Temporal weighting of binaural cues in human auditory cortex: an fMRI study

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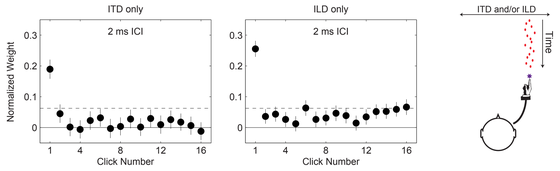
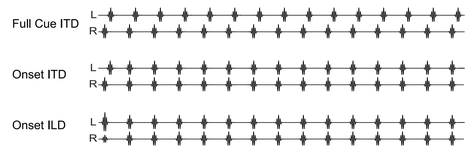
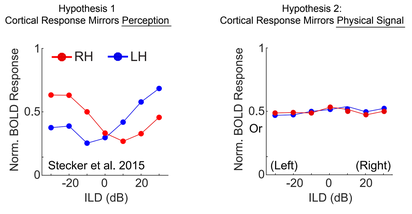
Background

Judgements of horizontal sound localization reflect weighted combinations of available acoustic cues including interaural level (ILD) and timing differences (ITD). Despite fluctuations in these cues in real world listening environments, perception of sound location remains stable. That stability reflects the perceptual dominance of cues occurring at particular times over the course of a sound: the ITD at sound onset, and the ILD at onset and offset. For both cues, the middle part of the sound appears remarkably ineffective, suggesting a dissociation between perception and the physical features of the stimulus (Stecker et al. 2013).

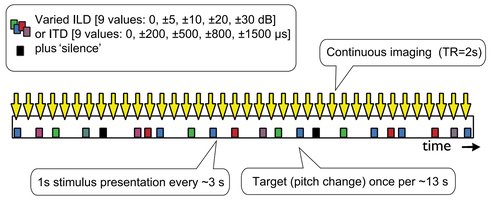




How does the onset cue manifest in the auditory cortical BOLD signal?

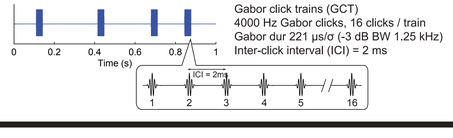


Experimental Design



Subjects: 10 per condition (18-35 yo, right handed,normal-hearing).
Stimuli: Presented via piezo insert earphones (Sensimetrics S14) in ear defenders. Four different conditions, 2 runs each: full cue ILD, onset ILD, full cue ITD, onset ITD.
Design: Event-related continuous carryover: each stimulus presented before and after every other
Task: press button in response to infrequent pitch change.
Imaging: Echo-planar imaging at 3T (Philips), TR=2s, 42 3-mm slices, 2.75 x 2.75-mm in-plane resolution
Pre-processing in FSL (FEAT): motion correction, .01 Hz high pass filtering, no smoothing

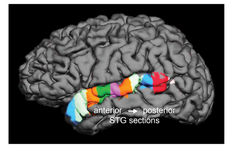
Stimuli

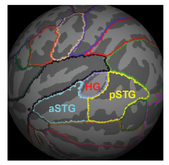


Gabor click trains (GCT)
4000 Hz Gabor clicks, 16 clicks / train
Gabor dur 221 µs/σ (-3 dB BW 1.25 kHz)
Inter-click interval (ICI) = 2 ms

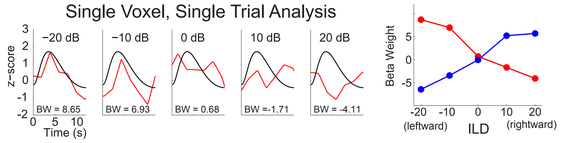
BOLD and ROI Analysis

- Z-transform timecourse of the Hemodynamic Response Function (HRF) for each voxel and interpolate for each trial
- Regress 12 s HRF post-stimulus with standard HRF (Glover 1999).
- Beta weight from the regression analysis quantifies single-trial stimulus-related activation for each voxel.
- Voxels extracted from Superior Temporal Gyrus (STG) and Heschl's Gyrus (HG) using Freesurfer Desikan (2006) atlas, define regions of auditory cortex.





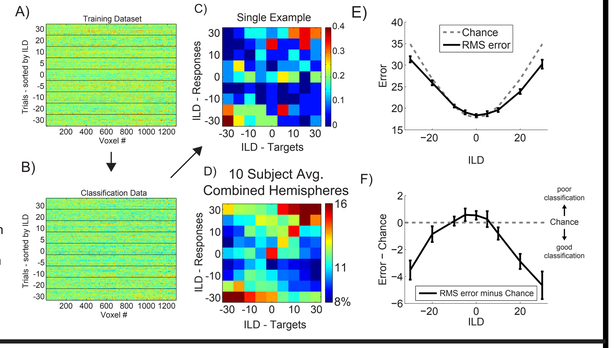
Single Voxel, Single Trial Analysis



Multi-Voxel Response Patterns: Training and Classification

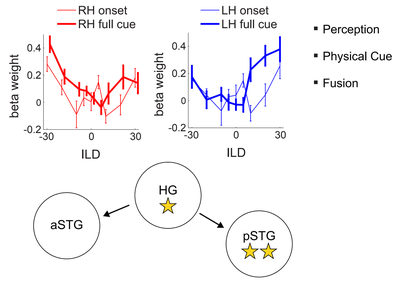
Multi-voxel Pattern Analysis, support vector machine training and classification

- Trial-to-trial voxel patterns were used to train a support vector machine (LIBSVM) on binaural cue conditions using half the (randomly selected) dataset (A). Then the other half of the data (B) was input to the SVM to determine classification performance (C).
- This procedure was repeated for each subject (500 times), and confusion matrices were averaged together (D).
- To measure performance, the Root Mean Squared Error (RMSe) was calculated at each binaural cue (E) and subtracted from chance (F).



Conclusions

- BOLD tuning to ILD in Heschl's Gyrus and posterior STG but not anterior STG. ☆
- BOLD tuning to onset ILD cues supports Hypothesis 1.
- Classification of onset ILD suggests transformation from physical-cue weighting in Heschl's Gyrus to perceptual weighting in posterior STG.☆☆
- Enhanced response to midline onset ILD unexpected; could reflect perceptual fusion/cue agreement.
- ITD sensitivity was surprisingly weak; although sound responses were observed in posterior subsections of STG.
- Envelope ITD cue at high frequency is perceptually salient, but cortical responses may require low frequency ITD.
- Spatial versus non-spatial tasks?



- Perception
- Physical Cue
- Fusion

Citations
Chang and Lin, (2011) ACM Trans. Intel. Sys. Tech. 2: 27:1--27. Software available at http://www.csie.ntu.edu.tw/~cjlin/libsvm.
Desikan et al., (2006), Neuroimage 31; 968-80.
Glover (1999), Neuroimage 9; 416-429.
Stecker et al., (2015) Neuroimage 120: 456-466.
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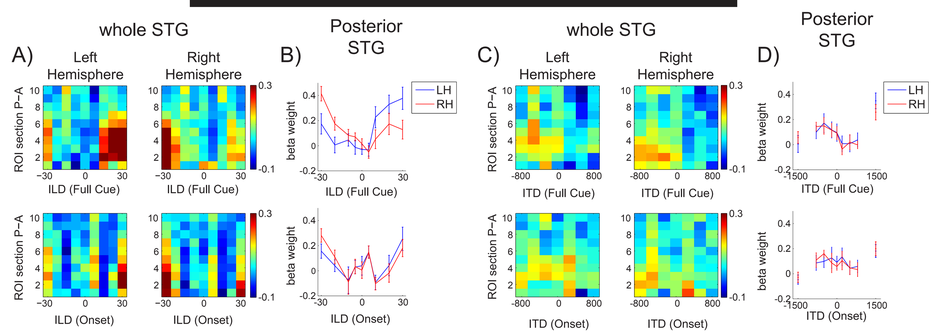
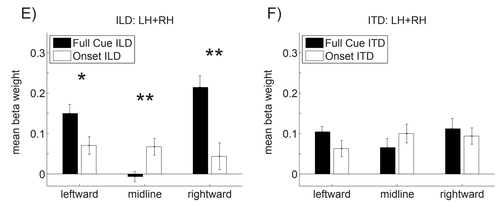
This work was supported by NIH R01-DC011548.

Univariate Results

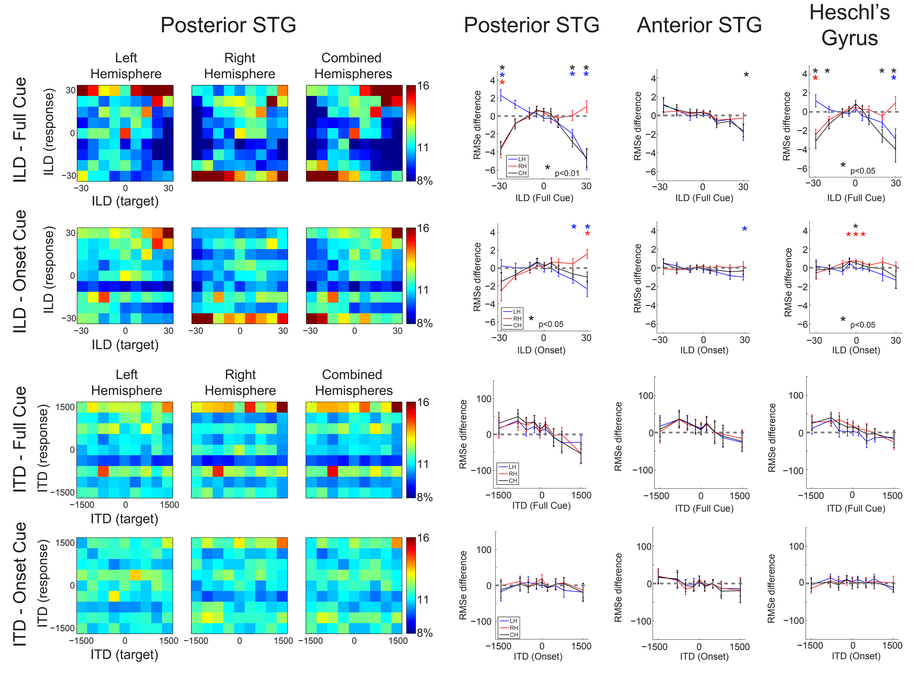


Univariate Responses in STG (Superior Temporal Gyrus)

- Full Cue ILD: contralateral dominance (A and B; top row)
- Onset ILD: increased activity around midline (A and B; bottom row)
- Significant increase around midline (right and left hemispheres combined, ** p<0.01; paired t-test)
- Full Cue and Onset ITD: Sound activity observed in posterior STG, but minimal modulation as a function of ITD (C, D, F)



Binaural Cue Classification



- Contralateral full cue ILDs best at classification.
- Onset ILD cues show similar, though weaker classification pattern.
- No increased classification observed at midline onset ILDs
- ITD cues: both body and onset fail to demonstrate convincing classification.