ERPs reveal predictive activation of word form features in sensory cortex

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Background & Rationale

Sentence comprehension is increasingly viewed as a process that actively predicts linguistic input rather than passively responding to the input after it arrives. Although this view is generally supported by numerous recent findings, much remains unknown about what information is predicted during sentence processing and by what neurocognitive mechanisms. **We investigated how fine-grained predictions can be, asking whether people predict the sensory features of individual words.**

Paradigm: Brain Activity During Omitted Words

- We recorded brain activity (EEG), while participants read sentences with words occasionally omitted from presentation.
- Specifically, we manipulated the lengths of words and asked whether brain activity was affected by the lengths of omitted words.
- We focused on the P1 ERP, which is a widely observed visual sensory response over occipital-temporal electrodes that has been associated with early stages of visual word recognition in numerous studies.
- **If the brain activity during an omitted word event is correlated with properties of the omitted word, this indicates that the activity was driven by predictions.**

Experimental Methods

Participants

- N = 26
- Healthy, young adults
- Right handed
- Mean age = XX
- Recruited from the University of Colorado community

EEG Data Collection

- 66 Ag/AgCl electrodes (Neuroscan Quick-Cap via SynAmps II amplifier)
- Sampling Rate = 1000 Hz

EEG Pre-processing

- Band-pass filter: 0.1 to 50 Hz
- Downsampled Rate = 200 Hz
- Epoched data from -200 ms to +1000 ms relative to word onset
- Baseline correction relative to the pre-stimulus interval
- Artifact rejection: +/- 100 uV

Stimulus Presentation

- 200 sentences like (1)-(2) (Table 1, Figure 1)
- Each sentence contained a semantically supported target noun.
- Two target noun categories:
  - **Short** target words
  - **Long** target words
- Two target conditions:
  - **Present** target words
  - **Omitted** target words

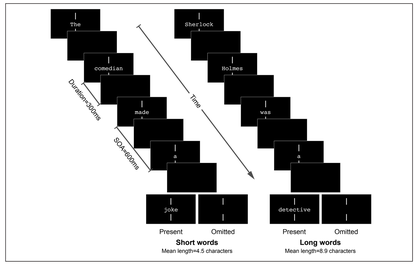


Table 1 (below): target word characteristics and examples.

Figure 1 (above): rapid serial visual presentation (RSVP) of sentences.

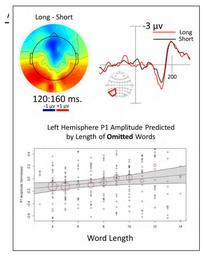
#	Target category	Characters	P(length)	P(omit)	Example
(1)	**Short** target word	Range=3-6, Mean=4.5	0.5	0.5	The comedian told a *joke* and ...
(2)	**Long** target word	Range=7-14, Mean=8.9	0.5	0.5	Sherlock Holmes was a *detective* and ...

ERP Results

Dependent variable:
Mean P1 amplitude (120-160 ms)

Predictor	B	t	p
Intercept	-0.209	-3.62	<0.001
Character Length	0.014	2.13	0.034
Word Presence	0.272	5.67	<0.001

Table 2: significant main effects observed via a mixed effects regression model.



Effects of word length (Long > Short) were observed even when the word was omitted from presentation.

Figure 2: Mean P1 ERP Amplitudes for long minus short words in the omitted word condition. The ERP waveform (upper right) represents activity at the left posterior electrodes. The regression plot (lower panel) shows the correlation between word length and P1 Amplitude.

Source Signals Analysis: Methods

We modeled the neural sources underlying the ERP activity in this study using spatiotemporal multidimensional scaling (MDS) to decompose the ERPs into a set of source signals that were constrained to a group-wise source space. We then explored the neuroanatomical systems underlying the ERP effects by modeling the neural generators of the P1 ERP sources using standardized low-resolution brain electromagnetic tomography (sLORETA).

Subject-level scaling

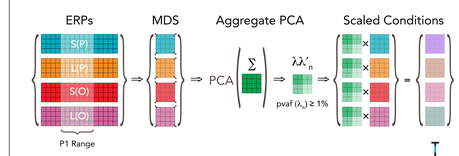


Figure 2: Subject-level scaling of condition responses via DISTATIS

Modified DISTATIS

- Multidimensional scaling (MDS)
- Four scaled conditions:
  - Short, present: S(P)
  - Long, present: L(P)
  - Short, omitted: S(O)
  - Long, omitted: L(O)
- Source space constrained via group-level scaling

Group-level scaling

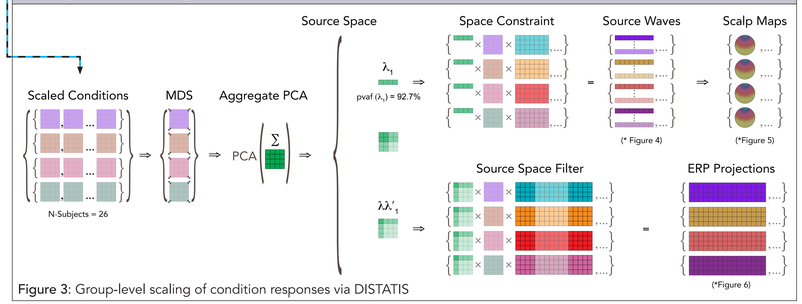


Figure 3: Group-level scaling of condition responses via DISTATIS

Source Signals Analysis: Results

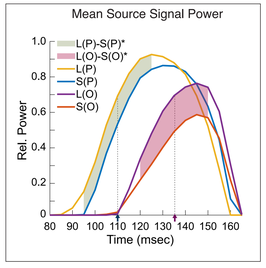
Comparison Statistics

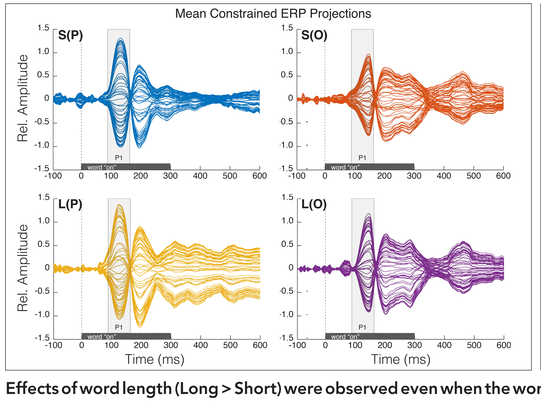
- Two comparisons:
  - L(P)-S(P)
  - L(O)-S(O)
- Permutation t-tests:
  - 10009 Independent t-tests at each point
  - FDR Corrected for multiple comparisons (over time)

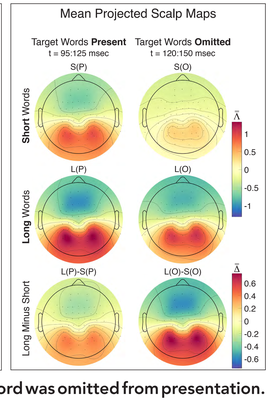
Figure 6 (below): Mean constrained ERP projections (see Figure 3). Shaded regions indicate stimulus and response windows for analyssis.

Figure 4 (right): Mean source signal power for each of four target conditions. Shaded regions between the signals indicate sequential significant differences between the test conditions. The arrows and dotted lines point to the median significant time point for each comparison.

Figure 5 (lower right): Mean projected scalp maps (see Figure 3) for each of four target conditions and for the comparison conditions. Colorbars indicate relative (to the mean) power.







Effects of word length (Long > Short) were observed even when the word was omitted from presentation.

Brain Source Localization

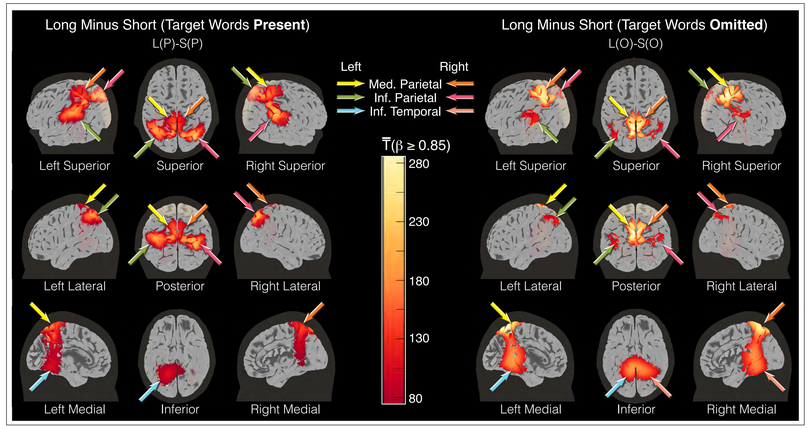


Figure 7 (above): Mean estimated brain sources for L(P)-S(P) (95 to 125 msec, left panel) and L(O)-S(O) (120 to 150 msec, right panel) each shown in nine views of the brain. The colorbar represents the mean sLORETA T-values for all participants constrained to the upper 15% of all mean T-values (β ≥ 0.85).

- Source solutions were computed for each P1 source signal from each participant using standardized low-resolution brain electromagnetic tomography (sLORETA).
- Solutions were constrained to the pial surface of a realistic (4-shell BEM) head model using the ICBM152 averaged MRI.
- Three neural regions showed significant effects of word length bilaterally: medial parietal, inferior parietal, and inferior temporal cortex.

Conclusions

- Effects of word length (Long > Short) were observed even when the word was omitted from presentation.
- Brain regions active during present word events were also active during omitted word events.
- Effects for omitted word events occur later (relative to word onset) than present word events.

#	Long > Short	Omission Effect	Associated Findings
(1)	Medial Parietal	Omitted > Present	Heavily interconnected with the medial-termporal lobe memory system; implicated in perceptual predictions
(2)	Inferior Parietal	Present > Omitted	Associated with grapheme-to-phoneme mappings during visual word recognision; robust multisensory integration
(3)	Inferior Temporal	Omitted > Present	Visual word form processing

Table 3 (above): Summary of effects and related findings for active brain regions with significant effects of word length (long > short).

- **Our findings indicate that these regions are part of a neural network of mechanisms involved not only in the bottom-up response to a word but also in predictions about word-forms during comprehension.**

References & Resources

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- Funding for this project was provided by the National Science Foundation (NSF-1829527) to authors AK and PG.