Does Segmentation Disrupt Dependency Processing? A Frequency-Tagging and ERP Study on Natural Language

Chia-Wen Lo[1] & Lars Meyer[1,2]

[1]*Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany*

[2]*Clinic for Phoniatrics and Pedaudiology, University Hospital Münster, Germany*

lo@cbs.mpg.de

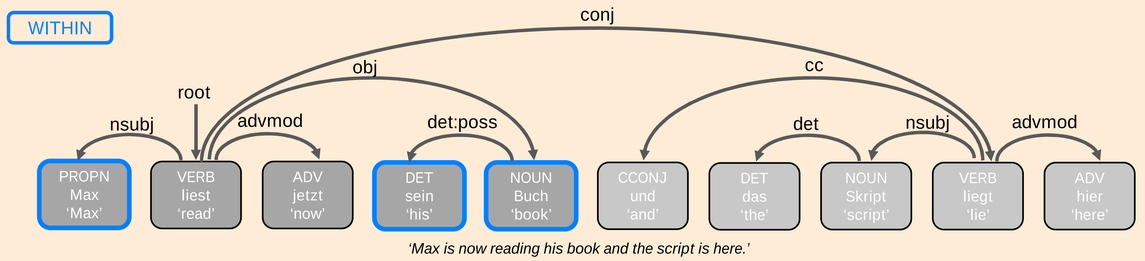
Introduction

1. Humans need to link the words and morphemes of a sentence to comprehend it. This can result in non-adjacent dependencies (NADs) that can span multiple words.
2. However, this ability is constrained in time by the capacity of our working memory.
3. In particular, cycles of neural oscillations in the delta band (< 4 Hertz) have been discussed to serve and constrain the formation of multi-word chunks [1-4].
4. Our recent finding in an artificial grammar learning has shown that language is sampled in chunks and the learning of NADs is restricted to chunks [5]. This suggests processing of NADs acorss chunks might be harder than within chunks.

If we sample and process speech chunk by chunk, how can we establish dependencies across different memory units or different processing cycles?

Stimuli

– Eight conditions were created by manipulating three factors: (i) whether there is gender agreement or not (i.e., agreement violation); (ii) gender (female/male); and (iii) agreement within a single chunk or across a chunk boundary.
– Each syllable was recorded separately as isochronous speech and adjusted to 320 ms.



Discussion

1. Spectral analysis: the sampling of chunks in both conditions
   ➢ Neural activity in the delta band underlines chunking [1-4] .
2. ERP analysis: Contrary to the findings in artificial grammar learning [5], an early negativity in the across-chunk condition, but not in the within-chunk condition.
   ➢ The influence of chunk boundary may attenuate because of the semantic and syntactic information, which are absent in artificial grammar.
   ➢ An early negativity might relate to active maintenance of dependency acorss chunks, requiring additional working memory capacity.

References

[1] Ding, N., Melloni, L., Zhang, H., Tian, X. & Poeppel, D. (2016). Cortical tracking of hierarchical linguistic structures in connected speech. Nature Neuroscience, 19, 158–164.
[2] Meyer, L., Henry, M. J., Gaston, P., Schmuck, N., & Friederici, A. D. (2016). Linguistic bias modulates interpretation of speech via neural delta-band oscillations. Cerebral Cortex, 27(9), 4293– 4302.
[3] Henke, L., & Meyer, L. (2021). Endogenous oscillations time constrain linguistic segmentation: cycling the garden path. Cerebral Cortex, 31:4289–4299.
[4] Henke, L., Lewis, A. G., & Meyer, L. (2023). Fast and slow rhythms of naturalistic reading revealed by combined eye-tracking and electroencephalography. The Journal of Neuroscience, 43(24), 4461–4469.
[5] Lo C-W, Meyer L (2024) Chunk boundaries disrupt dependency processing in an AG: Reconciling incremental processing and discrete sampling. PLoS ONE 19(6): e0305333.

EEG Methods

Participants and procedure

- N = 30 native German speakers (17 F, 13 M)
- Six 10-syllable sentences with a frequency-tagging paradigm (128 trials)
- Name recall task after each trial (Mean ACC: 71%)

Recording and statistics

EEG data were recorded 63 Ag/AgCl electrodes with online reference to the left mastoid.

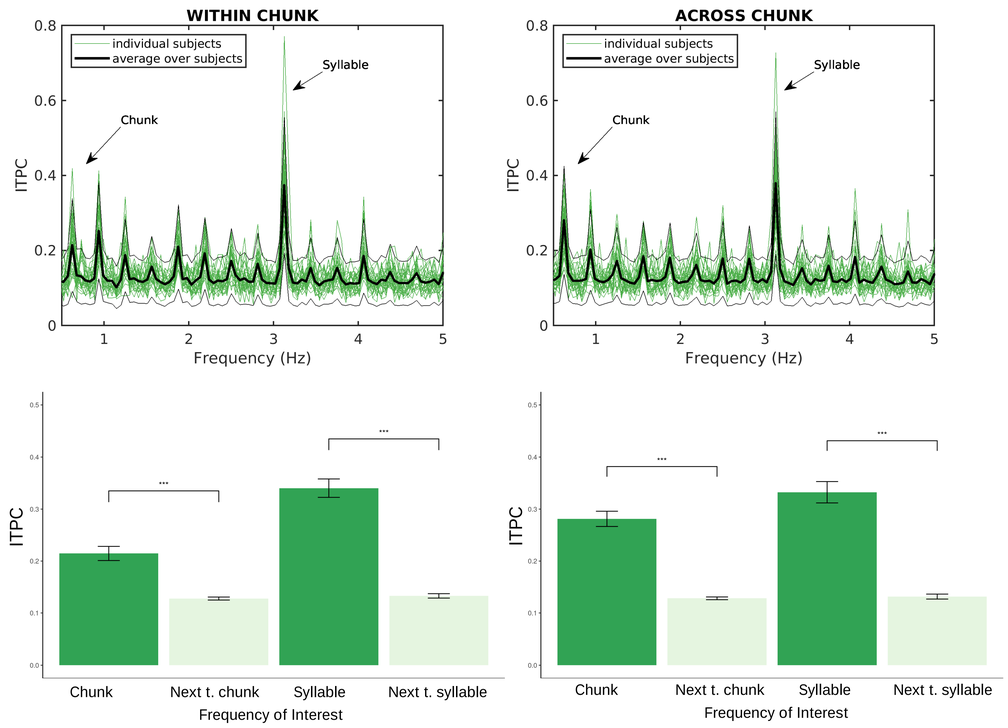
- Spectral analysis
– Data were filtered from 0.1–25 Hz and re-referenced offline to a common average.
– Manual artifact rejection and eye blinks removed via ICA.
– Inter-trial phase coherence (ITPC) was assessed from 0.5 to 5 Hz at 0.052 Hz intervals.
– The peak values of the chunk and syllable frequency were compared with the neighboring frequency bins via paired *t*-test.

- ERP analysis
– Data were filtered from 2–25 Hz and re-referenced offline to the average of the left and the right mastoid electrodes.
– Manual artifact rejection and eye blinks removed via ICA.
– The elements that form dependency and violation were time-locked from 100 ms pre-stimulus to 700 ms post-stimulus and then baseline-corrected.
– A non-parametric cluster-based permutation test was conducted across all electrodes.

Results

1 Spectral Analysis

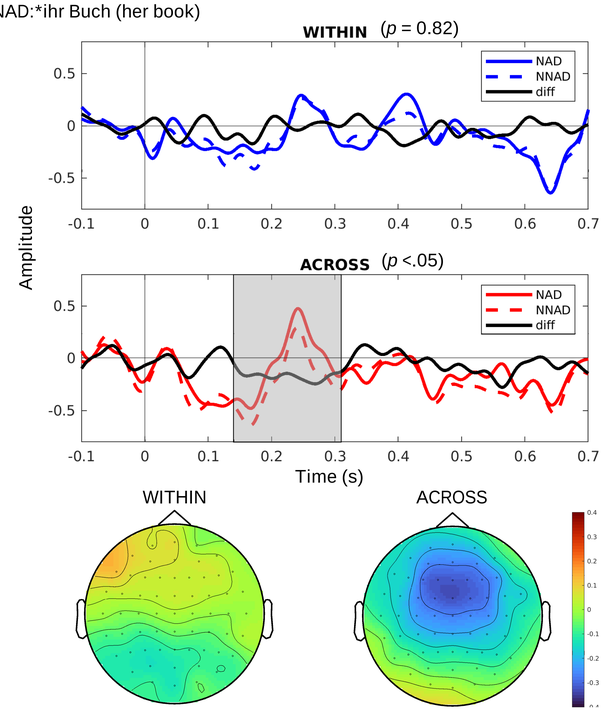
Peaks of chunk frequency were observed in both conditions.



2 ERP Analysis

A significant difference was found from 0.14-0.31 s in the across-chunk condition.

NAD: sein Buch (his book)
NNAD:*ihr Buch (her book)



SNL 2024