Discontinuous dependencies: Neural dynamics of incremental and non-adjacent constraints in spoken language comprehension

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Incremental spoken language comprehension

- ✓ The interpretation of a sentence evolves over time as each adjacent word is rapidly recognised and **integrated** into the developing representation, with **prediction** of upcoming words being a key process.
- ✓ Our previous work investigated the human neurobiological infrastructure enabling **adjacent words** to be integrated with the ongoing context in sentences like *The elderly man ate the apple*^{1,2}.

Our focus in this study

Incrementality in processing discontinuous dependencies

? How are **discontinuous dependencies between words** integrated into the developing representation?

adjacent dependency: is the girl the subject of kissed? - NO
The girl kissed by the father blushed.
discontinuous dependency: is the girl the subject of blushed? - YES

the girl is the discontinuous subject of the second verb blushed and not the adjacent subject of the first verb kissed.

? **What kinds of lexical information** (e.g., semantic or syntactic) form the incremental sentential interpretation in sentences with discontinuous dependencies? **When** and **where** are they processed in the brain?

- ✓ An example of discontinuous dependencies is the **garden-path effect**³: An initial interpretation of a sentence as main clause (subject noun + verb) must change to object reduced relative when a second verb must be integrated.
- ✓ Key variables: (1) Probability of the first noun to be the subject, (2) Probability of the first verb to be obligatorily transitive.

Experimental design

Stimuli: Auditory presentation.

- 60 Garden Path (GP) and 60 Reduced Relative (RR) sentences. Sole difference: GP have an optionally transitive VERB1 and RR have an obligatorily transitive VERB1.
- To increase variability in the stimuli: 120 transitive, Direct-Object (DO1–2) sentences with the VERB1 used in RR and GP.
- Fillers (non-experimental): 120 unambiguous and conjoined structures.

	SUBJNOUN	VERB1	COMPLEMENT	FINAL VERB
1 RR	The child	tossed	into the water	was frightened half to death.
GP	The child	plunged	into the water	was frightened half to death.
2 DO1	The man	tossed	the letter	out of the car window.
DO2	The man	plunged	the money	into the box.
3 Unam	The child	was	into the water	was frightened half to death.
Conj	The child	was tossed	into the water and	was frightened half to death.

Sentence-initial noun preferred as the subject over the object?
Likelihood of the noun appearing in subject over object position in the Baroni corpus⁵.

$$\text{Subject Preference} = \frac{LM_{\text{subj}}}{LM_{\text{obj}}}$$

LM: frequency-weighted co-occurrence count

Language models constructed to address our questions. Background shading denotes the epoch on which each model was tested.

Modelling incremental and non-adjacent constraints

Results: The developing representations as the sentence unfolds

1 SUBJNOUN epoch

3 COMPLEMENT epoch

Deviations from syntactic predictions given noun + verb detected. PP compatible with noun + verb in GP $\Rightarrow$ **garden-path effect strengthened** in GP.
When: Complement onset.
Where: Bilateral effects. LH temporal to prefrontal and back to middle and inferior temporal cortex. RH anterior temporal cortex, temporal pole, and superior frontal regions.

2 VERB1 epoch

4 FINAL VERB epoch

Discontinuous constraints from syntactic prediction given noun + verb on integration of the final verb in GP only. Re-interpretation of noun + verb from main clause to object reduced relative is not facilitated by noun + verb context in GP.
When: Final verb offset.
Where: LH middle frontal cortex and superior and middle temporal cortex.

LH: left hemisphere
RH: right hemisphere

Methods

Participants: 16 healthy right-handed British English speakers (range: 19–38 y).

Imaging: Simultaneous MEG (120 magnetometers & 240 planar gradiometers; Vector View) & EEG (70 electrodes; Easycap); T1-weighted MP-RAGE MRI scans (Prisma 3T); Preprocessing with MaxFilter and SPM12; Source reconstruction with MNE in SPM12.

Language modelling: Corpus and human-behavioural data.

Spatiotemporal searchlight representational similarity analysis⁴: Multivariate pattern analysis of the relation between the dissimilarity patterns of EEG/MEG data (neural activity) and language models in space and time. Spatiotemporal clusters of significant correlation defined with non-parametric, permutation-based statistics to correct for multiple comparisons (cluster-forming threshold: $p < 0.01$; cluster-mass threshold: $p < 0.05$).

Representational similarity analysis

Overview

These preliminary results reveal the spatiotemporal patterns (i.e., **when** and **where**) of the neural infrastructure underlying the incremental processing of discontinuous dependencies in spoken language comprehension.

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