

Homo loquens: Evolution of Cerebral Functions and Language

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Abstract—The paper reviews the state of the problem of evolution of language and brain. Various points of view are considered: nativism and connectionism, principle of modular organization of the higher psychic functions including language, and that of organization of all functions on the basis of the network and associative principle. There is also considered the justifiability of the idea of macromutation that has resulted in the appearance of language and a series of micromutations that have led to the same. Also considered are specific verbal disturbances including genetic ones.

Origin of language is the problem that until recently both linguists and representatives of other anthropological sciences were feared to consider, as, strictly speaking, the answer to the question as to how and when the human language appeared can be based only on reconstructions. The scientific community is divided into two camps — into those who think the human language to be although very complex, but nevertheless a successor of communicative systems of the nearest biological ancestors and into those who adhere to the unique system that performs not only communicative, but also peculiar thinking function and has a structure completely lacking in any other communicative systems. At the same time, researchers are divided into the so-called oralists claiming that our language has appeared from the acoustic communication of higher primates and into the manualists thinking that the gesture language was the first to appear and already on its cognitive base the language appeared later in the form that exists at present on Earth in more than 6000 variants. Evolutionary aspects of this also have both advocates and opponents, which also will be discussed in the present work.

Both in theoretical and in applied aspects, the evolutionary concept of Leon Abgarovich Orbeli and his pupils and followers headed by Natalya Nikolaevna Traugott paved the way of studying the language and other cognitive functions in ontogenesis and in pathology. It is important that the Western neurolinguistic science also uses such methods for the last few years, although unfortunately authors as a rule just do not know the frame of the physiological paradigm, in which they have been working.

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. Neurosciences discuss this from the point of view of how in general the brain activity occurs — 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 every year 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. Recently geneticists have also been involved in the general discussion because of the search for the so-called “language gene” or “gene of grammar”. In a close connection with this, there has been again activated discussion of the origin of language and, hence, of evolution not only of *Homo sapiens*, but also of *Homo loquens*.

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”.

This question has been turned back again and again for not one century, especially actively for the last few years. Of course, for the time after Darwin, very many facts have been accumulated and quite a few hypotheses have been put forward. Astonishingly, in spite of this, the question remains unclear and under intensive discussion. The search for the so-called “missing link” also continues, this role being played by more and more candidates, as anthropological material is obtained [2-8]. What has led to formation of the difference of man from other creatures inhabiting our planet — language and the extremely complex brain? Is it a mutation resulting in a special readjustment of the brain to provide most complex and special operations different from all other ones or a continual selection with gradually complicated cognitive possibilities?

No specialists object the statement that brain provides the higher psychic 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 them being possibly inborn. By these rules, specific algorithms are meant, which provide only language procedures.

In this connections, serious and often non-compromise discussions take place on the issue whether the human language capability is a function that neurophysiologically or even anatomically is separated from other cognitive functions. On the point of probability of organization of brain by the principle of modularity there are intensively studied manifestations of postulated single neuronal mechanisms in languages of different types [9-16].

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 [17, 18]. Among generativists adhering to the position of inborn language mechanisms there is no single opinion about origin of these mechanisms: Chomsky and Bickerton consider the “grammatical explosion” a result of macromutation, whereas Pinker — a result of natural selection of small mutations, i.e., of much slower process [4, 12, 19]. There also are opposite opinions [15]. Adepts of neobehaviorism in psychology and connectionist direction in linguistics consider learning the main factor of absorption and adequate functioning of language procedures [20-23]. 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 inborn symbolic rules.

At different time and from different sides, attempts were made to discuss the so-called mental grammar, actually the inborn *a priori* knowledge in general — a set of unrecognized

rules that allow not only acquiring language, but also formulating the life experience as a whole. The case in point is some *pre*-knowledge, the “mental grammar” in general, which is the basis both for language (in the first place) and for the non-verbal constructing of the picture that is more or less isomorphic to the human surrounding and to his available world. The debates of whether the grammar of thinking also covers the specifically language universalia are continuing. Of course it is clear that some “objective” picture also can be constructed by other creatures (otherwise, they would not be able to survive), and in this sense both we and they have some “mental grammar” based on fixed in genome and acquired mechanisms, but, most likely, it is different and suitable for description of “individual worlds”. However, in Jackendoff’s work [24] addressed to interdisciplinary audience an attempt is made to combine mentalism and nativism of basic generativist paradigms with theories of semantics, including the formal one, which have actively being developed for the recent years. Indeed, without such bridge between the “computer-organized” and, in this sense, self-sufficient brain and the external world the connection is not established and probably even is not required. To fill the gap between the brain and the world, the concept of *f-mind* is introduced — the functional cognition that is understood as the ability to code, with the aid of the natural language, certain combinations of the neuronal network states in the brain areas relevant to situation. If to continue this idea, it turns out that language is necessary to brain for describing itself. In this connection, it cannot help recollecting the paradoxical idea developed by Deacon in his well-known book “The Symbolic Species” [25]: «Languages have adapted to children’s brains much more than the brains have evolved to become linguistic“ Brain and language co-evolutionize, but the main adaptive role belongs to language. Thereby, children are already born with brain that is ready for syntactic procedures just due to development of language towards the most probable characteristics, which is fixed by brain genetically.

Brain is necessary, but not sufficient for thinking. Experience is required. Intellect is developing: the role of cortex in small children is very low (many neurons are formed after birth). It is commonly known that the total brain mass is less important than its internal organization and richness of connections that now become increasingly obvious to depend to a most great measure on the type and complexity of the tasks solved by brain. The potential possibility of talking depends on genetic factors, while the real verbal production, on experience.

When discussing constant debates of nativists and adepts of the primacy of learning, it is worth recollecting Schmalghausen [26] who wrote that all biological systems were characterized by the capability for self-regulation and among those of the self-regulation in ontogenesis there should be noted three main factors: (1) development according to genetic program; (2) development depending on the role of environment (for instance, the negative result of sensory deprivation leads to brain underdevelopment, the absence of adequate verbal surrounding — to the lack of language development, etc.; (3) the own conscious self-regulation is the property that increases with a rise of the range of biological objects on the evolutionary ladder as a result of the increasing role of individual, rather than group behavior. The sign of evolution is a rise of independence of the environment. Astonishingly, some general principles of evolution (as we understand them nowadays) reflect as different processes as evolution of living creatures and of natural and artificial languages [27-29].

Karl Pribram [30] notes that the organism external behavior is determined by a complexly organized mechanism formed by competent (as he formulates it) structures, whose functions depend on experience in a given environment. Even Chomsky himself, the most convinced adept of primacy of genetics for language, emphasizes difference between competence (some inborn 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 performance of a task. 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 hierarchic and even digital structure, i.e., the existence of levels — phonological, morphological, syntactical, and discourse. All this is permeated with semantic axis. Such structural specificity is commonly accepted as a unique peculiarity of a given system. Therefore, the search both for rules describing the proper linguistic phenomena and for genetic bases of language competence are based first of all on analysis of these characteristics.

Adepts of the classic modular approach think that use of the universal grammar rules is not only the main characteristics of man as a species, which has resulted from a peculiar mutation that is what has led to separation of this species from others inhabiting Earth, but also have a peculiar localization in the brain. Thereby, organization of the mental process is described as two kinds of procedures: (1) functioning of symbolic universal rules operating in the real time regime and based on procedures and inborn mechanisms triggered in operative memory; (2) retrieval of lexical and other gestalt-presented units from the long-term associative memory [13, 14].

Adepts of the diametrically opposite opinion think that all processes are based on associative memory procedures, and we deal with a complex reconstruction of the entire neuronal network, which also occurs according to the rules that are more complex, and difficult to be formalized [20, 21]. Hypotheses that do not coincide with either of these approaches are also possible [31, 32].

To check this, there is clinical material, data of ontolinguistics, and specially designed experiments with adult people speaking different languages, as well as modeling of artificial neuronal networks that are learnt according to the rules that hopefully imitate the implicit mastering language in childhood. Especial hopes are given to data of functional brain imaging in healthy people.

All these methods, apart from their indisputable advantages, also have essential disadvantages. Thus, it is evident that even the best computer neuronal network learnt according to the currently best known rules by no means can be compatible with real processes occurring during mastering of language by young children, at least because there is completely not considered (and cannot be considered) the whole diversity of the child's language surrounding, in particular the characteristics critical for such investigations — frequency of using various language units, to say nothing of non-verbal communication components that redistribute the specific weight of the learning components.

At the same time, functional imaging of brain provides an increasing amount of quite controversial data that are rather difficult for combining not only with paradigms, but even with results from other fields of the presumably common scientific object. An impression is formed that each of the branches of the common tree of the scientific knowledge, the knowledge of brain and the knowledge of language, has its own truth: right are aphasiologists describing agrammatism in disturbances of the Broca zone, but agrammatism in disturbances of the Wernike zone does not agree with any general concepts. Also right are investigators of language functions related to brain large hemispheres: they, like aphasiologists, have accumulated a gigantic factual material that essentially disagrees both with the principally “left-hemispheric” aphasiology and with a constantly increasing volume of data of brain imaging, which, in turn, appears to be opposed to all the above and the further, the more: with increase of the resolution capability of scanners, there rises paradoxically not only the number of revealed parameters, but also diversity of the total picture; a little more, and we will have information of almost every neuron — and what? This will make the situation even more complex and less compatible with data of other procedures. It becomes more and more obvious that some break-through of quite a different kind, methodological rather than methodical, is necessary.

As long ago as in 1949, Donald Hebb [33] proposed a model that reconciled the localizationistic and cholic approaches (or, rather, denied these both approaches) of cerebral control of the higher cognitive functions, specifically of the verbal ones. According to this

model, cell assemblies in the brain cortex can be arranged in neurobiological groups to form cognitive units of the type of words or Gestalts of different kind, for instance, of visual images. Such point of view differs fundamentally from the localizationistic approach, as it implies that neurons from different cortex areas can be simultaneously united into the single functional block. It also differs from the cholistic approach, as it denies determination of everything everywhere, but emphasized principal dynamics of the mechanism and a constant reorganization of the entire pattern depending on the cognitive task. This means that we deal with a finely tuned orchestra, in which location of conductor is unknown and unstable and possibly is not occupied at all, as the orchestra is self-organized with taking into account many factors [34] and is tuned to the dominant [35]. This is indirectly confirmed by data of distribution of engrams in memory: the same cognitive object turns out simultaneously to be a component of several associative multitudes — both on the axis of sensory modality and on the axes of different paradigmatic and synthagmatic connections. Hebb is also discussing a wave of excitation circulating and reverberating along various neuronal assembly loops, which can be described in neurophysiological terms as a spatial-temporal pattern of activity involving many neurons and not only in neocortex. It is remarkable that Hebb proposed interpreting the term CNS (“central nervous system”) more broadly - as “conceptual nervous system” [36].

These ideas were long criticized mainly due to that they seemed unable to be checked. However, more and more empirical studies have made the Hebb’s model to be considered quite thoroughly [37-39]. It is to be noted that the functionally appearing and cognitively substantiated assemblies themselves have a hierarchical organization, i.e., they can be submultitudes of others. Admission of such organization is necessary, for instance, to explain structure of the corresponding semantic representations, such as hyponyms and hyperonyms. A possibility of such “orchestrating” explains processes of the language learning in early childhood by reconciling nativists and connectionists. It also explains more logically the aphasiological data, for instance, disturbances of language procedures at any modality of the stimulus presentation (traditional approaches face with significant difficulties when it is necessary to explain such a multimodality). In the case of the correct model of dynamic and distributed neuronal assemblies the compensatory readjustment of functions becomes much less mysterious, especially when the main verbal zones are damaged or simply remote.

Of a most great interest are K. Anokhin’s investigations [40]. They have shown, in particular, that expression of genes in the adult nervous system, unlike the embryonic one, is included into mechanisms of self-organization of behavioral functional systems, which makes morphogenesis in the brain during learning to be controlled by systemic, cognitive processes. The idea that learning at the molecular-genetic level promotes processes of development by forming episodes of additional morphogenesis in the adult brain has essential consequences for development of models of the brain work, the material of which serve studies of the neuronal expression of genes during development and learning. As a result of reactivation of morphoregulatory molecules in the adult brain, neural cells acquire during learning the ability to reconstruct their synaptic connections inside the modified or newly formed functional systems. The main molecular-genetic elements and the stages of this molecular cascade turn out to be rather similar during learning and development.

A different meaning is also acquired by the cardinal issue of lateralization of the higher, first of all, human language functions [41-46]. The greater our knowledge of hemispheric mechanisms of providing cognitive processes, the less evident their lateralization in the left hemisphere. Moreover, it becomes increasingly obvious that we are not dealing in general with lateralization of some “objects” (phonemes, words, grammar, visual images, etc.). The controversial facts that perplex many researchers and break the already useful paradigm of the hemispheric organization of the higher functions become quite understandable as soon as we shift to the neurosemiotic description and talk about different sign systems or different ways of processing of information (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 context. According to the recently proposed hypotheses, we are dealing not with binarity, but with a continuum between the left-hemispheric and right-hemispheric poles, in which the proportion of participation of lateral assemblies is balancing depending on the task solved by the brain [47]. 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), sex 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).

Thus, we face opposition of schools, which can be reduced to the scheme of determinism (+ innateness of language) *versus* “chaos” or the ideas of study on the basis of probabilities, prognosis, and predictability. According to the former point of view, evolution has made a breakthrough leading to acquisition by brain of the capability for digital computing, use of recourse rules and mental representation that thereby have led to foundation of basis for thinking and language in the human meaning. Then the language capability underlay formation of the arithmetic code as the basis of mathematics. Some part of the scientific community claims at present that all this is based on a mutation resulting in the appearance of the “language gene” and hence, in separation of the human species; the price for the language turns out to be schizophrenic disturbances also based on disbalance of hemispheric functions [48-51].

In the focus of discussions about differentiated characteristics of human language and role of genetic factors there are studies of the so-called specific language impairments (SLI) and teaching of the higher primates to human languages and artificial sign systems. The former are aimed at demonstration of the modular organization of the language capacity and, as a consequence, of a partial impairment of language alone, without disturbances of memory, attention, intellect, and emotional sphere, whereas the latter, at the proof of the principal possibility of learning of another, non-human brain to universal language procedures. If such proof is obtained, the issue of specific and module-organized language mechanisms produced by the mutation providing the appearance of *Homo loquens* is eliminated. Also eliminated, due to its uselessness, is the issue of search for the “gene of language” caused by such a mutation.

Due to language peculiarities of people with language disturbances, genetic or family language impairments (FLI) are also considered [52-56]. The same area of studies also includes 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 [57].

For the 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 [58]. Very interesting are investigations of the verbal development in various types of twins [59, 60].

Specific language impairments are non-acquired disturbances characterized by language difficulties without disturbances of intellect, articulation, hearing, and psychoemotional 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 psycholinguistic experiments, people with such disturbances also demonstrate unusual characteristics: it is reasonable to accept a different organization of their mental lexicon and to emphasize disturbances of the morphological representation characteristic of norm, which is reflected both in understanding and in production of inflectional morphological operations. Here we see an example of how the human verbal activity at mastering and using language is based not on implicit procedures and deduced algorithms (regardless of whether they were passed genetically), but on explicitly formulated (sometimes in the literal meaning) rules and declarative memory, when words (possibly, lexemes), for instance, are stored as lists, whereas rules, separately, in some networks. The recently activated studies of such disturbances in people speaking different languages will allow not only identifying universal errors, but also relating

them with concrete pathology (possibly, genetic one, which does not necessarily indicate a specific “ language gene”).

Study of language possibilities of the higher monkeys also is the field of discussions. Adepts of inborn 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. The most severely criticized is anthropomorphism of this approach, an attribute of the features of language operations, which are peculiar only to humans to the primate behavior.

Of course, 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, a vector of natural selection is quite correlated. The adept of the idea of macromutation and, therefore, actually an anti-Darwinist Chomsky and his opponents Pinker and Bloom insisting on the natural selection that has led to formation of the language capacity , in my opinion, could have to be conciliated in the same way as Hebb’s model 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 to be as before in captivity of the binary way of thinking, with necessity of choosing between polar viewpoints: mutation or selection, modularity or neuronal network? Indeed, Darwin himself did not deny the role of random events (mutations) in evolution. In his “Origin of Species...” he writes: “It seems that previously I underestimated significance and spread of these latter forms of variations leading to firm modifications in structure independently of natural selection. But since recently my conclusions were misinterpreted and it was claimed that I ascribe modification of species exclusively to natural selection, I will seem to be allowed remarking that in the first and subsequent editions of this book I had put in the very well-seen place, such as the end of Introduction, the following words: “I am convinced that natural selection was the main, but not the exclusive factor of the modification”. However, this has not helped. The strength of obstinate distortion is very great; but history of science shows that action of this strength fortunately is not long [1; p. 412].

This statement was too optimistic. In fact, evolution had seemed to be canalized much earlier than the higher species appeared and is neuroevolution directed to development of brain, cognition, and language; in this meaning, if even the randomness did take place, it had consequences that are very fortunate to us.

I would like to finish again by the words of the wise Darwin: “In future, I predict opening of another important field of investigations. Psychology will be firmly based on foundation that has already been excellently laid by Mr. Herbert Spencer, such as the necessity of gradual acquisition of each mental quality and capability. Much light will be shed on origin of man and his history. Many prominent authors seem to be satisfied by the concept that each species was created independently. In my opinion, what we know about the laws imprinted in the matter by Creator agrees to the greater degree with dependence of the appearance and disappearance of the past and present Earth inhabitants on secondary causes similar to those that determine birth and death of species. When I consider all creatures not as results of individual creation acts, but as direct descendants of a few creatures living long before deposits of the first strata of the Cambridge system, they are ennobled in my eyes” [1; pp. 418-419].

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