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Review article

A revival of the *Homo loquens* as a builder of labeled structures: neurocognitive considerations

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ABSTRACT

The core capacity of human language is described as the faculty to combine words into hierarchical structures. This review aims to isolate the fundamental computation behind the language faculty together with its neural implementation. First, we present our central hypothesis by confronting recent linguistic theory with evolutionary arguments: linguistic humaniqueness is reflected in the labeling of word combinations forming asymmetric hierarchical structures. Second, we review the neurolinguistic literature, especially focusing on dual-stream connectivity models. We put forward that the dorsal pathway, especially the arcuate fascicle, is responsible for the rule-based combinatorial system, implementing labeling and giving rise to hierarchical structures. Conversely, the ventral stream is rather responsible for semantic associative operations. We further present evolutionary neuroanatomical evidence grounding our hypothesis. We conclude by suggesting further avenues of research as well as open questions to be addressed. With the aim to expand our knowledge on the neurobiology of language, we hope to provide a testable hypothesis for the origin of language syntax bringing together evidence from different fields.

Contents

1. Introduction

Language is as a powerful communicative tool which enables humans to exchange complex states of affairs with each other. The language system constitutes a rather recent evolutionary innovation, and appears to be unique to the human species. Given this uniqueness, a central aim for current cognitive research is to isolate some specific trait in humans, which would most plausibly support the emergence of language as a species-specific faculty. While this quest has stimulated psycholinguistic and neurolinguistic studies (Friederici and Singer, 2015), comparative research has also provided important insights about the commonalities and differences between humans and nonhuman primates (NHPs) (Berwick et al., 2013) In parallel, linguistic theory has accordingly addressed the new challenges arising from the findings of other fields (Bolhuis et al., 2014; Everaert et al., 2015). However, these attempts to isolate the language faculty are yet to achieve success. This apparent insufficiency might arise from the difficulty to integrate insights from these very disparate disciplines. Here, we try to overcome these shortcomings and provide

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a testable framework based on data collected by different disciplines, always bearing in mind a coherent big picture. The present framework will especially draw on evidence from cognitive neuroscience, which will accompany the argumentation along this paper.

A multidisciplinary approach to the question of language evolution and its brain implementation is the most adequate strategy to provide us with helpful empirically testable frameworks that can contribute to the progress of the field of biolinguistics (Boeckx, 2013; Bickerton, 2014b). A clear advantage of such a multidisciplinary perspective is the possibility to combine the constraints of the different fields to reduce the scope of hypotheses in consideration (Fitch, 2014). If we consider the language faculty to be a recent adaptation of our species, there are several aspects we must take into account. First of all, the fundamental language computation in focus should not only be in agreement with linguistic theory, but also with comparative cognitive research. This evolutionary difference should thus constitute a cognitive novelty in our species, in particular the cognitive process in question should not be present in our closest relatives. Otherwise, it would be difficult to explain how language developed exclusively in humans. Furthermore, we should carefully consider the neural implementation of this cognitive difference that originated language. This means that we must be able to provide a plausible neuroanatomical substrate for this computation that shows some novelty in humans in comparison with NHPs.

A striking fact about language is the possibility to combine words in a way that new relationships are established between them, and novel meanings arise, being conveyed by the way they are combined. Because of this, a fine-grained description of the algorithm holding this combinatorial process takes on a crucial role. One of the dominating views in the field is the hypothesis of merge being the crucial computation, put forward by the linguist Noam Chomsky (Chomsky, 2007; Bolhuis et al., 2014; Everaert et al., 2015). In this framework, the language faculty consists of a single computation—*Merge*—that combines two elements and gives rise to an unordered symmetrical set. *Merge* is therefore considered the basic hierarchy building computation that enabled humans to master language within the Minimalist Programme (Berwick and Chomsky, 2011; Bolhuis et al., 2014; but see also Boeckx and Benítez-Burraco, 2014). While we support the idea of a simple and parsimonious combinatorial computation at the basis of language, we will nonetheless try to elucidate why *Merge* might need expansion in order to provide explanatory adequacy in both cognitive and evolutionary domains. Here, we put forward that the labeling of the outcome of the operation *Merge* is a necessary cognitive prerequisite for a complete account of the uniqueness of human language processing. It is through labeling that asymmetric hierarchical structures can originate, thus distinguishing language from other communication systems (Murphy, 2015a, 2015b). In the following sections we will start by explaining our proposal from a language theoretical perspective. We will then integrate the hypothesis with current neuroscientific findings and discuss its concrete neural implementation. Subsequently we will provide comparative data in support of our view. In the final part, we will suggest possible avenues for future research.

2. The *Merge*-only hypothesis and why we need labels

We start by discussing the assumption that the evolutionary step that allowed humans to acquire language is a novel combinatorial faculty that generates hierarchical structures unique to the human communication system. At the center of the Minimalist Program (Chomsky, 1995) stands the computation *Merge*, defined as the combinatorial mechanism that brings two elements together to form an unordered set (Chomsky, 2013), as in:

$$\alpha\beta \rightarrow \{\alpha\beta\} \quad (1)$$

The expression above can be read as "take two elements α and β, and string them together to form a new set containing both". *Merge* can create a new set including words from any lexical categories (e.g., nouns, verbs, determiners, which correspond to terminal nodes), or sets that had already been formed by *Merge* itself. This possibility of a computation to take its own output as an input again is what defines recursion, a cornerstone in the discussion about the language faculty (Hauser et al., 2002). For the output of this computation to be correctly interpreted at the interfaces (either the sensorimotor interface or the conceptual intentional interface), the issuing sets need to be labeled. The label of the new set is attributed according to the labels of its elements and relationship established between their categories. *Labeling* determines a local asymmetry between the two items in the set, since one of the two elements assigns its label (let it be α) to the new merged object, in this case the label γ_α (2):

$$\alpha\beta \rightarrow \gamma_\alpha\{\alpha\beta\} \quad (2)$$

In linguistic theory, the element assigning the label to the merged object is said to project and it is called the selector or head of the structure formed by the two merged elements. Narita (2014) addresses how the labeling of the set resulting from *Merge* is closely related to the categories of the elements of the set. In order to illustrate how labeling arises, let us consider the example of one of the most essential asymmetries between categories in language – the asymmetry between nouns and verbs. In this case, the verb (V, "eat") is usually the selector, taking the noun (N, "apples") as its object. The verb hence imposes its label onto the other component with which it was merged, e.g. a verb phrase (VP, "eat apples"). In more abstract terms, this shows different elements in language play different roles when combines. Some elements in language are rather functional and dynamic, and usually refer to events. These establish the relationships between elements in a phrase and between phrases in a sentence, thus determining the hierarchical structure. In turn, other elements are mainly content-bearing and static, and rather refer to sorts. The constituents involved in (2) operate accordingly. The head α stands in an asymmetrical relationship with its complement β, based on the internal grammatical relationship between the two elements. The same analysis applies to the phrase "which apples". Formally, the concrete bare syntactic set {which, apple} resulting from the *Merge* of "which" and "apple" is labeled Determiner Phrase (DP) because it is a property of the determiner (D) to require a noun (N) as a complement (3). Therefore, the label received by the newly formed set expresses the asymmetric hierarchical nature of this same set. This happens because one of its elements, the determiner (D), projects its label to the newly formed phrase, a determiner phrase (DP):

$$\text{which, apple} \rightarrow_{\text{DP}}\{\text{whichapple}\} \quad (3)$$

In the Minimalist Program, for the sake of theoretical elegance, *Merge* is kept rather undefined. Consequently, the labeling algorithm is excluded from the basic language computations and labels are only established for interface requirements (Berwick and Chomsky, 2016). The definition of *Merge* is therefore left open regarding both the properties of its inputs (e.g., its category) and of the structure that constitutes its output (e.g., which label the merged set takes). This, however, appears to conflict with the desired explanatory adequacy of the language faculty from a biolinguistic perspective. In particular, it does not seem to be able to directly account for the evolutionary mechanisms of the emergence of language. When considering evolution, we must equate which could have been the difference to our ancestors, which could

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