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journal homepage: [www.elsevier.com/locate/neubiorev](http://www.elsevier.com/locate/neubiorev)The biology of language<sup>☆</sup>

This special issue of Neuroscience & Biobehavioral Reviews arose out of an Academy Colloquium, ‘The Biology of Language,’ held in the ‘Trippenhuis’, Amsterdam in Dec 2014. The Colloquium was organised by Johan Bolhuis, Martin Everaert and Riny Huybregts, under the auspices of the Royal Netherlands Academy of Sciences. Our aim for this special issue is the same as it was for the symposium: to provide an up to date overview of some of the core properties of the human language faculty, making clear how linguistics is part and parcel of the cognitive sciences (Everaert et al., 2015), open to inquiry about its biological foundations and its neural underpinnings (Berwick et al., 2013). To this end, we invited leading researchers – linguists as well as biologists and psychologists – to present their latest results. In particular, we focus on several aspects of language: General considerations of syntactic structure; Development of language; Neural mechanisms of language; and language evolution.

### 1. Bilingualism

The biological perspective on language was strongly influenced by Eric Lenneberg’s *Biological Foundations of Language* (1967), published 50 years ago. Lenneberg, and Chomsky (1964), advocated reinstatement of a biological view of language capacities. Later this approach began to be called “the biolinguistic program,” adopting a term suggested by Massimo Piattelli-Palmarini (1980). The biolinguistic perspective holds that language, like any other ‘mental organ’ – planning, memory systems, organization of action ... – is a biological system, a component of the mind/brain, a biological property of the individual language users. In his book Lenneberg approached language as a species-specific mental organ, internal to the mind, with non-trivial biological properties,

Lenneberg was (one of) the first to address an array of issues placing linguistics centre stage in the cognitive sciences and neuroscience, discussing dissociations between language and other cognitive faculties, language evolution, and he speculated about the genetics of language. He discussed the correlation between language development and maturational phenomena, stressing that there are anatomical and physiological processes whose maturation sets the pace for both cognitive development and language growth. Note that Lenneberg was careful in his assessment of the biological foundations of language, making clear fifty years ago that one should not expect to find ‘special genes’ for language. Although traits may be genetically and developmentally encoded, one rarely finds a direct link between genes and behavioural patterns (cf. Fisher, 2013).

Lenneberg’s work is well-known for its discussion of a critical age for language acquisition, often referred to as the Critical Period Hypothesis. As formulated by Lenneberg, this principle suggests that if no language has been learned by puberty, it cannot be learned in a normal, functional sense: “a steady state is reached, and ... the capacity for primary language synthesis is lost”. Without going into detail, cases of deaf, blind-deaf, and feral children point to evidence of a biologically determined critical period for the first language that is acquired (L1; Newport, 1990). A well-known case is that of Helen Keller, who achieved outstanding language mastery by touch (Piattelli-Palmarini and Berwick, 2012). It has been argued that Lenneberg’s original position on the time span of the critical period cannot be fully upheld (Pallier, 2013; Werker and Hensch 2015), but this conclusion is largely grounded on second language acquisition research, irrelevant for the point Lenneberg himself raised (Lenneberg, 1967, p. 176). In any case, the link between biology and language was firmly established and has been upheld ever since. For instance, the relationship between vocal communication in humans and birds has often been discussed, also in relation to the fact that sensitive periods are evidenced in both taxa.

Taking this biolinguistic perspective, Chomsky (2017) explains that the fundamental task of the study of language is to capture what may be called the Basic Property of the Faculty of Language: it provides the means for a language to yield a digitally infinite array of hierarchically structured expressions with systematic interpretations at interfaces with two other external systems, the sensorimotor system and the conceptual system for reasoning.

### 2. I-language

Generative grammar aims to construct a theory of language as a biological object, internal to the individual. Language, understood as I-language, with the “I” as “internal,” places the Basic Property at the heart of human language. The theory of I-language is called generative grammar, and the general theory of I-languages is Universal Grammar (UG). UG is the theory of the genetic component of the faculty of language, apparently species-specific (uniquely human) and domain-specific. UG characterises a possible set of I-languages and makes it possible to acquire a particular I-language

<sup>☆</sup> Editorial

(Chomsky, 1995).

As soon as the biolinguistics program was undertaken the problem of evolution of Universal Grammar arose (Berwick and Chomsky, 2016; Chomsky, 2017). Considering the place of language in human biology and evolution, Yang et al. (2017) propose an approach that integrates principles from Universal Grammar and constraints from other domains of cognition, and outline some initial results of biolinguistics, as well as challenges for future research.

Assuming the modern computational theory of mind, language must be a computational system. Consequently, such a system must be determined by a finite computational procedure, in other words, a generative procedure and so a special kind of recursive function. This is why the study of I-languages has been called “generative grammar.” This makes ‘syntax’ in the sense described in Everaert et al. (2015) central. Although there may not be general agreement about the nature of the ‘theory of syntax’, most, if not all, linguists would agree that there has to be some mechanism in the mind/brain generating an unbounded array of hierarchically structured expressions, each receiving a systematic and determinate interpretation at two interfaces, meaning and sound/sign (the latter called “externalization”) – a modern version of Aristotle’s familiar dictum that language pairs sound (and sign) with meaning.

Viewed this way language can be shown to be primarily a vehicle for thought and meaning without, sometimes, sound or sign. In other words, externalization is secondary in function, and, as Huybrechts (2017) shows, it can tell us something on how speech developed from language. This automatically implies that although language is used for communication, its core properties cannot be explained primarily in terms of communicative needs, and these need not play a role in language evolution in the relevant sense

### 3. Language evolution

It is stating the obvious that one cannot advance evolutionary claims about a complex behavioural phenotype without first positing explicit ideas as to its underlying phenotypic traits. So, answers to the question – what is it, ‘language’ – remain logically prior to answers to the question of how language emerged (Chomsky, 2017). On the question of language emergence, Berwick and Chomsky (2016) take the following position, building on earlier work: the emergence of language was relatively recent (150 -75 kya) and sudden, before there was evidence of behavioural modernity. More importantly, Berwick and Chomsky take language as biologically novel, exhibiting discrete infinity, hypothesized to be unique in the animal kingdom. In other words there are indeed features of human language that appear to have no significant analogue in the rest of the biological world. Importantly, what evolved is not ‘language’ per se, but the capacity for language. Further, it is crucial to distinguish the emergence of language, the result of biological evolution, from language change, the development of language over time; the latter should not strictly speaking be called ‘evolution.’

Tattersall (2017) argues that the best archaeological proxies for language are symbolic objects. And because there is no indication that any hominid behaved symbolically prior to *Homo sapiens*, which originated 200 thousand years ago but started behaving symbolically only 100 ky later, most probably the necessary neural underpinnings arose exaptively in the extensive developmental reorganisation that gave rise to anatomically distinctive *Homo sapiens*, and then were necessarily recruited subsequently for externalised language.

Reuland (2017) provides a functional analysis of the conditions for language to emerge, and analyses its role in imagination. It starts with some initial reflections on imagination and its evolutionary beginnings in relation to the role of working memory and tool use by chimpanzees and humans up to modernity. It then presents an analysis of what it takes to develop language, and how language gives rise to higher orders of imagination

Huybrechts (2017) shows that the capacity for language existed before human populations became separated but that the emergence of speech (externalized language) did not emerge until after these population divergences occurred. Click phonemes, present only in San populations, with their unique geneological, genetic and geographical distribution give an indication that speech emerged only after the capacity for language became fixated in the species.

### 4. Comparative evolutionary biology

Many traits in the domain of human communication are shared with other species. Hauser et al. (2002) put forward that serious comparative biological research is needed to answer the question whether there are features of natural language (taken as a cognitive module used for communication) which are uniquely human (cf. Bolhuis and Everaert, 2013). It is widely assumed that cognitive traits, including language, must have evolved gradually, based on the assumption that there is substantial ‘mental continuity’ between humans and other species (Corballis, 2017). To give a recent example. Engesser et al. (2016) claim that the southern pied babbler (*Turdoides bicolor*) shows signs of having protosyntax. That is, these birds have “two-signal constructs”, which would be an instance of “basic, intermediate compositional structures.” For Engesser et al. this supports the idea that (human-like) syntax could have evolved by progressing gradually over time. Alternatively (Berwick and Chomsky, 2016) the evolution of language is seen as the assembling of abilities, sensory-motor and cognitive, that are already in place into a novel phenotype that has recursive thought.

Zaccarella and Friederici (2017) discuss current behavioural studies dedicated to the comparison between human and non-human animals for the processing of different grammar types. They inspect the functional neuroanatomical structures of human and non-human primates more closely, including human developmental data, thereby suggesting interesting phylogenetic and ontogenetic differences.

Prather et al. (2017) and Mol et al. (2017) remind us that there are remarkable behavioural similarities between song learning in songbirds and speech acquisition in human infants that are absent in non-human primates (Bolhuis et al., 2010; Bolhuis and Everaert, 2013; Bolhuis and Moorman, 2015). Prather and colleagues review important neural parallels between birdsong and speech showing that song learning in birds and speech acquisition in humans may provide useful insights into the evolution and mechanisms of auditory-vocal learning. Mol et al. discuss songbirds’ sensitivity to prosody-like acoustic features and the role of such features in song segmentation and song learning in relation to infants’ sensitivity to prosody and the role of prosody in early language acquisition.

Beckers et al. (2017) discuss one of the methods used in comparative biology, artificial grammar learning, a popular paradigm to study syntactic ability in nonhuman animals. Subjects are first trained to recognise strings of tokens that are sequenced according to grammatical rules. The authors review stimulus design in a sample of studies that use particular sounds as tokens, and that claim or suggest that their results demonstrate a form of sequence rule learning. Beckers et al. conclude that acoustic confounds are a blind spot in artificial grammar learning studies of nonhuman animals.

## 5. Distinguishing language and speech

To correctly place some of the work in this special issue, we have to keep in mind that ‘language’ and ‘speech’ have to be distinguished. Language is modality-neutral. The spoken variety, speech, is the most common manifestation, but it is important to realise that, for instance, sign languages are also a manifestation of natural language, obeying constraints similar to spoken languages. But also touch, tactile perception, as used by the deaf-blind is a possible externalization. Language taken as I-language abstracts away from the specific way it is externalized, either through an articulatory-auditory modality, or as sign, or a haptic mode.

Hagoort (2017) specifies a general cognitive architecture for spoken language processing. This is followed by an account of how this cognitive architecture is instantiated in the human brain.

Ding et al. (2017) focus on rhythms in speech and music. They discuss major acoustic correlates of spoken and musical rhythms, and compare the modulation properties of speech and music. Langus et al. (2017) also discuss rhythm, but in a different way. They address our current knowledge on linguistic rhythm and highlight areas of interest for future research that are most likely to yield significant insights into the nature, the perception, and the usefulness of linguistic rhythm.

Goldin-Meadow and Yang (2017), on the other hand, focus on gestures, called homesigns, that deaf children use to communicate; children whose hearing losses prevent them from acquiring spoken language, and whose hearing parents have not exposed them to sign language. Importantly they show that even in the absence of external stimuli, deaf children reflexively construct homesigns that can be accounted for only by productive grammar rules.

## 6. Mind and brain

Our knowledge about the neural basis of language is still limited, and a matter of debate. It strongly depends on whether one takes ‘language’ as basically limited to ‘speech/ communication’, or as a computational cognitive mechanism – as we discussed in section 2. A firm body of work in language research connects experimental, theoretical and neurobiological work. At the centre of this work is the idea that computational theories of language, like the one sketched in section 2, must be used to investigate its neurobiological foundations. The results of recent brain imaging studies are consistent with taking language as an autonomous cognitive mechanism, leading to a novel view of its neural organization (Friederici, 2011; Berwick et al., 2013; Friederici et al., 2017).

Hagoort (2017) discusses a general cognitive architecture of spoken language processing and how this cognitive architecture is instantiated in the human brain. The spatial aspects as well as the temporal dynamics of the language networks, and the underlying neurophysiology, are discussed. A distinction is proposed between networks for coding/decoding linguistic information and additional networks for getting from coded meaning to speaker meaning.

Piattelli-Palmarini (2017) reviews several specific brain lesions - hydrocephaly, spina bifida and hemispherectomy – and their effects on language. He reports that core properties of language, especially syntax, are retained, but that in some cases the use of language is disturbed.

Zaccarella and Friederici (2017) focus on the neurobiological literature concerning the specific human ability to process linguistic hierarchies. They examine the neural reality of the Merge computation, being the most fundamental mechanism regulating natural language syntax, and offer new evidence for a possible localization of the neural substrate of Merge, providing a recent evolutionary neurobiological basis for the unique human faculty of language.

Goucha et al. (2017) aim to isolate the fundamental computation behind the language faculty together with its neural implementation. They put forward that one of the two dorsal pathways (particularly the arcuate fascicle connecting Wernicke’s and Broca’s areas) subserves the rule-based combinatorial system, among others giving rise to hierarchical structures, while ventral pathways underlie semantic associative operations.

## 7. Language Acquisition

Acquisition of an I-language appears ‘canalized’ by principles of UG, genetically encoded, and language-independent principles, either other cognitive processes or organism-independent principles (Chomsky, 2005, 2011; Berwick et al., 2011). On the basis of this faculty, any child can, indeed, acquire any natural language – seemingly different from and seemingly more complex than what we ourselves have learned, in a relatively short time span. Children do so on the basis of ‘noisy’ input, being able to separate what belongs to language and what not (Gervain et al., 2008). It has been shown that what is acquired vastly exceeds evidence available to the child. Child language sometimes exhibits properties for which there is no evidence at all in the environment, though they are found in other languages and are therefore compatible with UG (Crain, 2012).

There may be individual differences between individuals, as research on acquisition shows, but the individual is an instantiation of a species-invariable type in form and function. And here it is important to observe something that is central to generative theorizing on this point, and contrary to usage-based approaches: “Notice that we must distinguish between what an individual actually does and what he is capable of doing. The intraspecific similarity holds for the latter, not the former...” (Lenneberg 1967, p. 372).

Crain et al. (2017) describe the biolinguistic approach to language acquisition. They focus on how child and adult language differ both in sentence production and sentence understanding, arguing that the observed differences resist explanation using the cognitive mechanisms that are invoked by usage-based approaches. In contrast, the biolinguistic approach explains the qualitative differences between child and adult language. Explaining how child and adult language differ and demonstrating that children perceive unity despite apparent diversity are two of the hallmarks of the biolinguistic approach to language acquisition.

Langus et al. (2017) show how linguistic rhythm partially mimics the prosodic as well as the morpho-syntactic hierarchy of spoken language, thus providing learners with cues about the structure of the language they are acquiring. They survey experimental evidence on rhythm perception in young infants and native speakers of various languages to determine the properties of linguistic rhythm that are present at birth, those that mature during the first year of life, and those that are shaped by the linguistic environment of language learners.

Goldin-Meadow and Yang (2017) provide evidence that children using homesign can create a combinatorial linguistic system without external linguistic input, offering unique insight into how the capacity of language can result in rich language with effectively no input at all.

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Martin B.H. Everaert\*

Department of Linguistics, Utrecht University, The Netherlands

E-mail address: m.b.h.everaert@uu.nl

Johan J. Bolhuis

Departments of Psychology and Biology, Utrecht University, The Netherlands  
Department of Zoology and St. Catharine's College, University of Cambridge, UK

\* Corresponding author.