https://doi.org/10.1038/s41583-023-00734-5

What oscillations can do for syntax depends on your theory of structure building

Cas W. Coopmans [1,2] ✉, Anna Mai[2], Sophie Slaats[2], Hugo Weissbart [1] & Andrea E. Martin[1,2]

[1]Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, The Netherlands. [2]Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands.

✉e-mail: cas.coopmans@mpi.nl

Published online: 11 September 2023

In their timely Perspective article (Kazanina, N. & Tavano, A. What neural oscillations can and cannot do for syntactic structure building. *Nat. Rev. Neurosci.* **24**, 113–128 (2023))[1], Kazanina and Tavano argue that neural oscillations cannot linearly chunk (or segment) speech into syntactic constituents because constituents are defined in terms of hierarchical relations. Instead, they propose that oscillations could support syntactic structure building (SSB) through 'multi-scale integration' of hierarchically organized constituents. We agree with their arguments against the utility of chunking for SSB. However, the dichotomy between 'oscillations for chunking' and 'oscillations for integration' does not accurately represent the literature: the integratory role of oscillations is well-accepted[2,3], and chunking is not a candidate model of SSB. Here, we show that recent work on oscillations and syntax[4,5] does not assume chunking and we identify principal challenges for the integration proposal put forward by Kazanina and Tavano.

Syntax builds hierarchical structures, so sentences cannot be described in terms of sequential properties[6]. As phrases are hierarchically embedded in one another, phrase length is highly variable, and no regular 'phrase rhythm' occurs in sentences. On the basis of these facts, Kazanina and Tavano convincingly argue that oscillations cannot support SSB via naive phrase chunking. However, they incorrectly attribute this view to authors who have used oscillations to investigate neural sensitivity to syntax[4,5]. Contrary to Kazanina's and Tavano's claims, neither ref. 4 nor ref. 5 argues that phrase durations in natural language fall within a narrow frequency band or that phrases follow one another linearly without overlap. Thus, these results can be informative about the hierarchical nature of SSB without a chunking perspective on neural oscillations[7].

As Kazanina and Tavano point out, neural mechanisms for SSB must be able to encode structural relationships between hierarchically organized elements (for example, dominance, scope), but their proposed solution based on cross-frequency interaction faces critical challenges. First, it relies on a neurobiological model of sequence encoding, which represents 'horizontal' information about ordinal positions in a sequence[8]. However, what matters for hierarchical syntax is the 'vertical' relation between a constituent and its subordinate elements (for example, that 'eat cookies' is a verb phrase, not a noun phrase)[6], which is not represented in the neural sequence code. Second, it is unclear how 'relational' information, as found in long-distance dependencies, could be extracted. In Kazanina's and Tavano's multi-scale integration view, high-band-frequency encodings of non-adjacent words occupy different phases of low-band-frequency oscillations. But the crucial question — that is, how the dependency between distant words is then resolved — remains unanswered. Third, their integration proposal relies on a one-to-one correspondence between embedding of constituents and embedding of high-frequency into low-frequency oscillations. Kazanina and Tavano correctly argue against a temporal correspondence between the lengths of phrases and oscillatory cycles, but their proposal assumes an equally transparent correspondence between hierarchy in syntax and hierarchy in oscillations. Such a strict isomorphism between cognitive and neural units, whether temporal or hierarchical, is, in our opinion, unlikely to be correct[9].

To explain the potentially oscillatory underpinnings of SSB, Kazanina's and Tavano's multi-scale integration proposal remains underspecified, and would be strengthened if it explained how 'vertical' and 'relational' information, needed for truly hierarchical relationships, could be encoded. Only when this type of information is incorporated in a theory of structure building can we properly evaluate what oscillations can do for syntax[10].

There is a reply to this letter by Kazanina, N. & Tavano, A. *Nat. Rev. Neurosci.* https://doi.org/10.1038/s41583-023-00735-4 (2023).

References

1. Kazanina, N. & Tavano, A. What neural oscillations can and cannot do for syntactic structure building. *Nat. Rev. Neurosci.* **24**, 113–128 (2023).
2. Giraud, A.-L. & Poeppel, D. Cortical oscillations and speech processing: emerging computational principles and operations. *Nat. Neurosci.* **15**, 511–517 (2012).
3. Lewis, A. G. & Bastiaansen, M. A. predictive coding framework for rapid neural dynamics during sentence-level language comprehension. *Cortex* **68**, 155–168 (2015).
4. Ding, N., Melloni, L., Zhang, H., Tian, X. & Poeppel, D. Cortical tracking of hierarchical linguistic structures in connected speech. *Nat. Neurosci.* **19**, 158–164 (2016).
5. Kaufeld, G. et al. Linguistic structure and meaning organize neural oscillations into a content-specific hierarchy. *J. Neurosci.* **40**, 9467–9475 (2020).
6. Chomsky, N. *Syntactic Structures* (Mouton, 1957).
7. Coopmans, C. W., de Hoop, H., Hagoort, P. & Martin, A. E. Effects of structure and meaning on cortical tracking of linguistic units in naturalistic speech. *Neurobiol. Lang.* **3**, 386–412 (2022).
8. Jensen, O. & Lisman, J. E. Hippocampal sequence-encoding driven by a cortical multi-item working memory buffer. *Trends Neurosci.* **28**, 67–72 (2005).
9. Poeppel, D. & Embick, D. in *Twenty-First Century Psycholinguistics: Four Cornerstones* (ed. Cutler, A.) 103–118 (Routledge, 2005).
10. Martin, A. E. Language processing as cue integration: grounding the psychology of language in perception and neurophysiology. *Front. Psychol.* **7**, 120 (2016).

Acknowledgements

The authors thank S. ten Oever, A. G. Lewis and P. Hagoort for helpful comments on an earlier version of this work. A.E.M. was supported by the Lisa Meitner Research Group 'Language and Computation in Neural Systems' from the Max Planck Society and by the Netherlands Organisation for Scientific Research (grant number: 016.Vidi.188.029).

Competing interests

The authors declare no competing interests.