International Journal of Research in Medical and Basic Sciences, ISSN: 2455-2569
Vol.03 Issue-09, (September, 2017), ISSN: 2455-2569, Impact Factor: 4.457

The Evolution of Language: A Neurobiological Perspective

S Karthick[1*] and Sangita Barwa[2]

[1]Department of Humanities and Liberal Arts in Management, Indian Institute of Management Kozhikode, India.

[2]Department of Humanities and Social Sciences, National Institute of Technology, Rourkela, India.

Abstract

Language is the unique power bestowed upon human being to represent and share unbounded thoughts. Its evolution is one of the most interesting and significant evolutionary events which has occurred in the last 5–10 million years, and indeed during the entire history of life on earth.Language has a long evolutionary history and is closely related to the brain, but what makes the human brain uniquely adapted to language is unclear. The regions of the brain that are involved in language in humans have similar analogues in apes and monkeys, and yet they do not use language.Given its central role in human behavior, and in human culture, it is unsurprising that the origin of language has been a topic of myth and speculation since before the beginning of history. It is assumed to be arising from three distinct but interacting adaptive systems: biological evolution, cultural transmission and individual learning.A biological understanding of language would surely entail a full understanding of how brains generate, represent and manipulate concepts and such a broad understanding of cognitive neuroscience remains a distant hope today to understand neurobiology of language & language development some pessimistically suggest it is forever beyond the reach of the human mind.

Keywords: Language, Evolution, Neurobiological Perspective

Introduction

Language is the unique power bestowed upon human being to represent and share unbounded thoughts. It is critical to all human societies and has played pivotal role in the rise of human as if species in the last million years from peripheral and a minor member of the sub-Saharan African ecological community to the dominant species on the earth today.

The language evolution of human being is thus one of the most interesting and significant evolutionary events which has occurred in the last 5–10 million years, and indeed during the entire history of life on earth. Given its central role in human behavior, and in human culture, it is unsurprising that the origin of language has been a topic of myth and speculation since before the beginning of history. Since the 1960s, an increasing number of scholars with backgrounds in genetic, anthropology, speech science linguistics, neuroscience, and evolutionary biology and devoted themselves to understand various aspects of language evolution and language sciences.

The complexity of language evolution

The language of human is unique which is assumed to be arising from three distinct but interacting adaptive systems: biological evolution, cultural transmission and individual learning. (Fig. I). These are all adaptive systems in that these involve the transformation of information in such a way that it fits some objective functions. This is very obvious for the case of biological evolution: natural selection is the mechanism of adaptation for excellence. Variations in the transmitted genotype are selected for in such a way that the resulting phenotype is best fitted with the functions of reproduction and survival. Individual learning might be thought of as a processing of adaptation of the individual's knowledge. The knowledge of particular language persists over time only by virtue of it being repeatedly used to generate linguistic data, and this data being used as input to the learner – a type of cultural evolution termed iterated learning (Kirby and Hurford, 2002; Christiansen et al., 2002). In this sense, one can think of the adaptation of languages by himself to fit the needs of the language user, and more fundamentally, to the language learner.

When we discuss of language evolution in the broadest sense, one is referring to evolution on three different timescales the lifetime of an individual, a language and a species (Hurford, 1991; Wang, 1991). What is particularly interesting about language, and why its emergence on earth can be seen as a major transition in evolution is that there are intertwining among all three of these systems i.e. biological evolution, cultural transmission and individual leaning (Maynard and Szathmary, 1995). The structure of the learner is determined by the outcome of biological evolution. In the way, the pressures on linguistic transmission are determined in part by the learner's genetically given biases.

The final interaction among biological evolution, cultural transmission and individual learning is less obvious, but is the focus of much current thinking on language evolution. If there is some feature of language that must be acquired by every learner, and there is selection pressure on the reliable and rapid acquisition of that feature, then a learner who is born already knowing that feature will be at an advantage. This is the basic mechanism of genetic assimilation or the 'Baldwin Effect' whereby learned behaviors can become innate.

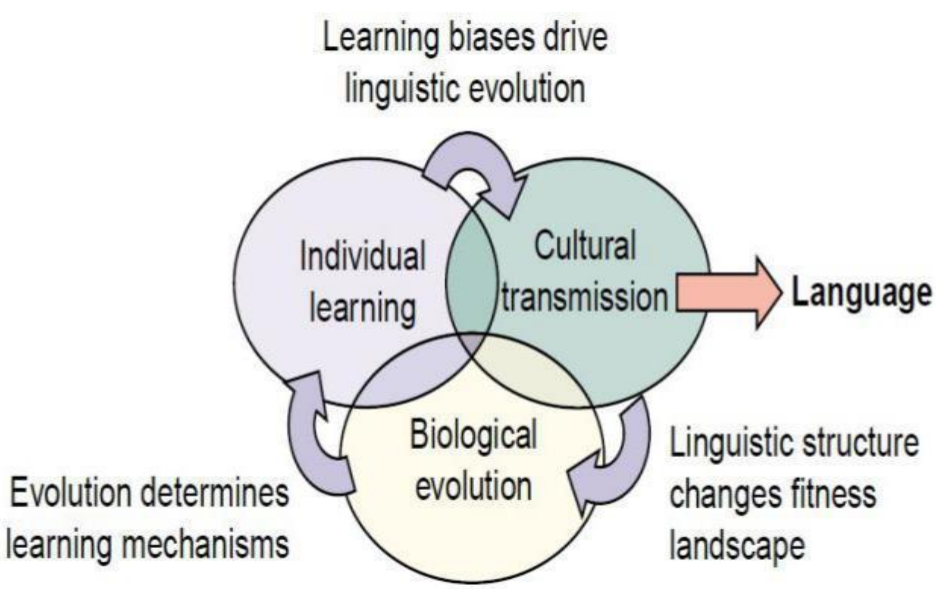

Fig. I (Adopted from Trends in Cognitive Science). Language arises from the inter working of three adaptive systems: individual learning, cultural transmission, and biological evolution. A key problem for an explanatory theory of language evolution will be understanding how these systems interact on three different timescales: the lifetime of the individual (tens of years), the language (thousands of years), and the species (hundreds of thousands of years).

It is possibly the strongest point of consensus among the researchers that to understand language evolution, it must be approached simultaneously from many disciplines (Christiansen et al., 2002; Hauser et al., 2002; Tomasello, 2002; Wray, 2002; Bickerton, 2003). As it needed to understand how language is structured, how does the brain of human works and what is it used for; how early language and modern language differ from one another and from other communication systems; in what ways the biology of hominids have changed; how we manage to acquire language during development; and how learning, culture and evolution interact. Hence, language evolution research must necessarily be cross-disciplinary in order to provide sufficient constraints on theorizing to make it a legitimate scientific inquiry. Researchers in the language evolution only cover parts of the relevant data, perhaps for the reason that it is nearly impossible to be a specialist in all the relevant fields. As a whole this field still appears to be moving in the direction of becoming more interdisciplinary. Collaborations among researchers in different fields with a stake in language evolution are likely to become increasingly more important (Rizzolatti and Arbib, 1998; Hauser et al., 2002,).

Language origin: speech or manual gesture?

Language evolution research is whether language originated from manual gestures or evolved exclusively in the vocal domain. It has been proposed on the other hand that vocal communication in apes is largely affective in nature and with least voluntary control, language is likely to have emerged from manual gestures rather than primate calls.In few versions of this account, the emergence of gestural language was predated by the evolution of a unique human ability for complex imitation.The successive change from a gestural to a primarily vocal language has been stated to be due to either increased tool use coming into conflict with the use of the hands for linguistic gestures or the 'recruitment' of vocalization through associations between gesture and sound (Arbib, 2002; Corballis, 2003).

The critics of the gestural theory of language origins on the other hand have argued that manual gestures suffer from two major disadvantages in comparison with spoken language: It requires direct line of sight and cannot be used at night (Dunbar, 2003). Many proposals instead have been directed to support the possible origin of language in the vocal domain. One of the key suggestion is that the basic structure of syllables derive from the succession of constrictions and openings of the mouth involved in chewing, sucking, and swallowing eventually evolving into phonetic gestures (MacNeilage, 1998, Studdert-Kennedy, 2000). It has been furthermore contended that this evolutionary process may subsequently have resulted in the major syntactic distinctions between noun-phrases and sentences (Carstairs-McCarthy, 2000).

Language evolution through computational modeling

The computational models are mostly process based theories of computational cognitive architecture. These models may be necessary for understanding a system as complex and diverse as language evolution. The area of agreement is the growing interest in using computational modeling to explore issues relevant for understanding the origin and evolution of language. Many researchers across a variety of different disciplines now either conduct language evolution simulations or refer to such work as evidence for particular theoretical perspectives. The modeling work has been used to inform high-level theories about biological adaptation for grammar (Pinker, 1994; Nowak and Komarova, 2001) or the exposure of the structure language through cultural transmission (Ragir, 2002; Deacon, 2003) but also at a more detailed level, as such of evolution of phonetic gesture systems (Browman and Goldstein, 2000) or a neural basis for grasping as a precondition language based on manual gesture (Arbib, 2002). Computational models are useful because these permit researchers to test specific theories about the mechanisms underlying the evolution of language. Given the number of different factors that may potentially influence language evolution, our intuitions about their complex interactions are often limited. It is exactly in these circumstances, when multiple processes have to be considered together, that modeling becomes a useful – and perhaps even necessary – The function of computational modeling in language evolution research can be divided up into three rough categories:

(1) Evaluation. Computational models are more as mathematical models, have the virtue that these enforce explicitness in the formulation of an explanation.

(2) Exploration. Computational simulations can be used (with caution) in the general ways to explore in which explanatory mechanisms or theoretical constructs interact. In this mode, simulations can help direct us to new theories.

(3) Exemplification. Lastly, computational simulations can be a valuable tool for demonstrating how an explanation works.

Computational modeling thus provides a powerful new tool for the study of language evolution and may suggest novel psychological experiments and so on and become more advance in terms of both psychological mechanisms and linguistic complexity (Christiansen et al., 2002).

Brain areas associated with speech and language during different stages of Development:

In most of the adults the left hemisphere of the brain is dominant for language function - lateralized. When it comes to language, the left hemisphere is primarily characterized by a capacity to analyze and sequence linguistic information, while the right hemisphere is known for its holistic perception. Right-hemispheric damage often results in problems with social communication, also referred to as pragmatics. Locke (1997) argued, in his theory of language development, that the right hemisphere sub-serves language development during the first two phases, when the child is oriented towards interaction with the caregiver and the collecting of whole utterances. The left hemisphere gradually takes command, as the child starts to analyze the different elements of language and the rules for their combinations. In this way, language lateralization develops. The fMRI studies suggest that early language processing is predominantly bilateral (Dick et al., 2008). The occurrence of lateralization is taken about one year earlier in girls than in boys, which corresponds with the earlier onset of puberty in girls. In children with brain damage, cognitive functions can be shifted to other brain regions, as for language, to the non-dominant and most often the right hemisphere. The possibility of brain repair, called plasticity, is more likely to occur before lateralization is completed (Carlsson, 1994).

The areas of the brain mainly involved in language processing for receptive language are Wernick's area located in the posterior part of the temporal lobe and adjoining parts of the parietal lobe, adjacent to the auditory cortex, and for expressive language are Broca's are located in the lower posterior part of the frontal lobe. The structures those which are integrated in a network and form a language implementer system. In the childhood, these areas gradually increase in thickness, corresponding to increased grey matter (Dick et al., 2008). This results in an asymmetry between the hemispheres, where the left hemisphere is larger than the right, particularly in the area of the plenumtemporal. Reversed or absent asymmetry has been seen in studies of children with language disorder (Dick et al., 2008). The area of Rolando, located in the precentral gyrus at the Rolandic fissure, which is the primary motor area involved in the motor control of the speech act, while the secondary motor area for initiating speech motor activity adjacent to it overlaps partly with Broca's area . The phonological encoding is considered to be localized in the perisylvian region, near the Sylvian fissure, of the dominant hemisphere, while articulatory retrieval is located in Broca's area (Baddeley et al., 1998). Hickok and Poeppel (2007) proposed a dual-stream model of speech processing involving auditory fields of the superior temporal gyrus bilaterally. A ventral stream processes speech signals for comprehension, projects towards the inferior posterior temporal cortex and is largely bilateral.

A novel model of the functional neuro-anatomy of language

Language is a core intellectual ability of humans that is supported by a complex neuro-cognitive mechanism. The classic model for the functional neuroanatomy of language suggests the presence of two major centers: one in the auditory cortex, which houses sound-based representation of words, and the other in the motor cortex, which houses motor-based representations of articulatory gestures required to produce word.

Speech perceptions studies have verified that bilateral superior temporal gyri (STG), which are bilateral Brodmann's areas 22, 41, 42, serve as auditory input centers, and bilateral occipital cortices (bilateral Brodmann's areas 17–19) serve as visual input centers for language (Buchman et al., 1986). The left supratemporal plane (pSTP) (the anterior part of left Brodmann's area 40) has been verified as a site for phonological encoding in word production, whereas the left angular gyrus (left Brodmann's area 39) has been verified as a site for memory of visual word forms (Levelt et al., 1998; Hickok et al., 1999; Price, 2000). These two regions have been reported to interface with widely distributed conceptual knowledge systems in cortex located primarily at the junction of the left temporal, occipital and parietal lobes that Wernicke's area (including parts of left Brodmann's areas 22, 37, 39, 40). Damage to Wernicke's area is associated with impaired comprehension but spared repetition (Damasio, 1992). The sound or visual-based system interfaces not only with the conceptual knowledge system, but also with frontal motor systems (Broca's area: Brodmann's areas 44, 45) via an auditory–motor interface system in the inferior parietal lobe. This circuit is the primary substrate for phonological and semantic working memory and probably plays a role in volitional speech production (Awh et al., 1996). In this model, the auditory cortex, supramarginal gyrus circuit, replaces the model for a direct sensory motor link via the arcuate fasciculus. Connectivity studies in nonhuman primates are consistent with the notion that there is not a direct connection between auditory cortex and the ventral posterior frontal lobe and with the claim that the parietal lobe is an important interface between these regions (Aboitiz and Garcia, 1997; Romanski et al., 1999). According to Poeppel and Hickok (2004), these regions are integrated into two streams: dorsal and ventral. The proposed ventral stream projects ventrolaterally towards the inferior posterior temporal lobe to serve as an interphase between sounds and concepts, whereas the dorsal stream projects to regions of the temporal parietal boundary [posterior aspects of the Sylvian fissure (Brodmann's area 43) and then into the frontal lobe (i.e. Broca's area). Structurally, Brodmann's areas 44 and 45 (inferior frontal cortex) are normally left lateralized. Hickok also proposed that there is a link between frontal lobe and the large-scale distributed network for conceptual representation (such as Brodmann's areas 9, 10, 23, 24, 28). Thus, the whole circuit of language processing is a highly distributed network.

Do Sign and Speech Engage the Same Regions - As brain functions?

The regions of the brain may function differently depending on a variety of factors even though brains look the same. There are many ways to rule out whether signed language makes use of identical brain systems to those used for spoken language, or whether these are different. In the first place, people who have access to both speech and sign can be investigated. Language either sign or spoken can be directly compared in these bilinguals. Soderfeldt et al., (1994; 1997) studies applied PET contrasted Sign Language of Swedish (SSL) and audiovisual spoken Swedish in hearing native signers.The first study found no significant differences between the two language inputs, whereas the latter study, using more sensitive image analysis and a more complex design found differences as a function of language modality. Auditory cortex in superior temporal lobe is activated more by spoken language, on the other hand parts of visual cortex (posterior and inferior temporal, and occipital regions) are activated more by signed language. But these may be a special population: hearing people who have had extensive experience not only with sign language of Swedish (SS but also with written and spoken Swedish. These findings only perhaps apply to hearing native signers while deaf native signers may show differences from the spoken language pattern. These studies have been noted that lifetime events, such as exposure to different types of language and whether one or several languages are mastered, can affect patterns of localization in hearing people when other languages than signed languages are considered.

The nature of neural plasticity in language learning

The term “neural plasticity” applies to processes operative at many levels of our neurocognitive system, an intrinsic property that persists throughout our lives (DeFelipe, 2006; Mahncke et al., 2006). Some changes in the brain are known to be genetically determined and “experience independent “whereas others are either “experience expectant” or “experience-dependent”, which require the reception of certain input from the external environment (Greenough et al., 1999). In language research, developmental data in normal and injured brains suggest that the neural organization for language is neither predetermined or strictly domain specific (Bates, 1999). Training studies indicate that language learning is not an irreversible age-bound event (Kuhl et al., 2001; Saffran, 2003).

Learning-induced enhancement in neural sensitivity has been consistently supported (Tremblay et al., 1997; Winkler et al., 1999; Menning et al., 2002), the construct of neural efficiency as a neural signature of learning has been controversial. Intuitively, higher ability should translate into more efficient use of brain resources. A variety of adult fMRI studies on learning effects have reported more focal brain activation (Zhang et al., 2005).

The complexity of neural plasticity can be exacerbated by the fact that the effects of perceptual learning are not limited to the perceptual domain. For instance, adult studies showed great benefits from audio-visual training (Zhang et al., 2001) and long-lasting effects of transfer from perception to production (Callan et al., 2003). Infant MEG data from new borns, 6-montholds, and 12-month-olds suggested an early basis for the perceptual-motor link for native speech in the left hemisphere (Imada et al., 2006).Given the fact that speech perception involves brain regions for acoustic–phonetic as well as auditory–articulatory mappings, learning induced plasticity can be associated with decreases, increases and shifts in brain activation to facilitate the behavioral improvement. Reallocation in hemispheric resources (relative dominance of left and right hemispheres, for instance), recruitment of additional brain regions, strength anatomical (increased white-matter density) and functional connections (increased coherence among regions) in neural pathways, and increases or decreases in brain activation can all take place in the course of phonetic learning (Zhang et al., 2001; Golestani et al., 2002; Callan et al., 2003; Wang et al., 2003; Golestani and Zatorre, 2004).

Neural plasticity in speech acquisition and learning

The basic goal of neuroimaging research in language is to link mind and brain for a better understanding of the neural circuits that support language(s) and the relationship between the changes in behavior and the changes in the brain. Research findings suggest that the implicit learning mechanisms that operate on the probabilistic transitions and statistical distributions of the language input are fundamental to language acquisition early in life, second language acquisition and artificial grammar learning (Kuhl et al., 2001; Zhang et al., 2000; Saffran, 2003; Lieberman et al., 2004; Mueller et al., 2005; McNealy et al., 2006).

Language development and effects of age

One of the significant query about the nature of language acquisition is the extent to how does age constrain its outcome, otherwise known as a sensitive or critical period (CP) for language. The notion that languages should be learned in childhood to be successfully learned has been held widely by educators for over a century (Colombo, 1982).The specific neurolinguistics hypothesis that the outcome of language acquisition is tied to brain development has a more recent history. It was proposed by Penfield (1959) who proposed first that language acquisition was related to brain plasticity. Lenneberg (1967) later assembled and arranged a variety of evidence linking the trajectory of language acquisition to brain growth curves in early development.

A possible investigation of critical period (CP) for language requires to identifying situations where the developmental onset of language acquisition varies naturally. Possibility of effects on the outcome of language acquisition associated with learning languages at various ages can be measured. The most common test of the Critical Period supposition has been spoken, second language (L2) learning because age of language 2 (L2) learning varies widely in the hearing population (Birdsong, 1999). A less common situation is the signed language acquisition of individuals who are born deaf (Mayberry, 1994; 2002).

A negative correlation of age of spoken Language 2 acquisition and language 2 grammatical outcome and/or significant differences in grammatical performance between native and non-native learners has been found. These effects were found using a variety of language measures including: sentence shadowing (Oyama, 1978), assessment of written transcripts of spoken interviews (Patkowski, 1980), and assessment of tape-recorded interviews (White and Genesee, 1996). Other studies reported effects for age of acquisition on L2 grammatical outcome using judgement of grammatical and ungrammatical sentences presented in either auditory or written forms (Newport, 1991; Birdsong, 1992; White and Genesee, 1996 Flege et al., 1999; Birdsong and Molis, 2001). In most studies the L2 tested was English; French was the L2 in one study (Birdsong, 1992). The first languages (L1) were Chinese, French, Italian, Korean, Spanish, or unspecified

Language development- Is it truly biological or cultural?

To understand the origin and evolution of language is the basis to understand humans. The relationship between the biological evolution of language ability and the cultural evolution of language itself is extremely complex and covered in controversy because these mechanisms correlate with each other despite the difference in their time scales (Mesoudi et al., 2011). The concept of co-evolution between language and brain, in which language adapts to the brain and the brain adapts to language, is considered important in integrating biological and cultural evolution of humans (Deacon, 1992). On the other hand, cultural linguistic change is often assumed to be much faster than biological change. Biological as well cultural theories have been put forwarded to justify these view points as follows:

Conclusion

Understanding the evolution of human language might be the hardest problem in science" (Christiansen and Kirby, 2003).Some of the sceptics have credibly concluded that scientists might spend their time more constructively on more tractable topics (Lewontin, 1998). Language has not been fossilized, and we lack time machines, so all of our data are indirect, and often several steps removed from the direct, conclusive evidence we might desire. But this is true of many problems in science that are considered legitimate pursuits, from the Big Bang to the origin of life, so this difficulty is not insuperable. A biological understanding of language would surely entail a full understanding of how brains generate, represent and manipulate concepts and such a broad understanding of cognitive neuroscience remains a distant hope today to understand neurobiology of language & language development some pessimistically suggest it is forever beyond the reach of the human mind(McGinn, 1991).

References

Aboitiz, F., & Garcıa, R. (1997). The evolutionary origin of the language areas in the human brain. A neuroanatomical perspective. *Brain Research Reviews, 25*(3), 381-396.

Arbib, M. A. (2002). fO The Mirror System, Imitation, and the Evolution of Language. *Imitation in animals and artifacts*, 229.

Awh, E., Jonides, J., Smith, E. E., Schumacher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science*, 25-31.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological review, 105*(1), 158.

Bates, E. (1999). Plasticity, localization and language development. The changing nervous system: Neurobehavioural consequences of early brain disorders, 214-253.

Bickerton, D. (2003). Symbol and structure: a comprehensive framework for language evolution. *Studies in the Evolution of Language, 3,* 77-93.

Birdsong, D. (1992). Ultimate attainment in second language acquisition. *Language,* 706-55.

Birdsong, D. (Ed.). (1999). *Second language acquisition and the critical period hypothesis.* Routledge.

Birdsong, D., & Molis, M. (2001). On the evidence for maturational constraints in second-language acquisition. *Journal of Memory and language, 44*(2), 235-49.

Browman, C. P., & Goldstein, L. (2000). Competing constraints on intergestural coordination and self-organization of phonological structures. Les Cahiers de l'ICP. *Bulletin de la communication parlée,* (5), 25-34.

Buchman, A. S., Garron, D. C., Trost-Cardamone, J. E., Wichter, M. D., & Schwartz, M. (1986). Word deafness: one hundred years later. *Journal of Neurology, Neurosurgery & Psychiatry, 49*(5), 489-499.

Callan, D. E., Tajima, K., Callan, A. M., Kubo, R., Masaki, S., & Akahane-Yamada, R. (2003). Learning-induced neural plasticity associated with improved identification performance after training of a difficult second-language phonetic contrast. *Neuroimage, 19*(1), 113-124.

Carlsson, G., Uvebrant, P., Hugdahl, K., Arvidsson, J., Wiklund, L. M., & Wendt, L. (1994). Verbal and non-verbal function of children with right-versus left-hemiplegic cerebral palsy of pre-and perinatal origin. *Developmental Medicine & Child Neurology, 36*(6), 503-512.

Carstairs-McCarthy, A. (2000). *The distinction between sentences and noun phrases: an impediment to language evolution?* na.

Christiansen, M. H., & Kirby, S. (2003). Language evolution: Consensus and controversies. *Trends in cognitive sciences, 7*(7), 300-07.

Christiansen, M. H., Dale, R. A., Ellefson, M. R., & Conway, C. M. (2002). The role of sequential learning in language evolution: Computational and experimental studies. In *Simulating the evolution of language* (pp. 165-187). Springer London.

Colombo, J. (1982). The critical period concept: research, methodology, and theoretical issues. *Psychological bulletin, 91*(2), 260.

Corballis, M. C. (2003). From mouth to hand: gesture, speech, and the evolution of right-handedness. *Behavioral and Brain Sciences, 26*(02), 199-208.

Damasio, A. R., & Damasio, H. (1992). Brain and language. *Scientific American, 267*(3), 88-109.

Deacon, T. W. (1992). Cortical connections of the inferior arcuate sulcus cortex in the macaque brain. *Brain research, 573*(1), 8-26.

Deacon, T. W. (2003). Multilevel selection in a complex adaptive system: the problem of language origins. *Evolution and learning: The Baldwin effect reconsidered,* 81-106.

DeFelipe, J. (2006). Brain plasticity and mental processes: Cajal again. *Nature reviews neuroscience, 7*(10), 811-817.

Dick, F., Richardson, F., & Saccuman, M. C. (2008). Using magnetic resonance imaging to investigate developmental language disorders. *Understanding Developmental Language Disorders. From Theory to Practice,* 53-66.

Dunbar, R. I. (2003). The social brain: mind, language, and society in evolutionary perspective. *Annual Review of Anthropology,* 163-181.

Flege, J. E., Yeni-Komshian, G. H., & Liu, S. (1999). Age constraints on second-language acquisition. *Journal of memory and language, 41*(1), 78-104.

Golestani, N., & Zatorre, R. J. (2004). Learning new sounds of speech: reallocation of neural substrates. *Neuroimage, 21*(2), 494-506.

Golestani, N., Paus, T., & Zatorre, R. J. (2002). Anatomical correlates of learning novel speech sounds. *Neuron, 35*(5), 997-1010.

Greenough, W. T., Black, J. E., Klintsova, A., Bates, K. E., & Weiler, I. J. (1999). Experience and plasticity in brain structure: Possible implications of basic research findings for developmental disorders. *The changing nervous system: Neurobehavioral consequences of early brain disorders*, 51-70.

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve? *Science, 298*(5598), 1569-1579.

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*(5), 393-402.

Hickok, G., Wilson, M., Clark, K., Klima, E. S., Kritchevsky, M., & Bellugi, U. (1999). Discourse deficits following right hemisphere damage in deaf signers. *Brain and language, 66*(2), 233-248.

Hurford, J. R. (1991). The evolution of the critical period for language acquisition. *Cognition, 40*(3), 159-201.

Imada, T., Zhang, Y., Cheour, M., Taulu, S., Ahonen, A., & Kuhl, P. K. (2006). Infant speech perception activates Broca's area: a developmental magnetoencephalography study. *Neuroreport, 17*(10), 957-962.

Kirby, S., & Hurford, J. R. (2002). The emergence of linguistic structure: An overview of the iterated learning model. In *Simulating the evolution of language* (pp. 121-147). Springer London.

Kuhl, P. K., Tsao, F. M., Liu, H. M., Zhang, Y., & Boer, B. (2001). Language/culture/mind/brain. *Annals of the New York Academy of Sciences, 935*(1), 136-174.

Lenneberg, E. H., Chomsky, N., & Marx, O. (1967). *Biological foundations of language (Vol. 68)*. New York: Wiley.

Levelt, W. J., Praamstra, P., Meyer, A. S., Helenius, P., & Salmelin, R. (1998). An MEG study of picture naming. *Journal of cognitive neuroscience, 10*(5), 553-567.

Lewontin, R. C. (1998). The evolution of cognition: Questions we will never answer. *An invitation to cognitive science, 4,* 107-32.

Lieberman, J. A., Lehman, A. F., Dixon, L. B., McGlashan, T. H., Miller, A. L., Perkins, D. O., & Cook, I. (2004). Practice guideline for the treatment of partients with schizophrenia. *American Journal of psychiatry, 161*(2 SUPPL.).

Locke, J. L. (1997). A theory of neurolinguistic development. *Brain and language, 58*(2), 265-326.

MacNeilage, P. F. (1998). The frame/content theory of evolution of speech production. *Behavioral and brain sciences, 21*(04), 499-511.

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. A., & Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences, 103*(33), 12523-28.

Mayberry, R. I. (1994). Theorizing about the relation between American Sign Language and reading. *Language acquisition by eye,* 221-59.

Mayberry, R. I., Lock, E., & Kazmi, H. (2002). Development: Linguistic ability and early language exposure. *Nature, 417*(6884), 38-38.

McGinn, M. (1991). Sense and certainty.

McNealy, K., Mazziotta, J. C., & Dapretto, M. (2006). Cracking the language code: neural mechanisms underlying speech parsing. *Journal of Neuroscience, 26*(29), 7629-39.

Menning, H., Imaizumi, S., Zwitserlood, P., & Pantev, C. (2002). Plasticity of the human auditory cortex induced by discrimination learning of non-native, mora-timed contrasts of the Japanese language. *Learning & Memory, 9*(5), 253-267.

Mesoudi, A., McElligott, A. G., & Adger, D. (2011). Introduction; Integrating Genetic and Cultural Evolutionary Approaches to Language. *Human biology, 83*(2), 141-51.

Mueller, J. L., Hahne, A., Fujii, Y., & Friederici, A. D. (2005). Native and nonnative speakers' processing of a miniature version of Japanese as revealed by ERPs. *Journal of Cognitive Neuroscience, 17*(8), 1229-44.

Newport, E. (1991). Contrasting conceptions of the critical period for language. *The epigenesis of mind: Essays on biology and cognition,* 111-30.

Nowak, M. A., & Komarova, N. L. (2001). Towards an evolutionary theory of language. *Trends in cognitive sciences, 5*(7), 288-295.

Oyama, S. (1978). The sensitive period and comprehension of speech. *NABE journal, 3*(1), 25-40.

Patkowski, M. S. (1980). The sensitive period for the acquisition of syntax in a second language. *Language learning, 30*(2), 449-468.

Penfield, W. (1959). The interpretive cortex. *Science, 129*(3365), 1719-1725.

Pinker, S. (1994). The Language Instinct. The New Science of Language and Mind. London (Penguin) 1994.

Poeppel, D., & Hickok, G. (2004). Towards a new functional anatomy of language. *Cognition, 92*(1), 1-12.

Price, C. J. (2000). The anatomy of language: contributions from functional neuroimaging. *The Journal of Anatomy, 197*(3), 335-359.

Ragir, S. (2002). Constraints on communities with indigenous sign languages: clues to the dynamics of language origins. *The transition to language,* 272-296.

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

Romanski, L. M., Bates, J. F., & Goldman-Rakic, P. S. (1999). Auditory belt and parabelt projections to the prefrontal cortex in the rhesus monkey.*Journal of Comparative Neurology, 403*(2), 141-157.

Saffran, J. R. (2003). Statistical language learning mechanisms and constraints. *Current directions in psychological science, 12*(4), 110-114.

Soderfeldt, B., RoNNBERG, J. E. R. K. E. R., & Risberg, J. (1994). Regional cerebral blood flow in sign language users. *Brain and language, 46*(1), 59-68.

Studdert-Kennedy, M. (2000). *Evolutionary implications of the particulate principle: Imitation and the dissociation of phonetic form from semantic function.* na.

Szathmáry, E., & Smith, J. M. (1995). The major evolutionary transitions. *Nature, 374*(6519), 227-232.

Tomasello, M., & Zuberbühler, K. (2002). Primate vocal and gestural communication. *The cognitive animal: empirical and theoretical perspectives on animal cognition. MIT Press, Cambridge,* 293-29.

Tremblay, K., Kraus, N., Carrell, T. D., & McGee, T. (1997). Central auditory system plasticity: generalization to novel stimuli following listening training.*The Journal of the Acoustical Society of America, 102*(6), 3762-3773.

Wang, W. S. Y (1991). Modelling endangered languages: The effects of bilingualism and social structure. *Lingua*, *118*(1), 19-45.

Wang, Y., Sereno, J. A., Jongman, A., & Hirsch, J. (2003). fMRI evidence for cortical modification during learning of Mandarin lexical tone. *Journal of cognitive neuroscience, 15*(7), 1019-27.

White, L., & Genesee, F. (1996). How native is near-native? The issue of ultimate attainment in adult second language acquisition. *Second language research, 12*(3), 233-65.

Winkler, I., Kujala, T., Tiitinen, H., Sivonen, P., Alku, P., Lehtokoski, A.,& Näätänen, R. (1999). Brain responses reveal the learning of foreign language phonemes. *Psychophysiology, 36*(5), 638-642.

Wray, A. (2002). Transition to Language.

Zhang, Y., Kuhl, P. K., Imada, T., Kotani, M. & Pruitt, J. (2001). Brain plasticity in behavioral and neuromagnetic measures: A perceptual training study. *Journal of the Acoustical Society of America, 110*, 2687.

Zhang, Y., Tan, Y. W., Stormer, H. L., & Kim, P. (2005). Experimental observation of quantum Hall effect and Berry's phase in graphene. *arXiv preprint cond-mat*/0509355.

Zhang, Z., Schwartz, S., Wagner, L., & Miller, W. (2000). A greedy algorithm for aligning DNA sequences. *Journal of Computational biology, 7*(1-2), 203-214.

****