The Effect of “Awake and Behaving” on Cortical Processing of Binaural Spatial Cues

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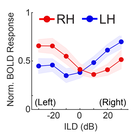
Background

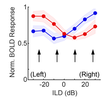
Measurement of brain activation in awake and behaving subjects is ideal for understanding functional processing of stimulus features and the interaction with behavioral output. Separating out the independent contributions of sensory processing, task-related attention, and the motor response prior to behavior can be difficult, particularly with fMRI, an imaging modality with limited spatial and temporal resolution. Previous studies on human auditory cortex (AC) have revealed modulation effects of task-related attention (Petkov et al. 2004; Woods et al. 2009; Rinne et al. 2012), and AC is known to respond to non-auditory/multimodal events (Brosch et al., 2005), in addition to sending motor output. However, many unanswered questions regarding the interaction of stimulus features, task-related activation, and behavioral responses remain.

What we know:
Contralateral bias

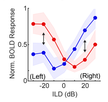


Processing/ Behaving

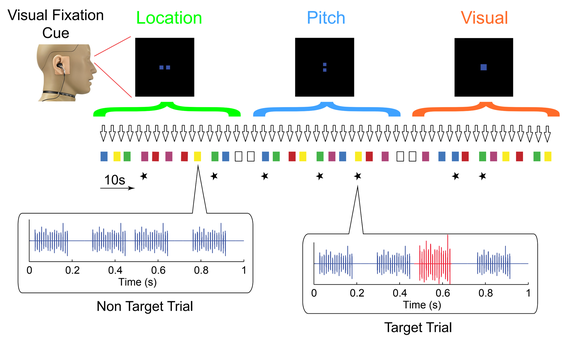
Hypothesis 1: Increase in BOLD signal



Hypothesis 2: Increased Feature Specific Tuning



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).

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

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).

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

Voxel-based BOLD Signal Estimation and ROI Analysis

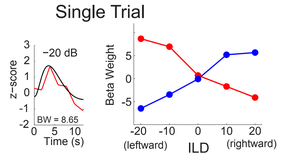
▪ Standard preprocessing: motion correction, high pass filtering (0.01 Hz), individual subject registration using FSL

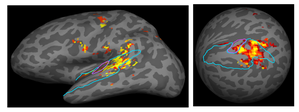
▪ Z-transform timecourse of the Hemodynamic Response Function (HRF) for each voxel and interpolate for each trial

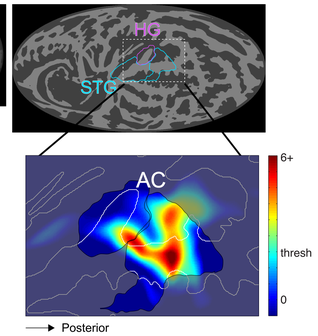
▪ Regress 12 s HRF post-stimulus with standard HRF (Glover 1999).

▪ The resulting beta weight from the regression analysis quantifies single-trial stimulus-related activation for each voxel.

Single Trial





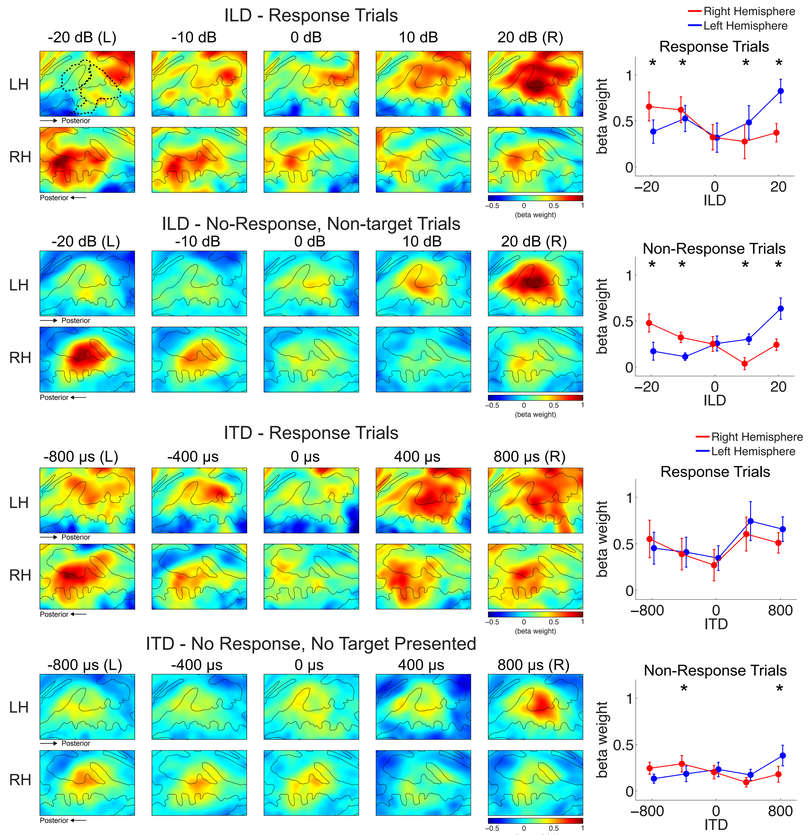


▪ A region of interest (ROI) defined the auditory cortex (AC) based on Desikan et al. (2006) parcellation of Heschl’s Gyrus and posterior Superior Temporal Gyrus.

▪ *Figures Above and Right*. Sound-Silence statistical contrast based on beta weights calculated for each voxel.

▪ Progression of figures illustrates projection of functional data from 3-d, to 2-d surface voxels plotted using Mollweide coordinates.

Response Trials vs. Non-Response, Non-target Trials



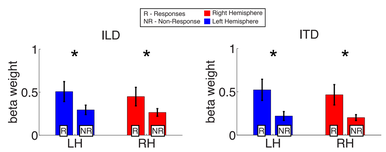
Comparison of Response vs. non-Response, non-Target trials.

▪ *Left (colored) panels*: Surface projections of beta weights across ILD and ITD illustrate the effect of trials where a response was made, compared to trials with no response, and no target presented.

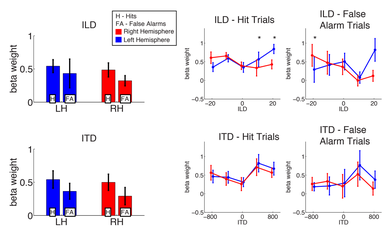
▪ *Bar plots below*: Significant increase in BOLD signal magnitude was observed when a response was made, supporting Hypothesis 1 (* denote p<0.01, paired t-test, errorbars represent SEM across subjects).

▪ *Error bar plots to the left*: Feature-specific tuning, characterized by contralateral bias is obscured during response trials, but clearly observed during non-response, non-target trials (* denote p<0.01, paired t-test, errorbars represent SEM across subjects).

▪ Increase in magnitude is accompanied by increased variability across subjects. May reflect differences in performance capability.



Hit and False Alarm Trials

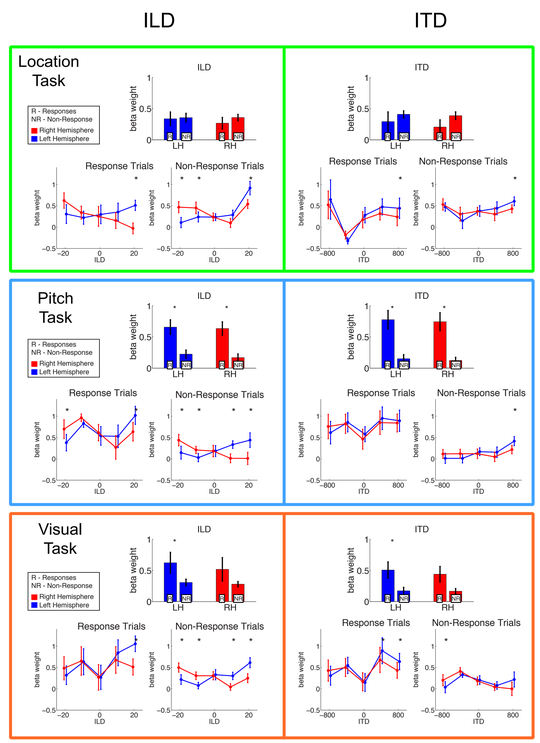


Comparison of response trials with and without presentation of a target. Hits verse false alarms.

▪ Trend towards larger activation when target was presented.

▪ Little evidence for increased sensitivity to spatial cue features.

Response Effect across Task



The Effect of Task on Response vs. Non-Response, Non-Target Trials

▪ As observed for the whole data set, response trials obscure contralaterally dominant tuning, and exhibit increased variability across subjects.

▪ Pattern of increased BOLD signal magnitude is observed for Pitch and Visual task, but *not* during the Location task.

▪ Pattern of results is conserved for both ILD and ITD, data collected with independent imaging runs.

▪ Effects of behavior are complicated!

Conclusion

▪ Auditory cortex is integrally involved in generating behavioral output, resulting in significantly increased BOLD signal during response trials.

▪ The increased BOLD signal masks the contralateral spatial cue sensitivity typically observed in studies of human sound localization using fMRI.

▪ Increased BOLD signal magnitude likely reflects recruitment of mixed type (auditory and multisensory) cortical processes (e.g. neurons) that may not be as sensitive to spatial cues as auditory processes. Brosch et al. (2005) reported the majority of A1 neurons to be multisensory, and a minority (41%) auditory only.

▪ This effect is mitigated in the location task, where no significant BOLD signal magnitude difference is observed between the response and non-response trials.

▪ This finding suggests an interesting interaction between the modality of the task type, and the specific stimulus feature being varied. In other words, a confluence of stimuli and task engagement minimizes the recruitment of additional processing resources otherwise indicated by increased BOLD signal.

References and Acknowledgements
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