What Genes and Brain Can Tell Us of How Symbolic Cognition Appeared in the Human Mind

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Abstract

In this article we provide a brief overview of some of the forefront research topics in human language evolution. We begin by briefly reviewing the bio-evolutionary framework usage in linguistics, then analyze central theoretical premises with regard to language organization in the brain and examine modern understanding of the importance of the specific brain structural features such as cerebral asymmetry and mirror systems for language evolution. We further discuss the contribution of some recent findings in genetics and anthropology to the field of bio-evolutionary linguistics and conclude by highlighting the importance of collaborative efforts of various scientific fields for understanding an accurate picture of such an interdisciplinary subject as language evolution.

Keywords: language origin and evolution, genetic basis for cognition and communication, cerebral mechanisms for higher functions, symbolic cognition

Darwin in his Origin of Species … [1; p. 187] writes: "... not one author posed the question as to why in some animals the cognitive capabilities are developed more than in others, whereas such development should have been useful for all? Why monkeys did not acquire human intellectual capabilities? This can be ascribed to various reasons, but since all of them are assumptive and their relative probability cannot be evaluated, it is useless to dwell upon this".

The problem of emergence of language in human evolution, as well as its cognitive foundation, is extremely complex and truly interdisciplinary in nature. Consequently, its successful solution requires integrated approaches and collaborative efforts of various fields, such as linguistics, psychology, genetics, physiology, etc. In this paper we provide an overview of several forefront topics of research at the confluence of the language evolution problem. Particularly, the paper is focusing on current views on genetic basis and cerebral mechanisms of the human language, its specificity and the difference with communication systems of other animals.

Various points of view on cerebral basis for cognitive and linguistic competence in respect to human evolutionary history are considered in the paper: nativism vs. connectionism, modular vs. network neurophysiologic organization of language and cognition, the idea of a macro-mutation vs. a series of micro-mutations that have resulted in the appearance of human language and cognition and consecutively given rise to quick cultural development.

As distinct from biology, **evolutionary ideas in linguistics** were not well recognized until recently. Despite earlier attempts to apply evolutionary approach to study of languages been taken by such prominent linguists as Sapir (1921) and Jespersen (1964), they were not initially taken seriously. This is because in the 20th century, through the influence of Saussure (1916), Jakobson (1966), and others up to Chomsky, language came to be viewed as a static system with a set of rules for the combination and substitution of elements, regardless of how it may have evolved from protolanguages to modern languages. Thus, the central idea in the study of language from an evolutionary perspective – that human languages evolve and become more effective –is traditionally quite paradoxical within linguistics, although it is generally accepted in biology.

Nevertheless, since the beginning of comparative linguistics and throughout its subsequent extensive development in the 20th century, there has been much discussion on the issue of language typology – comparing both related and widely separated languages, their possibly shared features and changes through time. Studies on the reconstruction of protolanguages are progressing rapidly (cf. Gamkrelidze 1985). Some general patterns of language evolution can be clearly seen in the family of Indo-European languages, possibly because these languages are best studied and can be traced back for the longest period of time (6-7 thousand years). Regularities revealed in Indo-European same languages have turned out to be applicable to the evolution of other language groups as well: Hamito-Semitic, Altaic, Uralic, and others. Thus, there appears to be regularities of evolution which are widely shared among different languages, and which can be traced at different layers, from that of phonology up to the sentence level.

It is important to bear in mind that these regularities are expressed differently, according to the type of language being considered. For example, in tone languages changes can take place almost only in tones. In languages of other phonological types changes may occur in the segmental sounds or phonemes. Furthermore, linguistic features are 'scattered' over different languages and are not necessarily present in each of them.

The contribution of paleo-anthropological research to the investigation of language evolution is well-acknowledged. Most relevant for the purposes of this paper are studies that further support the possibility of establishing a relationship between linguistic typology or differentiation and evolutionary affinities (Wind et al. 1992; Wallace 1994; Cavalli-Sforca et al. 1994; Read, 2008; Sia et al.2013). Demonstrating the congruence of genetic and linguistic evolution, Cavalli-Storza et al. conclude that linguistic and genetic evolution are closely related and that associations between linguistic families and the genetic history of humans is far from random. Reformulating Darwin's prediction (ch. 14 in 'Origin of Species', 1872) that information on the genealogical arrangement of man would enable to classify languages currently spoken., they indicate that when general principles of correlation between the genetic tree and linguistic families and super-families are established, predictions could be made on the time course – and even locations – of the origins of linguistic families.

A growing interest of researchers using a bio-evolutionary framework is focused on the mechanisms underlying the complexity of human behavior and language evolution, and their specific features (Hauser et al.2002; Dahl 2002; Cartmill et al.2014). The commonly outlined features are graduality, structural differentiation, and adaptivity. Mayr stresses that 'the evolutionary changes that result from adaptive shifts…are followed secondarily by a change in structure', and that 'during a succession of functions a structure always passes through a stage when it can simultaneously perform both jobs' (Mayr 1976, p. 106). Givón formulates six general principles that in his view control both language and biological evolution (Givon 2009): graduality of change; adaptive-selection motivation; functional change and ambiguity before structural change and specialization; terminal addition of new structures to older ones; local causation with global consequences, and uni-directionality of change. In recent years, attempts have been made to discuss language development in terms of processes recognized in biological evolution, such as neoteny, recapitulation, language hybridization, mono- and polygenesis, etc

It is not for the decades, if not for the century, that it is discussed as to **by what means the language is organized in the brain**. Neuroscientists discuss several important issues: how the brain activity occurs in general — in each of its parts and in the neuronal network as a whole; how the activity of neuronal assemblies is redistributed; how and why new functional connections are formed; how this is affected by information coming from outside and by genetic factors underlying the human language competence. Linguists are increasingly involved in such discussions and make attempts, using theoretical investigations and specially designed experiments inside their science, as well as the data obtained by neurosciences, to reveal structure of the human language or, to be more precise, its universal, basic properties that distinguish it from all known communicative systems and at the same time are characteristic of all national languages. As a result, both neurophysiologists and linguists hope to describe the most complex language facts in terms of neuronal activity (in a broad understanding), in other words, to relate the language processes to the physiological ones occurring in the brain.

It is evident that the 'realization' of human language is achieved through a combination of articulation, audition, and mental processing (Allott 2001). Therefore, it is expected to see evidence of evolutionary changes in peripheral–articulatory, auditory, and integrative systems of the brain. The latter, however, are a subject of constant controversy compared to the former two. While behaviorists and some artificial intelligence researchers treat the brain as a general purpose processor, Chomsky's followers describe it as a bundle of highly specialized 'instincts'('universal grammar' among them) designed by evolution to learn certain things (Donald 1993; Sia et al. 2013). Discussions over this dichotomy are never ending.

One of the key questions is the problem of independent or reciprocal evolution of human linguistic and cognitive abilities. No specialists object the statement that brain provides the higher psychological and especially language functions to perform some mathematic operations. It is obvious that brain deals, on the one hand, with some lists formed in the process of natural and specialized learning and, on the other hand, with sets of various rules, the most universal part of which possibly being innate. By these rules, specific algorithms are meant, which provide only language procedures. In this regard, serious and often non-compromise discussions take place on the issue of whether the human language capability is a function of neuro-physiology or is even anatomically separated from other cognitive functions.

On the point of probability of brain organization complying with the principle of modularity there are intensively studied manifestations of postulated single neuronal mechanisms in languages of different types. It is common knowledge that representatives of generative linguistics insist on the presence of the so-called human "language organ", or a language acquisition device; it is only with its help that formation of algorithms in the language ontogenesis is possible. Among generativists adhering to the position of innate language mechanisms there is no single opinion about the origin of these mechanisms: Chomsky and Bickerton consider the "grammatical explosion" a result of macro-mutation, whereas Pinker — a result of natural selection of small mutations, i.e., of a much slower process.

Adepts of neo-behaviorism in psychology and connectionist direction in linguistics consider learning the main factor of absorption and adequate functioning of language procedures. According to behaviorism, the child is known to be *tabula rasa* that is gradually filled with various schemes of behavior, including the verbal one, by the "stimulus-reaction" principle, which for understandable reason is by no means consistent with the idea of innate symbolic rules.

The organism's external behavior is determined by a complex mechanism formed by competent structures, whose functions depend on experience in a given environment. Even Chomsky himself, the most convinced adept of primacy of genetics for language, emphasizes the difference between competence (some innate knowledge of brain about language in general, not a particular language) and successful verbal activity — Competence vs. Performance. In theories of learning, by competence the sum of knowledge is understood, which determines limits of success of task performance. If the competence, including the genetic one, is equal to zero, no incentives are able to cause performance of a given task.

The most important characteristics of the human language are its productivity (a possibility to create and understand absolutely new messages) and its hierarchic and even digital structure, i.e., the existence of levels — phonological, morphological, syntactical, and discourse. All this is permeated with the semantic axis. Such structural specificity is commonly accepted as a unique peculiarity of a given system. Therefore, the search for both rules describing the proper linguistic phenomena and for genetic base of language competence are based first of all on the analysis of these characteristics.

There is no doubt that the hierarchy of syntax is necessary for such a complex, self-organizing system as language, in the same way as the hierarchy and dynamics of neuronal patterns are necessary for such a most complex system as the brain. In this context, these vectors of natural selection are quite correlated. The adept of the idea of macro-mutation and, therefore, actually an anti-Darwinist Chomsky and his opponents Pinker and Bloom who insist on the natural selection that has led to the formation of the language capacity , in our opinion, could have been conciliated in the same way as Hebb's model. It gives a possibility of conciliation of the modular and holistic paradigms. Is it worth adhering to centrism of syntax, if we live in the world of concepts? Is it worth keeping, as before, in captivity of the binary way of thinking, with necessity of choosing between polar viewpoints: mutation or selection, modularity or neuronal network?

At the same time, functional imaging of the brain provides an increasing amount of quite controversial data (Shapiro, Caramazza 2003, Démonet et al 2005). It is evident, that languages differ in the way they code semantic or functional relations. What is relatively new is that such language diversity is now realized by the majority of brain and language scholars, therefore experimental studies are becoming much more adequate. The same is true for cultural diversity of mental processes. As M. Donald (1991) puts it, we want to know not only what we are but also what we are becoming.

Cerebral asymmetry is claimed to be an important factor of human evolution and the basis for human linguistic competence. While the classic approach to cerebral asymmetry assumes that each hemisphere specializes in particular processes, cerebral specialization for cognition and language based on genetic mutations is currently interpreted differently from its classical model.

On the one hand, a basic distinction on language, motor, and visual-spatial lateralization is that the hemispheres differ qualitatively in their within- and between-hemisphere interactions. Left hemisphere representations of language and fine motor control have been proposed to be more "focal," permitting rapid cortical interactions with shorter conduction delays, whereas right-lateralized visuospatial attention mechanisms require greater inter-hemispheric integration due to the bilateral representation of visual space.

Data on cerebral lateralization are consistent with computational theories that see information processing to be more efficient when larger functions are decomposed into smaller independent processes, reducing functional interference. Hemispheric lateralization can be thought of as a special case of functional specialization. At the same moment, other cases, such as the division of labor in the visual system between space and form or category selectivity in occipito-temporal brain regions, may ultimately be found to be similar. In general the proposed preferences of each hemisphere for unilateral vs. bilateral interaction and how such preferences relate quantitatively to particular cognitive abilities have yet to be examined. It is worth mentioning that even domain-specific areas are functionally integrated into larger networks. In terms of language lateralization, it is suggested that Broca's area, responsible for speech production receives its specific function as part of a particular domain-specific network which involves the posterior STG for the language domain the parietal cortex for the action domain. Thus, a particular area's function should always be considered within a neural network of which it is a part of.

Networks involving the left-lateralized temporal and the inferior frontal cortex were shown to subserve syntactic processes, and bilateral temporal-frontal networks - semantics. However, the brain-imaging linguistic data are quite diverse, to say nothing of a genetic basis for brain functions supporting fuzzy subjective states and shared cognition (Krings et al 1997; Arbib2011; Lai et al., 2001; Givón, 2009; Jackendoff, 2003; Edelman, 2004; Tattersal 2004; Corballis, 2004 a,b; Rice et al., 2009; Friederici, 2011; Deacon, 2004, 2013; Chernigovskaya, 2004, 2007, 2013; Vallender, 2011; Grodzinsky, Nelken, 2014).

On the other hand, the greater our knowledge of hemispheric mechanisms providing cognitive processes, the less evident is their lateralization in the left hemisphere. Moreover, it becomes increasingly obvious that, especially in the case of language, we are not dealing with lateralization of some "objects" (phonemes, words, grammar, visual images, etc.) in general. The controversial facts that perplex many researchers and break the already useful paradigm of the hemispheric organization of the higher cognitive functions become quite understandable as soon as we shift to the neuro-semiotic description and talk about different sign systems or different ways of information processing (the same!) or even about different cognitive styles. But this means that we are speaking of the dynamic process organization that is each time new and depending on a context. According to the recently proposed hypotheses, we are dealing not with binarity, but with a continuum between the left-hemispheric and righthemispheric poles, in which the proportion of participation of lateral assemblies is balancing depending on the task solved by the brain.

The issue of the role of lateralization in human development was put repeatedly and in different aspects: the role of genetic factors and environment (for instance, of the type of learning or culture), sexual dimorphism, different rate of maturation of hemispheric structures, different rate of running of nervous processes (which might affect, for instance, the especial role of the left hemisphere in analysis of the phonemic procedures requiring a high rate of processing, with all consequences for the language dominancy).

Discovery of **brain mirror systems** by Rizzolatti and Arbib opens a new perspective for analyzing biological foundations of cognitive development, language and Theory of Mind - the ability to attribute mental states to others and thus possibly forming the basis of social interaction and communication. As the ability to understand others' beliefs and intentions (or 'mind reading') is critical for social discourse, it is therefore commonly conceived of being a core aspect of social cognition.

Discussions on Theory of Mind in phylogeny and ontogeny, in norms and pathology gain evolutionary perspective based on recent brain-imaging data that show a number of cortical regions subserving such ability (Baron-Cohen et al 1994; Levine et al 1999; Gallagher et al 2000; Castelli et al 2000; Brunet et al 2002; Vogeley et al 2001, Gusnard et al 2001). Theory of Mind is also discussed as a possible feature discriminating humans from other species. In this context the debates on the specificity of human higher cognitive functions, unique features of human language as opposed to the abilities we share with other animals are becoming more and more important (Bickerton, 2003; Pulvermueller, 1999; Falk 2004; Jackendoff, 2003; Hauser, Chomsky and Fitch, 2005).

We need neuronal mirror systems for language and social interaction: they code sounds, gestures, movements, face and voice qualities to express emotions and to understand intentions of the others. The ability to observe and comment on our own behavior is a reflection – probably the only feature still considered to be absolutely human specific after years of anthropological and ethological studies of cognitive faculties.

Embedding and recursion in syntax, quoting and Theory of Mind have likely been developing since autonomous vocal language arose in Africa from a genetic mutation around 200,000 years ago. The human fossil and archaeological records indicate that symbolic consciousness is not the culmination that natural selection would easily predict. Instead, they show that major change has been episodic and rare and that the passage from non-symbolic to symbolic cognition is relatively recent and unprecedented. Fully syntactical language is an essential requisite to share and transmit the symbolic meaning. However, while processing complex information in natural surroundings we face not only vagueness of language per se but that of the world itself causing ambiguity. There are many layers that sub-serve interpretation: anaphoric and deictic factors, shared pictures of the world, intonations, various types of humor, etc. To cope with it as well as to have the capacity for computing very quick temporal and frequency events all semiotic species along with humans have apparently developed systems that are coded not only behaviorally but also at least to some extend genetically.

At the same time, studies using comparative approach and investigating language capabilities of other primates, such as monkeys and apes, are a popular and, at the same moment, hotly debated field. Adepts of innate language symbolic rules and genetically determined specificity of the human language as a system cannot agree with interpretation of empirical data in terms of linguistic skills acquired in the process of special learning by primates. The most severe critique concerns the anthropomorphism of this approach, the attribution of the features of language operations, which are peculiar only to humans, to the primate behavior.

Discoveries in **genetics** become increasingly involved in various fields concerned with language evolution, from evolutionary anthropology to studies of abnormal linguistic phenotypes. Genetic data can reveal origins and evolution of language faculties and connect it to a broader range of cognitive abilities in other species that led to human higher mental functions.

There is a reason to believe that human gene FOXP2 might have altered the balance of cortico-basal ganglia circuits and learning depending on those circuits. Such a shift could be important for the evolution of vocal learning in general and for language and speech in particular. However, it was shown that FOXP2 is not a language gene as it was announced in the beginning, but is a hub that among other features regulates excitatory synapse density through SRPX2 - it may regulate neurite growth, dendritic morphology, and synaptic physiology of basal ganglia neurons that is crucial for speech and language evolution in humans. FOXP2 contributed to an increased fine-tuning of motor control necessary for articulation - the unique human capacity to coordinate the muscle movements in lungs, larynx, tongue and lips that are necessary for speech (Goodman 2001, Lieberman, 2013). Work on the fossil anthropoid sound-producing apparatus' simulation and on the synthesis of sounds that could be articulated by this apparatus is of considerable importance. It yet again suggests that although some of human ancestral or related species were capable of some sort of primitive speech production, it likely did not reach the articulatory complexity we see in humans. It is also significant to compare these data both with the cognitive level of hominids and the anthropological evidence on the development of particular cerebral areas. Valuable information on this topic is to be found in the studies of linguistic functions as related to cerebral mechanisms

(Chernigovskaya, 1994; Bichakjian, 2002; Gordon et al., 2013; Lieberman, 2013).

Ever since the discovery of FOXP2 the search for the so called "language gene" or "gene of grammar" continues and once again sparks the debate of the origin of language and, hence, of evolution not only of Homo sapiens, but also of Homo loquens.

Studies of presumably genetic or language impairments running in families are attracting sufficient attention due to language peculiarities of people with linguistic disturbances (Gopnik, 1999) and are also benefiting tremendously from genetic research. The aforementioned studies include, for example, such most interesting objects as, for instance, Williams' syndrome when a rather low intellectual level of patients is in a sharp contrast with a high level of language procedures.

In recent years, specialized genetic studies of families with often occurring verbal disturbances began to be carried out. Thus, for instance, a family with fixed problems of language acquisition for four generations is carefully studied linguistically and genetically. Very interesting are investigations of the verbal development in various types of twins. Specific language impairments are non-acquired disturbances characterized by language difficulties without disturbances of intellect, articulation, hearing, and psycho-emotional sphere. In such individuals there are noticed phonological, syntactical, and inflectional difficulties, especially for grammar agreement of a subject and a verb, marking of tense, the number in nouns, and comparative forms of adjectives.

In the past decades, there has been increasing progress in the development of the multidisciplinary domain of language origins and evolution. This progress has resulted from paradigms and data being shared between researchers who study such disparate subjects as historical linguistics and archeology, on the one hand, and primatology, anthropology, anatomy and neurosciences, on the other (Fitch, 2000; Bolhius, Everaert, 2013). There is a wealth of findings indicating that not only cross-disciplinary borrowing of data provides further knowledge, but that theoretical implications and analogies are no less valuable and productive. Despite the complexity of the topic of evolution of language and diversity of theoretical frameworks applied in the field, current collaborative efforts lead to promising results and open intriguing perspectives for the future of language evolution field.

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