Do Segment Boundaries Disrupt the Processing of Non-Adjacent Dependencies? Evidence from Neural Frequency Tagging and ERP

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Introduction

- Language processing requires comprehenders to link the words and phrases of sentences.
- This can result in non-adjacent dependencies (NADs) that can span multiple words.
- NADs can be inferred from artificial grammars by children and adults (e.g. [1],[7]).
- Recent proposal: language is sampled in chunks [6].
- We would introduce this as a conflict: (1) NADs can be learnt; but (2) language is sampled in chunks [2]. Thus, non-adjacent dependencies should be restricted to chunks.

- Is the processing of non-adjacent dependencies across chunks harder than within chunks?
- Does the methodology of Inter-subject coherent component analysis (ISCCA) optimize the extraction of EEG frequency components across subjects?

EEG Methods

Participants

N = 31 native German speakers listened to 6-syllable strings during an artificial grammar learning task.

Procedure

- Learning phase: participants listened to four 3-min audios that contain NADs either within or across segments and answered questions.
- Test phase: participants listened to 144 trials that either contain 8 chunks of NADs or not, in both within- and across-segment conditions, and answered a question after each trial.

Recording and statistics

EEG data were recorded at 500 Hz from 61 active electrodes. EEG pre-processing was done by applying the Harvard Automated Pre-processing Pipeline [5]. Data were band-pass filtered from 0.1 Hz to 25 Hz.

- Learning phase: Data were epoched to 12.64 s. Evoked Power (EP) were computed from 0.1 to 10 Hz in increments of 0.079 Hz and then applied the denoising source separation [3] and ISCCA [9]. The peak values of the frequency of chunk and syllable were compared with the neighboring frequency bins via one-way ANOVA.
- Test phase: The elements of dependency pairs were epoched from 100 ms pre-stimulus to 300 ms post-stimulus and then baseline-corrected. A Student's t-test was performed to evaluate the statistical significance of differences between conditions. Global field power (GFP) was also computed to assess magnitude of neuronal activity irrespective of polarity ([4], [8]).

Stimuli

German syllables (12 for targeted chunks and 12 for fillers) are recorded separately as isochronous speech. Each syllable lasts 250 ms and a 80 ms silence was inserted as a segment boundary between each chunk. Four dependency pairs were created for four lists. Twelve +NAD and —NAD chunks were randomly constructed for each list. Twenty-four filler chunks were created.

Learning Phase

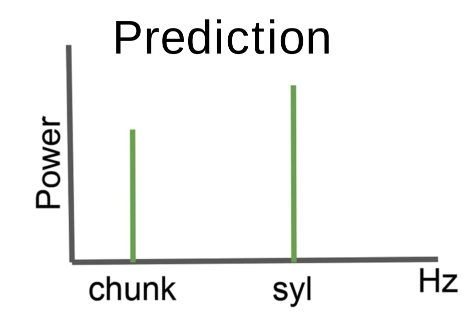
WITHIN (72 NAD and 72 fillers per audio)

ba fu pu me la gu ma de tu he go bi bo fu su na la mo

bi he pe lu ki go me fu ba na la mo pe ki lu ma le bu…

ACROSS (72 NAD per audio)

fa na su no we me pu ho fi bo gu mi fa pu mo fi we su bo ho mi no ba gu gu mo na fa we su ba ho me no mi fi …



Test Phase

WITHIN +NAD

bo fu su na la mo ki pe bu lu ma bi…

WITHIN —NAD

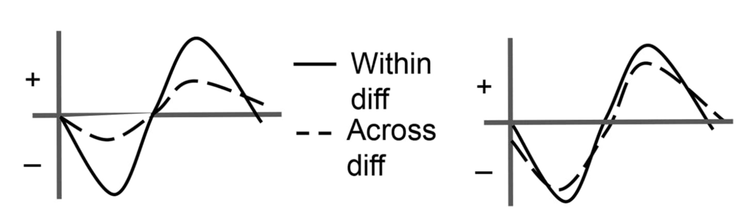
mi fu na mo bo ba ki le he pe ma li…

ACROSS +NAD

gu pu na su we ba bo ho me mi fi mo…

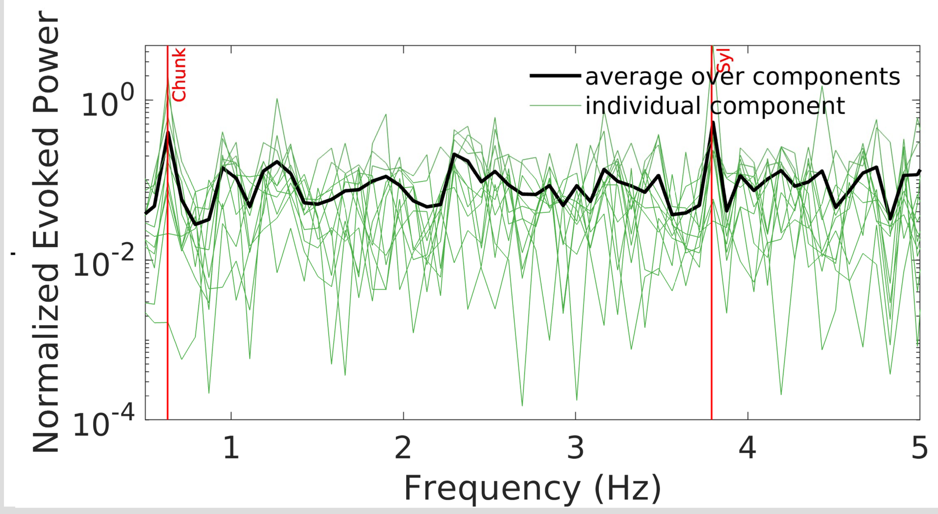
ACROSS —NAD

mi ba na pu we gu mo fa no me bo fi…

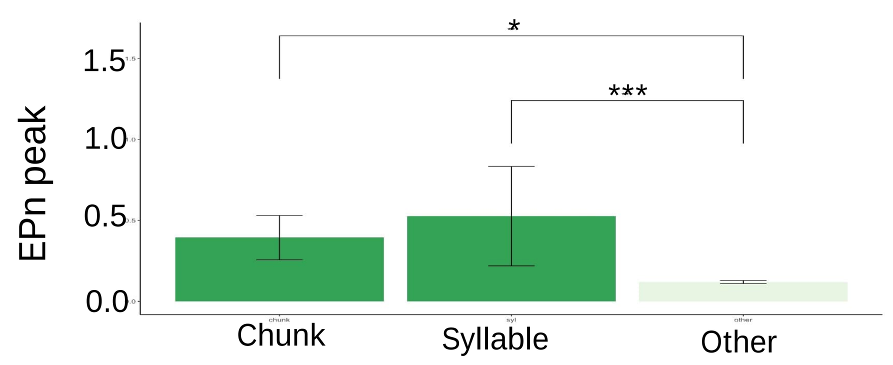


Results

Learning Phase



Comparison between conditions: $p < 0.001$

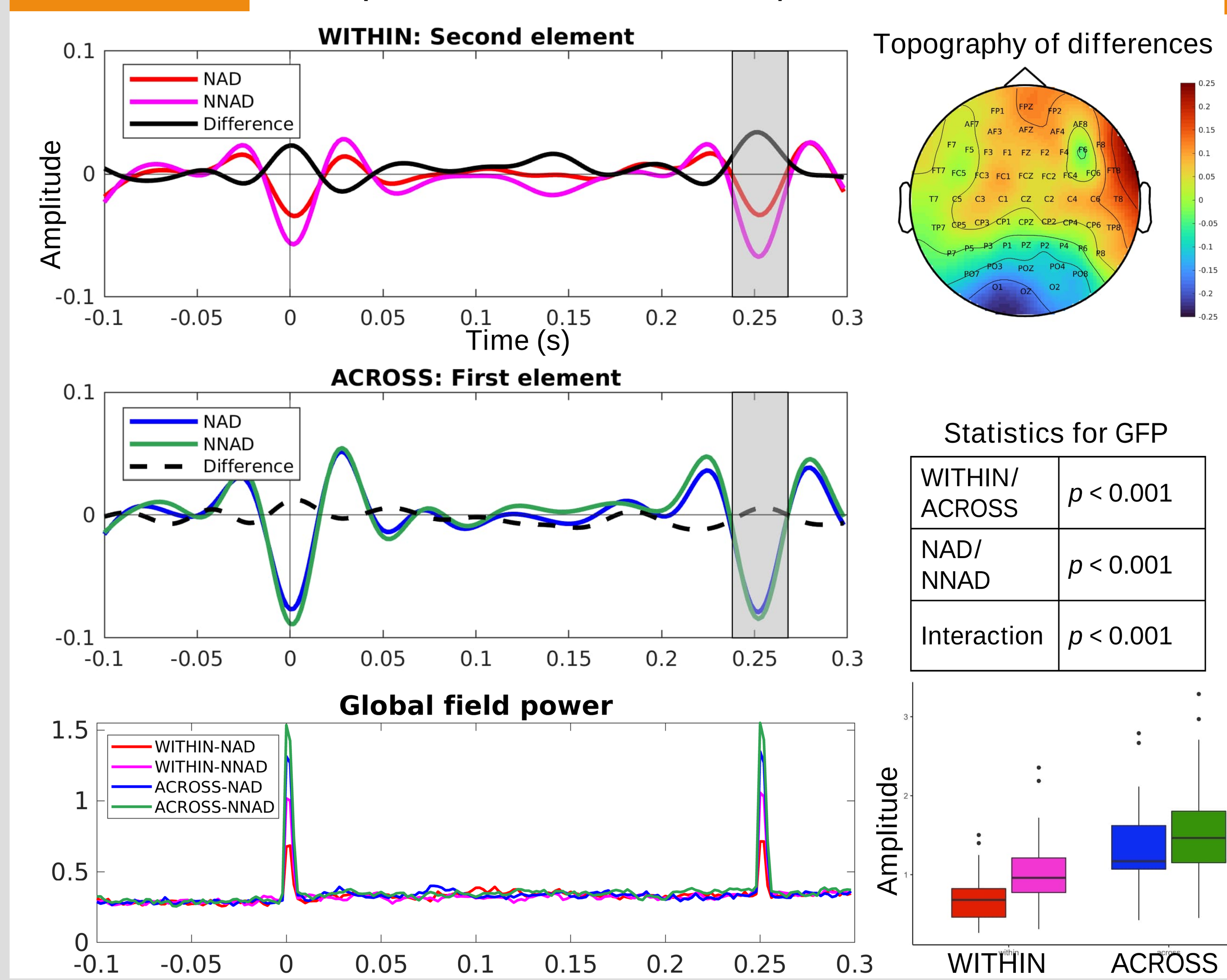


Tukey post-hoc test

Syllable – Chunk	$p = 0.67$
Chunk – Other	$p < 0.05$
Syllable – Other	$p < 0.001$

Test Phase

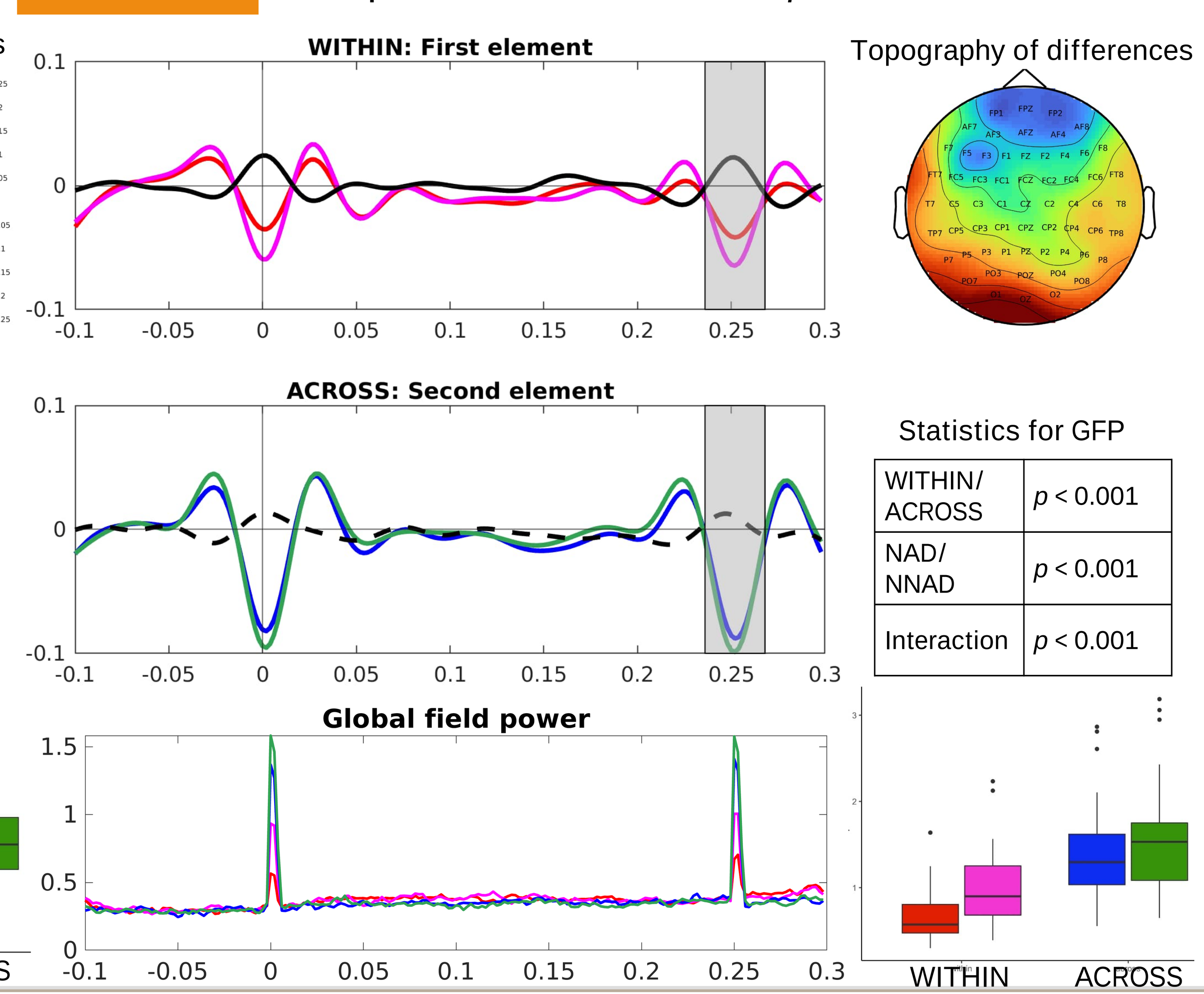
Position 5 Comparison of differences: $p < 0.01$



Statistics for GFP

WITHIN/ ACROSS	$p < 0.001$
NAD/ NNAD	$p < 0.001$
Interaction	$p < 0.001$

Position 2 Comparison of differences: $p = 0.45$



Statistics for GFP

WITHIN/ ACROSS	$p < 0.001$
NAD/ NNAD	$p < 0.001$
Interaction	$p < 0.001$

Discussion

Results

Learning Phase:

- Overall behavioral accuracy: 64% correct.
- Peak at chunk frequency can be observed via ISCCA analysis.
- Participants learn the chunks across conditions.

Test Phase:

- Overall behavioral accuracy: 68% correct.
- A statistical significance in comparison of the differences at the 5th position, but not the 2nd position, suggesting that participants learned the NADs easier within a chunk than across chunks.

- Processing of non-adjacent dependencies across chunks might be harder than within chunks.
- Via ISCCA analysis, both chunk and syllable peaks can be observed.

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