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REVIEW

Might language be telepathy?

Juliana NOVO GOMES
Visiting professor at the Federal University of Paraíba (UFPB)

Julia CATALDO LOPES
Federal University of Rio de Janeiro (UFRJ)

ABSTRACT

Seeking to decipher the process of understanding and producing language, Fedorenko reports three discoveries made by her laboratory during the last decade, achieved through behavioral, computational and brain imaging methodologies. First, Fedorenko proposes that regions that support the language are selective only to it. She then argues that regions that support syntactic processing are the same ones that support semantic processing. Finally, Fedorenko suggests that the primary driver for activation in the language region is semantic composition and not syntax, as the literature had been indicating: if a syntactically messed up input provides sufficient evidence for the semantic composition, the language network maximum response is achieved. Thus, syntactic properties could be constrained by communicative pressures. She concludes that, interpreted together, these results point to a strong integration between lexicon and syntax, approaching theoretical models such as construction and usage-based grammars.

RESUMO

Buscando decifrar o processo de compreensão e produção da linguagem, Fedorenko apresenta pesquisas com dados comportamentais, computacionais e de imageria cerebral das última década. Primeiramente, Fedorenko propõe que as regiões que suportam a linguagem são seletivas apenas a ela. Em seguida, argumenta que as regiões de processamento sintático são as mesmas que processam informações semânticas. Finalmente, Fedorenko sugere que o operador dominante para a região da linguagem é a composição semântica e não a sintática, como indicava a literatura vigente: se um input com problemas sintáticos fornece evidências suficientes para a composição semântica, a resposta máxima da rede linguística é

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EDITED BY
Raquel Freitag

REVISED BY
Mahayana Cristina Godoy

ABOUT THE AUTHORS
Juliana Novo Gomes
Contributed with Julia Cataldo Lopes. Papers: conceptualization, writing - original draft, analysis and editing.

Julia Cataldo Lopes
Contributed with Juliana Novo Gomes. Papers: conceptualization, writing - original draft, analysis and editing.

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alcançada. Assim, propriedades sintáticas poderiam ser restringidas por pressão comunicativa. Ela conclui que, tais resultados interpretados em conjunto, apontam para uma forte integração entre o léxico e a sintaxe, aproximando-se de modelos teóricos como as gramáticas baseadas no uso e a de construções.

KEYWORDS
Language Processing. Usage-based Grammars.
Syntax-Semantic Interface.

PALAVRAS-CHAVE
Processamento da Linguagem. Gramática do Uso.
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Evelina Fedorenko's lecture at Abralin ao Vivo – *The language system in the human mind and brain* – brought a buoyant account of contributions of recent behavioral, brain imaging, and computational findings to the functional architecture of language. She started off provoking the audience: "Language can be construed as a shortcut to telepathy". With that instigating remark, she unfolded her language model of how sequences of words can go almost *telepathically* from thoughts in one's head into thoughts in someone else's head. More specifically, she exemplifies how the production of an utterance (encoding) is perceived by someone else (decoding) and serves as the construction's basis of a more abstract representation, which becomes a thought in the listener's mind. Ultimately, in order to achieve success in the final step of the communication, the active content in the speaker's mind should be approximately similar to that in the listener's mind. She defends that, by now, each of the perceptual and motor components of language involved in a communicative framework is known to be supported by a separate set of mental computations, that are implemented in distinct parts of the brain. Human speech perception, for instance, relies on a high-level auditory cortex - highly specialized for speech signals compared to other kinds of sounds. But, the perceptual system regions seem to respond just as much to one's native speech, as it does to foreign or non-words speech (BLANK & FEDORENKO, 2017; MAHOWALD & FEDORENKO, 2016; SCOTT *et al*., 2016; FEDORENKO *et al*., 2010). Similarly, the visual word form area (VWFA), a visual processing region that is specialized in reading, responds very strongly and highly selectively to letters, but not to any kind of script stimuli. So apparently, those regions are not as sensitive to *meaning*, as to *perceptual features*. Thus, content in language became Fedorenko's group research goal: *How thoughts and high-level meanings can be inferred from linguistic utterances*. Among other research questions involving language in the brain, she highlighted three, whose results she discussed in this lecture.

The first research question focuses on examining two localization hypotheses: (a) that the regions that support language are selective for language only or (b) that those regions support other abilities. The second research question explores if the regions that support syntactic processing *vs.* word meanings are (a) distinct or (b) the same. Finally, their third research question concerns the big theoretical debate of whether the primary driver for activation in the language region is (a) structure building or (b) semantic composition.

The answer to the first research question of whether there are brain regions selective for language aims at showing that the language system plausibly develops in a similar way to that of the VWFA, that, according to Fedorenko, is an example of "experientially driven functional specialization through development", since in terms of evolution there has been no need for an innate machinery for reading yet. So, Fedorenko presents a study that uses previously defined language-responsive baseline regions trying to localize overlapping processing of linguistic and non-linguistic stimuli in those language specific regions. She first shows the results of a study undertaken with control speakers and global aphasics (lacking a properly functioning language mechanism). The results indicate a high-selectivity for linguistic input across language-specific brain regions, including across the whole frontal temporal network, contradicting many language processing models that suggest overlapping of different cognitive processing in language-specific brain regions, such as arithmetic, executive computation, music perception, actions/gestures perception, social skills, among others. Fedorenko argues that previous results that indicate that different cognitive regions overlap in language processing might be the consequence of flawed methodologies and reverse inferences (PRITCHETT *et al.*, 2018; FEDORENKO & VARLEY, 2016; FEDORENKO *et al.*, 2012; FEDORENKO *et al.*, 2011). Furthermore, results of FMRI studies show that severely impaired language individuals can nevertheless process arithmetic, causal reason, music, spatial navigation and social cognitions. Fedorenko, thus, concludes that other cognitions do not endure the same damages as language does and that language is not a requirement for high-level thought. She points out that the language specialization in the brain does not imply innateness. It is most likely that these abilities are developed through early experience. Hence, the answer to the first research question is: the regions that support language processing are *(a) selective for language.*

Her second research question is whether brain regions that support word meanings are the same as those that support syntactic processing. She reviewed some of the early linguistic theories on the processing of words and phrases (VANDENBERGHE *et al.*, 2002; BEMIS & PYLKKANEN, 2020; PALLIER *et al*, 2011; FRIEDERICI, 2011; TYLER ET AL., 2011; HAGOORT, 2005; HAGOORT, 2013; BORN-KESSEL-SCHLESEWSKY *et al.*, 2015; MATCHIN & HICKOK, 2020). Some of them suggest that linguistic mechanisms are distinct, but that word and phrasal meanings processing are qualitatively done in a similar fashion. Hence, Fedorenko highlights the utility of models that deal with the distinct linguistic experience tightly together. This way, she questioned the existence of brain regions dedicated only to syntax, and not coupled to word meanings. Her argument was divided into two main hypotheses: (i) combinatorial (syntactic/semantic) processing would be distributed across the language network: although a lot of studies argue that the core of syntactic processing happens in a

particular brain region, such studies point to at least three different areas (inferior frontal cortex, posterior temporal cortex and anterior temporal cortex) (FEDORENKO *et al*., 2010; SCOTT *et al*., 2016); (ii) any region that responds to syntactic processing would be at least similarly sensitive to the meaning of words as well (BLANK *et al*., 2014; MINEROFF *et al*., 2018; PAUNOV *et al*., 2019). Comparing FMRI and intracranial studies, the same response patterns were observed: lexical processing responses were always present and larger responses were found in structural building processing regions. Hence, Fedorenko answers the second question: the lexical access regions are *(b) the same as those that support syntactic processing*. These results are in line with behavioral studies' evidence and with the usage-based grammars approach.

Fedorenko then moved on to her last research question: is the primary driver for language processing activated more by structure building or by semantic composition? She began by reasoning why the preferred stimuli for language brain regions are sentences, as testified in the literature (FEDORENKO *et al*., 2016; GIBSON *et al*., 2013; LEVY *et al*., 2008; FERREIRA *et al*., 2002). She wonders *what it is about a sentence that makes it so appealing to processing.* She then presents an experiment comparing functional words in sentences (well-formed and with no meaning) with word list and no-word list. The result shows a build-up effect (an incremental activation related to the sentence build-up stimuli), and no effect in response to word-list or non-word list stimuli, suggesting to her more engagement in processing meanings in a sentence, than in processing structure.

In order to support a language model that explains how sequences of words can go nearly "telepathically" from one's head into thoughts into someone else's head, Fedorenko proposes a model in which even syntactic properties could be constrained by communicative pressures. Besides, she advocates that, as the language input is flawed, full of errors and interruptions, language implementation mechanisms seem to be designed for coping with syntactic error, in a way that plausible meaning is recoverable. Hence, interpretation should be driven by meaning, in spite of local and global structural constraints. Thereby, Fedorenko hypothesized that language network maximal response would be achieved as long as the input provides sufficient evidence for semantic composition. In order to test this hypothesis, Fedorenko reports a study using *local pointwise information* (PMI) to measure mutual and local dependence between words (COVER & THOMAS; 2012). Using the indices of PMI in response to sentences, such as "*On their last day they were overwhelmed by farewell messages and gifts*", compared to up to seven progressive scrambled versions of it, the study put to test the capability of combining words and extracting meaningful ideas even from damaged syntactic structure which does not support their semantic composition (MOLLICA *et al*., 2020). If the structural scrambling preserves the local PMI, then it would mean that semantic composition is the primary driver of the language region's responses. Results show that PMI indices stayed flat among six of the seven progressive swaps, indicating that the strong response to sentence processing was driven by meaning, since the structure was all messed up. In a follow-up experiment, in which semantic relation measures by the PMIs was minimized to the minimum level, results suffered a drop-off – the experimental sentences were not interpreted as being different from that in a list of unconnected words. Taken together, the two results indicate the importance of the locality component

(semantic composition) and not the structural building algorithm. Thus, Fedorenko's answer to her final question is: the primary driver for the language region activation is *(b) semantic composition*.

Fedorenko ended the lecture highlighting her contributions to the theoretical field of neural architecture of language, supporting that language, as a mechanism of exchanging thoughts, is guided by means of semantic composition analysis, as opposed to structural building. She advanced that although syntactic processing has been the main focus of a lot of theoretical and empirical work on Language processing, these theories have been misguided and the focus of current research should shift towards the understanding of how we manage to get meanings across. To take home, she implies that *telepathy* is all about exchanging meaning from one head to another.

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