Binaural tuning in human auditory cortex

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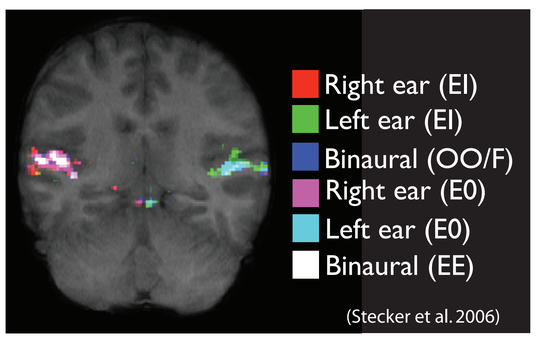
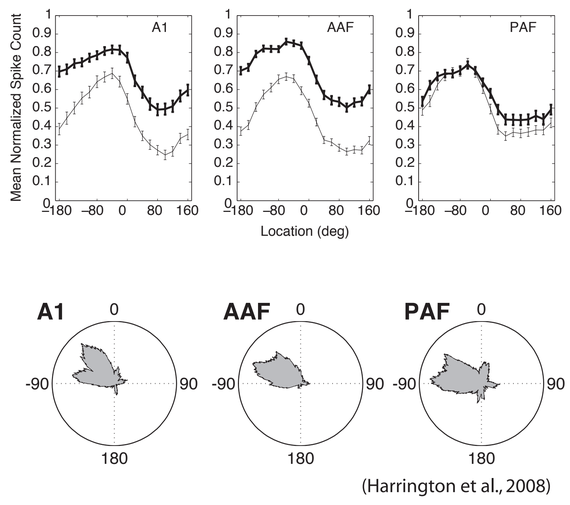
Contralateral bias in human AC fMRI BOLD response...



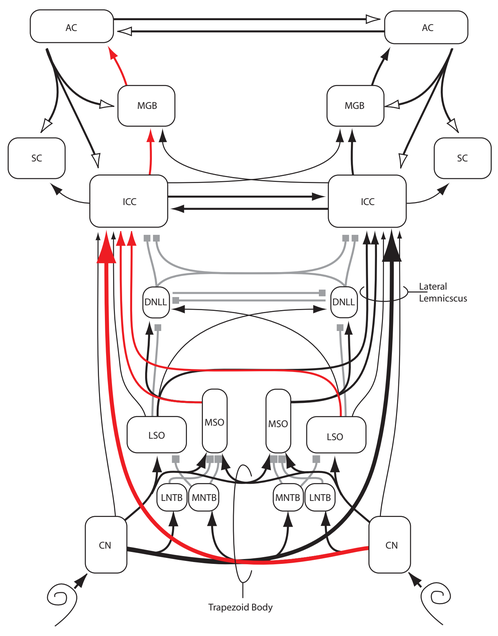
fMRI responses in human AC and inferior colliculus appear dominated by monaural (E0) input. Diotic responses (blue) closely coincide with regions and magnitude of contralateral responses (e.g., red in LH).

...appears consistent with population bias in AC spatial tuning....



Spatial responses of cat AC neurons strongly favor contralateral locations. Population response (top) and distribution of preferred azimuths (bottom) reveal contralateral bias, but favored locations coincide with acoustic axis of cat pinnae, suggesting monaural effects.

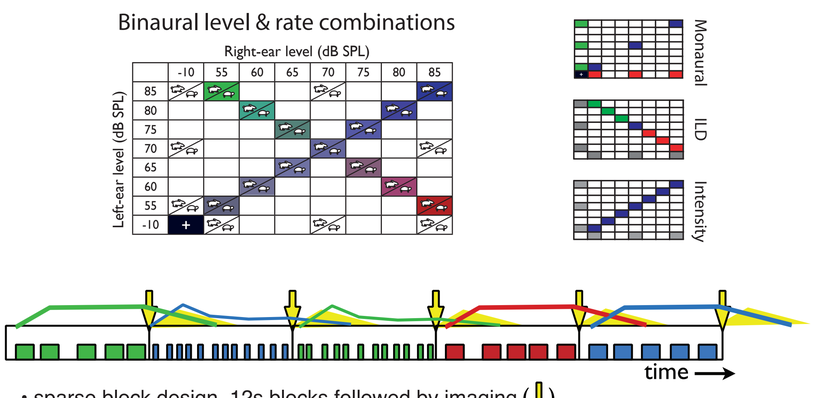
...but also with bias in monaural inputs to central structures.



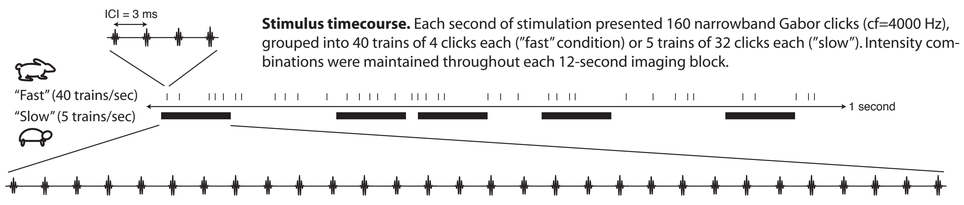
The ascending auditory pathway is dominated by contralateral monaural inputs. Black and red: excitatory inputs; line weights indicate projection magnitudes. Gray: inhibitory projections. Contralateral pathways to left AC highlighted in red for illustration. Major inputs to the inferior colliculus (ICC) include crossed monaural projections from cochlear nucleus (CN) and binaural projections from superior olivary nuclei (LSO & MSO).

Question: are BOLD responses in human AC tuned to binaural cues for sound location (interaural time and level differences)?

Study 1: Compare monaural, binaural BOLD responses

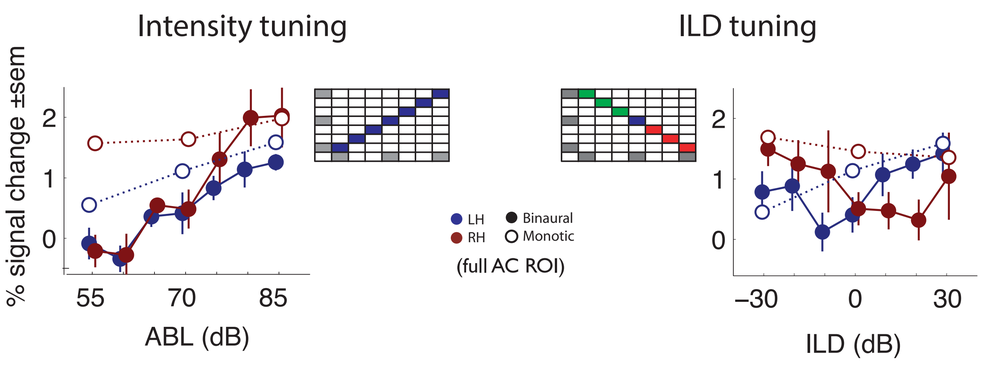


- sparse block design, 12s blocks followed by imaging
- blocks present 5 long or 40 short Gabor click trains / second
- intensity at each ear varied (55-85 dB SPL, or silent) randomly across blocks
- presented via piezoelectric insert earphones (Sensimetrics S14) in ear defenders
- task: detect rate pitch change (~once per 13 s)
- 10 normal hearing subjects (18-50y, 6 female, all right handed)
- whole-head EPI 2.75 x 2.75 x 3 mm, Philips 3T
- cortical-surface analysis with AC field ROIs (Woods et al 2010)



Stimulus timecourse. Each second of stimulation presented 160 narrowband Gabor clicks (cf=4000 Hz), grouped into 40 trains of 4 clicks each ("fast" condition) or 5 trains of 32 clicks each ("slow"). Intensity combinations were maintained throughout each 12-second imaging block.

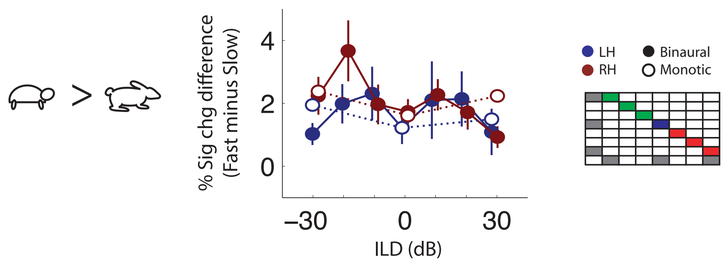
BOLD response inhibited, not facilitated, by binaural input



Inhibition Shapes Intensity Tuning Functions
responses to weak binaural sound [filled symbols] < response to equivalent contralateral sound (open)
i.e. influence of ipsilateral input is net inhibitory

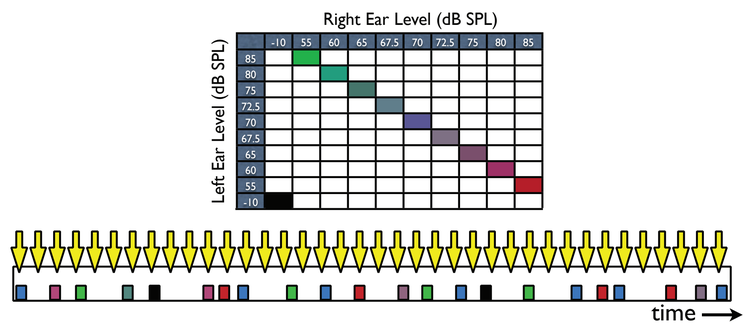
Inhibition Shapes ILD Tuning Functions
responses to midline ILD < equivalent contralateral monaural response
inhibitory effects extend to moderate ipsilateral ILD
large (>20 dB) ipsilateral ILD invoke stronger response (similar to monaural)

Response reduced by rapid stimulation, more so for moderate ILD



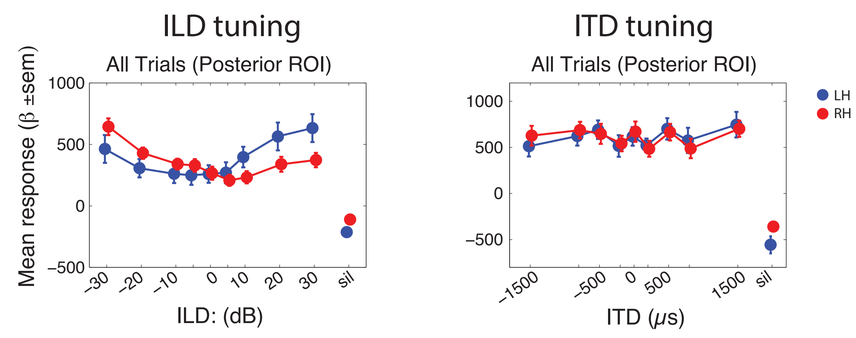
Advantage for slow stimulation (cf. Harms & Melcher 2002)
consistent with response or stimulus-specific adaptation over block duration
may reflect potentiation of inhibition; note shape of tuning to ILD

Study 2: Assess tuning, stimulus-specific adaptation, for ILD and ITD



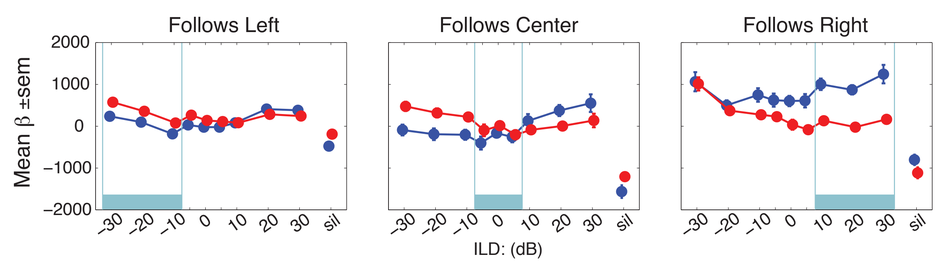
- event-related continuous carryover design, continuous (TR=2s) imaging
- stimuli: sets of 4 Gabor click trains (4000 Hz, 2 ms ICI)
- 1s stimulus duration per presentation, every ~3 s
- ILD varied -30 to +30 dB (plus 'silence') between presentations
- ITD varied -1500 to + 1500 μs (ITD and ILD tested in separate sessions)
- 10 normal-hearing subjects per condition (18-35 y, 5 female, right handed)
- other aspects as in study 1

BOLD response strongly modulated by ILD, weakly by ITD



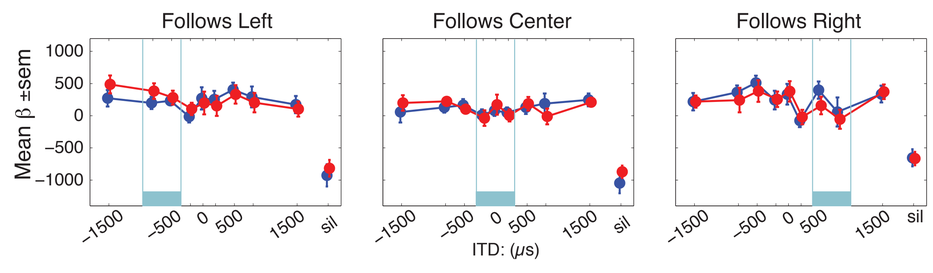
ILD tuning consistent with study 1 (response minima for moderate ipsilateral ILD)
ITD tuning appears minimal (i.e., BOLD response not strongly modulated by ITD)
despite good psychophysical sensitivity to ITD
possible that ITD tuning is spatially focused, idiosyncratic, or task-dependent

ILD repetition reduces ipsilateral response



Stimulus-history effect: reduced response to repeated ipsilateral ILD
i.e., potentiation of inhibition / increasing preference for contralateral sound

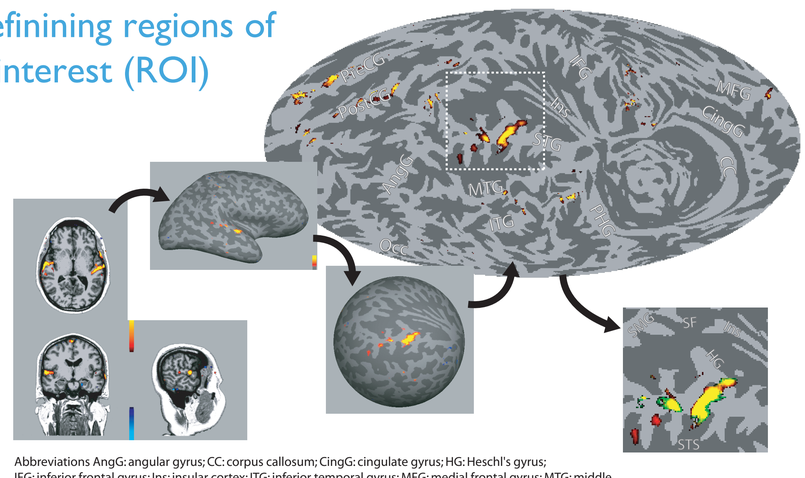
Weaker effects of stimulus history on ITD tuning



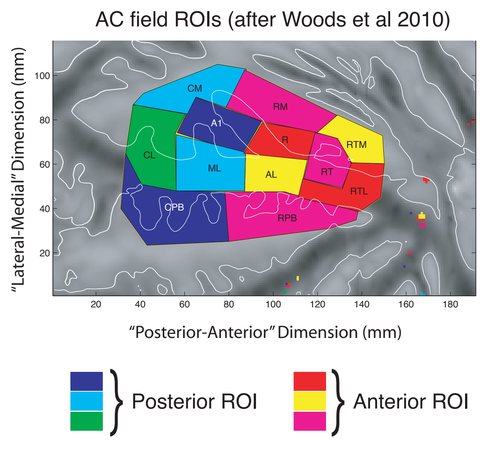
Similar but reduced effect observed for ITD as for ILD: reduction of ipsilateral response

Conclusions: averaged BOLD responses tuned to ILD, only weakly to ITD. Tuning reflects ipsilateral inhibition, potentiated by stimulus repetition.

Definining regions of interest (ROI)



Abbreviations AngG: angular gyrus; CC: corpus callosum; CingG: cingulate gyrus; HG: Heschl's gyrus; IFG: inferior frontal gyrus; Ins: insular cortex; ITG: inferior temporal gyrus; MFG: medial frontal gyrus; MTG: middle temporal gyrus; Occ: occipital cortex; PHG: parahippocampal gyrus; PostCG: postcentral gyrus; PreCG: precentral gyrus; SF: Sylvian fissure; SMG: supramarginal gyrus; STG: superior temporal gyrus; STS: superior temporal sulcus



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References

Harms, Melcher (2002). *J. Neurophysiol.* 88(3):1433-50.
Harrington, Stecker, Macpherson, & Middlebrooks (2008). *Hear. Res.* 240:22-41.
Stecker, Rinne, Herron, Liao, Kang, Yund, & Woods (2006). *Assoc. Res. Otolaryngol. Abs.* 29:426.
Woods, Herron, Cate, Yund, Stecker, Rinne, & Kang (2010). *Front. Sys. Neurosci.* 4:155.

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