Decoding Lexical and Supralexical Processes in American Sign Language Comprehension

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2024 Cognitive Neuroscience Society
Funded by NIH DC010997 awarded to K. Emmorey and SDSU; NSF GRF awarded to B. Terhune-Cotter

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Introduction

- Neural differences between lexical and supralexical processes in sign language comprehension have not been clearly delineated.
- Studies using *lexical lists* (lists of unconnected signs) and *sentences* have implicated similar regions: the inferior frontal gyrus (IFG) and superior temporal cortex (STC). [1, 2]
- Studies attempting to isolate signed syntactic processing primarily activate the left IFG [1, 2]; however, the anterior and posterior STC [1, 3] and the supramarginal gyrus [4] have also been implicated.
- A recent study found largely nonoverlapping networks in the temporal lobe for syntactic processing versus lexical processing, with more anterior syntactic activation and posterior lexical activation. [3]
- **Our goal:** to compare neural processing of lexical information (nouns vs. verbs) with that of supralexical information (sentences vs. individual signs) while strictly controlling the psycholinguistic properties of the signs used in both comparisons.

Stimuli

- We developed two ASL conditions with 16 content signs per block : **lexical lists** and **sentence sets** (see Table 1 for examples).
- We selected the 320 most frequently occurring nouns and verbs from the ASL-LEX 2.0 database[5].
  - These were arranged into lexical lists: half were **noun lists** and half were **verb lists**.
- These 320 signs were scrambled and used to create the sentence sets.
  - 60 signs were replaced with new signs of similar frequency and iconicity to create semantically plausible sentences.
- As a language localizer task, we used signed narratives contrasted with a blurred baseline (see *Scan Protocol* for a baseline example).

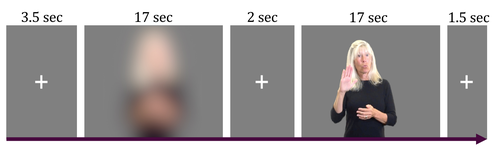
Example Sentence Blocks	
We will REGISTER with CITY_2 END MONTH	My DENTIST SIGNING_FLUENTLY
They MENTION, will CHARGE my CREDIT_CARD	WANT_2 PLAY, GO_AHEAD don't STOP
SEE-SEE, REDUCE COFFEE might HELP CALM	GAS this AREA ALWAYS EXPENSIVE
Their RESPONSIBILITY MATH, my SCIENCE, EVEN_1	I FEEL they MISS FISHING
	We SHARE WINE BOTTLE

Example Lexical List Blocks							
nothing	tree	college	restaurant	chop	meditate_2	discuss	dont_care
chocolate	place	butterfly	shoes	mail_2	see_see	escape	think_over
door	socks	road	tablet	kiss_fist	visit	fix	charge
dress	voice	office	chair	register	study	eat_1	brush_teeth

Table 1: Two examples of 17s blocks for the sentential and lexical conditions. Capitalized words in the sentences signify content words which were used or matched in the lexical blocks.

Scanning & Analysis

- We scanned 15 deaf signers who learned ASL before age 5 (M_{age} = 31 [24 – 49]; 7F/8M).
- Data were processed using SPM and custom scripts. MVPA analyses were conducted with the Decoding Toolbox, and univariate analyses with the *spm_ss* package; all analyses were conducted with MATLAB.
- Univariate contrasts were constrained by individual fROIs within group-level regions (Fig 1). [6]
- A linear mixed-effects model (*lme4* in R) was conducted to test for differences in univariate effect sizes across contrasts and ROIs (Fig 2).
- We conducted two multivariate pattern analyses (MVPAs) for each pair of conditions: **sentences vs. lexical lists** and **nouns vs. verbs**.
  - Leave-one-run-out whole-brain 12-mm searchlight analyses using an SVM classifier with unsmoothed individual images.
  - Data were normalized to a common template space and smoothed with an 8FWHM kernel before testing for group effects.



Scan Protocol:
Five 17s blocks per condition.
Jittered-length ISI fixations.
Four 7m functional runs.
5m MPRAGE anatomical scan.

Figure 1: Group-level parcels from the *sentences > degraded baseline* contrast, derived by conducting a group-constrained subject-specific analysis in *spm_ss*. Individual activation maps thresholded at p < 0.001 (uncorr.) were intersected with these parcels to create individual functional regions of interest for the univariate analysis.

Results

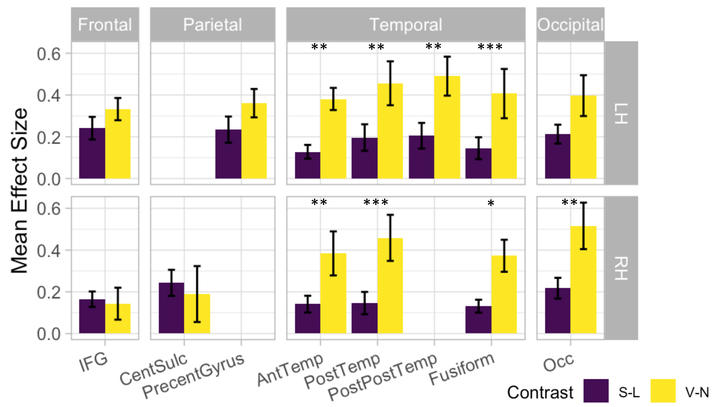


Figure 2: Mean effect sizes per ROI for each univariate contrast of interest. The spatial locations of ROIs are displayed in Figure 1. FDR-corrected *p*-values: * = $p < .05$; ** = $p < .01$; *** = $p < .001$.

- The entire sign language network responds more strongly to verbs vs. nouns and to sentences vs. lexical lists (Fig 2).
- V>N effect sizes are larger than S>L effect sizes in temporal and RH occipital regions (LH occipital region $p = 0.07$) (Fig 2).
- MVPA results show sensitivity to lexical information within bilateral STC, LH angular gyrus, and bilateral occipital cortex (Fig 3).
  - Activation within STC is more widespread in the LH (into anterior STC).
- In contrast, only small regions within bilateral IFG are sensitive to supralexical information (Fig 4).

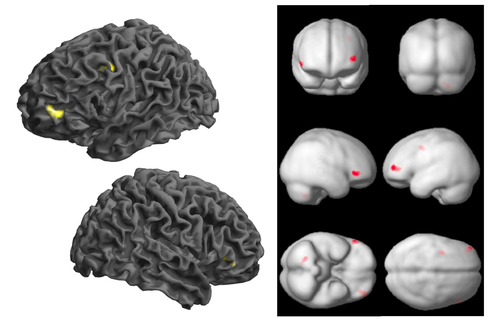


Figure 3: Neural regions which were significantly more accurate than chance in classifying *sentences v. lexical lists* ($p < 0.001$, uncorr.).

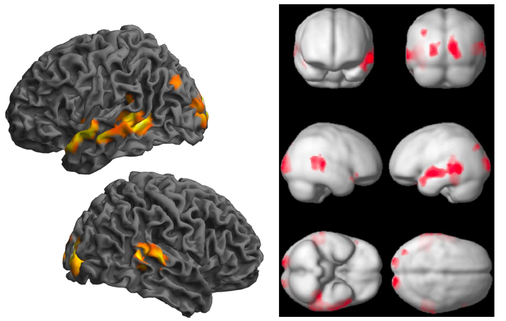


Figure 4: Neural regions which were significantly more accurate than chance in classifying *noun lists v. verb lists* ($p < 0.001$, uncorr.)

Conclusions

- Our finding that verbs elicit stronger activation across the language network as compared to nouns replicates data from spoken/written language that verbs recruit language regions more strongly than nouns. [7]
  - However, ASL verbs and nouns have distinct movement patterns, which might account for some occipital and parietal regions implicated in differentiating verbs vs. nouns. [8]
- Lexical information is much more robustly represented in the sign language comprehension network as compared to supralexical information; this result replicates a similar MVPA study with spoken English. [9]
- Although lexical and supralexical representations are distributed throughout the language network, occipital and temporal regions seem to be primarily associated with the representation of lexical information, while the IFG appears to be distinctly implicated in supralexical processing.
- Univariate contrasts show bilateral activation across the network, except a distinct LH bias in the IFG. However, multivariate analyses show a larger bias to the LH in temporal cortex for discriminating lexical and supralexical information.

[1] MacSweeney et al., 2006, *Hum Brain Map*
[2] Emmorey et al., 2015, *Lang Cogn Neuro*; Emmorey et al., 2014, *Front Psyc*; Mayberry et al., 2011, *Brain Lang*
[3] Matchin et al., 2022, *J Cogn Neuro*
[4] Stroh et al., 2019, *Neuroimage*
[5] Sehyr et al., 2021, *J Deaf Stu Deaf Ed*
[6] Fedorenko et al., 2010, *J Neurophys*
[7] Bedny et al., 2008, *J Neurosci*
[8] Pyers & Emmorey, 2022, *Lang Cogn*
[9] Fedorenko et al., 2012, *Neuropsychologia*