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Elliot Murphy, *The oscillatory nature of language*. Cambridge: Cambridge University Press, 2020. Pp. xiii + 321.

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As David Poeppel and David Embick explain (Poeppel & Embick 2005, Embick & Poeppel 2015), theoretical linguistics and psycho/neurolinguistics generally work with conceptual units of disparate granularity, often assuming that their research programs are mutually independent following rigid interpretations of the classical distinctions between COMPETENCE and PERFORMANCE (Chomsky 1965) or COMPUTATIONAL and ALGORITHMIC/IMPLEMENTATIONAL levels of analysis (Marr 1982).[1] Crucially, this conceptual mismatch between disciplines has hindered the development of integrative accounts that fruitfully combine their respective insights. In this book, Elliott Murphy pursues an interesting solution to this cross-disciplinary problem, focusing on the implications of a particular type of brain activity – neural oscillations – for a competence-based model of language aimed at explaining how the brain computes syntactic structures. Culminating Murphy's ideas developed in earlier publications (see e.g. Murphy 2015, Benítez-Burraco & Murphy 2019), this book represents a thoughtful attempt to integrate two alternative approaches to syntax – theoretical linguistics and neurolinguistics – within the broader context of evolution and cognitive neuroscience.

The book begins with an introductory chapter presenting the central concepts from linguistic theory and neural oscillations. Although the proposed model is primarily based on theoretical constructs from mainstream generative linguistics (Merge, Labelling, features, etc.), the explored issues are likely relevant for other linguistic frameworks. This chapter also advances the ambitious goal of affirmatively responding to a fundamental question: is there 'a neurally implemented computation that builds syntactic structure and does not compute any meaning' (Pylkkänen 2019: 64)? According to Murphy, neural oscillations – the OSCILLOME, in

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Murphy's terms – provide the answer. Neural oscillations reflect rhythmic electrophysiological activity originating from neural populations, which can be recorded using various techniques. These oscillations are typically classified, according to their frequencies/temporal rates – ranging from lower/slower to higher/faster rhythms – into FREQUENCY BANDS: delta (< 4 Hz) < theta (4–8 Hz) < alpha (9–12 Hz) < beta (13–30 Hz) < gamma (> 30 Hz). Following the strategy advocated by Poeppel and Embick to boost cross-disciplinary advancement, Murphy tries to establish a direct link between decomposed computational operations and corresponding properties of such oscillatory frequency bands.

Chapter 1 introduces Murphy's background assumptions about language – largely corresponding to biolinguistic approaches within the framework of generative linguistics. Accordingly, language is conceived as a biological system examined in terms of internal cognitive computations rather than externally-oriented communication. In addition, the crucial human-specific component of language is the capacity to recursively generate hierarchically organized syntactic phrases (i.e. phrases within phrases). Following generativist assumptions, hierarchical phrase structure is understood to be generated by the computational operation Merge, which can itself be decomposed into two sub-operations: Concatenation (non-hierarchical binary combination) and Labelling (specification of syntactic categories that impose hierarchy). After reviewing animal studies suggesting that non-human species lack hierarchical syntactic capacities, Murphy defends the LABELLING HYPOTHESIS: Labelling is the critical evolutionary novelty specific to humans. Crucially, this chapter precisely outlines the connection between theoretical and experimental approaches to language. Building on previous accounts, it assumes 'transparent mapping between syntax and sentence processing; namely, the computational level denotes the offline properties of the system (it can search, merge, copy, label, etc.) and the algorithmic level denotes its real-time execution' (49) (for further discussion, see Martorell 2018). Murphy interestingly considers neural oscillations at the algorithmic level of analysis, pointing to their relevance in the temporal unfolding (WHEN) and order (HOW) of executed operations, which goes substantially beyond the common algorithmic interpretation of psycholinguistic behavioural evidence (see Martorell 2018).

Chapter 2 engages with the neurolinguistic literature. Before addressing neural oscillations, it briefly reviews anatomical evidence – mainly from neuroimaging studies – on implementation of language in classical brain regions from frontal (e.g. Broca's) and temporal (e.g. Wernicke's) areas as well as the fibre tracts that connect them (for a review, see Goucha, Zaccarella & Friederici 2017). As Murphy discusses, while this implementation-level approach may reveal WHERE in the brain certain operations are localized, its temporal imprecision cannot capture the intricate time-varying properties of brain dynamics that operate at much faster timescales (for further discussion, see Poeppel & Embick 2005, Embick & Poeppel 2015). By contrast, as Murphy argues, neural oscillations exhibit algorithmic-like temporal sensitivity, making them the perfect candidate to explain WHEN and HOW language operations dynamically manifest in brain regions. Going beyond the more

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traditional analyses of electrophysiological signals such as event-related potentials, current neurolinguistic research is increasingly focused on neural oscillations (for a recent review in the context of syntactic processing, see Martorell et al. 2020). Murphy critically examines a broad range of cognitive neuroscience findings on neural oscillations, considering various types of electrophysiological studies on language (single-word, sentence-level comprehension, etc.), but also research on other cognitive domains (auditory/visual attention, memory, navigation, etc.). By interpreting these linguistic and non-linguistic findings with respect to their computational roles, Murphy seeks to accommodate them in the proposed model of syntactic computation. A distinctive feature of Murphy's approach is the emphasis on cross-frequency interactions between these brain rhythms, apart from their independent contributions (see below). Also interesting is the attention to the involvement of brain regions beyond the cortex (i.e. subcortical areas, especially the thalamus) in coordinating syntax-sensitive oscillations. By providing the building blocks of the model, Murphy exhaustively underscores the significance of exploring new avenues for syntactic computation: from the mostly static localizationist approach of neuroimaging studies to the dynamic perspective of interactive and distributed oscillatory networks.

Chapter 3 expands the discussion on the role of neural oscillations in syntactic computation, providing a fully detailed picture of the proposed model. As noted above, the model is based on interactions across neural oscillations and, more concretely, focuses on their distinctive hierarchical relationships: faster/higher frequencies are embedded within slower/lower frequencies. This results in a hierarchy of nested oscillations, displaying multi-dimensional interactions (technically, between amplitude and phase) across all frequency bands. Specifically, in Murphy's model, fast gamma oscillations represent linguistic features (mainly morpho-syntactic features such as tense, person, number, or gender), which are concatenated into lexicalized syntactic objects as they are embedded in slow theta oscillations. These theta-embedded gamma oscillations – assumed to reflect Concatenation – then slow down becoming beta oscillations – assumed to reflect Labelling – as they combine with other lexicalized objects, giving rise to hierarchical configurations. Furthermore, these theta-embedded beta oscillations indexing hierarchical phrases are in turn embedded in even slower delta oscillations, resulting in sentence-level structures with multiple simultaneously nested phrases. Thus, the model seems to provide a neurally plausible explanation for syntactic computation through the dynamic interplay of such hierarchically organized neural oscillations. Going even further, Murphy also claims that the hierarchical status of syntactic structures – along with certain limitations on the kinds of syntactic relations possible in language – emerges directly from the hierarchical organization of neural oscillations. In other words, neurobiological constraints would determine the characteristics of potential syntactic structures, thus arguing for a close mapping between linguistic and neural levels. Note that this claim aligns with evolutionary considerations prevalent in biolinguistic approaches, which stress the critical role of non-linguistic principles (so-called 'third factors') in shaping certain aspects of

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language. Likewise, it also highlights the domain-general perspective of the model on the computational properties of syntax, as manifested in the frequent reference to non-linguistic research results. This chapter also includes interesting suggestions on potential extensions of the model, which concern recent developments in generativist syntactic theory (e.g. memory workspaces) and also recent findings in cognitive neuroscience (e.g. travelling oscillations).

Finally, Chapter 4 reviews the main claims from previous chapters, synthesizing the core components of the model. It also discusses how the model meets Poeppel and Embick's call for cross-disciplinary progress. This chapter concludes by noting some questions that still need to be addressed in future developments of the model.

A distinctive characteristic of the book is its constant attention to cross-disciplinarity, making several substantial points on this issue. Firstly, by explicitly stating the transparent relationship between computation and algorithm (Chapter 1, see above), it provides a linking hypothesis crucial to make the discussed oscillatory findings directly relevant for the proposed competence-based model. Otherwise, linguistic and neurolinguistic discoveries would pertain to radically distinct domains and any correspondence would remain merely coincidental. Secondly, this computation-algorithm connection is achieved by targeting decomposed computational operations (i.e. Merge subdivided into Concatenation and Labelling), in accordance with Poeppel and Embick's suggestions. Critically, because of these important linking hypotheses and regardless of the ultimate validity of the specific proposal, Murphy manages to make an apparently plausible conceptual match between linguistic constructs and the potential function of neural oscillations. In addition, despite the focus on bridging the computational and algorithmic (OSCILLOMIC) levels, the model also considers the implementation of such oscillatory dynamics. Therefore, Murphy's approach is simultaneously formulated at all three of Marr's levels, thereby constituting an interdependent computational-algorithmic-implementational account. Likewise, using Chomsky's terms, the proposed model is jointly concerned with competence AND performance. Based on these considerations, it represents a legitimate example of how to proceed with multi-level integration across language disciplines.

However, an important concern arising from the general argumentation is the presumably exclusive role of syntax – as opposed to semantics – in the proposed oscillatory model. Although Murphy recognises the involvement of semantic factors in cross-frequency interactions (e.g. fast gamma oscillations may represent some sort of semantic features), most of the reviewed findings are interpreted as primarily reflecting the syntactic aspects of language. This is also made explicit in the introductory chapter, when providing an affirmative response to Pylkkänen's (2019) question about the feasibility of neural-level syntax independent of meaning. It is critical to note that syntax and semantics are certainly intertwined (e.g. structure and meaning correlate with each other to a considerable extent), and this makes it extremely challenging to tease them apart in any experiment (for further discussion, see Pylkkänen 2019, Martorell et al. 2020). Moreover, a certain amount of evidence allegedly supporting Murphy's model comes from studies that have conflated syntactic and semantic aspects in their experimental manipulations (e.g. lacking linguistic stimuli exclusively differing in either structure or meaning). Similar concerns surround the interpretation of findings from non-linguistic domains. Although making connections between specifically linguistic and domain-general processes is critical for any biologically plausible theory – and for understanding them from an evolutionary perspective – distinguishing between syntax-like and semantics-like components might be even more elusive in certain non-linguistic experiments. Therefore, it is unclear to what extent the oscillatory findings that Murphy interprets as purely structural might actually reflect the (additional) involvement of meaning (for further discussion, see Martorell et al. 2020). Carefully controlled experiments are definitely needed to elucidate these concerns and, more generally, to test Murphy's model empirically.

To conclude, the book emphasizes the growing importance of neural oscillations for the study of language. Most significantly, it highlights the value of integrating findings from diverse (non-)linguistic theoretical and experimental approaches in the context of linguistic computations. This cross-disciplinary orientation is precisely what makes the book potentially interesting for researchers from a wide range of disciplines – even beyond the language domain.

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