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

We thank Coopmans et al. for their comments on our recent Perspective (Kazanina, N. & Tavano, A. What neural oscillations can and cannot do for syntactic structure building. *Nat. Rev. Neurosci.* **24**, 113–128 (2023))[1], which are valuable (Coopmans, C. W., Mai, A., Slaats, S., Weissbart, H. & Martin, A. E. What oscillations can do for syntax depends on your theory of structure building. *Nat. Rev. Neurosci.* https://doi.org/10.1038/s41583-023-00734-5 (2023))[2].

In the 'Oscillations for chunking' section, which is the focus of the first point of Coopmans et al.'s commentary[2], we argued that the approach and claims from a study of a 'toy' grammar[3] do not straightforwardly generalize to the study of syntactic structure building in natural language[4]. Reference 3 used a highly limited grammar and demonstrated neural tracking of its phrases and sentences. Owing to the restricted, isochronous stimuli, its findings are compatible with either chunking or integration views, or even with a non-oscillatory account (see page 119 of our Perspective[1]). Reference 4 specifically aimed to investigate neural tracking of syntactic structure in natural language, yet simplifications were made: there was no overlap between the word and phrase frequency ranges; only two-word constituents were chosen to represent the phrase level; and phrases were operationalized as following one another without overlap (see Table 1 in ref. 4). Our contention is that, considering these choices, which are all essential from the chunking perspective, the approach in ref. 4 fell short of accounting for how syntactic structure is constructed in natural language: abstracting away from overlapping word and phrase durations, varying phrase length, phrases nested within other phrases and non-adjacent relations invalidates the core aim of elucidating natural language.

In the 'Oscillations for integration' section, we reviewed two proposals[5,6] that used phase coding to encode syntactic relations and hold promise in our view. Coopmans et al.[2] identify three challenges for these proposals. First, using principles used for sequence encoding as in ref. 5 would lead to a failure to represent 'vertical' relations in the hierarchy. However, while phase coding is used to encode sequence order[7], 'sequence order' is nothing but a readout[8], that is, an interpretation of what that code represents; other readouts are conceivable. For syntactic encoding, the phase code could encode grammatical rules. For example, a verb (V) and a noun phrase (NP) within the same cycle can be read out as a verb phrase (VP) in accordance with the rule VP → V + NP, thereby effectively encoding vertical relations. This view naturally addresses the second challenge, that is, handling of long-distance dependencies: notwithstanding their linear order, non-adjacent dependency elements can be each phase-coded into a slow-wave cycle. The parser assumes a crucial function in determining which elements can be read out together and how — which is precisely why we advocated, in our Perspective, for the integration of a well-developed parsing theory alongside any neurobiological approach to structure building.

Finally, Coopmans et al. make the excellent point that no valid neurobiological solution can be entrenched in a one-to-one correspondence between hierarchy in syntax and hierarchy in oscillations. Such a correspondence is implied in the DORA[6] (discovery of relations by analogy) model (and, presumably, VS-BIND[5] (vector-symbolic sequencing of binding instantiating dependencies)) and was pointed out in our discussion of DORA's 'strict layering' (see page 123 of ref. 1): put simply, if creating 'dry fur' requires a certain frequency, then 'dusty dry fur' requires a slower frequency, and so on for each next level of hierarchy. Any framework that uses phase coding for syntactic structure building should find means to encode an adequate level of hierarchical depth while staying within the limits of the oscillatory depth. To this end, we find promise in the idea of implementing recursion through a two-level abstract chunking structure and a backward loop from the lower to the higher level[9,10]. Currently, this is largely an algorithmic level proposal; future research on the underlying neurobiological mechanisms will evaluate its implementational feasibility.

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Competing interests

The authors declare no competing interests.