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REVIEW

The language–ready brain

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ABSTRACT
Researchers have been interested in the neurobiological bases of language processing since some centuries. In such sense, Professor Peter Hagoort's lecture at Abralin Ao Vivo successfully enriched the debate regarding the neurocognitive bases of language. The present review provides the reader with a detailed summary of the major topics addressed in the conference. The Classical Model for language production and comprehension (also known as the Wernicke-Lichtheim-Geschwind model) and its limitations, and the Memory, Unification, Control (MUC) Model, proposed by Hagoort (2005, 2013, 2016), and its contributions for the study of the neurobiology of language were discussed. Moreover, relevant relations were made in the present review regarding the priming paradigm, syntactic and semantic unification processes and the domain-general circuits recruited for the full operation of the language system.

RESUMO
Pesquisadores têm se interessado pelas bases neurobiológicas do processamento da linguagem há séculos. Assim, a conferência do professor Peter Hagoort no evento Abralin Ao Vivo contribuiu ricamente para o debate acerca das bases neurobiológicas da linguagem. A presente resenha fornece ao leitor um resumo detalhado das principais questões abordadas na conferência. Discutem-se o Modelo Clássico de produção e compreensão da linguagem (também conhecido como o modelo Wernicke-Lichtheim-Geschwind) e suas limitações, assim como o Modelo Memória, Unificação e Controle (MUC), proposto por Hagoort (2005, 2013, 20016), e suas

contribuições para o estudo da neurobiologia da linguagem. Além disso, nessa resenha são feitas relações pertinentes sobre o paradigma de *priming*, os processos de unificação sintática e semântica e o recrutamento de circuitarias de domínio geral para a plena operação da linguagem.

KEYWORDS
Neurobiology of Language. Peter Hagoort. MUC.

PALAVRAS-CHAVE
Neurobiologia da Linguagem. Peter Hagoort. MUC.

What are the components of the language system? How are they implemented in the organization of its underlying brain structures? Aiming at presenting some possible answers for such questions, Prof. Hagoort gave a lecture at Abralin Ao Vivo entitled *The core and beyond in the language-ready brain.* Indeed, he succeeded at conducting its viewers through an informative account of his research as well as at providing them with an overview of the psycholinguistic and neurobiology of language fields of research. The present review will display some of the main topics approached by Prof. Hagoort. While doing so, we will enrich the discussion by making further considerations based on his published work as well as on the work of other researchers from the field of psycholinguistics and neurobiology of language.

Before presenting his model, Hagoort made some considerations regarding the Classical Model for language production and comprehension (also known as the Wernicke-Lichtheim-Geschwind model). Based on the seminal work of Broca (1861), Wernicke (1874) and Lichtheim (1884), the Classical Model proposes that language comprehension and production are subserved by two areas located in the left perisylvian cortex: Broca's area (in the left inferior frontal cortex, LIFC) and Wernicke's area (in the left temporal cortex) respectively. These areas are proposed to be connected by the arcuate fasciculus (AF). However, despite the importance of the Classical Model as the first attempt at describing a cognitive architecture for language processing, it had some limitations. Firstly, it was based on single word processing. As such, it could not account for the dynamicity present in online language processing. Secondly, it indicated that comprehension and production are subserved by different cortical areas/circuitries. However, current research has shown that this might not be the case (*cf*., WEBER; INDEFREY, 2009; MENENTI *et al.*, 2011; SEGAERT *et al.*, 2012). Finally, Prof. Hagoort presented his own neurobiological model of language processing, the Memory, Unification and Control (MUC) Model.

The MUC model (HAGOORT, 2005; 2013; 2016) proposes that language processing relies upon three functional components. Being the only language-specific component, Memory is responsible for the storage of linguistic knowledge in the neocortical memory structures (HAGOORT, 2016). After being retrieved, such linguistic knowledge must be combined in order to build larger syntactic structures. Thus, the retrieved lexical items are combined together in the Unification workspace of the model. In this regard, the left inferior frontal cortex (LIFC) is crucial for the binding of such syntactic frames (HAGOORT, 2003). Finally, the Control component is related to the fact that the language system operates considering communicative intentions and actions (HAGOORT, 2005). For example, Control is responsible for the inhibition of irrelevant information during language interaction and, consequently, is used by a bilingual in order to suppress an irrelevant language.

Importantly, the aforementioned presence of domain-general components at the MUC model is in consonance with Jackendoff's (2002) claim that language processing relies upon independent combinatorial systems. Moreover, the domain-general nature of the Unification and the Control components is largely supported by experimental data. As mentioned by Prof. Hagoort during his lecture, the Unification component is shared with other domains such as music and arithmetic. Indeed, Van de Cavey and Hartsuiker (2016) found evidence of the existence of structural connections between sentences, music and arithmetic. Moreover, the Control component involves areas that are, for example, traditionally related with working-memory capacity (*e.g.*, the dorsolateral prefrontal cortex) and that can be triggered during sentence comprehension (CAPLAN; WATERS, 1999).

The pursuit of a suitable experimental approach to study issues of both language processing and representation is ongoing. Current research has successfully been using the syntactic priming paradigm when addressing such issues, as explained by Prof. Hagoort. Syntactic priming relates to the effect of facilitation that previous processing of a stimulus A has on the processing of stimulus B.[1] Among other qualities of the priming paradigm, its capacity of determining whether or not two stimuli share some level of representation is of keen importance for debate of language processing and representation and their implementation in the brain (BRANIGAN; PICKERING, 2017). Thus, if the Classical model was accurate and language comprehension and production were indeed subserved by different brain structures, cross-modality priming effects should not be found.

Cross-modality syntactic priming effects refer to the occurrence of priming effects between stimuli that do not share the same modality (e.g., production to comprehension or comprehension to production). In a series of event-related fMRI experiments, Segaert and colleagues (2012) found the same adaptation effects in left inferior frontal gyrus (IFG), left middle temporal gyrus (MTG) and bilateral supplementary motor area (SMA) regardless of modality change. That is, they found the same neuronal populations to be recruited during language comprehension and production. Such results, according to Prof. Hagoort during his lecture, can be further used as evidence against the Classical model.

Moving away from syntactic unification, Prof. Hagoort also addressed the topic of semantic unification. In order to successfully comprehend and produce language one should go beyond constructing syntactically appropriate sentences. Indeed, some sort of combinatorial operation should be

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1 For the first study on syntactic priming, see Bock (1986); for a critical review on structural priming, see Pickering and Ferreira (2008); and for an experimental approach to linguistic representation, see Branigan and Pickering (2017).

implemented in order to construct a coherent interpretation of multi-word utterances (HAGOORT, 2017). Based on issues regarding the specificities of the semantic unification two opposite approaches arose: the strict compositionality and the situation model accounts (KINTSCH; RAWSON, 2005). According to the former, syntax is the core machinery of binding operations. Differently, the latter account views linguistic expressions as processing instructions used to create a mental representation of a text. Providing evidence for situation model accounts, Prof. Hagoort presented a study by Van Berkum *et al.* (2008) that used event-related potentials (ERPs) to investigate the unification of information about the speaker and the message. The results showed that language comprehension rapidly considers the social context. Such integration about the speaker and the message occurs prior to 200-300 milliseconds after the onset of a spoken word. Accordingly, the construction of meaning is only possible when considering the social aspects of language use (VAN BERKUM *et al.*, 2008).

At the final moments of his lecture, Prof. Hagoort addressed the claim that the language system in the brain has components that are beyond the core regions of Broca and Wernicke. That is, language processing depends upon a much more extended network constituted by specialized core regions and a domain-general periphery (FEDORENKO; THOMPSON-SCHILL, 2014). Such periphery is constituted by circuits that are not specialized for language; however, they need to be recruited for the sake of successful linguistic interaction. One example is the attentional network, which seems important for perceiving linguistic phenomena such as topicalization during listeners sentence comprehension and speakers sentence production. The other is the Theory of Mind (ToM) network, which seems crucial for speakers to make inferences about each other's minds during the language (de)coding process and sentence construction (JACOBY; FEDORENKO, 2018; PAUNOV; BLANK, FEDORENKO, 2019).

Overall, Prof. Hagoort succeeded at addressing important topics from the field of psycholinguistics and neurobiology of language. For example, he explained that the connectivity of the language network is much more extended than previously thought. Moreover, the labor distribution of core regions in the left perisylvian cortex during language comprehension and production is structurally different than proposed in the Classical Model. Such inconsistencies between the Classical Model and the more recent experimental evidence about the cognitive architecture of language processing create a fertile land for the dawning of new accounts on the neurobiology of language. In sum, Prof. Hagoort’s approach is tripartite (Memory, Unification and Control) and his model labor division is not absolute. That is, the operation of the language system depends upon dynamic domain-general and -specific networks which enable the human brain to seek the intentions behind the speakers’ articulations. Finally, as stated by Prof. Hagoort, all these processes are paramount to the shaping and mastering of the operations of language in its full glory.

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