Neural speech restoration at the cocktail party: Auditory cortex recovers masked speech of both attended and ignored speakers

Computational Sensorimotor Systems Lab

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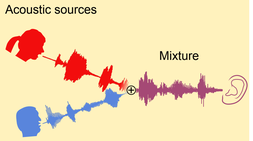
Motivation

- Listening to speech in the presence of two talkers
- The acoustic stimulus is an additive mixture of two speech waveforms (monophonic presentation)



- How do listeners segregate features of the attended speaker from the mixture?
- Previous work shows early neural representation of the acoustic mixture (~50 ms latency) and later representation of attended speaker (~100 ms) (Puvvada and Simon 2017; O'Sullivan et al. 2019)
- **Are early representations restricted to passive spectro-temporal filtering of the mixture, or do they also involve active extraction of acoustic features?** Are such features actively segregated and represented as auditory objects, even for the speaker that is ignored?
- Here we focus on **acoustic onsets**:
  - Important for auditory object formation and, consequently, stream segregation
  - Simultaneous onsets in multiple frequency bands indicate that the different spectro-temporal elements have a common physical source

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Methods

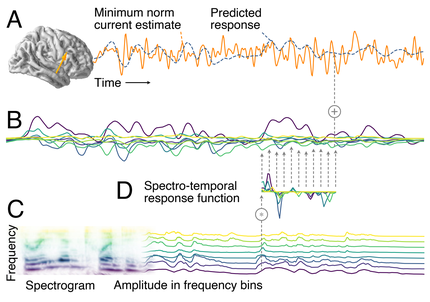
Participants listened to 1 minute long **audiobook segments** in two conditions:

- Single talker
- Two talkers: one male, one female;
  - Task: attend to one speaker, ignore the other
  - Attention counterbalanced across trials and participants

Whole head magnetoencephalography (**MEG**)

- Localized to cortical surface (minimum norm estimates)

Brain responses were modeled as linear convolution of predictor variables representing the stimuli with to-be-estimated **temporal response functions (TRFs)**.



A) Sample response in one current dipole. Model fit was evaluated through the Pearson correlation between measured and predicted responses. **B)** The predicted response was the sum of the responses to different predictor time series, modeling concurrent brain responses to different stimulus features. **C)** For model estimation, spectrograms were decomposed into 8 frequency bins. **D)** Multi-dimensional kernels, estimated with a coordinate descent algorithm, quantify the frequency-specific responses to the stimulus: spectro-temporal response functions (STRFs).

Model comparisons were performed to evaluate the contribution of each predictor to the model fit: For each predictor, the cross-validated model fit (Fisher *z*-scored correlation coefficient) of the full model was compared to a model in which this predictor was omitted.

Results

1. Single talker

Single speaker reading audiobook excerpts

A) Predictor variables

- Onsets: acoustic onsets, extracted from the gammatone spectrogram, using a neurally inspired edge detector (Fishbach, Nelken, and Yeshurun 2001)
- Envelope: sustained acoustic signal from the gammatone spectrogram

B) Cross-validated model fit ($p \leq .05$, corrected)

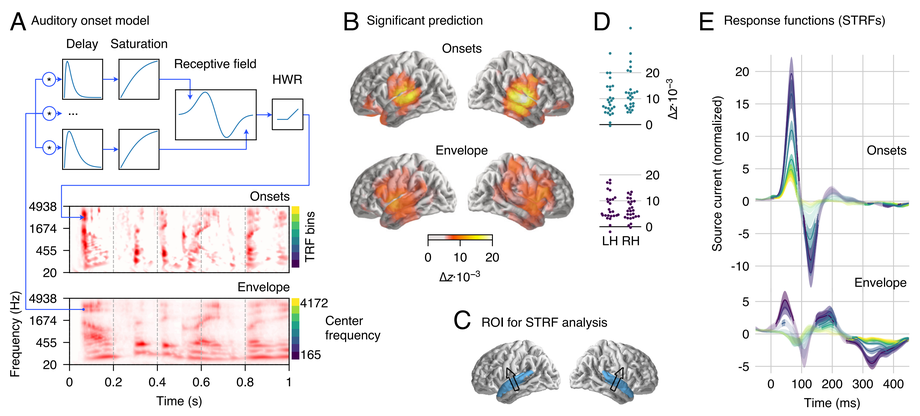
- Both representations improved prediction of brain responses, localization consistent with sources in superior temporal gyrus (STG)

C) Region of interest (ROI) positive values for upward current

D) Model fit for each subject averaged in the STG ROI

E) Spectro-temporal response functions (STRFs) in STG

- Onsets: strong upward peak (~70 ms latency) followed by downward peak (~130 ms)
- Envelopes: diminished compared to acoustic onsets



2. Two talkers

Two talkers, male/female, equal loudness

A) Predictors

- Acoustic onsets and envelopes each for:
  - The acoustic mixture (heard by participants)
  - The unmixed to-be attended speaker
  - The unmixed to-be ignored speaker

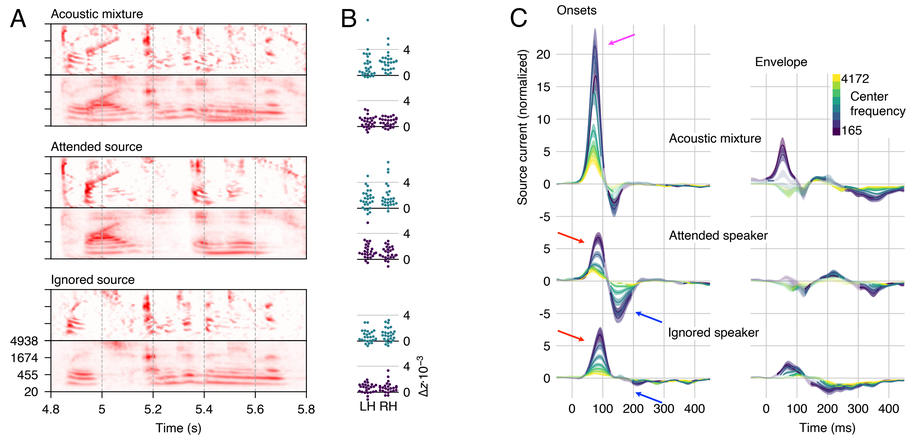
B) Model fits

- Significant representation of the ignored speaker even after controlling for the acoustic mixture and the attended speaker

C) Temporal response functions

Onsets:

- Early response to onsets in the acoustic mixture
- Additional, early response to onsets in either of the sources; **suggests that onsets in both speakers are initially recovered, even if they are not overtly present in the mixture**
- Later, negative response to onsets only in the attended source



3. Masked onsets

A) The two-talker results suggest that onsets in both speech sources are represented, even if they are masked in the mixture by the other source. To further explore this, overt and masked onsets were modeled separately for each of the speakers.

- Overt onsets: occur in one of the speakers, and are also apparent as onsets in the acoustic mixture *min(mixture, source)*
- Masked onsets: occur in one of the speakers at times where there is no corresponding onset apparent in the mixture *max(source – mixture, 0)*

B) Model fits: even masked onsets in the ignored speaker significantly improve model fit

C) Temporal response functions (TRFs)

Early, upward peak: feature extraction

- Large response to mixture: bottom-up response
- Recovery of masked onsets in both sources

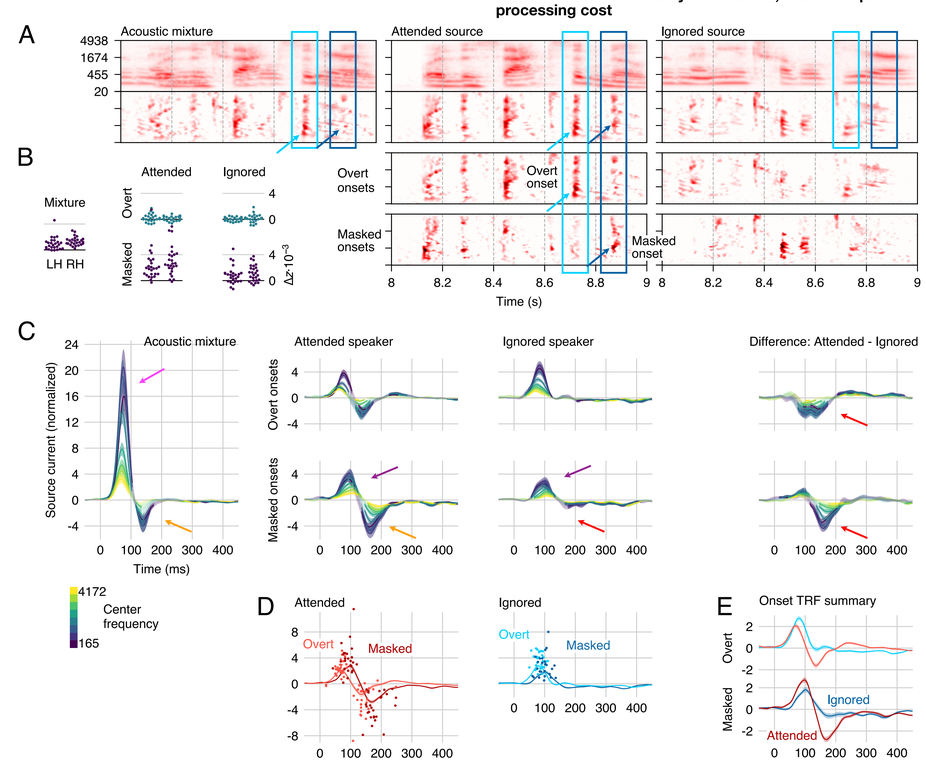
Later, downward peak: selective attention

- Amplitude similar for overt and masked onsets
- Strong effect of attention

D/E) Peak latency analysis

- Responses peak significantly later for masked onsets compared to overt onsets

Onsets in ignored speech are not just passively perceived when they are overt in the acoustic signal, but are actively recovered even when they are masked, with a temporal processing cost



Discussion

Main result: Acoustic features (onsets) in the ignored speaker are represented in auditory cortex even if they are not apparent in the acoustic mixture

- Suggests reconstruction of features that are masked in the input, neural "filling in"
- Suggests auditory object representations, including (small) influence of selective attention, even in early responses

Active segregation of features of the ignored speech could explain behavioral results:

- Speech comprehension in the presence of another talker is harder than in the presence of spectrally matched noise
- In multi-speaker environment, unintentional switching to unattended speaker is more likely than simple inability to understand attended speaker
- Auditory (proto-) objects of the ignored speaker could explain attentional capture and bottom-up switching to ignored speaker

References

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