Available online at www.sciencedirect.com

ScienceDirect

Journal of Communication Disorders 42 (2009) 263–271

Journal of Communication Disorders

Evolving the language-ready brain and the social mechanisms that support language

Michael A. Arbib *

Computer Science, Neuroscience and the USC Brain Project, University of Southern California, HNB 03, Los Angeles, CA 90089-2520, USA

Received 9 March 2009; accepted 26 March 2009

Abstract

We first review the mirror-system hypothesis on the evolution of the language-ready brain, stressing the important role of imitation and protosign in providing the scaffolding for protospeech. We then assess the role of social interaction and non-specific knowledge of language in the emergence of new sign languages in deaf communities (focusing on Nicaraguan Sign Language). *Learning outcomes:* (1) Readers will understand the difference between mirror systems in humans and monkeys, and see how the evolution of imitation and protosign required the biological evolution of mirror systems with linkages to diverse regions beyond the mirror system. (2) Readers will see how social structure complements brain mechanisms in yielding language through cultural evolution supported by having language-ready brains, rather than through possession of an innate Universal Grammar. (3) Readers will understand that ontogeny does not recapitulate phylogeny, but will appreciate what mechanisms currently operative in modern children acquiring language may also have served early humans during the cumulative invention of the idea of language.

1. The evolution of the language-ready brain

1.1. Language within an action-oriented perspective

The guiding hypotheses for the evolutionary approach to language offered here are:

1. Language did not evolve as a separate ''faculty''. Rather, brain mechanisms for the perceptual control of action provided the ''evolutionary substrate'' for the language-ready brain.
2. Manual dexterity provides a key to understanding human speech: Birdsong provides an example of superb vocal control but has never become the substrate for a language. By contrast, primates are precocious in their manual dexterity and so we seek to establish that humans exploit this dexterity to become the unique primates possessing language (Arbib, 2005a).

As support for this, we note that speaking humans, even blind ones, make extensive use of manual co-speech gestures (McNeill, 2005), and that children raised appropriately can learn the sign languages of the deaf (Klima & Bellugi, 1979) as readily as hearing children learn a spoken language.

* Tel.: +1 213 740 9220; fax: +1 213 821 3046.
E-mail address: arbib@usc.edu.

0021-9924/$ – see front matter
doi:10.1016/j.jcomdis.2009.03.009

A simple example will suggest that grammar may be placed in the same context as praxis (practical manual actions) when we consider how sentential form as involving strategies for achieving a communicative goal akin to those required to hit a moving target. Consider a restaurant manager whose communicative goal is to get a waiter to serve a particular customer (Arbib, 2006). He keeps replanning his sentence until he thinks that any ambiguity is resolved:

Serve the man on the left.
Still ambiguous?
Serve the young man on the left.
Still ambiguous?
Serve the young man on the left in the green sweater.
Still ambiguous? Apparently not, and so he says it to the waiter.

We see here a sentence planning strategy of repeating the construction. Add adjective or relative clause until (you think) ambiguity is resolved, adapting and ‘‘unfurling’’ a nested hierarchical structure to extract a set of actions to reach a communicative goal.

1.2. Canonical and mirror neurons for grasping in the Macaque

To get to our theory of the evolution of the language-ready brain (which grew from the early formulations of Arbib & Rizzolatti, 1997; Rizzolatti & Arbib, 1998), we first briefly recall some facts about the macaque brain (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Briefly, area AIP in the parietal cortex extracts ‘‘affordances’’ for grasping, i.e., it classifies objects not in terms of their identity but in terms of how they may be grasped (Sakata et al., 1998). Area F5 of the premotor cortex *has many different types of neurons*, but we are particularly interested in two classes of neurons whose firing is correlated with specifics types of manual actions: *Mirror neurons* discharge both when the monkey makes hand movements of a specific kind (e.g., a precision pinch, or tearing paper) and when the monkey observes a human or monkey making more or less similar actions (we may distinguish broadly or strictly congruent mirror neurons); whereas *canonical neurons* are grasp-related neurons which fire during execution but not observation (see Rizzolatti & Sinigaglia, 2008, for an excellent review of both macaque and related human data). The two neuron types are anatomically segregated in F5.

Monkey F5 (with its mirror system for grasping) is homologous to human Broca’s area. But Broca’s area has traditionally been implicated in speech production, while brain imaging links a human mirror system for grasping to Broca’s area (Grafton, Arbib, Fadiga, & Rizzolatti, 1996). The gap between hand and language is reduced when one notes that Broca’s area has been implicated in sign language as well as speech (Emmorey, 2002; Poizner, Klima, & Bellugi, 1987). Note that we speak of a mirror *system* for humans when we have a brain region activated in brain imaging both for observation and execution of a broad class of actions. We assume, but have no proof, that such a system has its property because it contains mirror neurons like those observed by single-cell recording in the monkey.

Different brain regions (not individual neurons) may be implicated in the human brain as mirror systems for different classes of actions, and many researchers have attributed high level cognitive functions to human mirror regions such as imitation (Buccino et al., 2004), intention attribution (Iacoboni et al., 2005) and language (Rizzolatti & Arbib, 1998). However, monkeys do not imitate or learn language. Thus, any account of the role of human mirror systems in imitation and language must include an account of the evolution of mirror systems and their interaction with more extended systems within the human brain—‘‘*beyond the mirror system*’’.

1.3. The mirror system hypothesis

By a *language-ready brain* I mean one that equips an infant to be able to learn a human language. As far as we know, *Homo* sapiens is the only creature with such a brain. However, I argue that the first creatures who had a language-ready brain did not yet have language—just as we believe that our distant ancestors had brains that could support the ability to read long before any human culture developed a writing system.

The original *mirror system hypothesis* (Arbib & Rizzolatti, 1997; Rizzolatti & Arbib, 1998) argued that the evolutionary basis for *language parity* (i.e., the ability of the hearer to gather, approximately, the intended meaning of the speaker – and similarly for signed language) is provided by the mirror system for grasping, rooting speech in communication based on manual gesture. In other words, we trace a path from praxis to communication.

I have hypothesized (Arbib, 2002, 2005a) that a language-ready brain resulted from the evolution of a progression of mirror systems and linked brain regions ''beyond the mirror'' that made possible the full expression of their functionality:

1. Grasping and manual praxic actions (shared with monkeys).
2. Imitation of grasping and manual praxic actions: first simple imitation (imitating simple novel behaviors that are focused on animals and/or objects–but only through repeated exposure; an ability shared with chimpanzees) then complex imitation (acquiring novel sequences in a single trial if the sequences are not too long and the components are relatively familiar; this is unique to the human line).
3. Pantomime of grasping and manual praxic actions.
4. Pantomime of actions outside the panto-mimic's own behavioral repertoire (e.g., flapping the arms to mime a flying bird).
5. *Protosign:* conventional gestures used to formalize and disambiguate pantomime (e.g., to distinguish ''bird'' from ''flying'').
6. *Protosign & protospeech* (an expanding spiral): conventionalized manual, facial and vocal communicative gestures (''protowords'') separate from pantomime (Arbib, 2005b).

I then argue, controversially, that a brain with the above systems in place was language-ready, and that it was cultural evolution in *Homo sapiens* that yielded language incrementally. I thus distinguish two evolutionary processes in the transition from monkey-like action recognition (posited to be shared with the monkey-human common ancestor) to human language:

1. *Biological evolution:* From a mirror system to a language-ready brain. Research here makes strong use of comparative neurobiology (Arbib, 2007; Deacon, 2007) and primatology (Arbib, Liebal, & Pika, 2008).
2. *Cultural evolution:* From hominids with a language-ready brain and rudimentary manual-vocal communication to humans with full language capability. Here the stress is on the rich historical processes whereby groups of language arose and ''cross-pollinated'' (Croft, 2000; Dixon, 1997).

In this regard, it is worth stressing that the brain's language structures reflect more than just genetics, and that functional hemispheric specialization depends on both genetic and environmental factors (Petersson, Reis, Askelof, Castro-Caldas, & Ingvar, 2000). Illiterate subjects are consistently more right-lateralized than literate controls even though the 2 groups showed a similar degree of left–right differences in early speech-related regions of superior temporal cortex. Further, the influence of literacy on brain structure related to reading and verbal working memory affects large-scale brain connectivity more than grey matter. We see here that a cultural factor, literacy, influences the functional hemispheric balance.

1.4. Grammar in perspective

It will be useful to contrast two ways to characterize a language:

1. *Autonomous syntax/generative grammar* (associated particularly with the work of Noam Chomsky, 1965, 1981, 1992) sees the grammar of a language as comprising a relatively compact set of autonomous syntactic rules which put words together in very general ways and without regard for the meaning of the result. The use of these rules to express meaning is then the problem of a semantics rather separate from syntax.
2. *Construction grammar*, by contrast, offers a more or less language-specific set of constructions (Croft, 2001; Fillmore, Kay, & O'Connor, 1988; Goldberg, 2003) which combine form (how to aggregate words) with meaning (how the meaning of the words constrains the meaning of the whole). The latter seems more hospitable to accounts (historical linguistics/cultural evolution) of how languages emerge and change over time (Croft, 2000).

Many proponents of generative semantics holds that the basic rules of the syntax of *all* human languages are contained in a *Universal Grammar* which is genetically encoded in humans such that – at least in one version of the theory (Baker, 2001; Chomsky & Lasnik, 1993) – it can establish within the infant brain a range of parameters which enable the child to acquire the syntax of its native language by setting each parameter simply by hearing a few sentences to determine which value of the parameter is consistent with them. I find this grossly implausible but have no space here to develop the argument.

In an example of language acquisition that can now be seen as related to construction grammar (though before this theory was introduced – see Tomasello, 2003 for a more extended account), Hill (1983) showed that the child may first acquire what the adult perceives as two-word utterances as *holophrases* (e.g., ‘‘want-milk’’ without understanding that this has pieces with different meanings) prior to developing a more general construction (e.g., want *x*) in which ‘‘*x*’’ can be replaced by the name of any ‘‘wantable thing’’. Further experience will yield more subtle constructions and the development of word classes like ‘‘noun’’ defined by their syntactic roles in a range of constructions rather than their semantic role.

How does this relate to our claim for the cultural evolution of language from protolanguage? Ontogeny does not recapitulate phylogeny. Adult hunters and gatherers had to communicate about situations outside the range of a modern 2-year-old. Moreover, unlike modern human children, protohumans were not communicating with adults who already used a large lexicon and set of constructions to generate complex sentences. Nonetheless, I argue that protolanguage and language emerged through the invention of an increasingly subtle interweaving of (proto)words and (proto)constructions, and that the same basic mechanisms may have served both protohumans inventing language and modern children acquiring the existing language of their community. Among the mechanisms serving inventing and acquiring a language are:

1. The ability to create a novel gesture or vocalization and associate it with a communicative goal.
2. The ability to learn to perform and perceive such a gesture or vocalization, even if ‘‘invented’’ by another.
3. Moreover, commonalities between two structures could yield the isolation of that commonality as a gesture or vocalization betokening some shared aspect of the event, object or action denoted by each of the two structures. Wray (2000) showed how this might have operated in protohumans while Kirby (2000) developed a related computer model.
4. The isolation of such fragments from holophrases could in time lead to the emergence of a construction for ‘‘putting the pieces back together’’, with the pieces becoming instances of a widening class of slot fillers.

‘‘Semantic fractionation’’, as here defined helps define new meaningful elements and serves as the basis for developing new constructions. Similarly ‘‘motor fractionation’’ (whether manual or vocal) – which operates without regard for shared meaning – may similarly define new meaningless elements as the basis for phonology (Arbib, 2008).

2. A new sign language creates/is created by a community

We now turn from biological evolution to cultural evolution on a very fast time scale, looking at the emergence of Nicaraguan Sign Language in a mere thirty years or so. I will argue that this was possible only because and when the broader community provided deaf Nicaraguans with social structures and knowledge of the *idea* of language.

2.1. Home sign

Deaf babies exposed to a sign language (a full human language based on manual and facial gestures rather than speech) from birth follow a similar timetable of linguistic development to that of hearing children acquiring spoken language. Lacking a sign language, families in which a deaf child is raised by non-signing parents instead develop home sign, a rudimentary form of communication between the deaf child and other family members which comprises a small ‘‘vocabulary’’ of manual gestures (‘‘signs’’) together with a few strategies for combining signs into longer messages (Goldin-Meadow, 2003; Goldin-Meadow & Feldman, 1975).

I want to stress that home sign is the product of a *community* (albeit a very small one). It is often suggested that the deaf child develops home sign; but I emphasize that is the product of the *collective efforts of the family* to communicate. Clearly, home sign does not rest on direct input from either a spoken language or a sign language since these are children of speaking parents who do not know sign language. But there is *indirect* input: The child sees gestures – both deictic gestures and more descriptive gestures – used by other family members as part of speech acts. These family members show the child that pointing and pantomime can be used to communicate and the child's caregiver will provide a structured environment such as pointing at pictures in picture books. The ''indirect input'' from speech is even less direct. The child sees family members take turns to speak and gesture, sometimes to no apparent end, but in other cases with clear links to emotional impact or achieving instrumental goals. All this creates for the child an understanding of the general notion of dialogue conducted by a blend of gesture and facial expression.

2.2. Nicaraguan Sign Language (NSL): A new sign language

Before the 1980s, deaf Nicaraguans had little contact with each other. Children developed idiosyncratic home sign within their families but no sign language emerged. However, a vocational school for the deaf opened in 1981 in Managua. Instruction was conducted in Spanish, with minimal success but the children began to develop a new, gestural system for communicating with each other – in part by consolidating the different home signs each had developed. The gestures soon expanded to form a rudimentary sign language. By 1986 the early collection of gestures developed into an expressive sign language, Nicaraguan Sign Language, which is still in a state of flux, as the sign-lexicon and constructions keep changing.

Senghas, Kita, & Özyürek (2004) is one study of such change (see Russo & Volterra, 2005; Senghas, Özyürek, & Kita, 2005 for a commentary and response) comparing the performance of the first, second and third cohorts (Deaf Nicaraguans who acquired NSL in the first, second or third 10 years of its existence). Subjects were asked to use their hands to describe a segment of a Tweety Bird and Sylvester cartoon in which Sylvester, having swallowed a bowling ball, ''rolls'' down the hill. Manner (rolling) and path (downward) are expressed simultaneously in the co-speech gesture of Spanish speakers as well as in the signs of many by early cohort NSL signers. By contrast, third-cohort NSL signers tend to express manner and path sequentially, first signing ''rolling'' and then ''downward''. In other words, gestures seen rarely in early cohorts become entrenched as accepted signs of NSL by the third cohort.

We thus see that NSL is not a copying of Spanish co-speech gestures. This separation of manner and path is a novel conventionalization, though it must be noted that many sign languages do express manner and path simultaneously. NSL is developing its own signs, not simply copying other sign languages.

Recall from the last section that observation of a commonality between two communicative structures could yield the isolation of that commonality as a gesture or vocalization betokening some shared aspect of the event, object or action denoted by each of the two structures. We also saw that such ''semantic fractionation'' might lead in time to the emergence of a construction for ''putting the pieces back together'', with the pieces becoming instances of a widening class of slot fillers.

If manner and path are expressed separately, it may no longer be clear that the two aspects of movement occurred within a single event. *Roll* followed by *downward* might mean ''rolling, then descending''. Senghas et al. (2004) show that NSL developed a way to put the pieces back together: NSL now has the X-Y-X construction, such as *roll-descend-roll*, to express simultaneity. This string can serve as a structural unit within a larger expression like *cat* [*roll descend roll*], or it can even be nested, as in *waddle* [*roll descend roll*] *waddle*. This construction never appeared in the gestures of the Spanish speakers and is also quite unlike any construction of spoken Spanish.

2.3. Creating a community

My hypothesis is that NSL differs from home sign because the existence of a community provides more opportunities to use signs and choose signs, so that although some get lost to the community, increasingly many gain power by being widely shared. An ''engine'' for this process is provided by the fact that, since knowledge of another language is possessed by some members of the community, they seek to translate this knowledge into the new medium (as is proven for the lexicon), and some of these attempts to capture a given property will become widespread.

Some have claimed that NSL arose ''from scratch'', suggesting that the community of deaf Nicaraguans who developed it lacked exposure to a developed language. But did deaf Nicaraguans ''reinvent language'' or ''invent a language''? I argue for the latter case and outline how knowledge of other languages may have complemented the language-readiness of the brain in the development of NSL (Arbib, 2009). The foundational document for this analysis is Laura Polich's book analyzing the changing social matrix that supported the emergence of NSL, *The Emergence of* *the Nicaraguan Deaf Community in Nicaragua: "With Sign Language You Can Learn So Much"* (Polich, 2005). We have seen that there was no evidence of sign language in use in Nicaragua in 1975 and that the turning point came when a vocational school was established that kept adolescents and young adults together ''at a time when they were carving out their identities and craving a peer group in which to try out and enact their abilities to be social actors'' (Polich, p.146). Note this key emphasis on the concepts of s*ocial actor, peer group* and *creating one's identity* which complement our earlier emphasis on brain mechanisms.

Polich charts the transition from a deaf person in Nicaragua having no peer group and thus having the passive social role of an outcast to a Deaf person who has a language which empowered him/her to be a true social actor within the Deaf community created by the enriched communication that came with the expanding capabilities of NSL.

Note that NSL did not develop in a vacuum, nor simply as a resulting of children pooling what their individual versions of home sign. Teachers played an important role in developing a community which provided social opportunities for the deaf children, going beyond the classroom. Ruthy Doran, a hearing person who taught the deaf children at the vocational school and also did much to create a social environment for them, told Polich:

> There wasn't a sign language [around 1980] . . . But we were able to understand one another. We would . . . use a lot of the gestures that everyone around here (in Nicaragua) uses and we had a set of some signs that the students made up. (They aren't used now.) We had special signs like for the days of the week that we had used with each other for years, and they had learned new signs . . . which they taught me. And when everything else failed, we would write words down, or else act it out. (p. 78–79).

Thus, in its early stages the community being formed included hearing people who spoke Spanish, while even those who could not speak had at least a small vocabulary of written Spanish. The talk of community must not blind us to the fact that each aspect of the language had to meet two conditions: (a) A specific individual or dyad used it for the first time (or the first time that they and others knew about), and (b) others, understanding its meaning, came to use it themselves.

It is true that, ''In the early 1980s, many deaf Nicaraguans knew no grammar,'' but false that, ''In the early 1980s, no deaf Nicaraguans knew grammar.'' The impressive achievement of creating this new language, NSL, did not have to rest solely on innate capabilities of the human brain (which distinguish us from other primates, for example) but could indeed exploit the cultural innovations of existing language communities.

Both individuals and institutions played a crucial role in the emergence of NSL and the Nicaraguan Deaf community (the capital ''D'' in deaf indicates that this was not simply a group of deaf people but a group united by the sharing of a sign language).

Many early members of the Deaf Association which emerged to support the development of this community credit Javier Gómez López with teaching all the others the version of NSL of that time. As Polich (2005) documents, his interest in sign language began in the late 1970s when he was given a sign language dictionary during an athletic trip to Costa Rica. He was dedicated to making sign language a functional communication system for himself and his friends, and to sharing this knowledge with other deaf Nicaraguans. He would seek out anyone who knew sign language or had access to a dictionary to improve his vocabulary, and would simultaneously teach what he learned to the others. Moreover, Javier was active in the workshops around 1990 in which Association members met in small groups to discuss which variations of signs should be adopted as ''standard''. Indeed, the second cohort of NSL signers did far more than spontaneously create new signs in isolation – they studied both Spanish dictionaries and ASL (American Sign Language) videos as a basis for devising new signs to expand NSL.

In 1991, the Royal Swedish Deaf Association began to finance the collection of entries for a professionally published sign language dictionary, eventually published in March 1997. But the Swedes did not teach Swedish Sign Language. Rather, they helped the Nicaraguans systematize what they had achieved in the early stages of creating NSL, and provided models of expressiveness of sign language which would have spurred the development of new modes of expression in NSL. Moreover, they provided a model for becoming first-rate members of a Deaf community rather than second-rate members of an oral society – though, alas, the job-market for the deaf in Nicaragua remains sorely restricted.

2.4. What took us so long?

It has been argued that the brain of *Homo sapiens* was biologically ready for language perhaps 200,000 years ago but, if increased complexity of artifacts like art and burial customs correlate with language of some subtlety, then human languages as we know them arose at most 50,000 to 90,000 years ago (Noble & Davidson, 1996). But if we accept the idea that it took humans with modern-like brains 100,000 years or more to invent language-as-we-know-it, we must ask what advantage the NSL community had that early humans lacked.

I have suggested that NSL differs from home sign because (a) the existence of a community provides more opportunities to use signs and choose signs, so that some get lost to the community while increasingly many gain power by being widely shared; and (b) that, since knowledge of another language is possessed by some members of the community, they seek to translate this knowledge into the new medium.

Early humans would share (a) but not (b) with the deaf Nicaraguans.

The very *idea* of language can have a catalytic effect. It seems almost inconceivable that the very idea of language had to be invented, but we know that writing was only invented some 5,000 years ago. We believe that no genetically based changes in the *Homo sapiens* brain were required to support literacy, but we have seen that literacy can change the brain as it develops. Moreover, many societies have lasted till modern times with no written form for their spoken language.

Yet, once one has the idea of writing, it is a straightforward exercise to invent a writing system. Around 1820, Sequoyah, a Cherokee who knew very little English and was illiterate invented a Cherokee syllabary, with 86 characters to represent the sounds of the Cherokee language, inspired solely by the idea of writing (Walker & Sarbaugh, 1993).

We can conclude, then, by summarizing the *extended mirror system hypothesis* as involving the following evolutionary innovations:

1. *A mirror system for grasping*: Mirror neurons can be recruited to recognize and encode an expanding set of novel actions. This stage is subdivided into (a) providing feedback for dexterous manual control; and (b) acting with other brain regions to make useful information available for interacting with others.
2. *Simple imitation* followed by *complex imitation*.
3. *Protosign*: Emerging as the ability to engage in pantomime evolves into the ability to make conventional gestures to disambiguate or supplant pantomime.
4. *Protospeech*: Early protosign provided the scaffolding for early protospeech after which both developed in an expanding spiral till protospeech became dominant.

I have suggested that this sufficed for the emergence of the language-ready brain, but that the emergence of ‘‘full-blown language’’ with syntax and compositional semantics was ‘‘post-biological’’. The discussion of the emergence of NSL suggests how such *cultural evolution* was as much devoted to the discovery of *ideas of what language could do* as it was to the discovery of particular grammatical rules and constructions. Indeed, once these ideas are available to a community, then the invention of novel lexical items and constructions can occur on a timescale of decades rather than millennia.

Appendix A. Continuing education

1. Mirror systems contain only mirror neurons.
   a. True
   b. False
2. Complex imitation and pantomime are among the intermediate stages that, according to the mirror system hypothesis, bridge from a mirror system for grasping to a mirror system that supports protolanguage. Evolution of mirror systems provides a complete explanation of the necessary changes.
   a. True
   b. False
3. A family with a deaf child and non-signing parents will create home sign as an ad hoc communication system.
   a. True
   b. False
4. The emergence of Nicaraguan Sign Language in NSL.
   a. depended on individuals
   b. depended on institutions
   c. both
   d. neither

5. Fractionation and the formation of novel constructions are important in both the phylogeny and ontogeny of language. The key difference between the two time scales is the brain structure of the infants involved.
   a. True
   b. False

References

Arbib, M. A. (2002). The mirror system, imitation, and the evolution of language. In K. Dautenhahn & C. L. Nehaniv (Eds.), *Imitation in animals and artifacts. Complex adaptive systems* (pp. 229–280). Cambridge, MA: The MIT Press.

Arbib, M. A. (2005a). From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics (with commentaries and author's response). *Behavioral and Brain Sciences, 28*, 105–167.

Arbib, M. A. (2005b). Interweaving protosign and protospeech: Further developments beyond the mirror. *Interaction Studies: Social Behavior and Communication in Biological and Artificial Systems, 6*, 145–171.

Arbib, M. A. (2006). A sentence is to speech as what is to action? *Cortex, 42*(4), 507–514.

Arbib, M. A. (2007). Premotor cortex and the mirror neuron hypothesis for the evolution of language. In Kaas, J. H., & Preuss, T. M. Eds. *Evolution of nervous systems: A comprehensive reference*. 4 (pp.417–422). Amsterdam: Elsevier Academic Press. Primates.

Arbib, M. A. (2008). Holophrasis and the protolanguage spectrum. *Interaction Studies: Social Behavior and Communication in Biological and Artificial Systems, 9*(1), 151–165.

Arbib, M. A. (2009). Invention and community in the emergence of language: A perspective from new sign languages. In S. M. Platek & T. K. Shackelford (Eds.), *Foundations in evolutionary cognitive neuroscience: Introduction to the discipline* (pp. 117–152). Cambridge: Cambridge University Press.

Arbib, M. A., Liebal, K., & Pika, S. (2008). Primate vocalization, ape gesture, and human language: An evolutionary framework. *Current Anthropology, 49*(6), 1053–1076.

Arbib, M. A., & Rizzolatti, G. (1997). Neural expectations: A possible evolutionary path from manual skills to language. *Communication and Cognition, 29*, 393–424.

Baker, M. (2001). *The atoms of language: The mind's hidden rules of grammar.* New York: Basic Books.

Buccino, G., Vogt, S., Ritzl, A., Fink, G., Zilles, K., Freund, H., et al. (2004). Neural circuits underlying imitation learning of hand actions: An event-related fMRI study. *Neuron, 42*, 323–333.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: The MIT Press.

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

Chomsky, N. (1992). A minimalist program for linguistic theory. In K. Hale & S. J. Keyser (Eds.), *The view from building 20: Essays in linguistics in honor of Sylvan Bromberger* (pp. 1–52). Cambridge, MA: The MIT Press.

Chomsky, N., Lasnik, H. (1993). The theory of principles and parameters. In: J. Jacobs, A.V. Stechow, W. Sternefeld, T. Vennemann (Eds.), Syntax: An international handbook of contemporary research Vol. 1 (pp. 506–556). Berlin: De Gruyter (Reprinted in The minimalist program, pp. 167–218, by N. Chomsky, 1995, Cambridge: MIT Press).

Croft, W. (2000). *Explaining language change: An evolutionary approach*. Harlow, UK: Longman.

Croft, W. (2001). *Radical construction grammar: Syntactic theory in typological perspective*. Oxford: Oxford University Press.

Deacon, T.W. (2007). The evolution of language systems in the human brain. In: J.H. Kaas, T. M. Preuss (Eds.), Evolution of nervous systems, A comprehensive reference. Vol. 4 - Primates (pp. 529–547). Amsterdam: Elsevier.

di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research, 91*(1), 176–180.

Dixon, R. M. W. (1997). *The rise and fall of languages*. Cambridge: Cambridge University Press.

Emmorey, K. (2002). *Language, cognition, and the brain: Insights from sign language research*. Mahwah, NJ: Lawrence Erlbaum and Associates.

Fillmore, C. J., Kay, P., & O'Connor, M. K. (1988). Regularity and idiomaticity in grammatical constructions: The case of let alone. *Language & Cognitive Processes, 64*, 501–538.

Goldberg, A. E. (2003). Constructions: A new theoretical approach to language. *Trends in Cognitive Science, 7*(5), 219–224.

Goldin-Meadow, S. (2003). *The resilience of language: What gesture creation in Deaf children can tell us about how all children learn language*. New York: Psychology Press.

Goldin-Meadow, S., & Feldman, H. (1975). The creation of a communication system: A study of deaf children of hearing parents. *Sign Language Studies, 8*, 225–234.

Grafton, S. T., Arbib, M. A., Fadiga, L., & Rizzolatti, G. (1996). Localization of grasp representations in humans by positron emission tomography. 2. Observation compared with imagination. *Experimental Brain Research, 112*(1), 103–111.

Hill, J. C. (1983). A computational model of language acquisition in the two-year-old. *Cognition and Brain Theory, 6*, 287–317.

Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology, 3*(3), e7910.1371/journal.pbio.0030079.

Kirby, S. (2000). Syntax without natural selection: How compositionality emerges from vocabulary in a population of learners. In C. Knight, M. Studdert-Kennedy, & J. R. Hurford (Eds.), *The evolutionary emergence of language*. Cambridge: Cambridge University Press.

Klima, E., & Bellugi, U. (1979). *The signs of language*. Cambridge, MA: Harvard University Press.

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

Noble, W., & Davidson, I. (1996). *Human evolution, language and mind: A psychological and archaeological inquiry.* Cambridge: Cambridge University Press.

Petersson, K. M., Reis, A., Askelof, S., Castro-Caldas, A., & Ingvar, M. (2000). Language processing modulated by literacy: a network analysis of verbal repetition in literate and illiterate subjects. *Journal of Cognitive Neuroscience, 12*(3), 364–382.

Poizner, H., Klima, E., & Bellugi, U. (1987). *What the hands reveal about the brain*. Cambridge, MA: MIT Press.

Polich, L. (2005). *The emergence of the deaf community in Nicaragua: "With sign language you can learn so much"*. Washington, DC: Gallaudet University Press.

Rizzolatti, G., & Arbib, M. A. (1998). Language within our grasp. *Trends in Neuroscience, 21*(5), 188–194.

Rizzolatti, G., & Sinigaglia, C. (2008). *Mirrors in the brain: How our minds share actions, emotions, and experience (F. Anderson, Trans.)*. Oxford: Oxford University Press.

Russo, T., & Volterra, V. (2005). Comment on "Children creating core properties of language: Evidence from an emerging sign language in Nicaragua". *Science, 309*, 56.

Sakata, H., Taira, M., Kusunoki, M., Murata, A., Tanaka, Y., & Tsutsui, K. (1998). Neural coding of 3D features of objects for hand action in the parietal cortex of the monkey. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences, 353*, 1363–1373.

Senghas, A., Kita, S., & Özyürek, A. (2004). Children creating core properties of language: Evidence from an emerging sign language in Nicaragua. *Science, 305*, 1779–1782.

Senghas, A., Özyürek, A., & Kita, K. (2005). Response to comment on "Children creating core properties of language: Evidence from an emerging sign language in Nicaragua". *Science, 309*, 56c.

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

Walker, W., & Sarbaugh, J. (1993). The early history of the Cherokee syllabary. *Ethnohistory, 40*(1), 70–94.

Wray, A. (2000). Holistic utterances in protolanguage: The link from primates to humans. In C. Knight, M. Studdert-Kennedy, & J. Hurford (Eds.), *The evolutionary emergence of language: Social function and the origins of linguistic form* (pp. 202–285). Cambridge: Cambridge University Press.