Multi-Voxel Pattern Represenation of Interaural Time and Level Difference Cues in Human Auditory Cortex

Higgins NC and Stecker GC

Department of Hearing and Speech Sciences Vanderbilt University

Background

Background

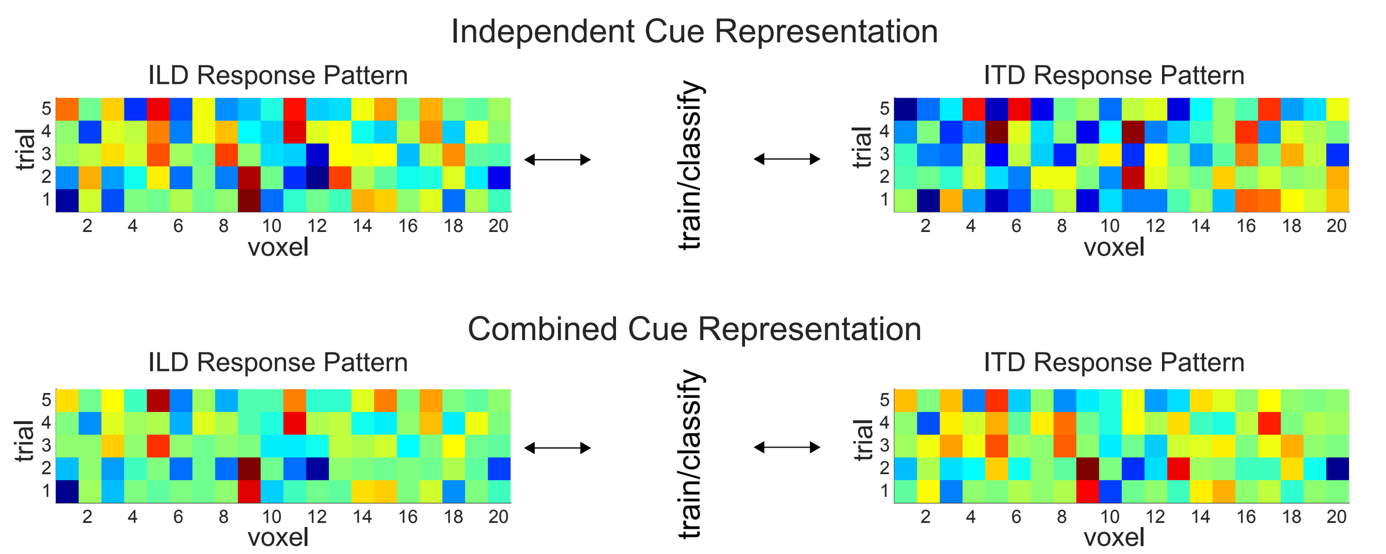
Auditory cortex (AC): plays a key role in sound localization.
Responses are sensitive to interaural time and level differences (ITD and ILD).
fMRI: strong contralateral preference to ILD, weak contralateral preference for ITD.
fMRI, MEG, EEG, lesion studies support partially overlapping ITD, ILD representations.

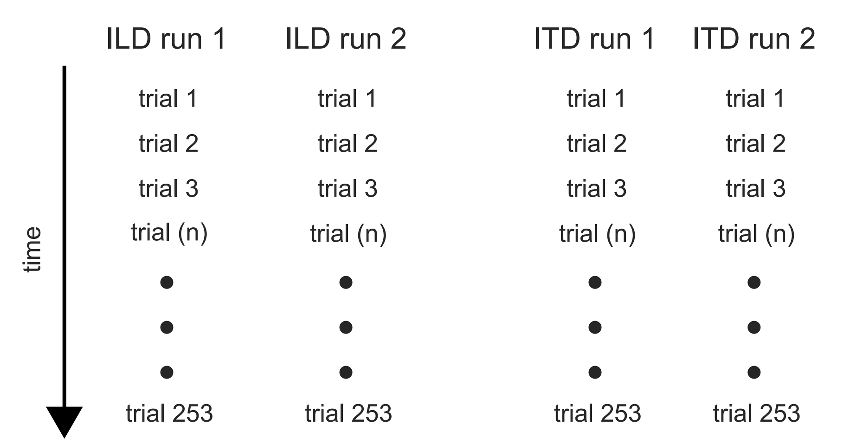
Questions

1. Can multi-voxel patterns classify binaural cue values (ILD or ITD)?
2. Are voxel patterns cue-specific or cue-indpendent?
Can ILD voxel patterns classify ITD voxel patterns, and vice versa?

Approach

Multi-voxel pattern analysis (MVPA) using support-vector machines (SVM).
- few assumptions regarding response magnitude.
- consistently weak responses can contribute as much as consistently strong responses.
- allows for functional interpretation of results.

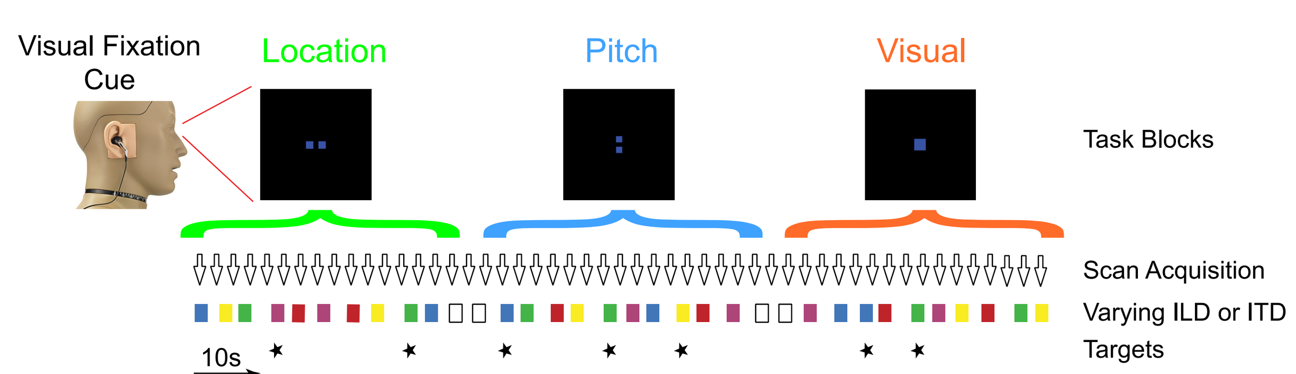




SVM training and classification

- within ILD runs
- within ITD runs
- Cross Cue: train SVM with ILD; use SVM to classify ITD
- Cross Cue: train SVM with ITD; use SVM to classify ILD

Experimental Design



Task Cue: Detect intermittently presented targets consisting of a change in Location (right/left), Pitch (higher/lower), or Visual cue (brighter/darker).

▪ Task blocks presented in random order, 30 seconds duration, 7 blocks per run, 10 trials in each block.

Scan Acquisition: Continuous event-related imaging paradigm (TR = 2s, 42 slices, 2.75 x 2.75 x 3mm), at 3T (Phillips).

Participants: N=10 total (3 male, 7 female) normal hearing adults (22-35 years), right handed native English speakers.

Acoustic Stimuli: trains of 16 white noise bursts, 1 ms burst duration, burst rate = 100 Hz at 90 dBpe SPL. Trains presented in 1 second "trials", each with 4 stimulus intervals. Intertrial interval range from 1-5 s.

▪ Interaural Level Difference (ILD) [-20, -10, 0, 10, 20 dB] or Interaural Time Difference (ITD) [-800, -400, 0, 400, 800 μs] varied across trials. Only ILD or ITD presented within a run, and trial order was counterbalanced (continuous carryover design).

Targets: The 3 target "types" are presented throughout the run regardless of the task cue; participants are instructed to respond only when detecting the specifically cued target.

▪ Targets presented at rate of 2/7 trials.

▪ Location targets: 5 dB change in ILD runs, 200 μs change in ITD runs. Pitch targets: 40% increase or decrease in burst rate. Visual targets (fixation box brighter or dimmer).

Voxel-Based Functional Analysis

▪ Standard preprocessing: motion correction, high pass filtering (0.01 Hz), individual subject registration using FSL.

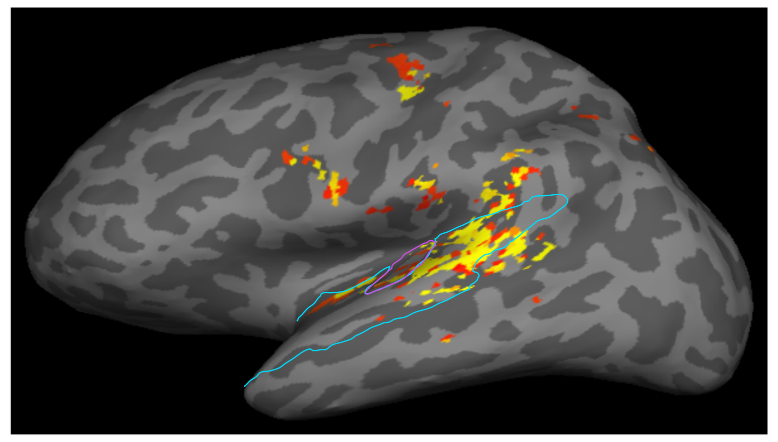
▪ Z-transform the signal timecourse in each voxel; interpolate and extract 12-s response following each trial.

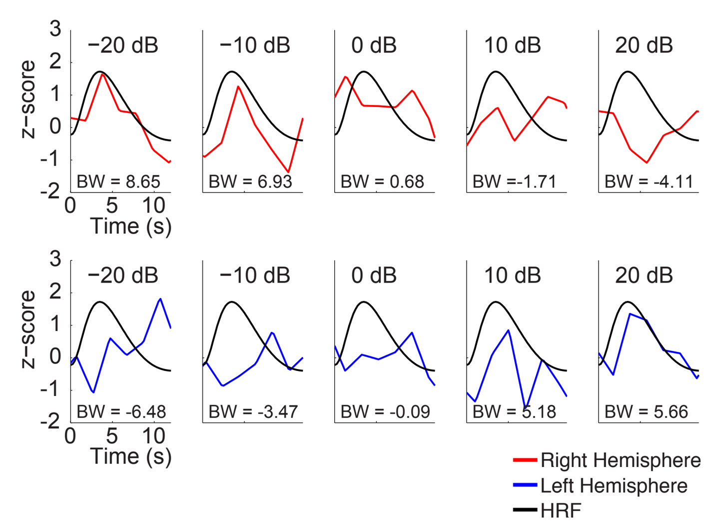
▪ Regress single-trial timecourse with 12-s standardized hemodynamic response function (HRF from Glover 1999).

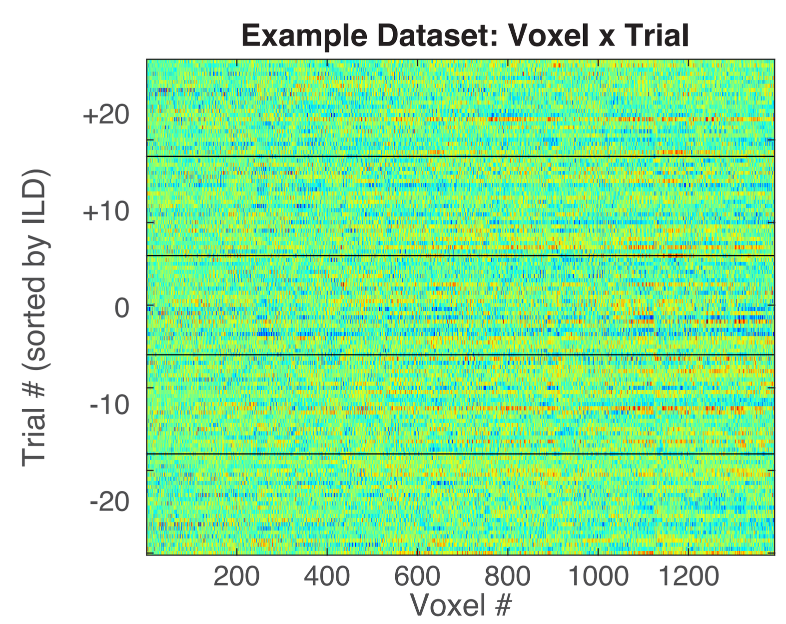
▪ Regression (beta) weights quantify single-trial response magnitudes in each voxel.

▪ A region of interest (ROI) defined the auditory cortex (AC) based on Desikan et al. (2006) parcellation of Heschl's Gyrus and posterior Superior Temporal Gyrus.

▪ Voxels within ROI define patterns for MVPA with `libsvm`.





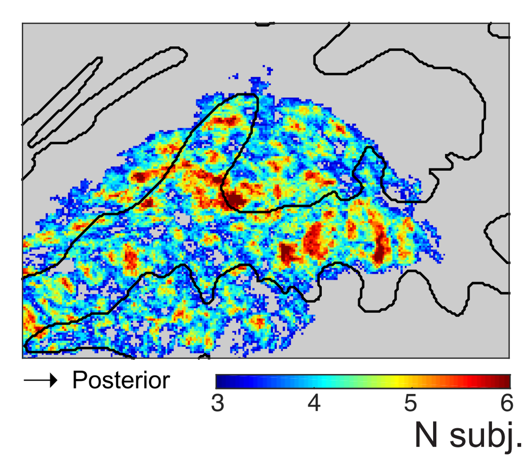


Which voxels contribute to cross-cue classification?

Methods

- Compute classification weight for each voxel.
Degree of association (+ or -) with contralateral response.
Cross-cue conditions only (ILD→ITD or ITD→ILD).
- Identify top 25th percentile; project to flattened cortical surface.
- Figures plot intersubject overlap in highly-weighted voxels.
- Averaged across training conditions (ILD→ITD, ITD→ILD).

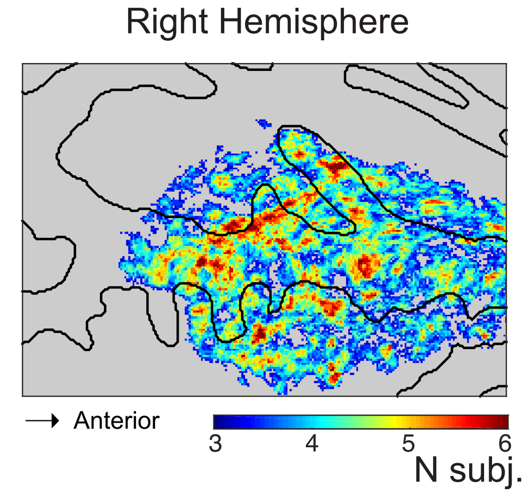
Left Hemisphere



Results

- High degree of overlap suggests regions contributing to cross-cue classification (presumably, cue-independent responses).
- Posterior-lateral Heschl's Gyrus, and posterior-lateral planum temporale are consistently represented.

Right Hemisphere



References

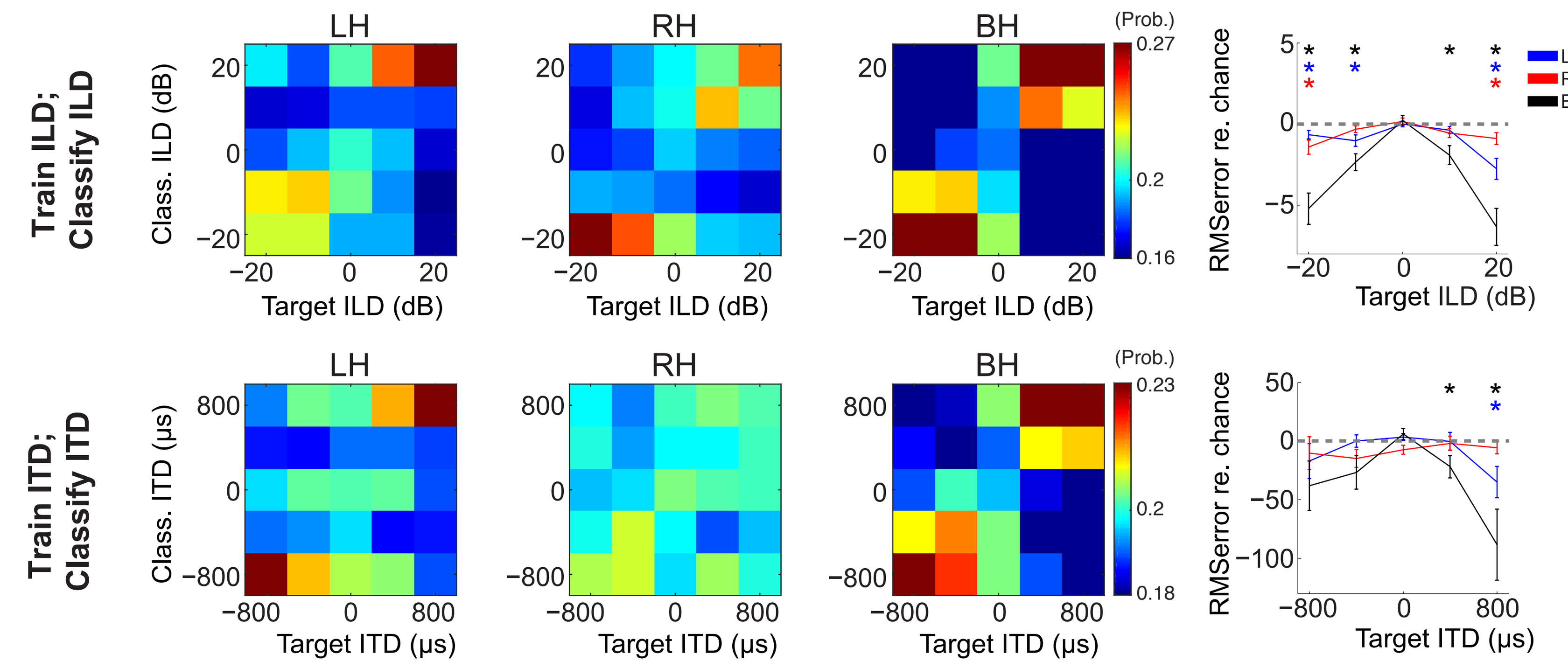
Chang and Lin, (2011) ACM Trans. Intel. Sys. Tech. 2: 27:1–27.
Desikan et al., (2006), Neuroimage 31; 968-80.
Glover (1999), Neuroimage 9; 416-429.
Salminen et al., (2015), Hear Res. 327; 143-152.

Acknowledgements

Thanks to Teemu Rinne for experimental design.

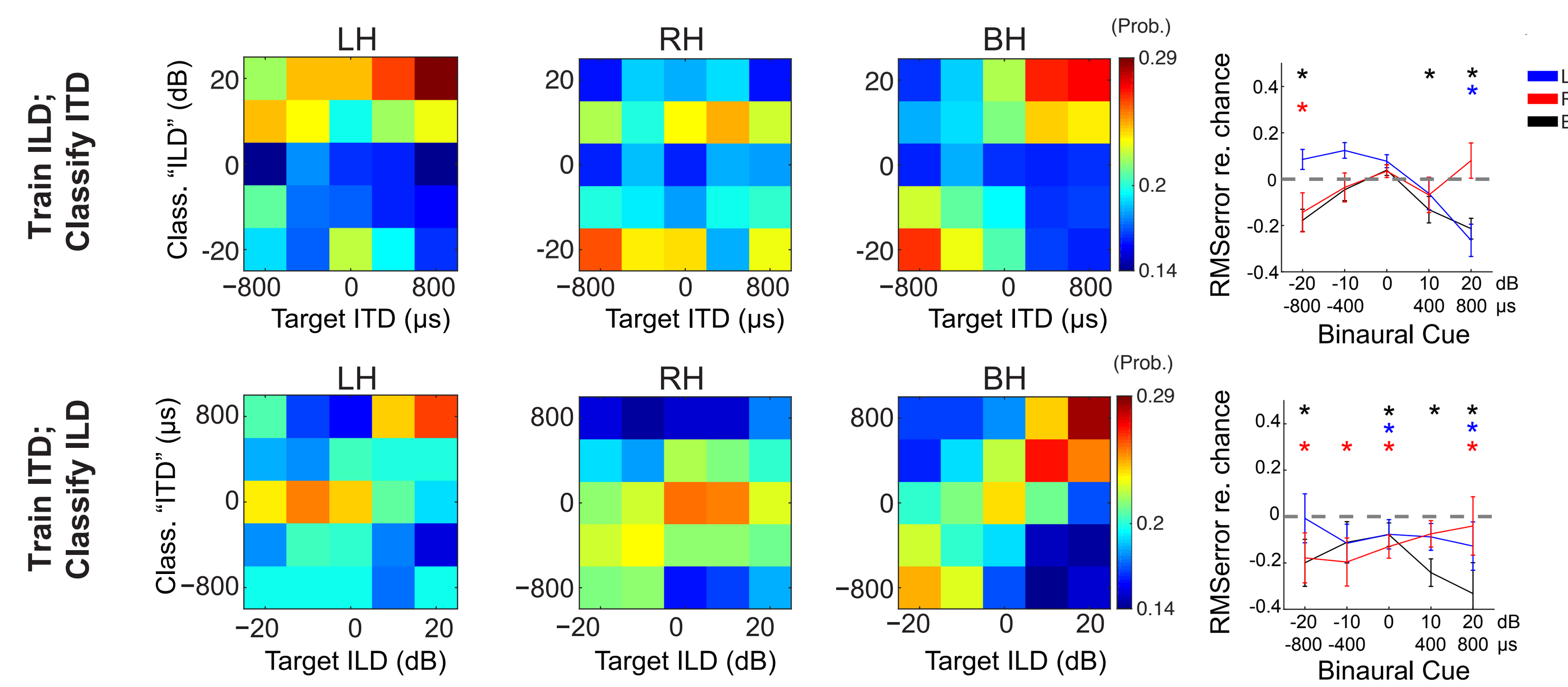
This work was supported by NIH R01-DC011548.

SIngle-Cue ILD or ITD Classification



*Confusion matrices plot probability as a function of the target (x-axis) and classified response (y-axis) for 5 binaural conditions (chance = 0.2). Root mean squared error (right column) was plotted with respect to chance for each binaural condition for left (blue), right (red) and both (black) hemisphere datasets. * denote p<0.05 (uncorrected) based on 1000 fold permutation test.*

Cross-Cue Classification



Single-Cue Classification

▪ Robust classification of contralateral ILDs in each hemisphere.

▪ Poor ITD classification in right hemisphere (RH).

▪ Combining voxels across both hemispheres (BH) reduced classification error at lateral locations.

Cross-Cue Classification

▪ Better-than-chance classification in both hemispheres, including midline positions.

▪ Successful classification for both cue combinations (ILD→ITD and ITD→ILD).

▪ Better ITD classification when trained with ILD.

Conclusions

▪ AC representation of ILD and ITD manifests in fMRI via reliable multi-voxel patterns.

▪ Patterns of activity are at least partially consistent across individual subjects.

▪ Cross-cue classification supports the existence of cue-independent spatial representations, or AC populations with matched ITD & ILD tuning.

▪ DO NOT rule out cue-specific representations within subregions of AC.