

Neuronal entrainment to phrases with different structures

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Ding et al. (2016, 2017) introduced a MEG/EEG paradigm in which monosyllabic words are auditorily presented at a fixed rhythm. It has been shown that when these sequences are built by phrases and sentences of fixed lengths, the peaks at their frequencies can be measured in the power spectrum density (PSD) of the whole trial. The interpretation of these peaks in terms of tracking hierarchical syntactic representations has been challenged by Frank and Yang (2019), who showed that regularities in the semantic similarity across words in the sequence can simulate these PSD patterns. Further studies showed that these peaks are larger for sentences than for word lists with comparable semantic rhythmicity (Lu et al. 2023) and for regular versus reversed sentences (Lo et al. 2022), allowing to exclude that these peaks represent just the regularity of semantic distance between subsequent words. However, as Frank and Yang (2019) argued, other regularities of lexical and distributional properties can also contribute to these peaks. Kazanina and Tavano (2023) opened the debate about the neurophysiological mechanism underlying these peaks, contrasting oscillation for chunking with oscillation for integration, with some relevant implications with respect to statistical versus rule-based models of sentence processing.

In our EEG study we presented subjects with sequences (10 per condition) of 72 Italian syllables (duration 17s), visually presented at the center of the screen (SOA 233ms) which build sequences of 6-syllable sentence formed by two 3-syllable phrases. Italian language has few monosyllabic words, a richer inflection, and more freedom in word order with respect to languages previously tested with this paradigm (mainly Chinese and English). This allowed us to create two different experimental conditions (*Type*): the *mixed* condition (1) has little regularity of lexical boundaries and of distributional properties of words and syllables (e.g. syllable frequency, part of speech, number of characters, presence of inflections); the *copular* condition (2) in which these regularities become massive. We contrasted both type of stimulation with randomized sequences of the same syllables (*Language* condition). The choice of syllable-by-syllable visual presentation is aimed to have more anatomical distance between areas which are expected to show entrainment linked to perceptual and lexical level processing (visual areas) and areas expected to show entrainment due to compositional processes (fronto-temporal language network).

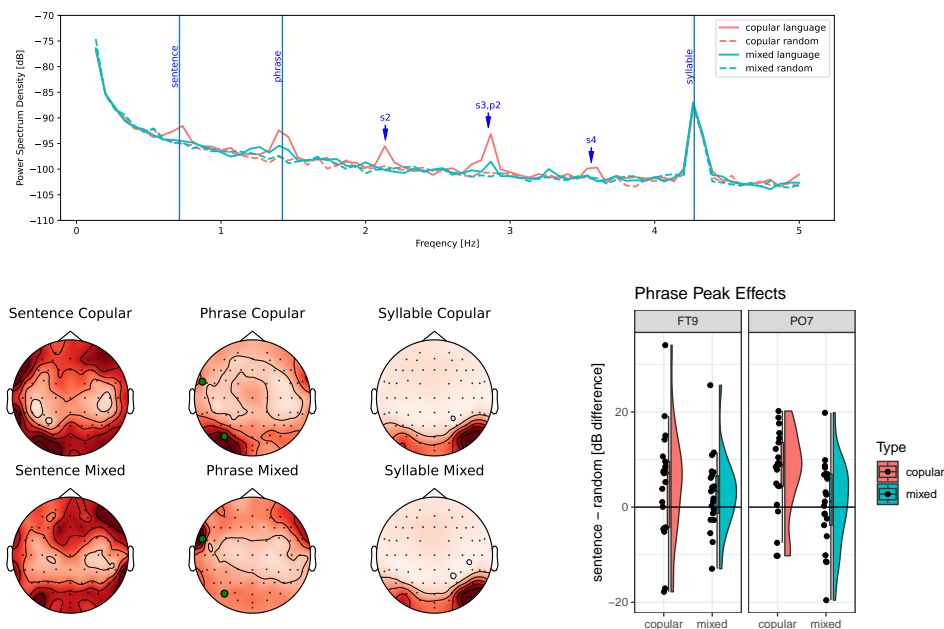
Preliminary results (21 subjects out of 34) clearly show that, throughout the whole scalp, entrainment peaks for phrases and sentences are larger for the *copular* condition than for the *mixed* condition. The topographical distributions of the phrase peaks differ across conditions: for the *copular* sequences it is maximal on posterior sites (over the visual word form area) while for the *mixed* sequences it is maximal on temporal sites (over the left anterior temporal lobe). ANOVAs on the phrase peak amplitude show a *Language by Type* interaction at PO7, $F_{(1,20)} = 8.56$, $p < 0.05$, but not at FT9 ($F_{(1,20)} < 1$) where only the main effect of *Language* emerges, $F_{(1,20)} = 6.72$, $p < 0.05$. The topographic pattern of the sentence peak is less clear, especially for the *mixed* condition.

The much larger effects for the *copular* sequences suggest, in line with Frank and Yang (2019), that these peaks are clearly boosted by regularity in the distributional properties of the sequences. These peaks are, however, also present in the *mixed* condition and, in some sites, with similar amplitude, suggesting that also part of the Ding et al. (2017) effects might be attributed to genuine compositional processes. The fact that in the *mixed* condition more robust peaks appear at phrase rather than at sentence level could be discussed within both the oscillation for chunking and the oscillation for integration hypotheses. Limitations of the time duration of structural units are to be considered within the chunking mechanism proposed by Meyer et al. (2022) and within the oscillation for integration (Kazanina and Tavano, 2023) different end of sentence processes (e.g.

wrap-up and working memory buffer cleaning) could have different relevance and be differently facilitated in the parallelistic *copular* condition or in the *mixed* condition.

Mixed Condition	Copular Condition
(1) a. GIO.VAN.NI COR.RE.VA john was running	(2) a. IL CA.NE È SA.NO the dog is healthy
b. SE TI VA LO SAI TU if you _{dat} like it _{cli} know you	b. IL MA.RE È VA.STO the sea is wide
c. IL PA.NE È BUO.NO the bread is good	c. IL SO.LE È CAL.DO the sun is warm
d. IL GAT.TO SCAP.PA.VA the cat run away	d. IL VEN.TO È LIE.VE the wind is delicate
e. MAN.GIA.RE MI PIA.CE eat me _{dat} like	e. LA MAM.MA È FOR.TE the mother is strong

Examples of the sentences used for the two Type conditions, the points indicate syllable borders. All sentences are grammatical and meaningful and only a subset of the structures used in the mixed condition are reported here.



Upper panel: power spectrum density averaged across all channels. Lower left panel: maps of the amplitudes of the sentence, phrase and syllable peaks (independently scaled, A.U.) TP9 and PO7 are highlighted in green on the phrase maps. Lower right panel: rain and cloud plots of the effects on the two sites.

References: Ding et al. (2016) Nat. Neurosci. 19, 158–164. Ding et al. (2017). Front. Hum. Neurosci. 11:481. Frank & Yang (2019) PLOS ONE, 13(5), e0197304. Kazanina & Tavano (2023) Nat. Rev. Neurosci. 24, 113–128. Lo et al. (2022) Neurobiol. Lang, 3(4), 538–555. Lu et al. (2023). Cerebr. Cort, 33, 4448–4458. Meyer et al. (2022) Lang. Cogn. Neurosci, 35(9), 1089–1099.