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Assessing binaural interaction in functional magnetic resonance imaging of human inferior colliculus and auditory cortex

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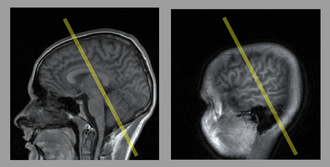
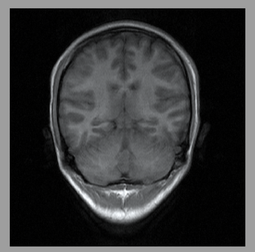
Imaging Methods





Goal is to maximize IC activation.
Historically difficult (studies vary)

Concerns:
- Acoustic signal to noise
- Physiological noise (vascular?)
- Spectral bandwidth
- Transient responses?

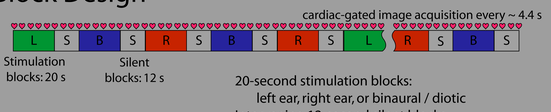
Gradient-echo BOLD fMRI
1.5 Tesla Phillips Eclipse

Single 10mm slice targeting IC and Heschl's Gyrus
Single slice minimizes scanner noise

Cardiac-gated imaging every ~4.4 seconds
(not synchronized to stimulus)

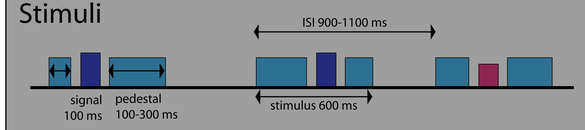
PPG-gated TR > 4 s, TE = 39 ms, flip angle = 90˚,
Slice thickness10 mm, in-plane 1.875 x 1.875 mm,
voxel matrix 128 x 128, FOV 24 x 24 cm,

Block Design



20-second stimulation blocks:
left ear, right ear, or binaural / diotic
Intervening 12-second silent blocks
20 blocks per condition each run
9 subjects, 2 runs per subect

Stimuli



pedestal
non-target (88%)
rare target (12%)

Auditory: Intense (85 dB SPL), modulated sound stimuli
Iterated rippled noise (Gaussian) carrier (16 iterations @ 10 ms)
Sinusoidal amplitude modulation (35 Hz, 90%)
Presented w/ Stax MRI-002 inside Bilsom blue muffs
Visual stimuli: colored circles w/ changing luminance
Both modalities: 600 ms pedestal-signal-pedestal stimuli
~ 1s ISI, randomized independently across modality
Signal increment (88%) or decrement (12%)
Decrement (oddball) VISUAL detection task

Event-related analysis of sound-related activation

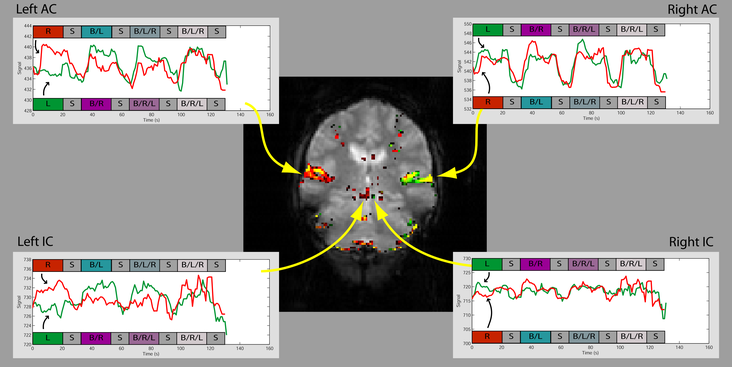
Images are sequenced relative to stimulation block times.

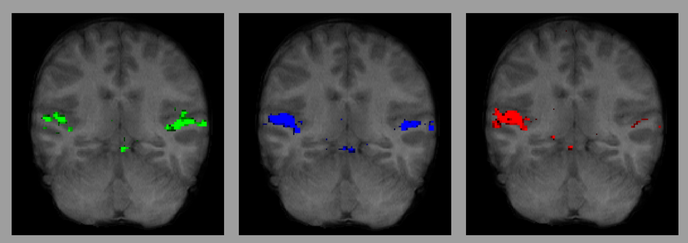
Can compute a running average of signal level in voxel/region.

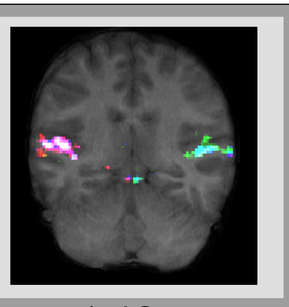
Images can be assigned to blocks after accounting for hemodynamic delay (~4 s). Used to compute % signal change.

Figure: Image plots % signal change for two comparisons. Red: Right-Silence (% difference between silence and right-ear stimulation). Green: Left-Silence. Yellow (Red+Green) indicates regions of overlap (i.e. response to either ear). Differences are thresholded at 0.4% (dark red / green) and cut off at 0.8% (bright)Data are from a single 32-minute run.

Insets: Time course of BOLD signal relative to onset of Right (red) or Left (green) stimulation blocks in four regions of interest:Left and right IC and the lateral half of activity observed onHG or adjacent regions of Superior Temporal Cortex (AC).Note pattern of response to alternating sound and silentblocks. Due to block randomization, subsequent epochs of averaged activity reflect multiple stimulus conditions.







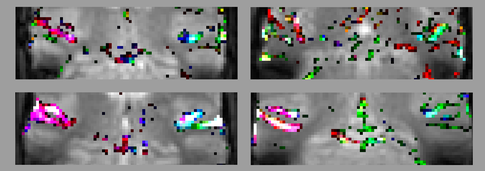
Group analysis by ANOVA reveals contralateral response in IC, bilateral response in AC

Combined group data were analyzed using ANOVA (Clare et. al 1999), which provides a sensitive technique for detecting repeatable activations without assumptions regarding the delay or shape of activation time course. Data were grouped into 5-s bins relative to the block timing, and ANOVA computed from the signal variace within and between time bins.

Above: F values from the ANOVA analysis are plotted for right-ear (right panel, red), left-ear (left panel, green), and binaural (center, blue) stimulation. F values are thresholded at $F_{(4,1710)}$=10 and cut off at 20.

Far right: F values from above overlaid with one another. Red, green, and blue color values mix normally, so that magenta indicates region of overlap between right-ear and binaural activation, cyan indicates left-ear and binaural response, and white indicates regions responding strongly in all three conditions.

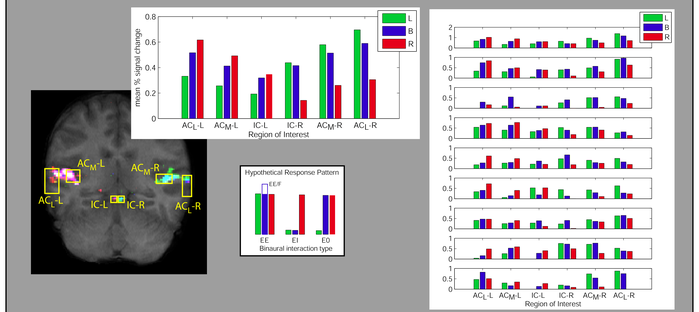
The results indicate stronger responses to contralateral than ipsilateral sound throughout IC and AC. Note, however, that extensive regions of AC (white) respond bilaterally to monotic or diotic stimulation (i.e., some evidence of EE-type binaural interaction), whereas IC activations appear more strictly contralateral (E0-type binaural interaction). Restricted regions surrounding the core of AC activation appear to respond more strongly to contralateral monotic than diotic stimulation (EI-type binaural interaction), as evidenced by red and green regions.



Binaural interactions in individual session data

Above: % signal change plotted in three conditions (red: right ear; green: left ear; blue: binaural stimulation) for four individual subjects (separate panels; one run each). Data are overlaid to produce red-green-blue color mixtures. Although the individual raw data are noiser than the group-averaged statistical data, similar patterns can be observed. IC activations are strongly contralateralized, as are regions of AC activation.

Echoing the group data, images generated from single sessions reveal extensive regions of EE-type binaural interaction (white) in the AC, indicating similar responses regardless of presentation ear. Overall, however, contralateral responses are most extensive, as evidenced by extensive regions of E0-type (magenta and cyan), and more restricted regions of EI-type (red and green) interaction. The latter appear more extensive in individual subject than group-averaged data.



Quantifying activation in regions of interest

Left: Six regions of interest (ROIs) were manually defined for each subject:
IC-L; IC-R: Left and right inferior colliculi, respectively. Identified anatomically.
AC_M-L; AC_M-R: The medial portion of AC activation. Identified visually (% change: all sound - silence).
AC_L-L; AC_L-R: The lateral portion of AC activation, extending somewhat ventrally and caudally along STG.

Right: Mean % signal change across voxels within the defined ROI and across sessions are plotted for each subject.

Center: Mean % signal change within each ROI, averaged across sessions and subjects. Note that activations are larger overall in lateral AC than in IC, but in addition, responses to contralateral stimulation in particular are enhanced within the AC. The overall result, of E0-type interactions in IC giving way to more diverse binaural interactions (via enhanced responses to both flavors of monotic sound), appears yet again.

Supported by VA Research Service, NIDCD DC005814, and Academy of Finland (103170, 108799)