Cognition 180 (2018) 135–157

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original Articles

# Grounding the neurobiology of language in first principles: The necessity of non-language-centric explanations for language comprehension

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ARTICLE INFO

*Keywords:*
Language
Neurobiology
Context

ABSTRACT

Recent decades have ushered in tremendous progress in understanding the neural basis of language. Most of our current knowledge on language and the brain, however, is derived from lab-based experiments that are far removed from everyday language use, and that are inspired by questions originating in linguistic and psycholinguistic contexts. In this paper we argue that in order to make progress, the field needs to shift its focus to understanding the neurobiology of naturalistic language comprehension. We present here a new conceptual framework for understanding the neurobiological organization of language comprehension. This framework is non-language-centered in the computational/neurobiological constructs it identifies, and focuses strongly on context. Our core arguments address three general issues: (i) the difficulty in extending language-centric explanations to discourse; (ii) the necessity of taking context as a serious topic of study, modeling it formally and acknowledging the limitations on external validity when studying language comprehension outside context; and (iii) the tenuous status of the language network as an explanatory construct. We argue that adopting this framework means that neurobiological studies of language will be less focused on identifying correlations between brain activity patterns and mechanisms postulated by psycholinguistic theories. Instead, they will be less self-referential and increasingly more inclined towards integration of language with other cognitive systems, ultimately doing more justice to the neurobiological organization of language and how it supports language as it is used in everyday life.

## 1. Introduction

The last two decades have witnessed extensive methodological advances in the non-invasive study of brain activity. These advances allow researchers to address questions that have been at the core of the neurobiology of language since its inception, addressing the structural and functional basis of phonetic, semantic and syntactic processing. Neuropsychological analysis of brain damage was the dominant method for understanding neural function for over 150 years (see Levelt, 2012), but offered only a relatively gross picture of neural function in language processing, which could not capture the unfolding of neural events among transiently activated brain regions. In contrast, the current state of the art allows characterizing comprehension as a product of network-level interactions at different temporal and spatial scales, and offers promise towards explaining how the brain supports language comprehension in naturalistic, everyday language use.

Yet, the theoretical focus in research into the neurobiological organization of language has largely been maintained on those questions originating in linguistics and psycholinguistics, and theoretical progress in the neurobiology of language has maintained a remarkably stable and linear course of advancement. Experimental work has largely followed a research program wherein: (i) a linguistic function or operation

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[1] This research was supported by European Research Council Starting Grant ERC-STG #263318 NeuroInt to UH, a Fondazione Cariplo-Regione Lombardia grant to MM (grant number 2017-1633), and a Netherlands Organization for Scientific Research (NWO) Vidi grant to RW (grant number 276-89-007). UH's work was conducted in part while serving at and with support of the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

https://doi.org/10.1016/j.cognition.2018.06.018
Received 8 June 2017; Received in revised form 5 June 2018; Accepted 24 June 2018

is defined, (ii) an experimental paradigm manipulates a variable that operationalizes this function, and (iii) regions or networks whose activity or connectivity varies systematically with the levels of the independent variable are interpreted as supporting, subserving, mediating, computing, implementing, or otherwise performing the cognitive process in question. This neurolinguistic approach has catalyzed and advanced research in the neurobiology of language: matching activity patterns to function assists diagnosis in cases of stroke or trauma, is core to studying brain-behavior correlations, and allows sophisticated meta-analyses to draw conclusions about brain regions associated with linguistic functions. Beyond their compatibility with the premises of the lesion-symptom mapping work that initiated the neurobiology of language, several other factors contribute to make neurolinguistic models the tool of choice for studying language in the brain. They set up constrained hypotheses, are for the most part conceptually precise and, by social convention, often limit themselves to examining a single brain region or tightly defined networks. All these factors contribute to clearly written scientific reports, communicating results that map onto the linguistic and psycholinguistic communities' common ground.

However, targeting the neurobiological basis of experimentally isolable processes has offered little by way of understanding how the brain supports language comprehension *as it is carried out in everyday naturalistic discourse*. This means comprehension of ideas presented across multiple sentences. The fact that neurobiological accounts of syntax and semantics drawn from tightly controlled studies may not scale to the discourse level is only one concern. More importantly, the existing paradigm simply does not intend to address questions that are crucial for understanding the neurobiology of Naturalistic Language Comprehension (NLC henceforth). Examples are the interaction between semantic processes and memory encoding or retrieval during comprehension, or the impact of context on online comprehension processes. Thus, there is a real question about whether data from simple experiments are relevant to understanding everyday language processing.

If extrapolation from basic paradigms is not a productive analytic method, how can we study and interpret which principles organize brain activity during NLC? Based on work by us and others, we argue here that addressing this question requires a different explanatory framework. This framework attributes a central role to neurobiological mechanisms that implement language but are not essentially linguistic; holds that context must be considered as fundamental for understanding the neurobiology of language comprehension rather than an additional consideration; and argues that neurobiological accounts of comprehension must divorce from the idea that it is largely dependent on activity within a central language network. In the next subsection we provide a synopsis of these main tenets of the framework, which we then present in detail in the subsequent sections of the manuscript.[2]

### 1.1. Theoretical tenets

*Limiting language-specific interpretations:* Brain activity observed during language comprehension is frequently interpreted in terms of core linguistic processes. Such computations include but are not limited to monotonic integration of information, establishing coherence, and prediction. Despite this, several studies suggest that these effects are parsimoniously explained by basic computations that are not limited to language comprehension, although often documented in areas associated with language comprehension. For this reason, linguistic-related constructs such as semantic or syntactic complexity should not constitute the default interpretive framework. Rather, from first principles, such effects should be adopted after considering alternatives that can be formulated in terms of generic predictive and compositional processes not unique to language. Processes that co-occur during naturalistic comprehension, such as memory operations or emotional responses also fall within this category. Section 2 presents this argument.

*Broadening the notion of context and emphasizing its necessity:* There have been several demonstrations of the impact of context on language comprehension (for reviews, see Hagoort & van Berkum, 2007; van Berkum, 2008). Our argument for an essential role for context in neurobiological explanation derives from a synthesis of this work, as well as recent developments in computational modeling of language. First, during language comprehension, very diverse types of context appear to be integrated within the same time frame. These include prior textual context (co-text), the social context of the communication such as characteristics of the speaker, or personal context such as the beliefs of the comprehenders, or their mood. In addition, contextual integration appears to implicate a limited set of networks that are often involved in semantic processing. We present several generic, non-linguistic computational architectures that can support this broad sort of contextual integration. Our second argument for taking context as an organizing factor is based on studies that suggest that neurobiological conclusions drawn from studies where single-sentences are presented outside of context do not naturally extend to more naturalistic contexts. This is a problem of external/ecological validity. Section 3 presents the argument for opening up the notion of context.

*Letting go of the notion of a stable language network:* Concentrating on a neurobiological language network, defined anatomically or functionally, as a starting point for investigation results in an incomplete understanding of the diverse brain networks that implement NLC and their temporal dynamics. Neuroimaging research shows that during discourse comprehension, brain networks are brought online and offline dynamically, depending on the content comprehended, and that comprehenders' preferences with respect to the type of information on which they focus shape the organization of activity in regions central to comprehension. In addition, brain regions considered outside the canonical language network, such as, for example, posterior midline areas of the human brain often involved in vision, play crucial and largely ignored roles in comprehension. Findings from other neurobiological domains further suggest that assuming a fixed functional language network may be a weak starting position. In developing this point we address several misconceptions often used to support the existence of functional networks for language. First, anatomical connectivity imposes only moderate constraints on functional connectivity or on networks deployed for specific tasks, so it is tenuous to argue that anatomical connectivity constraints result in invariant functional networks. Second, functional networks are inherently non-stationary, and their core topological features are strongly influenced by context, making it difficult to speak of 'a network'. Section 4 presents this argument for letting go of the idea of a core stationary anatomical-functional language network as a neurobiological explanatory construct.

### 1.2. Main aims and structure

Our main aim is to argue for a substantial shift in perspective in how cognitive scientists, who are consumers of neurobiological research, and cognitive neuroscientists who produce this research think about the neurocognitive basis of language comprehension as understood in natural contexts (we avoid here a discussion of production due to the limited neurobiological literature on the topic). We present a research agenda that can advance our understanding of the principles that organize brain activity during language comprehension. Beyond advancing neurobiological knowledge, this progress is also likely to challenge theoretical positions on language in the cognitive sciences. To this end we present a large body of experimental findings, but only in order to illustrate the utility of this approach, as we do not purport to provide an overview of how the brain organizes language.

[2] For readability, we omit references in this section unless necessary for tracking ideas' provenance, as the empirical findings are presented in length in subsequent sections.