exposures. These episodic traces form a confirmed core from which children then generalize conservatively (Valiant, 1984). For example, the child can learn to correct errors such as *why he not go home*? by learning the FBPs that will produce the correct form *why didn't he go home*?

Although the LPLA does not represent a true logical problem, the formulation of this issue has helped researchers in focusing on ways in which children deal with recovery from overgeneralization. To illustrate this line of research, we can consider what is involved when a child produces an error, such as *I falled the ball* instead of *I dropped the ball*. The production of this error is supported by the application of the transitive FBP to the verb *fall*, despite the fact that this intransitive verb is not within the confirmed core of that FBP. Pinker (1989) argues that such overgeneralizations can arise because a verb like *fall* may be perceived as similar semantically to verbs like *roll* or *bounce* that can function as either transitives or intransitives. Brooks and Tomasello (1999) found some empirical support for this notion, but only after Age 4;6. Moreover, they found consistent support for the idea that FBPs or constructions (Goldberg, 2006) become consolidated and entrenched through learning (Brooks, Tomasello, Dodson, & Lewis, 1999). As a result, if an older child begins to talk about dropping a ball, there will be a moment of competition between *fall* and *drop*, and the latter will quickly dominate based on the precision of its semantic match and the support it receives from association with the direct object *ball*.

Category-Based Patterns

There is a third level of argument generalization, above the levels of the IBP and the FBP. This is the level of the category-based pattern (CBP). Just as feature-based constructions emerge from a process of generalization across IBPs, so these more global CBPs emerge from generalization across feature-based constructions. For example, in English, there are literally dozens of verb groups that share a common placement of the subject before the verb. Together, these constructions give support for a CBP supporting SV (subject-verb) word order in English. The English CBPs of SV and VO (verb-object) work together to produce prototypical SVO (subject-verb-object) order (MacWhinney, Bates, & Kliegl, 1984). Other languages promote different combinations of global patterns. In Hungarian, for example, SV, OV, and VO orders operate to express alternative varieties of object definiteness, producing SVO and SOV orders. Italian combines SV and VO patterns with secondary but significant use of VS (Dell'Orletta, Lenci, Montemagni, & Pirrelli, 2005) to produce SVO and VSO orders. Chinese, Hungarian, Czech, and other languages often rely on a pattern that places the topic before the comment (Firbas, 1964), as in *pancakes, I only eat on Sundays*.

The sequential processing system is grounded on the individual IBPs that encode all the rich detail of individual constructions. Higher-level FBP and CBP constructions emerge when extending patterns to new verbs (Tomasello, 2000), largely after Age 4, and when organizing the whole network of IBPs into a more smoothly functioning whole. However, the stored episodic phrases that support IBPs remain available throughout development.

MORPHOLOGY

Morphology is a system that links syntax, lexicon, and phonology. Exactly how these three systems interact depends on whether we are producing words through rote, combination, or analogy (MacWhinney, 1975b). Consider a form such as *knives* as the plural of *knife*. Rote retrieval of *knives* occurs when we have simply learned this form as a whole unit, much as we would have to learn that *children* is the plural of *child*. Combinatorial formation occurs when we produce *knives* by adding the plural suffix-*s* to the stem *knife*. However, if we produce *knives* through this route, then we must also trigger a morphophonological process that alters final /f/ to /v/ before the plural. Finally, we can produce knives through analogy based on comparison with *leaves*, *lives*, *wives*, and *halves*. All three of these processes can operate competitively in the production of inflected words like *jumped* and *bent* as well as derived words like *knives* or *happiness* (Stemberger & MacWhinney, 1986).

Amalgams

Language learning begins with the encoding of a rich set of episodic traces. If these patterns are stored in overlapping neural areas, generalizations will emerge naturally from the ways in which patterns are stored. We have seen how this core principle applies in articulation, audition, lexicon, and syntax. It also applies to morphology. At first, children seem blissfully unaware of the presence of grammatical markings, treating multimorphemic words as if they were single units. For example, a child might use the word *cookies* even before learning the singular *cookie*. At this point, we can refer to the unanalyzed two-morpheme combination *cookies* as an *amalgam* (MacWhinney, 1978). The child language literature is replete with examples of uses of inflected amalgams before the child has learned the stems. For example, Brown et al. (1969, p. 41) reported use of *can't, won't,* and *don't* at a time when *can, will,* and *do* were absent. Similarly, Leopold (1949, p. 8) reported use of *sandbox* when *sand* was absent. Children also use inflected forms before they have acquired the inflections. Kenyeres (1926) reported that his daughter used the inflected Hungarian word *kenyeret* (bread + accusative) at 16 months, when there was no other evidence for productive use of the accusative -*et*. It makes sense that the word should be learned in this form, because this is how it appears in sentences such as *Do you want some bread*? Moreover, Hungarian children often use *kalapáccsal* (hammer-with) before demonstrating productive use of either the stem *kalapács* (hammer) or the instrumental suffix -*val*. Of course, for the child, the main interest value of a hammer involves its use as an instrument.

Multiword phrases can also be acquired initially as amalgams. Peters (1977) noted that when her 14-month-old subject could control only 6 to 10 words, he said quite clearly, o*pen the door*. Similarly, my son Ross produced n*o, Mommy, I don't want to go bed* and *I like it; I love it* at a time when the first two-word combinations were just emerging. It is possible that these precocious forms derive from stored full-sentence templates that just happen to work correctly as full units or amalgams in a particular situational context. Although amalgams can produce precocious successes, they can also lead to grammatical errors. For example, if children learn *like it* and *want some* as amalgams, they may produce errors such as *I like it the ball* or *I want some a banana*. Clark (1977, p. 350) reported the utterance *hat on gone now* in which *hat on* is apparently a unit that could have been acquired from sentences like *has his hat on*.

Evidence for the nonproductivity of early affixes or word endings comes from the fact that, when they first appear, affixes are seldom overgeneralized (MacWhinney, 1974). Children begin by saying *went* and *saw,* and over-regularizations such as *goed* or *sawed* typically do not occur before correct irregular forms are produced. When errors like *goed* and *sawed* begin to appear, they serve as evidence of the productivity of the past tense suffix, as well as evidence of its earlier nonproductivity. After a few weeks, the child corrects these errors and returns to correct use of *went* and *saw*. This pattern of correct performance with an intermediate period of overgeneralization produces a U-shaped curve that has a different developmental profile for each verb. Children make fewer morphophonologic errors on common irregular words than on rare irregular words (MacWhinney, 1978; Marcus et al., 1992). This effect indicates that children rely on rote to produce at least some inflected forms. Frequent forms can be acquired as chunks or amalgams because they are heard so often.

The absence of productivity for a suffix should not be taken as absence of the underlying concept. For example, Brown and Bellugi (1964) found that children would refer to *many shoe* and *two shoe* at a time when there is still no clear evidence for the productivity of the plural suffix. However, the words *many* and *two* by themselves show that the child not only thinks in terms of the concept of plurality but also has succeeded in finding two ways of expressing this concept. At this point, acquisition of the plural is driven not by the child's need to express concepts, but by the need to match the formal structures of the adult language.

The learning of the most frequent morphological patterns begins early, but it is not until Age 10 that children learn how to change the long vowel of words like *opaque* to a short vowel as in *opacity* (Tyler & Nagy, 1989). Researchers have studied the course of this development using a test devised by Berko (1958). In this test, children are shown a novel figure with a novel name, such as *wug*. They are then shown a second similar figure and asked *what are these*? If they give the answer *wugs*, then there is evidence for productivity of the plural suffix. Morphological learning has two dimensions. One is the order of acquisition of the affixes, which is largely determined by their frequency of use in the language. For example, the progressive suffix *-ing* and the plural *-s* are very frequent and learned quite early. The other dimension is the order of acquisition of phonological alternations such as *opaque-opacity* or *knife-knives*. MacWhinney (1978) studied the learning of 12 such patterns in Hungarian. The order of acquisition of these patterns by Hungarian children between 1;6 and 5;0 was strongly predicted by the number of word types to which they applied in the child's lexicon, as well as the reliability of their application.

The attempt to model the learning of English regular and irregular past tense forms such as *jumped, went, bent, sent, thought, bought, flew, knew*, etc. has been at the center of a lively debate between symbolic (Pinker & Mehler, 1988) and neural network (Rumelhart & McClelland, 1987) approaches to language learning. Although neural networks can provide the accurate accounts of the overall process (MacWhinney & Leinbach, 1991), they fail to provide a sufficiently clear account of aspects of rote learning and lexical comparison (MacWhinney, 2000). In order to model the U-shaped curve of *went - goed - went,* models need to implement a clear dual-route separation and competition between rote and combination. They also need to account for processes of lexical analysis that allow older children to produce *underwent*, rather than *undergoed* without going through the same U-shaped curve that arpse *went - goed - went*. To make further progress on models of the learning of morphology, it will be necessary to expand lexical models such as DevLex (Li et al., 2007) to include methods for combining lexical items into morphological combinations through analysis and syntactic control.

MENTAL MODELS

Language is designed to allow us to share our ideas. To do this, we must structure our ideas in ways that can be encoded through grammatical devices. This is done by building mental models that place actions and objects into grammatical roles. For example, when we say *the cat climbed the tree*, we place the cat into the role of Actor (but not causal Agent) and *the tree* into the role of Goal. Although the specific shapes of these roles vary markedly, all languages provide methods for expressing basic relations such as location, time, source, goal, actor, experiencer, recipient, quality, and coreference. Often these roles are expressed through grammatical case or theme marking. Grammatical roles work much like roles in a theatrical play, allowing us to generate stereotyped expectations for relations and events that map to a myriad of relations and events in the real world. Mental models link these roles to actions and events in the form of propositions or predicate-argument structures (Kintsch, 1974; Sowa, 2000). The theory of embodied cognition (Fischer & Zwaan, 2008; MacWhinney, 2008) holds that mental models rely on the core organizing principle of a fictive self as Actor. During language comprehension, we use the words and grammatical devices in sentences as cues to the construction of mental models (Gernsbacher, 1990). In these models, the fictive self creates a cognitive simulation (Feldman, 2006) of the message underlying each sentence.

Linguistic Relativity

The learning of the exact shape of the grammatical roles required for a given language depends on the same mechanisms of episodic encoding and generalization that we have considered for the other language levels. To the degree that this extraction of these role patterns is influenced by the grammar of the language, there would be evidence in support of Whorf's (1967) ideas regarding linguistic relativity, or the idea that language has a pervasive impact on thought. For example, nominative languages like English assign prominence to the perspective of the active, causative self by placing it in the role of sentential subject. This organization may reflect attention to a central role for the active self throughout cognition and social relations. Ergative languages, such as Djirbal or Mayan, assign prominence to the undergoer of an action, much as we do in English when we say *the corn was grown by the farmer*, rather than *the farmer grew the corn*. These languages tend to focus more on the things that undergo changes, rather than the agents that bring about those changes.

Language can also influence the ways in which mental models organize space and time. For example, Salish (Whorf, 1967) emphasizes spatial and topological constraints on actions, describing the cleaning of a gun with a ramrod by saying that dryness arises at the interior of a long hollow object. Although these Whorfian effects tend to move our thoughts in one direction or another, particularly in terms of memories for events (Brown & Lenneberg, 1954), the effects are often quite weak and easily reversed (Carroll & Casagrande, 1958; Fausey & Boroditsky, 2011). This is not surprising, given the fact that mental models are also constrained by many other nonlinguistic and social forces.

Studies of grammatical development provide evidence in favor of some aspects of the Whorfian view. For example, Choi and Bowerman (1991) studied children's learning of ways of marking the verb *open* in Korean and English. Korean provides no single verb corresponding to English *open*. Instead, it provides the child with six verbs describing different types of openings. For example, *pellita* describes both opening the mouth and spreading the legs apart; *ttutta* describes both the eyes opening and the sun rising; *ppayta* describes both opening a latched drawer and taking off a ring; and *phyelchita* describes both opening a book and spreading out a blanket. If there were some universal concept of opening available to all children, we would expect that one of these six Korean verbs would be chosen as basic and overgeneralized. However, Korean children seem to simply pick up each verb directly without worrying about some overarching concept and without producing overgeneralizations. Although this type of learning can be viewed as support for Whorf's position regarding the shaping of mental models, it can also be viewed as reflecting the highly episodic nature of the learning of new grammatical patterns. In fact, these two interpretations are mutually compatible.

Vygotskyan Approaches

Although nonhuman primates and other higher mammals can generate systematic mental imagery (Köhler, 1925) and symbolic behavior (Tomasello, Call, & Gluckman, 1997), the shape of their imagery and symbolism is not constrained by the need to formulate language. In contrast, as children come to learn language, the structure of their mental models becomes increasingly influenced by the ever-present task of "thinking for speaking" (Slobin, 1996). During the transition from infancy to childhood, there are continual changes in the shape of these linkages. In this regard, developmentalists have often pointed to sensorimotor experience as a necessary foundation for the cognitive development. In his description of stage V of sensorimotor development, Piaget (1954) emphasized the idea that the first words and gestures arose from specific actions on objects, such as the use of the sound *brm-brm* when playing with the movement of a toy car. Werner and Kaplan (1963) further developed this notion by emphasizing the idea that children initially merge the vehicle (the word) and the referent (the object). This merger involves sound symbolism, mimesis, physiognomic associations, synaesthesia and sensorimotor enactment, which Werner and Kaplan describe in rich detail with hundreds of examples from observations of children. Over time, the symbol begins disentangled or distanced from the organic qualities of the referent, allowing cognition to become increasingly disembodied.

Developmentalists such as Vygotsky (1934), Bruner (1992), and Nelson (1998) have also examined the role of mental model construction in the learning of the wider social narrative. Vygotsky thought of cognitive development in terms of the growth of a system of inner speech in which propositions were connected through covert internal linkages. Werner and Kaplan developed this idea through their notion of progressive distancing between the symbolic contents of inner speech and the real-world referent. This process begins with a tight physiognomic association between the symbol or "vehicle" and its referent and terminates with the construction of symbols as autonomous from the properties of their referents. This view of progressive symbolic distancing is also in general accord with Pierce's theory of symbolic functioning (Zlatev, in press).

Elaborating Vygotsky's ideas in a very different way, Bruner (1987, 1992), Nelson (1998), and others have examined how the children's ability to internalize routines can serve as the basis for acquiring socially constructed games, routines, and stories. Ninio and Snow (1988) noted that the high level of social content in early words like *hi*, *Mommy*, *gimme*, and *more* reflected the basically social orientation of early communications. These facts support Vygotsky's claim that language develops first inside a highly social milieu, and later becomes internalized to support inner speech and mental model construction. The consequences of Vygotsky's analysis for understanding socialization are enormous. Modern societies present us with an enormously complex system of related concepts and frames, based nearly exclusively on verbal and written input. The process of acquiring these structures, routines, and scripts (Spradley, 1972) continues across the entire life span. In a very real sense, we can view culture as a roadmap or guidebook for life, and the way in which this guidebook is conveyed to new generations is largely through language and conversation.

Narrative mental models are constructed from the point of view of the human agent as protagonist. We use this method to remember how to order food at McDonald's by encoding the perspectives of ourselves as clients, as well as those of the clerks who take the orders. Mental models can also construct views of objects and systems as working mechanisms upon which we can operate. This method is important for understanding the learning of science (Greeno & MacWhinney, 2006), mathematics (Nuñez & Lakoff, 2000), and mechanical devices. For this encoding, we use a variety of physicalist primitives, or p-prims (diSessa, 1993), together with notions of force dynamics (Talmy, 1988) and basic causation (Hume, 1748).

Perspective Theory

Because narrative and dialogue often involve rapid shifts between actors, they must provide the listeners with clear cues for conducting perspective shifting. We can refer to this system of cues for agentive and spatial perspective maintenance and shifting as the Perspective Shift System. All the major grammatical constructions serve the basic purpose of tracking perspective shift. These include passivization, relativization, clefting, pronominalization, dislocation, existentials, shift reference, split ergativity, serialization, complementation, conjunction, ellipsis, adverbialization, long-distance anaphora, reflexivization, PP-attachment, and participial ambiguity (Givón, 1984). Consider the example of the English passive construction. If we say *the dog chased the cat*, then we are taking the perspective of the dog and imagining a dog chasing a cat. However, if we say *the cat was chased by the dog*, then we take the perspective of the cat and imagine a cat running away from the dog. If we say *the dog chased the bird that flew away*, we begin with the perspective of the dog, but then shift perspective to the bird, as we imagine it flying away. Consider how perspective shifts in the following simple narrative:

> There's a bakery on Ellis next to the bank. Jim has asked me to go there to bring him home some bagels. Unfortunately, I arrived late in the afternoon and the bagels were already stale. When I handed Jim the package, he wanted to pay me. Reluctantly I accepted, because refusing would have upset him.

In this passage, the construction of a mental model begins with delineation of a spatial frame for the bakery. We then shift to an exchange in which both Jim and the narrator engage in a shared perspective for a dialog. The rest of the passage then moves to the perspective of the narrator, with Jim playing a background role when he tries to pay. Typically, one of the actors in a passage is in the role of front perspective, with a second perspective in the background.

For children, the linking of language to mental models is a challenge both in comprehension and production. When reading stories to children, we often find that they forget who is playing what role. This is true even when we repeatedly practice stories with them, such as play acting the Three Little Pigs or the Billy Goats Gruff. It is difficult for a 4-year-old to recite full stories from beginning to end without dropping important segments. In fact, the full control over the use of grammatical devices for perspective shifting is not complete until about Age 10 (Franks & Connell, 1996; Karmiloff-Smith, 1979).

Perspective and Gesture

The embodied nature of mental model construction derives in large measure from the close linkage between language and gesture. Like other primates (Tomasello et al., 1997), our hominid ancestors were able to use gesture to gain attention, initiate play, mark emotions, and construct iconic descriptions. At the same time, they used vocalizations for warnings and various emotional expressions. As Darwin (1872) argues, it is unlikely that language could move from the hands to the mouth. Instead, gesture provided a fertile social framework for keeping humans engaged in protoconversations, during which the gradual elaboration of linguistic patterns could complement communication in the gestural-prosodic mode. Throughout this process, gesture and language functioned as a coupled dynamic system. As McNeill (2005) has argued, gesture and language arise from common growing points within the system of embodied mental models. The tight temporal synchrony between gesture and language (Kita & Özyürek, 2003; McNeill, 1985) provides evidence for their linkage to a common source.

When we look at the development of gestures in children, we see the same slow process of elaboration and refinement that we find in other areas of communicative development. Some of the first recognizable gestures are the pointing movements that appear at about 10 months (Bates, Bretherton, Snyder, Shore, & Volterra, 1980).

At first, these gestures are hard to distinguish from the act of reaching (Werner & Kaplan, 1963). However, by 13 months, children can point at an object and then glance at the parent, indicating a request to pay attention. By Age 3, pointing becomes a clearly structured act that is coordinated with language designed to discuss and manipulate objects (Zlatev, in press). Compared to the complex mixture of iconic gestures, beats, postures, and gazes we see in adults, children's use of gesture is much easier to analyze, because their vocabulary of conventionalized gestures is far more limited. Still, the basic coordination of gesture with language is well developed by Age 3 (Iverson & Goldin-Meadow, 2005; Iverson & Thelen, 1999). Both Bühler (1934) and Werner and Kaplan (1963) emphasize the ways in which deictic gestures that are initially grounded in the local physical field achieve symbolic status through symbolic distancing. In adults, the construction of abstract deictic fields provides the backbone of some of our most complex symbolic interactions (Goodwin, 2000; Silverstein, 2008).

CONVERSATION

Earlier we saw how the linkage of language to narrative provided an important platform for the acquisition of social structures. However, social patterns can also be learned through conversation. In fact, many aspects of narrative structures are initially acquired through conversational interactions between children and their parents. In these interactions, parents work with their children to establish common ground through processes such as scaffolding, shared reference, and recasting.

Much of conversational competence can be described in terms of simple rules for turn-taking (Sacks, Schegloff, & Jefferson, 1974), speech act adjacency pairs (Mann & Thompson, 1992), and local cues for the expression of affect (Crystal, 1975). The full system for conversational interaction involves a rich interplay between gesture, prosody, lexicon, discourse, syntax, gaze, and posture (Kendon, 1982). Perhaps the best way to think of conversation is in terms of the interface between the social world, mental models, and language structure with all the structures of each of these systems being made available online at the time of interaction.

Babies and their parents engage in conversations even before the child has begun to produce words. These conversations may involve shared smiles, gazes, coos, and grunts (Snow, 1977). Parents of prelinguistic children will speak to them as if they were real conversational participants. (For examples of this, one can browse the transcripts linked to audio at the CHILDES database: http://childes.psy.cmu.edu/data, such as the Brent corpus, or use the online browser at http://childes.psy.cmu.edu/browser.) As children acquire more and more of language, they begin to elaborate a process that Karniol (2000) analyzes as "preference management." Using transcribed conversations from CHILDES and similar sources, Karniol shows how parents and children manage to get what they want from one another through the control of preferences or values within conversations. From the very beginning, these parent-child dialogs demonstrate the extent to which children acquire language not to just solve problems or express themselves, but also to participate fully in conversational interactions. Conversations allow us to engage socially as members of dyads and groups. To the degree that there is a fundamental urge to produce language, it is in large part an urge not just to talk, but also to converse. Here, as in other language areas, learning begins with episodic encoding of particular adjacency pairs between parent and child. In particular, the child tracks how the parent responds to what they say and do. These episodic patterns are then generalized into the various rules of conversation.

This urge to socialize affects mothers, as well as infants. Papousek and Papousek (1991) showed that mothers use rising pitch contours to engage infant attention and elicit a response, falling contours to soothe their babies, and bell-shaped contours to maintain their attention. In general, these patterns are useful not only for directing attention to new words, but also for involving babies in the "melody" of conversation (Locke, 1995), even before they have learned "the words."

Conversations between mothers and their infants involve a variety of alternating activities. Infants tend to produce positive vocalization when gazing into their parents' eyes (Keller, Poortinga, & Schomerich, 2002) When infants produce negative young vocalizations, parents often respond by touching and cuddling them. However, infants will produce more vocalizations when parents vocalize to them, rather than merely responding with touch or gesture (Bloom, Russell, & Wassenberg, 1987). A longitudinal study of naturalistic talk (Snow, Pan, Imbens-Bailey, & Herman, 1996) found a continuing increase in child speech acts during 10-minute segments from 4 at 14 months to 7 at 20 months and 11 at 32 months. This ongoing growth of participation in conversations emphasizes the extent to which infants are being mainstreamed into a world of continual conversational turn-taking.

The logic of parent–child conversational turn-taking is not fundamentally different from that used between adults. The basic rule underlying all forms of turn-taking (Sacks et al., 1974) is that, at any given moment, one of the participants is said to "have the floor." While that participant holds the floor, the other participants are supposed to pay attention to the conversational contribution. At some point the speaker begins to yield the floor and thereby invites a new conversational contribution. Signals that invite a new contribution include pauses, questions, and drops in intonation. Of course, conversations are not controlled as carefully as the flow of traffic through signal lights. Often there are collisions between speakers, resulting in overlaps. At other times, there are complete breaks in the interaction. All of these features can be detected in vocal-visual interactions between mothers and children as young as 6 months (Farran, Hirschbiel, & Jay, 1980). What distinguishes parent–child dialogues from adult–adult dialogs is the extent to which the parent uses specific devices to interpret children's ill-formed actions as conversational actions, and the extent to which the parent attempts to maintain and guide the interaction, both verbally and physically (Korat, 2009).

Toward the end of the first year, children develop increasing ability to control conversations through specific routines. The most well-developed routine is pointing. Children show reliable responding to pointing by about 10 months. They are able to look at their parents' faces, and use their gaze and pointing to locate objects. Soon after this, by about 12 months, children begin to produce their own communicative pointing (Lempers, 1979). In the period between 12 and 15 months of age, just before the first words, children also develop a set of intonational patterns and body postures intended to communicate other detailed meanings (Halliday, 1975).

Parents provide interpretive scaffolding for many of the child's early communicative behaviors (Bruner, 1992). After the child produces a smile, the parent may then respond with a full-fledged verbal interpretation of the meaning implicit in the smile, as in, *is David having fun?* If the child shakes a spoon, the mother will attempt to interpret this gesture, too, suggesting, *ready for dinner?* Beginning around 9 months, this sequence of child action and maternal interpretation takes on a choral quality involving alternating, rather than overlapping, contributions (Jasnow & Feldstein, 1986). By combining verbal responses with the child's gestures, mothers are able to produce a scaffold on which children can construct a vision of communicative interactions.

LANGUAGE AND BRAIN

The basic configuration of language areas in the brain was understood by the end of the 19th century (Lichtheim, 1885). We know that recognition of phonological patterns involves processing in the auditory cortex (BA 41) and the planum temporale and angular gyrus (BA 39, part of Wernicke's area). This information then extends through one pathway to areas around the superior temporal sulcus (STS) and through another toward motor regions (Hickok & Poeppel, 2004) via the arcuate fasciculus. Articulatory control depends on the activations of commands in motor cortex, along with modulation from the inferior frontal gyrus (IFG, BA 44, Broca's area). Additional fine-grained control input comes from the cerebellum and the basal ganglia. Semantic and syntactic processing depends on a network connecting IFG and STS through the superior longitudinal fasciculus, the inferior longitudinal fasciculus, and the uncinate fasciculus. IFG includes areas that are differentially sensitive to phonological, semantic, and syntactic processing (Bookheimer, 2007). Although temporal areas control many aspects of lexical processing, the details of embodied meanings are widely distributed throughout the brain (Mitchell et al., 2008).

Knowing the anatomy and connectivity of languages areas in the brain is an important first step toward understanding how the brain creates language. However, if we wish to gain a fuller understanding of normal and disordered language processing and development, we need to go beyond basic cortical mapping to consider how areas communicate information patterns in real time. This transmission of information depends crucially on the ways in which areas are connected. Moreover, the patterns of connectivity between and within areas are not hard-wired into the DNA, but must emerge through self-organization during neuroembryogenesis (Stiles et al., Chapter 2, this *Handbook*, this volume) and subsequent learning. To construct a more detailed model of how information is transmitted in the brain, we need to rely simultaneously on evidence from neuroimaging (fMRI, MEG, ERP, NIRS, DTI), neuroanatomy, basic neuroscience, cognitive neuropsychology, and psycholinguistic analysis. If we take all of these sources of information into consideration, we find that the shape of possible language processing models is tightly constrained. The three most severe constraints on models are that (1) linguistic information encoded in local cortical structures must be integrated across areas online during language processing, (2) information can only be transmitted between areas in the form of patterns of connection and timing of signals, and (3) the detailed pattern of these connections must emerge through self-organization, albeit with heavy genetic guidance. These three constraints also provide us with a way of understanding language disorders as problems in the timing of signals caused by disorder in patterns of connections. To understand how such problems can arise, we need to examine in further detail what we now know about online neural processing.

Components

We have been analyzing language learning in terms of patterns of episodic encoding and generalization across seven levels of language structure: auditory processing, articulatory processing, lexicon, syntax, morphology, mental models, and conversation. The patterns extracted during learning on these seven levels are stored in partially distinct cortical areas in ways that facilitate communication between levels. But this does not mean that each level is in a distinct cortical module. Even a function as comparatively modular as audition (Fodor, 1983) is structured across several regions of temporal cortex at various levels of processing generality (Hickok, 2009). Although our understanding is still quite incomplete, we can offer the following sketches of brain circuits for the seven levels and the shape of their interactions.

Auditory Processing

The encoding and processing of sounds is already fairly advanced by the time it reaches primary auditory cortex in the posterior superior temporal gyrus (pSTG). Within this area, there are multiple tonotopic maps, each of which appears to represent a different view or processing slant on the whole range of the frequency spectrum. Work with rhesus monkeys has shown that the auditory system involves three levels of auditory processing with different tonotopic maps (Langers & van Dijk, 2012; C. Lee, Imaizumi, Schreiner, & Winer, 2004). This pattern of multiple parallel isotopically organized maps is similar to the pattern of multiple parallel maps found in the motor system. Throughout the auditory pathway, the tonotopic organization created by the mapping from hair cells in the cochlea to the auditory nerve is preserved.

From primary auditory cortex, processing then continues in both a ventral and dorsal stream (Hickok & Poeppel, 2004). The ventral stream, which is the most fundamental, connects to lexical processing in the posterior segments of the middle temporal gyrus (MTG) and the inferior temporal gyrus (ITG). These auditory and lexical processing areas lie immediately next to the hippocampal and parahippocampal regions that can provide support for extensive episodic encoding of new sounds and words.

Articulatory Processing

Speech production relies on commands to the muscles generated from motor cortex as further modulated by the cerebellum (Middleton & Strick, 1998). The learning of these patterns and their linkage to lexical forms constitutes a major challenge during language development. The DIVA (Directions into Velocities of Articulators) model (Guenter & Perkell, 2003) shows how articulatory gestures can be learned through a reciprocal loop to auditory processing that achieves a transduction of auditory form to articulatory form. Hickok and Poeppel (2004) localize this pathway to areas at the boundary between the parietal and temporal lobes which then connect through white matter tracts to frontal areas for speech production.

During real time processing, the operative linkage is between particular lexical items and their articulatory representation. When mental models and syntax in frontal cortex have activated a given lexical item in temporal cortex, that item must then activate motor commands in IFG and motor cortex. This circuit involves the process of gating in which a form in one area that has passed over a threshold of activation will then fire and trigger or gate activation in the next area. During production, mental models gate syntax, syntax gates lexicon, and lexicon gates articulation. Multiple lexical items are often ready to fire in parallel (Dell, Juliano, & Govindjee, 1993; Stemberger, 1985). However, each word must wait for its appointed moment for entry into the slots opened up by IBPs. When that moment comes, the word fires the articulatory gestures that it commands in motor cortex. The sequence mechanism must gate lexical items in a smooth way that minimizes stuttering, false starts, and pauses. This means that all signals from Broca's to Wernicke's must arrive on time in a coordinated way. Failures in the timing of this gating can produce disfluencies in first language learning, second language learning (Yoshimura & MacWhinney, 2007), developmental language disorders, stuttering, and aphasia (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997).

The physical separation between all these areas, the presence of noise, competition between forms, and possibilities for errors in connection and timing may all contribute to the generation of errors (Dell, 1995). Because of the fragility and complexity of the production system, it is not surprising to find that it is heavily involved in various child language disorders, such as articulatory dysfunction, stuttering, and timing problems. Children with motor disorders arising from mutations of the FOXP2 gene (Enard, 2011) also show clear articulatory problems, perhaps arising from lower levels of axon sprouting during early neuronal development (Fisher & Scharff, 2009).

Lexical Processing

The lexicon provides an intersection between audition, articulation, morphology, orthography, and syntax. Because of their linkages to so many dimensions of processing, words can trigger activations across the whole brain (Mitchell et al., 2008). At the same time, the competition between words as controlling units is organized locally (Li et al., 2007) in the middle and inferior gyri of the temporal lobe. This temporal system includes monomorphemic units like *dog* and *peach*, compounds like *desktop*, rote-memorized derivations like *opacity*, and formulaic expressions like *the more the merrier*. As these forms become increasingly combinatorial, they are controlled more and more by frontal syntactic processes (Bookheimer, 2007; Penfield & Roberts, 1959).

Morphological Processing

There is no separate cortical area devoted to morphological processing. Rather, morphology is a system that emerges at the triple interface between the lexicon, syntax, and output phonology. Let us consider first the acquisition of nominal gender marking in German. For this system, children must learn, for example, that spoons are masculine, forks are feminine, and knives are neuter. The choice of the shapes of articles, adjectives, and pronouns will then all depend on the gender of the noun. To learn this system, children can use some cues derived from the sounds of words, but in many cases they have to simply pay attention to the shapes of the articles with which they co-occur. So, one powerful way of learning this type of morphological class is through syntactic co-occurrence. The neuronal implementation of this system can emerge from the topological organization of the vocabulary into local fields, so that nouns in each of the three genders are organized into separate areas of lexical space. However, this type of organization must be viewed as an overlay on the more basic organization into parts of speech that groups all nouns as separate from other parts of speech such as verbs. The possibility that lexical space involves multiple overlapping maps should not be surprising, because we know that other areas such as auditory and motor space have multiple overlapping maps of this type.

The other major type of morphological patterning is the system of morphophonology that we discussed earlier. This is the system that modifies the long vowel of *opaque* to the short vowel in the derived word *opacity*. We can view this process as a conversion of a standard underlying form, if it operates in a similar way across all phonological environments. However, in many cases, these patterns are not fully general. This means that both forms of the stem must be stored as allomorphs and a process must then apply to select the right allomorph for a given combination. For the learning of these patterns, we again see the importance of the transition from episodic encoding to generalized pattern. At first, children will learn both *jumped* and *caught* by rote. Later on, they will form *rolled*, *wanted*, and **catched* by generalized pattern. Then they will strengthen the episodic rote forms of *caught*, *taught*, *bought*, and *thought* until these similar forms can give rise to their own minor pattern that will compete with the general *-ed* pattern. Although this processing involves coordinations between lexicon and phonology, it is basically all controlled within lexical areas.

Syntactic Processing

The Competition Model (MacWhinney, 1987) characterizes syntactic learning in terms of acquisition of a system of item-based patterns (IBPs), feature-based patterns (FBPs), and category-based patterns (CBPs). Over time, the child learns to join these various positional patterns into a single network with IFG to control both comprehension and production. Although this network is learned, the processing principles that apply the knowledge encoded in this network are not learned. Rather, they emerge from fundamental properties of the cognitive system (O'Grady, 2005), as it expresses language in real time. The constraints of online communication (Hopper, in press) require the projective sequential network in IFG to communicate with both the lexicon in temporal cortex and mental models in frontal cortex. In production, the representations of mental models are already active, and the work of syntax is to coordinate lexical activation in a way that will facilitate sequential output. In comprehension, words are recognized by the lexicon and the syntax has the responsibility of fitting these words together into structures that can build up coherent mental models. This process is governed by a network of neural circuits (Pulvermüller, 2003) that works incrementally to fulfill pattern expectations in accord with these seven principles:

1. Sounds, as processed by auditory cortex, activate competing words in temporal lexical cortex, as they are heard in speech (Marslen-Wilson & Warren, 1994).
2. Each new word activates its own IBPs in IFG, together with related FBPs (Trueswell, Tanenhaus, & Kello, 1993).
3. IBPs then initiate tightly specified searches for slot fillers (MacDonald, Pearlmutter, & Seidenberg, 1994) through connections back to temporal lexical cortex.
4. Slots may be filled either by single words or by whole phrases. In the latter case, the attachment is made to the head of the phrase.
5. To fill a slot, a word or phrase must receive support from cues for word order, prosody, affixes, or lexical class (MacWhinney, 1987).
6. If several words compete for a slot, the one with the most cue support wins (Kempe & MacWhinney, 1999).
7. Processing commitments are made when the difference in the activation of two competitors passes over a threshold (Ratcliff & Smith, 2004).

Design features 4 through 7 all involve an ongoing dialog between syntactic patterns represented in IFG and items stored in lexical fields in temporal cortex. Problems in this dialog can affect the fluency of production and comprehension in real time. In this process, the timeframe of the constraints of face-to-face interaction is the critical determinant of the emergent shape of these processes. Consider the German noun phrase *am Haus meiner Mutter* (at my mother's house). The initial preposition *am* is a contraction of *an* "to" and *dem* "the." When producing *am,* the child must already know that the following noun will be neuter. If the following noun were feminine, then the form would be *an der,* rather than *am*.

Mental Model Processing

Recent work in neuroscience has benefitted from four fundamental insights, each relating to the construction of mental models. First, in the 1980s, we learned that the visual system separates processing into an image-oriented ventral stream and an action-oriented dorsal stream (Goodale, 1993). Second, we have learned from imaging work through the last decade that the brain relies on a perception-action cycle to interpret incoming messages. This cycle involves the generation of mental representations for objects in terms of the ways in which we typically act on them (Knoblich, 2008). Much of this cycle is grounded on interactions that include the action-oriented processing of the dorsal stream. Third, we have learned that the brain provides specific mechanisms for mapping the body images of others onto ours. One consequence of this ability is the fact that the "mirror" neurons (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) controlling actions, facial gestures, and postures can fire equally strongly when the actor is the self or the other. As we are now learning, these mirror neurons are components of a general system for social cognition. The larger system also includes mechanisms in the superior temporal cortex for facial processing (Pelphrey, Morris, & McCarthy, 2005) and eye contact (Pelphrey et al., 2003), as well as amygdala and striatal areas for empathy and projection (Decety & Grèzes, 1999). Fourth, Koechlin and Summerfield (2007b) have shown how the frontal lobes utilize a method of episodic extraction to encode more specific events in the prefrontal area and more general patterns in more anterior areas. This system is important not just for matching mental models to language, but also for cognitive and social pattern extraction more generally.

Conversation Processing

The processing of conversational patterns relies on two major neuronal systems: the social neural system (Gallese, Keysers, & Rizzolatti, 2004; Meltzoff & Decety, 2003) and the mental model system (Koechlin & Summerfield, 2007a). The social neural network supports the contact needed for face-to-face interaction. This is a highly distributed system including face recognition in the fusiform face area, pheromone processing in the accessory olfactory bulb, imprinting in the striatum, hormonal regulation, gaze processing in the anterior superior temporal sulcus (aSTS), emotional reaction in the amygdala, and encoding of social relations in prefrontal and orbital cortex.

The second system constructs a continually updated mental model of the ideas of the other person to be integrated with one's own goals and understandings of social conventions. This processing may conflict with other impulses and drives (Freud, 1940), requiring high levels of self-regulation. Some children are able to self-regulate early on. Others, including those with attention deficit hyperactivity disorder (ADHD), have greater control problems (Barkley, 2004). Children with autism can have even deeper problems computing the social relations and perspective taking necessary to conduct successful conversational interactions. The highest level of developmental control in the area of conversation involves not just emotional regulation but the ability to construct not only a mental model of the self and the other, but also a mental model of the other's view of the self. This level of perspective taking is beyond the reach of most children and is often difficult even for adults (Ruby & Decety, 2004). As Robert Burns (1786) put it, "O wad some Pow'r the giftie gie us to see oursels as others see us." (Oh, that some power the gift would give us to see ourselves as others see us.)

Declarative and Procedural Encoding

Cognitive psychologists have often emphasized a fundamental contrast between declarative and procedural encodings (Squire, 1992). Declarative encodings are initially consolidated through hippocampal processing of episodic traces. They involve associative relations, rather than sequential structures. Procedural encodings are consolidated through operation of the basal ganglia and the dorsal stream of processing (Ullman, 2004). They involve the automation of sequences of actions in order to produce fluent, coordinated behavior. Prototypically, lexical learning is based on declarative encoding, whereas syntactic learning is based on procedural encoding. However, to the degree that sequences of words become unitized into fluent sequences, both processes can be involved. For example, when we memorize a poem, song, or speech by heart, we are in effect achieving a proceduralized combination of declarative items. The more that children and other learners can convert sequences into procedures or chunks, the more fluent their language (Ellis, O'Donnell, & Römer, in press; Sidtis, in press).

This mixing of the two types of learning is also fundamental to the position of syntax as an interface between the lexicon and mental models. During comprehension, syntax places lexical items into roles for mental model construction. During production, it takes configurations from mental models and activates lexical items in terms of part of speech information, as well as general semantic activation. The operation of syntax upon the lexicon involves the basic dynamics of combination through item-based and feature-based patterns. On the lexical level, this often leads to a competition between rote and combination (MacWhinney, 1975b).

On the phrasal level, combinations constructed through item-based patterns can be recursively structured into clusters. This capacity for recursive construction is supported by the presence of recursive structure at the mental model level. Consider how we comprehend the phrase *another little dog*. In this phrase, it is crucial that *little dog* be considered a unit upon which *another* operates through a separate IBP. In other words, this phrase is not just a combination of *another dog* and *little dog*, but a hierarchical composition. In terms of mental model construction, this works out smoothly by imagining one little dog and then imagining yet another one. In production, the prior availability of a model of this type supports the lexicalization of the internal cluster and then the activation of the external operator. In this way, mental models can control syntactic recursion.

Errors in Connectivity

The coordination of processing across the seven language levels relies on the ability of neurons to send well-timed signals across the white matter tracts connecting major brain regions. In adults and children with focal lesions (MacWhinney et al., 2000), these tracts can be damaged or even severed. When this happens in early childhood, recovery can involve shifting of left hemisphere language processing to the right or local reorganization in the left. However, complete regrowth of whole brain areas and whole white matter tracts is not possible, even in childhood (Recknor & Mallapragada, 2006).

Childhood language disorders arise not from a complete loss of connectivity, but from errors in the pattern of connections. During neurogenesis, cortical areas pull away from each other, but maintain a pattern of connections across white matter that allows communication across a topological grid. For a normal child, such connections develop consistently and directly and can be used directly in first language acquisition. However, if the white matter pathways are damaged or if connections become tangled during early development, gating will be slow and activation will be erratic (Willshaw & Von der Malsburg, 1976). Connectivity errors of this type may well underlie Specific Language Impairment (SLI) or stuttering (Fisher, 2010).

Timeframes

Our review of the neurolinguistic basis of language development has focused on issues of connectivity and fluency. However, there is another major dimension to neurolinguistic development that we should also consider. This is the dimension that involves the brain's response to differential timeframes. Consider the role of timeframes in auditory processing. Within a timeframe of a few milliseconds, the auditory system encodes formant transitions and various distributions of resonance. Within a timeframe of about 200 ms, the system uses this spectral information to recognize different segments within syllabic units. Within a still longer timeframe, top-down processing from word and sentence recognition can lead to effects such as phonemic restoration (Warren & Warren, 1970) or the lexical context effect (Ganong, 1980). Across even longer timeframes of hours and days, the system will adapt to speaker and dialect variation, eventually picking up a long-term ability to process different accents. At still longer timeframes, the system can learn to process new languages. Some aspects of the learning of second language phonology can extend even across decades (Ingvalson, Holt, & McClelland, 2012).

The formation of memory traces across so many divergent timeframes requires the use of a diverse set of neural mechanisms. Simple neural activation is enough to encode short-term habituation. At the next level of timeframes, the hippocampus works to retain activation through resonant processing (McClelland et al., 1995; Wittenberg, Sullivan, & Tsien, 2002). This processing then leads to episodic storage in the medial temporal lobes (Daselaar, Veltman, & Witter, 2004). Additional mechanisms then continue to modify these initial encodings through the processes of generalization that we have discussed throughout this chapter. We have also noted how the frontal lobes provide a hierarchical system of executive control involving increasingly complex and longer-term structures as one moves from the posterior to anterior frontal areas (Koechlin & Summerfield, 2007b).

During infancy, language development focuses first on the shorter timeframes, as the child works to control motor output and to record episodic information. However, as the child builds up lexical, syntactic, social, and cognitive structures, it is possible to encode information about what will happen later in the day, what happens at preschool, and even when some holiday or party will be happening. Children also begin to use the physical world as a way of tracking longer timeframes. They will notice if something is missing from their toy shelf, or a new flower is in the garden. This same type of noticing will start to apply to language. During the fourth year, children start to pay attention to particular linguistic objects. They may remember and comment on funny ways of saying some word or the problems they have with forming irregular past tenses such as *caught* or *flew*. As they approach the task of learning to read, they start to recognize words and letters that they know as opposed to ones that they cannot decipher. Still later, they can compare alternative versions of fairy tales, predict when a neighbor child will return from school to play, or even remember where they accidentally left a favorite toy. All of this learning depends on the accretion of information and memories over increasingly longer timeframes.

MULTILINGUAL DEVELOPMENT

In predominantly monolingual countries like the United States or Japan, it is easy to forget that the majority of the people in the world are bilingual or multilingual. The ways in which bilingualism can arise are highly diverse. In areas such as Southeast Asia or the Balkans, villages and cities may be composed of people from two different language communities living next to each other and interacting on a daily basis. In multilingual countries such as Switzerland, Canada, or Belgium, children's parents may each speak a different language, and their children may speak one of these languages at home and another with their peers. In Africa and South Asia, children may acquire the national language from their life in the capital city, but a local family language when they return to the countryside during vacation times to live with their rural family. In countries such as Paraguay, there is a native language (Guarani) spoken in the household and a colonial language (Spanish) spoken in public places.

In multilingual households, children are exposed to two or more languages from birth. Consider the case in which the mother addresses the child in German and the father addresses the child in English. Unless either of the parents engage in radical code-mixing, this means that the child will be hearing English words in an English context and German words in a German context. This type of continual input separation will lead to a fairly clear separation of the two languages, even when they are as similar phonologically as Spanish and Catalan (Nazzi, Jusczyk, & Johnson, 2000). After nearly two years of practice distinguishing the two languages, it is not surprising that, when the child begins producing multiword utterances, there is only a small amount of between-language confusion (De Houwer, 2005).

Immigrants

However, not all children in multilingual environments receive consistently balanced input. In the United States, immigrant families often find it difficult to maintain the strength of the home language against omnipresent exposure to English, particularly after the child goes off to school. A common result in such cases is that the child develops a basic conversational fluency in the first language, but fails to develop higher levels of literacy (He & Xiao, 2008). Results of this type also occur for some children even in bilingual areas of countries like Belgium (De Houwer, 2009). Even for children who continue use of both languages, there can be some competition and transfer of lexical and syntactic structures between languages (Döpke, 1998; Yip & Matthews, 2000).

Children who move to a new country after having acquired the basics of their first language can usually acquire a second language within a period of several months or a year. For example, Kenyeres (1938) found that his 7-year-old Hungarian daughter learned French to a nativelike level within a year. Not all children are as successful, particularly if the home environment is not as supportive as that of a linguist like Kenyeres. Moreover, there is some evidence that, after about Age 6, children find it increasingly difficult to acquire a fully nativelike accent in their second language. In a study of Italian immigrants to Toronto, Flege, Yeni-Komshian, and Liu (1999) found that, if immigrants arrive to Canada after Age 6, they are likely to preserve some trace of an Italian accent. However, even older learners can lose all traces of a foreign accent, if they get good phonetic training (Bongaerts, 1999).

Although children show a good ability to acquire multiple languages, they are also particularly susceptible to language loss. An extreme case of this type was reported by Burling (1959) who took his son with him for fieldwork in the Garo Hills of Myanmar. By the age of 2;6, the child had become a fluent learner of Garo. Then, however, on the airplane ride home, the boy tried to speak Garo with the stewardess and found that she could not reply. He never used Garo again. Pallier et al. (2003) studied a group of Korean adoptees who had come to France at a mean age of 8. Although these children had stopped using or understanding Korean at the time of testing, they showed an atypical neural organization for French, which had now become their native language. These various findings indicate that children's representations of languages are generally more flexible than those of adults and, in this sense, more vulnerable.

A Critical Period for Language Learning?

Researchers have also suggested that there may be a sharp drop at puberty in the capacity to pick up the syntax of a second language (J. S. Johnson & Newport, 1989). However, more comprehensive studies indicate that there is no sharp drop at this point, but only a slow and gradual decline. A census-based study of hundreds of Chinese and Mexican immigrants to California (Hakuta, Bialystok, & Wiley, 2003; Wiley, Bialystok, & Hakuta, 2005) showed that the disadvantage for older learners is equal to the disadvantage arising from the lack of higher education in one's home country. Thus, educated older immigrants learn about as well as less-educated younger immigrants.

Emergentist accounts of the differential outcomes for simultaneous and successive bilingualism focus on the mechanisms of transfer, isolation, and entrenchment (MacWhinney, 2012). When two languages are acquired in parallel from birth, neither dominates over the other and each is acquired in its own right. When a second language is learned after early childhood, the words of the weaker language are initially parasitic on those of the first (Kroll & Tokowicz, 2005). In terms of the DevLex model (Li et al., 2007), this parasitism is expressed by locating the new words in the same lexical space as their translation equivalents. In terms of articulatory form, new words in the second language are initially composed of phonemes from the first languages. With time, these entrenched L1 gestures are restructured for use in L2. Similarly, syntactic patterns from the first language are also used to order sentences in the second language. Over time, as second language forms strengthen, they can compete with the stronger L1 forms and L2 gradually takes on its own independent shape. In this regard, it is particularly important that the learner starts to think and reason in the second language, thereby acquiring new attitudes, thoughts, and linguistic patterns.

Later learning of a second language is also affected by powerful social factors. Young children receive a high level of support from their family. When they have trouble expressing themselves, they are given assistance, scaffolding, and encouragement. Adults carefully select their language to match the child's developmental level (Sokolov, 1993). In comparison, older learners receive far less support and sometimes criticism and even ridicule. Whereas younger learners are quickly integrated into play groups and social circles, older nonnative children and teenagers may be excluded from peer group membership. During adulthood, learning of a second language can be further impeded by considerations of social status and ethnic allegiance. However, older children and adults can compensate for these risk factors by seeking out supportive contexts such as sports teams, clubs, and religious groups, and by maximizing their use of second language media and other learning materials.

SUMMARY

Human language is a system that links together a series of older primate abilities into a new system, using expanded methods for articulation, lexical organization, and syntax. This system relies on seven linguistic levels, each of which is represented by complex, distributed neural systems. On each of these levels, learning begins with the episodic encoding of particular strings, experiences, and sounds. Children then generalize across these stored experiences to extract higher level patterns, which then compete during processing. Each of the levels of language development involves the fundamental Darwinian processes of proliferation, competition, and selection. This basic competition is further modified by the operation of emergent processes such as self-organization, dynamic coupling, timeframe meshing, neuronal gating, topological neuronal connectivity, identification, imitation, and perspective taking.

Beyond its use for communication, language serves to structure thought and wider social relations in patterns that operate at diverse time scales, ranging from the moment, to the minute, the interaction, the life span, and the evolution of the species. As they learn language, children are able to reveal to us more and more about their thoughts, goals and wishes. At the same time, they become more deeply involved in social processes and the wider community. Although these social structures rely on abilities that we can find in other higher mammals, their elaboration in human culture is quite extreme, reflecting in large part the ability of language to support complex cognitive and social structures. Despite their complexity, these structures are all learnable by human children, using processes of mental model construction guided by perspective taking. In fact, we can say that human society is capable of achieving such great complexity precisely because the building blocks of this complexity are learnable by human children engaged in linguistic interactions.

OPEN QUESTIONS

The study of child language development has made continual progress in both theory and method. However, there are several core questions that remain largely unanswered. Although we have many rich longitudinal corpora from middle-class children growing up in professional families in first-world countries, we know virtually nothing about the details of language development in tribal peoples, marginalized communities, and lower-class groups. We have no data at all from such huge language families such as Niger-Congo, Austronesian, or Trans-New Guinea. For the United States, we have only one publicly available corpus gathered from lower-class African American families and none from Latino families.

Although analyses of lexical, syntactic, and morphological development are now quite precise, the study of gestural and phonological development is far less systematic, although these gaps may soon be addressed through the development of computational tools that support these analyses. Also, despite decades of intensive work, out understanding of the bases of language disorders is still sketchy. Hopefully, new attempts to map out patterns of connectivity in the brain, as well as other advances in neuroscience, may lead to breakthroughs in understanding language disorders.

The biggest open question is how to develop detailed models of links between cognitive processing of language and its use in the social milieu. In this chapter, I have suggested that this can be done through a careful study of the ways in which language patterns respond to pressures operating across diverse timeframes. This means that we need to view specific phrases, words, sounds, and constructions as responsive to social pressures, personal goals, usage patterns, and generalizations arising from similar forms stored in memory. Fleshing out the mechanics of these interactions is the major task for the future of child language research.

REFERENCES

Akhtar, N., Carpenter, M., & Tomasello, M. (1996). The role of discourse novelty in early word learning. *Child Development, 62*, 635–645.

Allen, R., & Gardner, B. (1969). Teaching sign language to a chimpanzee. *Science, 165*, 664–672.

Ambridge, B., & Lieven, E. (in press). A (neo-)constructivist account of child language acquisition. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Ament, W. (1899). *Die Entwicklung von Sprechen und Denken beim Kinder*. Leipzig, Germany: Ernst Wunderlich.

Anglin, J. M. (1970). *The growth of word meaning*. Cambridge, MA: MIT Press.

Arbib, M. (2010). *Beyond the mirror: Evolving language and our social selves*. New York, NY: Oxford University Press.

Arriaga, R., Fenson, L., Cronan, T., & Pethick, S. (1998). Scores on the MacArthur communicative development inventory of children from low and middle income families. *Applied Psycholinguistics, 19*, 209–223.

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1999). Statistical learning in linguistic and nonlinguistic domains. In B. MacWhinney (Ed.), *The emergence of language* (pp. 359–380). Mahwah, NJ: Erlbaum.

Astuti, R., Solomon, G., & Carey, S. (2004). Constraints on conceptual development: A case study of the acquisition of folkbiological and folksociological knowledge in Madagascar *Monographs of the Society for Research in Child Development*, 1–135.

Augustine, Saint. (1952). *The Confessions* (Vol. 18). Chicago, IL: Encyclopedia Britannica. Originally published 397 A.D.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development, 62*, 875–890.

Baldwin, D. A., Markman, E. M., Bill, B., Desjardins, R. N., Irwin, J. M., & Tidball, G. (1996). Infants' reliance on a social criterion for establishing word-object relations. *Child Development, 67*, 3135–3153.

Bandura, A., Ross, D., & Ross, S (1963). Imitaiton of film-mediated aggressive models. *Journal of Abnormal and Social Psychology, 66*, 3–11.

Barkley, R. (2004). Attention-deficit/hyperactivity disorder and self-regulation: Taking an evolutionary perspective on executive functioning. In R. F. Baumeister & K. D. Vohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 301–323). New York, NY: Guilford Press.

Baron-Cohen, S., Baldwin, D. A., & Crowson, M. (1997). Do children with autism use the speaker's direction of gaze strategy to crack the code of language? *Child Development, 68*, 48–57.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy*. New York, NY: Academic Press.

Bates, E., Bretherton, I., Snyder, L., Shore, C., & Volterra, V. (1980). Vocal and gestural symbols at 13 months. *Merrill-Palmer Quarterly, 26*, 407–423.

Berko, J. (1958). The child's learning of English morphology. *Word, 14*, 150–177.

Berry, M., & Eisenson, J. (1956). *Speech disorders: Principles and practices of therapy*. New York, NY: Appleton-Century-Crofts.

Bickerton, D. (1990). *Language and species*. Chicago, IL: University of Chicago Press.

Blanchard, D., Heinz, J., & Golinkoff, R. (2010). Modeling the contribution of phonotactic cues to the problem of word segmentation. *Journal of Child Language, 37*, 487–511.

Bloom, K., Russell, A., & Wassenberg, K. (1987). Turn-taking affects the quality of infant vocalizations. *Journal of Child Language, 14*, 211–227.

Bloom, L. (1971). Why not pivot grammar? *Journal of Speech and Hearing Disorders, 40*, 40–50.

Bloom, P. (2000). *How children learn the meanings of words*. Cambridge, MA: MIT Press.

Bohannon, N., MacWhinney, B., & Snow, C. (1990). No negative evidence revisited: Beyond learnability or who has to prove what to whom. *Developmental Psychology, 26*, 221–226.

Bongaerts, T. (1999). Ultimate attainment in L2 pronunciation: The case of very advanced late L2 learners. In D. Birdsong (Ed.), *Second language acquisition and the Critical Period Hypothesis*. Mahwah, NJ: Erlbaum.

Bookheimer, S. (2007). Pre-surgical language mapping with functional magnetic resonance imaging. *Neuropsychological Review, 17*, 145–155.

Booth, J. R., MacWhinney, B., Thulborn, K. R., Sacco, K., Voyvodic, J., & Feldman, H. (1999). Functional organization of activation patterns in children: Whole brain fMRI imaging during three different cognitive tasks. *Progress in Neuropsychopharmocology and Biological Psychiatry, 23*, 669–682.

Bowerman, M. (1978a). The acquisition of word meaning: An investigation into some current conflicts. In N. Waterson & C. Snow (Eds.), *The development of communication*. New York, NY: Wiley.

Bowerman, M. (1978b). Systematizing semantic knowledge: Changes over time in the child's organization of word meaning. *Child Development, 49*, 977–987.

Bowerman, M. (1988). The "no negative evidence" problem. In J. Hawkins (Ed.), *Explaining language universals* (pp. 73–104). London, England: Blackwell.

Boysson-Bardies, B., & Vihman, M. M. (1991). Adaption to language: Evidence from babbling and first words in four languages. *Language, 67*, 297–320.

Braine, M. (1963). On learning the grammatical order of words. *Psychological Review, 70*, 323–348.

Braine, M. (1971). On two types of models of the internalization of grammars. In D. I. Slobin (Ed.), *The ontogenesis of grammar: A theoretical symposium*. New York, NY: Academic Press.

Braine, M. (1976). Children's first word combinations. *Monographs of the Society for Research in Child Development, 41* (Whole No. 1).

Branigan, G. (1979). Some reasons why successive single word utterances are not. *Journal of Child Language, 6*, 411–421.

Brent, M., & Siskind, J. (2001). The role of exposure to isolated words in early vocabulary development. *Cognition, 61*, 93–125.

Brooks, P. J., & Tomasello, M. (1999). How children constrain their argument structure constructions. *Language, 75*, 720–738.

Brooks, P. J., Tomasello, M., Dodson, K., & Lewis, L. B. (1999). Young children's overgeneralizations with fixed transitivity verbs. *Child Development, 70*, 1325–1337.

Brown, R. (1958). How shall a thing be called? *Psychological Review, 65*, 14–21.

Brown, R. (1973). *A first language: The early stages*. Cambridge, MA: Harvard University Press.

Brown, R, & Bellugi, U. (1964). Three processes in the child's acquisition of syntax. In E. H. Lenneberg (Ed.), *New directions in the study of language*. Cambridge, MA: MIT Press.

Brown, R., Cazden, C., & Bellugi, U. (1969). The child's grammar from I to III. In J. P. Hill (Ed.), *Minnesota symposium on child development* (pp. 28–73). Minneapolis: University of Minnesota Press.

Brown, R., & Hanlon, C. (1970). Derivational complexity and order of acquisition in child speech. In J. R. Hayes (Ed.), *Cognition and the development of language* (pp. 11–54). New York, NY: Wiley.

Brown, R., & Lenneberg, E. (1954). A study in language and cognition. *Journal of Abnormal and Social Psychology, 49*, 2454–2462.

Bruner, J. (1987). *Actual minds, possible worlds*. Cambridge, MA: Harvard University Press.

Bruner, J. (1992). *Acts of meaning*. Cambridge, MA: Harvard University Press.

Bühler, K. (1934). *Sprachtheorie*. Oxford, England: Fischer.

Burling, R. (1959). Language development of a Garo and English speaking child. *Word, 15*, 45–68.

Burns, R.. (1786). *Poetical works of Burns: Cambridge Edition*. Cambridge, England: Cambridge University Press.

Campbell, N. A., Reece, J. B., & Mitchell, L. G. (1999). *Biology* (5th ed.). Menlo Park, NJ: Addison Wesley.

Carroll, J. B., & Casagrande, J. B. (1958). The functions of language classifications in behavior. In T. N. E. Maccoby & E. Hartley (Eds.), *Readings in social psychology*. New York, NY: Holt, Rinehart, and Winston.

Cartwright, T. A., & Brent, M. R. (1997). Syntactic categorization in early language acquisition: formalizing the role of distributional analysis. *Cognition, 61*, 121–170.

Choi, S., & Bowerman, M. (1991). Learning to express motion events in English and Korean: The influence of language-specific lexicalization patterns. *Cognition, 41*, 83–121.

Chomsky, N. (1957). *Syntactic structures*. The Hague, The Netherlands: Mouton.

Chomsky, N. (1980). *Rules and representations*. New York, NY: Columbia University Press.

Chomsky, N. (1981). *Lectures on government and binding*. Cinnaminson, NJ: Foris.

Chomsky, N. (2010). Some simple evo devo theses: How true might they be for language. In R. Larson, V. Déprez & H. Yamakido (Eds.), *The Evolution of Language: Biolinguistic Perspectives* (pp. 45–62). Cambridge, England: Cambridge University Press.

Christiansen, M., & Chater, N. (2008). Language as shaped by the brain. *Behavioral and Brain Sciences, 31*, 489–558.

Clark, E. (1997). Conceptual perspective and lexical choice in acquisition. *Cognition, 64*, 1–37.

Clark, E. (in press). Common ground. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Clark, R. (1977). What's the use of imitation? *Journal of Child Language, 4*, 341–358.

Cole, R. A., & Scott, B. (1974). Toward a theory of speech perception. *Psychological Review, 81*(4), 358–374.

Colunga, E., & Smith, L. (2008). Knowledge embedded in process: the self-organization of skilled noun learning. *Developmental Science, 11*, 195–203.

Cruttenden, A. (1970). A phonetic study of babbling. *British Journal of Disorders of Communication, 5*, 110–117.

Crystal, D. (1975). *The English tone of voice: Essays in intonation, prosody and paralanguage*. London, England: Edward Arnold.

Darwin, C. (1872). *The expression of the emotions in man and animals*. London, England: John Murray.

Daselaar, S., Veltman, D., & Witter, M. (2004). Common pathway in the medial temporal lobe for storage and recovery of words as revealed by event–related functional MRI. *Hippocampus, 14*, 163–169.

Davis, K. (1947). Final note on a case of extreme social isolation. *American Journal of Sociology, 52*, 432–437.

De Houwer, A. (2005). Early bilingual acquisition: Focus on morphosyntax and the Separate Development Hypothesis. In J. F. Kroll & A. M. B. DeGroot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches*. New York, NY: Oxford University Press.

De Houwer, A. (2009). *Bilingual first language acquistiion*. New York, NY: MM Textbooks.

DeCasper, A. J., & Fifer, W. P. (1980). Of human bonding: Newborns prefer their mothers' voices. *Science, 208*, 1174–1176.

DeCasper, A. J., Lecanuet, J., & Busnel, M. (1994). Fetal reactions to recurrent mother speech. *Infant Behavior and Development, 17*, 159–164.

Decety, J., & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences, 3*, 172–241.

Dell, G S. (1995). Speaking and misspeaking. In L. Gleitman & M. Liberman (Eds.), *An invitation to cognitive science*: *Vol. 1. Language* (pp. 183–208). Cambridge, MA: MIT Press.

Dell, G. S., Juliano, C., & Govindjee, A. (1993). Structure and content in language production: A theory of frame constraints in phonological speech errors. *Cognitive Science, 17*, 149–195.

Dell, G. S., Schwartz, M. F., Martin, N., Saffran, E., & Gagnon, D. A. (1997). Lexical access in aphasic and nonaphasic speakers. *Psychological Review, 104*, 811–838.

Dell'Orletta, F., Lenci, A., Montemagni, S., & Pirrelli, V. (2005). Climbing the path to grammar: A maximum entropy model of subject/object learning. *Paper presented at the Association for Computational* Linguistics: PsyComp Models, Ann Arbor, MI.

Dickinson, D. K., & Moreton, J. (1991). Predicting specific kindergarten literacy skills from three-year-olds' preschool experiences. *Merrill-Palmer Quarterly, 15*, 249–258.

diSessa, A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*, 105–225.

Donald, M. (1998). Mimesis and the Executive Suite: missing links in language evolution. In J. R. Hurford, M. G. Studdert-Kennedy & C. Knight (Eds.), *Approaches to the evolution of language* (pp. 44–67). New York, NY: Cambridge University Press.

Donegan, P. (in press). The emergence of phonological representation. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Döpke, S. (1998). Competing language structures: The acquisition of verb placement by bilingual German-English children. *Journal of Child Language, 25*, 555–584.

Dromi, E. (1987). *Early lexical development*. New York, NY: Cambridge University Press.

Eimas, P. D., Siqueland, E. R., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science, 171*, 303–306.

Ellis, N., O'Donnell, M., & Römer, U. (in press). Usage-based language learning. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Enard, W. (2011). FOXP2 and the role of cortico-basal ganglia circuits in speech and language evolution. *Current Opinion in Neurobiology, 21*, 1–10.

Everett, D. (2007). Challenging Chomskyan linguistics: The case of Pirahã. *Human Development, 50*, 297–299.

Farran, D., Hirschbiel, P., & Jay, S. (1980). Toward interactive synchrony: The gaze pattern of mothers and children in three age groups. *Journal of Behavioral Development, 3*, 215–224.

Fausey, C., & Boroditsky, L. (2011). *English and Spanish speakers remember causal agents differently*. Paper presented at the Cognitive Science 2011, Boston, MA.

Feldman, J. (2006). *From molecule to metaphor: A neural theory of language*. Cambridge, MA: MIT Press.

Firbas, J. (1964). On defining the theme in functional sentence. *Travaux Linguistiques de Prague, 1*, 267–280.

Fischer, M., & Zwaan, R. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*, 825–850.

Fisher, S. (2010). Genetic susceptibility to stuttering. *New England Journal of Medicine, 362*, 750–752.

Fisher, S., & Scharff, C. (2009). FOXP2 as a molecular window into speech and language. *Trends in Genetics, 25*, 166–177.

Flege, J. E., Yeni-Komshian, G. H., & Liu, S. (1999). Age constraints on second–language acquisition. *Journal of Memory and Language, 41*, 78–104.

Fodor, J. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.

Franks, S. L., & Connell, P. J. (1996). Knowledge of binding in normal and SLI children. *Journal of Child Language, 23*, 431–464.

Freud, S. (1940). *An outline of psychoanalysis*. New York, NY: Norton.

Frith, C. D., & Frith, U. (1999). Interacting minds—a biological basis. *Science, 286*, 1692–1695.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences, 8*, 396–403.

Ganong, W. (1980). Phonetic categorization in auditory word perception. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 110–115.

Gelman, S. A. (1998). Categories in young children's thinking. *Young Children, 53*, 20–26.

Gentner, D. (2005). The development of relational category knowledge. In L. Gershkoff-Stowe & D. Rakison (Eds.), *Building object categories in developmental time* (pp. 245–276). Mahwah, NJ: Erlbaum.

Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Hillsdale, NJ: Erlbaum.

Givón, T. (1984). *Syntax: A functional-typological introduction* (Vol. 1). Amsterdam, The Netherlands: J. Benjamins.

Gogate, L. J., Bahrick, L. E., & Watson, J. D. (2000). A study of multimodal motherese: The role of temporal synchrony between verbal labels and gestures. *Child Development, 71*, 878–894.

Goldberg, A. (2006). *Constructions at work: The nature of generalization in language*. Oxford, England: Oxford University Press.

Goldfield, B. (1993). Noun bias in maternal speech to one-year-olds. *Journal of Child Language, 13*, 455–476.

Golinkoff, R., Hirsh-Pasek, K., & Hollich, G. (1999). Emergent cues for early word learning. In B. MacWhinney (Ed.), *The emergence of language* (pp. 305–330). Mahwah, NJ: Erlbaum.

Goodale, M. A. (1993). Visual pathways supporting perception and action in the primate cerebral cortex. *Current Opinion in Neurobiology, 3*, 578–585.

Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics, 32*, 1489–1522.

Gopnik, A., & Choi, S. (1995). Names, relational words, and cognitive development in English and Korean speakers: Nouns are not always learned before verbs. In M. Tomasello & M. Merriman (Eds.), *Beyond names for things* (pp. 63–80). Hillsdale, NJ: Erlbaum.

Greeno, J., & MacWhinney, B. (2006). *Learning as perspective taking: conceptual alignment in the classroom*. Paper presented at the ICLS '06: Proceedings of the 7th International Conference on Learning Sciences.

Grossberg, S. (1978). A theory of human memory: Self-organization and performance of sensory-motor codes, maps, and plans. *Progress in Theoretical Biology, 5*, 233–374.

Guenter, F. H., & Perkell, J. S. (2003). A neural model of speech production and its application to studies of the role of auditory feedback in speech. In B. Maasen, R. D. Kent, H. Peters, P. van Lieshout & W. Hulstijn (Eds.), *Speech motor control in normal and disordered speech* (pp. 29–50). Oxford, England: Oxford University Press.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59*, 267–333.

Hakuta, K., Bialystok, E., & Wiley, E. (2003). Critical evidence: A test of the critical period hypothesis for second language acquisition. *Psychological Science, 14*, 31–38.

Halliday, M. (1975). *Learning to mean: explorations in the development of language*. London, England: Edward Arnold.

Harris, Z. S. (1951). *Structural linguistics*. Chicago, IL: The University of Chicago Press.

Hauser, M., Chomsky, N., & Fitch, T. (2002). The faculty of language: What is it, who has it, and how did it evolve? *Science, 298*, 1569–1579.

He, A., & Xiao, Y. (Eds.). (2008). *Chinese as a heritage language: Fostering rooted world citizenry*. Washington, DC: National Foreign Language Resource Center.

Hebb, D. (1949). *The organization of behavior*. New York, NY: Wiley.

Herbst, T. (2007). Valency complements or valency patterns? In T. Herbst & K. Götz-Votteler (Eds.), *Valency: Theoretical, descriptive and cognitive issues* (pp. 15–35). Berlin, Germany: Mouton de Gruyter.

Hickok, G. (2009). The functional neuroanatomy of language. *Physics of Life Reviews, 6*, 121–143.

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: A framework for understanding aspects of the functional anatomy of language. *Cognition, 92*, 67–99.

Hopper, P. (in press). An emergentist approach to grammar. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Hoyer, A., & Hoyer, G. (1924). über die Lallsprache eines Kindes. *Zeitschrift für angewandte Psychologie, 24*, 363–384.

Hubel, D., & Weisel, T. (1963). Receptive fields of cells in striate cortex of very young, visually inexperienced kittens. *Journal of Neurophysiology, 26*, 994–1002.

Hume, D. (1748). *An inquiry concerning human understanding*. London, England: T. Cadell.

Hunt, E. (1962). *Concept learning: An information processing approach*. New York, NY: Wiley.

Huth, A., Nishimoto, S., Vu, A., & Gallant, J. (2012). A continuous semantic space describes the representation of thousands of object and action categories across the human brain. *Neuron, 76*, 1210–1224.

Huttenlocher, J. (1974). The origins of language comprehension. In R. Solso (Ed.), *Theories in cognitive psychology: The Loyola symposium* (pp. 331–388). Potomac, MD: Erlbaum.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27*(2), 236–248.

Hyams, N., & Wexler, K. (1993). On the grammatical basis of null subjects in child language. *Linguistic Inquiry, 24*(3), 421–459.

Ingvalson, E., Holt, L., & McClelland, J. (2012). Can native Japanese listeners learn to differentiate /r-l/ on the basis of F3 onset frequency? *Bilingualism: Language and Cognition, 15*, 255–274.

Irwin, O. C. (1936). *Infant speech*. New York, NY: Harcourt, Brace.

Iverson, J., & Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological Science, 16*, 367–371.

Iverson, J., & Thelen, E. (1999). Hand, mouth and brain. *Journal of Consciousness Studies, 6*, 19–40.

Jakobson, R. (1968). *Child language, aphasia and phonological universals*. The Hague, The Netherlands: Mouton.

James, W. (1890). *The principles of psychology*. New York, NY: Holt, Rinehart, & Winston.

Jasnow, M., & Feldstein, S. (1986). Adult-like temporal characteristics of mother-infant vocal interactions. *Child Delevopment, 57*, 754–761.

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology, 21*, 60–99.

Johnson, M. (1992). Imprinting and the development of face recognition: From chick to man. *Current Directions in Psychological Science, 1*, 52–55.

Jusczyk, P. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Jusczyk, P., Jusczyk, A. M., Kennedy, L. J., Schomberg, T., & Koenig, N. (1995). Young infants' retention of information about bisyllabic utterances. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 822–836.

Kandel, E. R., & Hawkins, R. D. (1992). The biological basis of learning and individuality. *Scientific American, 266*, 40–53.

Karmiloff-Smith, A. (1979). *A functional approach to child language: A study of determiners and reference*. New York, NY: Cambridge University Press.

Karniol, R. (2010). *Social development as preference management*. New York, NY: Cambridge University Press.

Katz, N., Baker, E., & Macnamara, J. (1974). What's in a name? A study of how children learn common and proper names. *Child Development, 45*, 469–473.

Kay, P., & Fillmore, C. J. (1999). Grammatical constructions and linguistic generalization: The "What's X doing Y?" construction. *Language, 75*, 1–33.

Keil, F. C., & Batterman, N. (1984). A characteristic-to-defining shift in the development of word meaning. *Journal of Verbal Learning and Verbal Behavior, 23*, 221–236.

Keller, H., Poortinga, Y., & Schomerich, A. (2002). *Between culture and biology: Perspectives on ontogenetic development*. New York, NY: Cambridge University Press.

Kempe, V., & MacWhinney, B. (1999). Processing of morphological and semantic cues in Russian and German. *Language and Cognitive Processes, 14*, 129–171.

Kendon, A. (1982). The study of gesture: Some observations on its history. *Recherches Sémiotiques/Semiotic Inquiry, 2*(1), 45–62.

Kenyeres, E. (1926). *A gyermek elsö szavai es a szófajók föllépése*. Budapest, Hungary: Kisdednevelés.

Kenyeres, E. (1938). Comment une petite hongroise de sept ans apprend le français. *Archives de Psychologie, 26*, 521–566.

Kilborn, K., & Cooreman, A. (1987). Sentence interpretation strategies in adult Dutch-English bilinguals. *Applied Psycholinguistics, 8*, 415–431.

Kintsch, W. (1974). *The representation of meaning in memory*. Hillsdale, NJ: Erlbaum.

Kita, S., & Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal? Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and Language, 48*, 16–32.

Klima, E., & Bellugi, U. (1966). Syntactic regularities in the speech of children. In J. Lyons & R. J. Wales (Eds.), *Psycholinguistics papers*. Edinburgh, Scotland: Edinburgh University Press.

Knoblich, G. (2008). Bodily and motor contributions to action perception. In R. Klatzky, B. MacWhinney & M. Behrmann (Eds.), *Embodied cognition*. Mahwah, NJ: Erlbaum.

Koechlin, E., & Summerfield, C. (2007a). An information theoretical approach to prefrontal executive function. *Trends in Cognitive Sciences, 11*, 229–235.

Koechlin, E., & Summerfield, C. (2007b). An infromation theoretical approach to prefrontal executive function. *Trends in Cognitive Sciences, 11*, 229–235.

Köhler, W. (1925). *The mentality of apes* (Vol. 32). London, England: K. Paul, Trench, & Trubner.

Kohonen, T. (2001). *Self-organizing maps* (3rd ed.). Berlin, Germany: Springer.

Konishi, M. (1995). A sensitive period for birdsong learning. In B. Julesz & I. Kovacs (Eds.), *Maturational windows and adult cortical plasticity* (pp. 87–92). New York, NY: Addison-Wesley.

Korat, O. (2009). The effect of maternal teaching talk on children's emergent literacy as a function of type of activity and maternal education level. *Journal of Applied Developmental Psychology, 30*, 34–42.

Kroll, J., & Tokowicz, N. (2005). Bilingual lexical processing. In J. F. Kroll & A. M. B. DeGroot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches*. New York, NY: Oxford University Press.

Kuczaj, S., & Brannick, N. (1979). Children's use of the Wh question modal auxiliary placement rule. *Journal of Experimental Child Psychology, 28*, 43–67.

Kuhl, P. K. (2010). Brain mechanisms in early language acquisition. *Neuron, 67*, 713–727.

Kuhl, P. K., & Miller, J. D. (1978). Speech perception by the chinchilla: Identification functions for synthetic VOT stimuli. *Journal of the Acoustical Society of America, 63*, 905–917.

Labov, T., & Labov, William. (1978). The phonetics of cat and mama. *Language, 54*, 316–852.

Ladefoged, P. (1980). What are linguistic sounds made of? *Language, 56*, 485–502.

Lakoff, G. (1987). *Women, fire, and dangerous things*. Chicago, IL: Chicago University Press.

Langers, D., & van Dijk, P. (2012). Mapping the tonotpic organization in human audiotyr cortex with minimally salient acoustic stimulation. *Cerebral Cortex, 22*, 2024–2038.

Lee, C., Imaizumi, K., Schreiner, C., & Winer, J. (2004). Concurent tonotopic processing streams in auditory cortex. *Cerebral Cortex, 14*, 441–451.

Lee, T. H. (1999). Finiteness and null arguments in child Cantonese. *Tsinghua Journal of Chinese Studies, 33*, 1–16.

Lempers, J. (1979). Young children's production and comprehension of nonverbal deictic behaviors. *Journal of Genetic Psychology, 135*, 93–102.

Leopold, W. (1949). *Speech development of a bilingual child: a linguist's record: Vol. 3. Grammar and general problems in the first two years*. Evanston, IL: Northwestern University Press.

Lewes, G. H. (1874). *Problems of life and mind*. London, England: Trübner & Co.

Lewis, M. M. (1936). *Infant speech: A study of the beginnings of language*. New York, NY: Harcourt, Brace, and Co.

Li, P., Zhao, X., & MacWhinney, B. (2007). Dynamic self-organization and early lexical development in children. *Cognitive Science, 31*, 581–612.

Lichtheim, L. (1885). On aphasia. *Brain, 7*, 433–484.

LoBue, V., Rakison, D., & DeLoache, J. (2010). Threat perception across the life span: Evidence fo multiple converging pathways. *Current Directions in Psychological Science, 19*, 375–379.

Locke, J. (1995). Why do infants begin to talk? Language as an unintended consequence. *Journal of Child Language, 23*, 251–268.

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). Lexical nature of syntactic ambiguity resolution. *Psychological Review, 101*(4), 676–703.

MacNeilage, P. (1998a). Evolution of the mechanisms of language output: comparative neurobiology of vocal and manual communication. In J. R. Hurford, M. G. Studdert-Kennedy & C. Knight (Eds.), *Approaches to the evolution of language*. New York, NY: Cambridge University Press.

MacNeilage, P. (1998b). The frame/content theory of evolution of speech production. *Behavioral and Brain Sciences, 21*, 499–546.

MacNeilage, P., Davis, B. L., Kinney, A., & Matyear, C. (2000). The motor core of speech: A comparison of serial organization patterns in infants and languages. *Child Development, 71*, 153–163.

MacWhinney, B. (1974). *How Hungarian children learn to speak*. Berkeley: University of California Press.

MacWhinney, B. (1975a). Pragmatic patterns in child syntax. *Stanford Papers and Reports on Child Language Development, 10*, 153–165.

MacWhinney, B. (1975b). Rules, rote, and analogy in morphological formations by Hungarian children. *Journal of Child Language, 2*, 65–77.

MacWhinney, B. (1978). The acquisition of morphophonology. *Monographs of the Society for Research in Child Development, 43*, Whole no. 1, pp. 1–123.

MacWhinney, B. (1987). The Competition Model. In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 249–308). Hillsdale, NJ: Erlbaum.

MacWhinney, B. (1989). Competition and lexical categorization. In R. Corrigan, F. Eckman & M. Noonan (Eds.), *Linguistic categorization* (pp. 195–242). Philadelphia, PA: Benjamins.

MacWhinney, B. (1995). *The CHILDES Project: Tools for analyzing talk* (2nd ed.). Hillsdale, NJ: Erlbaum.

MacWhinney, B. (Ed.). (1999). *The emergence of language*. Mahwah, NJ: Erlbaum.

MacWhinney, B. (2000). Lexicalist connectionism. In P. Broeder & J. Murre (Eds.), *Models of language acquisition: Inductive and deductive approaches* (pp. 9–32). Cambridge, MA: MIT Press.

MacWhinney, B. (2004). A multiple process solution to the logical problem of language acquisition. *Journal of Child Language, 31*, 883–914.

MacWhinney, B (2005a). Can our experiments illuminate reality? In L. Gershkoff-Stowe & D. Rakison (Eds.), *Building object categories in developmental time* (pp. 301–308). Mahwah, NJ: Erlbaum.

MacWhinney, B. (2005b). Item-based constructions and the logical problem. *ACL 2005*, 46–54.

MacWhinney, B. (2008). How mental models encode embodied linguistic perspectives. In R. Klatzky, B. MacWhinney, & M. Behrmann (Eds.), *Embodiment, ego-space, and action* (pp. 369–410). Mahwah, NJ: Erlbaum.

MacWhinney, B. (2009). The emergence of linguistic complexity. In T. Givon & M. Shibatani (Eds.), *Linguistic complexity* (pp. 405–432). New York, NY: Benjamins.

MacWhinney, B. (2012). The logic of the Unified Model. In S. Gass & A. Mackey (Eds.), *The Routledge handbook of second language acquisition* (pp. 211–227). New York, NY: Routledge.

MacWhinney, B. (in press). Item-based patterns in early syntactic development. In T. Herbst (Ed.), *Valency relations*. Berlin, Germany: Springer.

MacWhinney, B, Bates, E., & Kliegl, R. (1984). Cue validity and sentence interpretation in English, German, and Italian. *Journal of Verbal Learning and Verbal Behavior, 23*, 127–150.

MacWhinney, B, Feldman, H. M., Sacco, K., & Valdes-Perez, R. (2000). Online measures of basic language skills in children with early focal brain lesions. *Brain and Language, 71*, 400–431.

MacWhinney, B, & Leinbach, J. (1991). Implementations are not conceptualizations: Revising the verb learning model. *Cognition, 29*, 121–157.

MacWhinney, B., Leinbach, J., Taraban, R. & McDonald, J. (1989). Implementations and not conceptualizations: Revising the verb learning model. *Cognition*, *29*, 121–157.

MacWhinney, B, & Li, P. (2008). Neurolinguistic computational models. In B. Stemmer & H. Whitaker (Eds.), *Handbook of the neuroscience of language* (pp. 229–236). Mahwah, NJ: Erlbaum.

Mann, W. C., & Thompson, S. A. (1992). *Discourse description*. Amsterdam, The Netherlands: Benjamins.

Maratsos, M., & Déak, G. (1995). Hedgehogs, foxes, and the acquisition of verb meaning. In M. Tomasello & M. Merriman (Eds.), *Beyond names for things* (pp. 377–404). Hillsdale, NJ: Erlbaum.

Marcus, G., Ullman, M., Pinker, S., Hollander, M., Rosen, T., & Xu, F. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development, 57*(4), 1–182.

Markman, E. (1990). Constraints children place on word meanings. *Cognitive Science, 14*, 57–77.

Marler, P. (1991). Song-learning behavior: The interface with neuroethology. *Trends in Neuroscience, 14*, 199–206.

Marslen-Wilson, W., & Warren, P. (1994). Levels of perceptual representation and process in lexical access: Words, phonemes, and features. *Psychological Review, 101*, 653–675.

Massaro, D. (Ed.). (1975). *Understanding language: An introduction-processing analysis of speech perception, reading, and psycholinguistics*. New York, NY: Academic Press.

Mavilya, M. (1972). Spontaneous vocalization and babbling in hearing impaired infants. In G. Fant (Ed.), *International symposium on speech communication abilities and profound deafness* (pp. 163–171). Washington, DC: Alexander Graham Bell Association for the Deaf.

McCandliss, B. D., Fiez, J. A., Protopapas, A., Conway, M., & McClelland, J. L. (2002). Success and failure in teaching the /r/-/l/ contrast to Japanese adults: Test of a Hebbian model of plasticity and stabilization in spoken language perception. *Cognitive, Affective, and Behavioral Neuroscience, 2*, 89–108.

McCarthy, D. (1954). Language development in children. In L. Carmichael (Ed.), *Handbook of child psychology*. New York, NY: Wiley.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: Insights from the successes and failures of connectionist models of learning and memory. *Psychological Review, 102*, 419–457.

McNeill, D. (1985). So you think gestures are nonverbal? *Psychological Review, 92*, 350–371.

McNeill, D. (2005). *Gesture and thought*. Chicago, IL: Chicago University Press.

Meltzoff, A. N., & Decety, J. (2003). What imitation tells us about social cognition: A rapprochement between developmental psychology and cognitive neuroscience. *Philosophical Transactions of the Royal Society of London B, 358*, 491–500.

Menyuk, P. (1969). *Sentences children use*. Cambridge, MA: MIT Press.

Merriman, W. (1999). Competition, attention, and young children's lexical processing. In B. MacWhinney (Ed.), *The emergence of language* (pp. 331–358). Mahwah, NJ: Erlbaum.

Mervis, C. (1984). Early lexical development: The contributions of mother and child. In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 339–370). Hillsdale, NJ: Erlbaum.

Mesoudi, A., Whiten, A., & Laland, K. (2006). Towards a unified science of cultural evolution. *Behavioral and Brain Sciences, 29*, 329–383.

Middleton, F. A., & Strick, P. L. (1998). Cerebellar output: Motor and cognitive channels. *Trends in Cognitive Sciences, 2*, 348–354.

Miller, G. A. (1965). Some preliminaries to psycholinguistics. *American Psychologist, 20*, 15–20.

Miller, G., Beckwith, R., Fellbaum, C., Gross, D., & Miller, K. (1990). Introduction to WordNet: An on-line lexical database. *International Journal of Lexicography, 3*.

Miller, K. D., Keller, J. B., & Stryker, M. P. (1989). Ocular dominance column development: Analysis and simulation. *Science, 245*, 605–615.

Mitchell, T. M., Shinkareva, S. V., Carlson, A., Chang, K-M., Malave, V. L., Mason, R. A., & Just, M. (2008). Predicting human brain activity associated with the meanings of nouns. *Science, 320*, 1191–1195.

Monaghan, P., & Christiansen, M. (2010). Words in puddles of sound: modelling psycholinguistic effects in speech segmentation. *Journal of Child Language, 37*, 545–564.

Mowrer, O. (1960). *Learning theory and the symbolic processes*. New York, NY: Wiley.

Murray, J. D. (1988). How the leopard gets its spots. *Scientific American, 258*, 80–87.

Naigles, L. G., & Gelman, S. A. (1995). Overextensions in comprehension and production revisited: Preferential looking in a study of dog, cat, and cow. *Journal of Child Language, 22*, 19–46.

Namy, L., & Waxman, S. (1998). Words and gestures: Infants' interpretations of different forms of symbolic reference. *Child Development, 69*, 295–308.

Nazzi, T., Jusczyk, P., & Johnson, E. K. (2000). Discriminating languages from the same rhythmic class: Evidence from English-learning 5-month-olds. *Journal of Memory and Language, 3*, 1–19.

Nelson, K. (1998). *Language in cognitive development: The emergence of the mediated mind*. New York, NY: Cambridge University Press.

Nicoladis, E. (2001). Finding first words in the input. In J. Cenoz & F. Genesee (Eds.), *Trends in Bilingual Acquisition* (pp. 131–148). New York, NY: Benjamins.

Ninio, A., & Snow, C. (1988). Language acquisition through language use: The functional sources of children's early utterances. In Y. Levy, I. Schlesinger & M. Braine (Eds.), *Categories and processes in language acquisition* (pp. 11–30). Hillsdale, NJ: Erlbaum.

Nuñez, R., & Lakoff, G. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York, NY: Basic Books.

O'Grady, W. (2005). *Syntactic carpentry*. Mahwah, NJ: Erlbaum.

Ochs, E., & Schieffelin, B. B. (1983). *Acquiring conversational competence*. London, England: Routledge & Kegan Paul.

Ohala, J. J. (1974). Phonetic explanation in phonology. In A. Bruck, R. Fox, & M. La Galy (Eds.), *Papers from the parassession on natural phonology* (pp. 251–274). Chicago, IL: Chicago Linguistic Society.

Oller, D. K. (2000). *The emergence of the speech capacity*. Mahwah, NJ: Erlbaum.

Oller, D. K., & Eilers, R. E. (1988). The role of audition in infant babbling. *Child Development, 59*, 441–449.

Overton, W. (2006). Developmental psychology: Philosophy, concepts, methodology. In R. M. Lerner (Ed.), *Theoretical models of human development*. Volume 1 of the *Handbook of child psychology* (6th ed., pp. 18–88). Editors-in-Chief: W. Damon & R. M. Lerner. Hoboken, NJ: Wiley.

Oviatt, S. (1980). The emerging ability to comprehend language: An experimental approach. *Child Development, 51*, 97–106.

Pallier, C., Dehaene, S., Poline, J. B., LeBihan, D., Argenti, A. M., Dupoux, E., & Mehler, J. (2003). Brain imaging of language plasticity in adopted adults: Can a second language replace the first? *Cerebral Cortex, 13*, 155–161.

Papousek, M., & Papousek, H. (1991). The meanings of melodies in mothers in tone and stress languages. *Infant Behavior and Development, 14*, 415–440.

Pelphrey, K. A., Mitchell, T. V., McKeown, M. J., Goldstein, J., Allison, T., & McCarthy, G. (2003). Brain activity evoked by the perception of human walking: Controlling for meaningful coherent motion. *Journal of Neuroscience, 23*, 6819–6825.

Pelphrey, K. A., Morris, J. P., & McCarthy, G. (2005). Neural basis of eye gaze processing deficits in autism. *Brain, 128*, 1038–1048.

Penfield, W., & Roberts, L. (1959). *Speech and brain mechanisms*. Princeton, NJ: Princeton University Press.

Peters, A. M. (1977). Language learning strategies: Does the whole equal the sum of the parts? *Language, 53*, 560–573.

Piaget, J. (1952). *The origins of intelligence in children*. New York, NY: International Universities Press.

Piaget, J. (1954). *The construction of reality in the child*. New York, NY: Basic Books.

Piattelli-Palmarini, M. (1980). *Language and learning: The debate between Jean Piaget and Noam Chomsky*. Cambridge, MA: Harvard University Press.

Pickering, M., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences, 27*, 169–226.

Pinker, S. (1989). *Learnability and cognition: the acquisition of argument structure*. Cambridge, MA: MIT Press.

Pinker, S., & Mehler, J. (1988). *Connections and symbols*. Cambridge, MA: MIT Press.

Pulvermüller, F. (2003). *The neuroscience of language*. Cambridge, MA: Cambridge University Press.

Quine, W. (1960). *Word and object*. Cambridge, MA: MIT Press.

Ratcliff, R., & Smith, R. L. (2004). A comparison of sequential sampling models for two-choice reaction time. *Psychological Review, 111*, 333–367.

Recknor, J. B., & Mallapragada, S. K. (2006). Nerve regeneration: Tissue engineering strategies. In J. D. Bronzino (Ed.), *The biomedical engineering handbook: Tissue engineering and artificial organs*. New York, NY: Taylor & Francis.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*, 131–141.

Ruby, P., & Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of Cognitive Neuroscience, 16*, 988–999.

Rumelhart, D., & McClelland, J. (1987). Learning the past tenses of English verbs: Implicit rules or parallel distributed processes? In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 195–248). Hillsdale, N.J.: Erlbaum.

Rumelhart, D., McClelland, J., & the PDP Research Group. (1986). *Parallel distributed processing*. Cambridge, MA: MIT Press.

Sacks, H., Schegloff, E., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language, 50*, 696–735.

Sandhofer, C., Smith, L., & Luo, J. (2000). Counting nouns and verbs in the input: Differential frequencies, different kinds of learning? *Journal of Child Language, 27*, 561–585.

Schafer, G., & Plunkett, K. (1998). Rapid word learning by 15-month-olds under tightly controlled conditions. *Child Development, 69*, 309–320.

Schlesinger, I. (1974). Relational concepts underlying language. In R. L. Schiefelbusch & L. L. Lloyd (Eds.), *Language perspectives—Acquisition, retardation, and intervention* (pp. 129–151). Baltimore: University Park Press.

Sebastián-Galles, N., & Bosch, L. (2005). Phonology and bilingualism. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 68–87). New York, NY: Oxford University Press.

Shrager, J. F., & Johnson, M. H. (1995). Waves of growth in the development of cortical function: A computational model. In B. Julesz & I. Kovacs (Eds.), *Maturational windows and adult cortical plasticity* (pp. 31–44). New York, NY: Addison-Wesley.

Sidtis, D. (2011). Formulaic expression in mind and brain: Empirical studies and dual-process model of language competence. In J. Guendozi, F. Loncke, & M. Williams (Eds.), *The handbook of psycholinguistic and cognitive processes: Perspectives in communication disorders* (pp. 247–272). New York, NY: Psychology Press.

Sidtis, D. (in press). Formulaic language: Acquisition, use, and neurological foundations. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Silverstein, M. (2008). Axes of evals. *Journal of Linguistic Anthropology, 15*, 6–22.

Simon, H. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society, 106*, 467–482.

Slobin, D. I. (1996). From "thought and language" to "thinking for speaking." In J. J. Gumperz & S. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 70–96). Cambridge, MA: Cambridge University Press.

Smith, L. (1999). Children's noun learning: How general processes make specialized learning mechanisms. In B. MacWhinney (Ed.), *The emergence of language* (pp. 277–304). Mahwah, NJ: Erlbaum.

Smith, N. V. (1973). *The acquisition of phonology: A case study*. Cambridge, England: Cambridge University Press.

Snow, C. E. (1977). The development of conversation between mothers and babies. *Journal of Child Language, 4*, 1–22.

Snow, C. E., Pan, B., Imbens-Bailey, A., & Herman, J. (1996). Learning how to say what one means: A longitudinal study of children's speech act use. *Social Development, 5*, 56–84.

Sokolov, J. L. (1993). A local contingency analysis of the fine-tuning hypothesis. *Developmental Psychology, 29*, 1008–1023.

Sowa, J. (2000). *Knowledge representation: Logical, philosophical, and computational foundations*. Pacific Grove, CA: Brooks/Cole.

Spradley, J. (Ed.). (1972). *Culture and cognition: Rules, maps, and plans*. New York, NY: Chandler.

Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience, 4*, 233–243.

Stager, C. L., & Werker, J. (1997). Infants listen for more phonetic detail in speech perception than in word learning tasks. *Nature, 388*, 381–382.

Stemberger, J. (1985). *The lexicon in a model of language production*. New York, NY: Garland.

Stemberger, J., & MacWhinney, B. (1986). Frequency and the lexical storage of regularly inflected forms. *Memory and Cognition, 14*, 17–26.

Sugarman, S. (1982). Developmental change in early representational intelligence: Evidence from spatial classification strategies and related verbal expressions. *Cognitive Psychology, 14*, 410–449.

Talmy, L. (1988). Force dynamics in language and cognition. *Cognitive Science, 12*, 59–100.

Tamis-LeMonda, C., & Bornstein, M. H. (2002). Maternal responsiveness and early language acquisition. In R. Kail & J. Reese (Eds.), *Advances* *in child development and behavior* (Vol. 29, pp. 89–127). San Diego, CA: Academic Press.

Tardif, T. (1996). Nouns are not always learned before verbs: Evidence from Mandarin speakers' early vocabularies. *Developmental Psychology, 32*, 492–504.

Templin, M. (1957). *Certain language skills in children*. Minneapolis: University of Minnesota Press.

Terrace, H. S., Petitto, L. A., Sanders, R. J., & Bever, T. G. (1980). On the grammatical capacity of apes. In K. Nelson (Ed.), *Children's language* (Vol. 2, pp. 371–495). New York, NY: Gardner.

Tesniére, L. (1959). *Elements de syntaxe structurale*. Paris, France: Klincksieck.

Thierry, G., Vihman, M., & Roberts, M. (2003). Familiar words capure the attention of 11–month-olds in less than 250 ms. *Neuroreport, 14*, 2307–2310.

Thiessen, E. (2007). The effect of distributional information on children's use of phonemic contrasts. *Journal of Memory and Language, 56*, 16–34.

Thiessen, E., & Erickson, L. (in press). Perceptual development and statistical learning. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.

Thiessen, E., & Yee, M. (2010). Dogs, bogs, labs, and lads: What phonemic generalizations indicate about the nature of children's early word-form representations. *Child Development, 81*, 1287–1303.

Tinbergen, N. (1951). *The study of instinct*. New York, NY: Clarendon Press.

Tomalin, M. (2007). Reconsidering recursion in syntactic theory. *Lingua, 117*, 1784–1800.

Tomasello, M. (2000). The item-based nature of children's early syntactic development. *Trends in Cognitive Sciences, 4*, 156–163.

Tomasello, M. (2003). *Constructing a first language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.

Tomasello, M, & Ahktar, N. (1995). Two-year-olds use pragmatic cues to differentiate reference to objects and actions. *Cognitive Development, 10*, 201–224.

Tomasello, M., Call, J., & Gluckman, A. (1997). Comprehension of novel communicative signs by apes and human children. *Child Development, 68*, 1067–1080.

Trueswell, J. C., Tanenhaus, M. K., & Kello, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(3), 528–553.

Tucker, D. (2002). Embodied meaning. In T. Givon & B. Malle (Eds.), *The evolution of language out of pre-language* (pp. 51–82). Amsterdam, The Netherlands: Benjamins.

Tyler, A., & Nagy, W. (1989). The acquisition of English derivational morphology. *Journal of Memory and Language, 28*, 649–667.

Ullman, M. (2004). Contributions of memory circuits to language: The declarative/procedural model. *Cognition, 92*, 231–270.

Valiant, L. G. (1984). A theory of the learnable. *Research Contributions, 27*(11), 1134–1142.

van der Lely, H. (1994). Canonical linking rules: Forward vs. reverse linking in normally developing and specifically language-impaired children. *Cognition, 51*, 29–72.

Vihman, M. (1996). *Phonological development: The origins of language in the child*. Cambridge, MA: Blackwell.

von Bertalanffy, L. (1968). *General system theory: Foundations, development, applications*. New York, NY: George Braziller.

Vygotsky, L. S. (1934). *Thought and language*. Cambridge, MA: MIT Press.

Warren, R. M., & Warren, R. P. (1970). Auditory illusions and confusions. *Scientific American, 223*, 30–36.

Wäsz-Hockert, O., Lind, J., Vuorenkoski, V., Partanen, T., & Valanne, E. (1968). The infant cry: A spectrographic and auditory analysis (Vol. 29). Lavenham, England: Lavenham Press.

Waxman, S., & Kosowski, T. (1990). Nouns mark category relations: Toddlers' and preschoolers' word-learning biases. *Child Development, 61*, 1461–1473.

Waxman, S., & Markow, D. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology, 29*, 257–302.

Werker, J.. (1995). Exploring developmental changes in cross-language speech perception. In L. Gleitman & M. Liberman (Eds.), *An invitation to cognitive science: Vol. 1. Language* (pp. 87–106). Cambridge, MA: MIT Press.

Werner, H., & Kaplan, B. (1963). *Symbol formation: An organismic-developmental approach to language and the expression of thought*. New York, NY: Wiley.

Whorf, B. (1967). *Language, thought, and reality*. Cambridge, MA: MIT Press.

Wiley, E., Bialystok, E., & Hakuta, K. (2005). New approaches to using census data to test the Critical-Period Hypothesis for second language acquisition. *Psychological Science, 16*, 341–343.

Willshaw, D. J., & Von der Malsburg, C. (1976). How patterned neural connections can be set up by self-organization. *Proceedings of the Royal Society of London B, 194*, 431–445.

Wittenberg, G., Sullivan, M., & Tsien, J. (2002). Synaptic reentry reinforcement based network model for long-term memory consolidation. *Hippocampus, 12*, 637–647.

Woodward, A. L., & Hoyne, K. L. (1999). Infants' learning about words and sounds in relation to objects. *Child Development, 70*, 65–77.

Wyttenback, M., May, M., & Hoy, D. (1996). Categorical perception of sound frequency by crickets. *Science, 273*, 1542–1544.

Yip, V., & Matthews, S. (2000). Syntactic transfer in a Cantonese-English bilingual child. *Bilingualism: Language and Cognition, 3*, 193–208.

Yoshimura, Y., & MacWhinney, B. (2007). The effect of oral repetition in L2 speech fluency: System for an experimental tool and a language tutor. *SLATE Conference, 25–28*.

Zlatev, J. (in press). The emergence of gestures. In B. MacWhinney & W. O'Grady (Eds.), *The handbook of language emergence*. Hoboken, NJ: Wiley.