Interaural Level Difference tuning in auditory cortex of the human and the rat

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Background

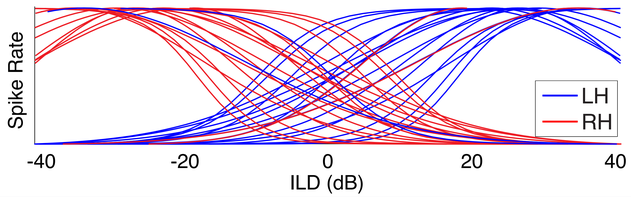
In the auditory system, the lack of a point-to-point representation of horizontal space necessitates the internal computation of the interaural level difference (ILD).

The **Opponent Channel Model** describes a mechanism for spatial encoding based on the relative spiking output of multiple neurons.

- The majority of neural responses in each hemisphere of the auditory cortex (AC) are broadly responsive to contralateral locations referred to as **contralateral bias**, with a minority sensitive to ipsilateral locations (approximately 15%, Stecker et al. 2005)
- This model is strongly supported by animal studies using electrophysiological recordings (Stecker et al. 2005; Delgutte et al. 1999; Wise and Irvine 1985; Higgins et al. 2010)

Evidence for contralateral bias in human cortex is less clear, particularly with regards to ILD since the majority of human imaging studies have used monaural and/or diotic stimuli (Woods et al. 2009; Teshiba et al. 2012).

Here we present two types of data: 1) rat auditory cortical responses to ILD stimuli using traditional electrophysiological techniques; and 2) human imaging data to ILD stimuli using sparse fMRI. The objective is to present the parallel elements of the two data sets to better understand cortical processing of the ILD cue.



Methods - Rat Electrophysiology

Objective

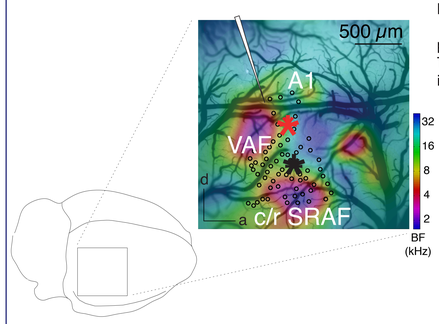
Characterize neural sensitivity to comprehensive range of ILD and ABL stimuli in auditory cortex of anesthetized rat.

Experimental protocol

Adult male rats were anesthetized and supplemented with sodium pentobarbital to maintain areflexia. Skull and dura were removed to expose temporal cortex in the right cerebral hemisphere. Intrinsic optical imaging was used to locate and identify auditory cortex based on frequency organization, then metal electrodes were used to record multi-unit responses. In a small number of experiments tetrode Michigan electrodes were used, and responses were spike sorted afterwards to isolate single unit activity.

Stimulus Presentation

Noise bursts 50 ms duration were presented at 2 Hz at varying ILD and ABL. Sound level in each ear was independently presented with a range from 0-75 dB at 5 dB increments. Sounds were presented with an RME DIGI 9652 sound card via hollow ear bars.



Methods - Human fMRI

Objective

Characterize BOLD (blood oxygen level dependent) signal in response to stimuli varying in ILD.

Stimulus Presentation

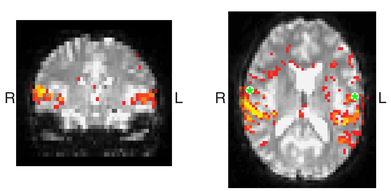
4000 Hz (carrier frequency) Gabor click trains, 3-ms interclick interval (ICI). Presented in 5 trains of 32 clicks per second, and sound level was assigned independently at each ear ranging from 55-85 dB SPL or silent (-10 dB). Stimuli were presented via piezo insert earphones (Sensimetrics S14) in ear defenders. Participants were tasked with detecting rare (once per ~13s) presentation of 2-ms ICI by button press.

Data Collection

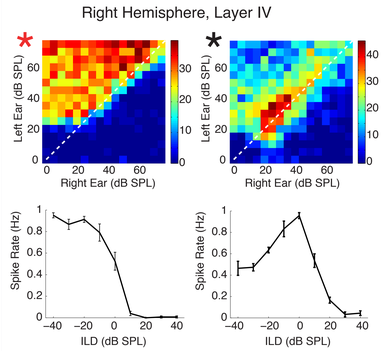
Data were collected with a sparse imaging protocol in seven participants. Twelve second blocks were presented at varying binaural level combinations. Silent blocks occurred every 4th block and image was acquired at end of each block. Three runs of 57 blocks were presented to each participant.

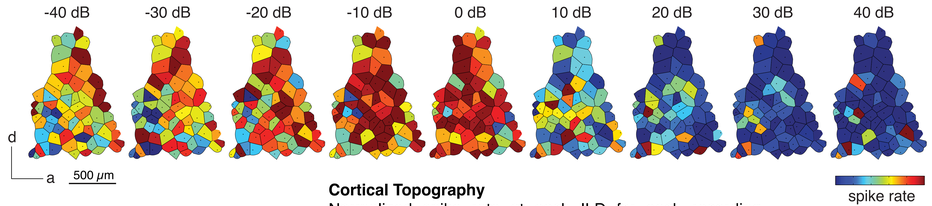
Imaging Methods

BOLD echoplanar imaging (Philips, 3 Tesla scanner) was performed with a TR of 12 seconds, one frame per block. Thirty-two 4.5 mm slices were acquired, with 3 mm x 3 mm in-plane resolution.



Rat AC - Spike Rate as a Function of ILD



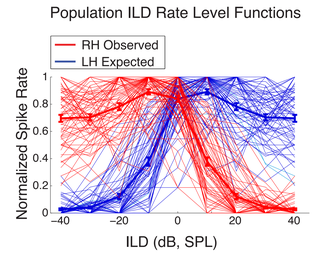


Individual Responses

Across four different cortices a wide variety of responses are observed, including peaked responses around ILD=0. Despite this variety the majority exhibit the most spike rate to contralateral ILDs.

Cortical Topography

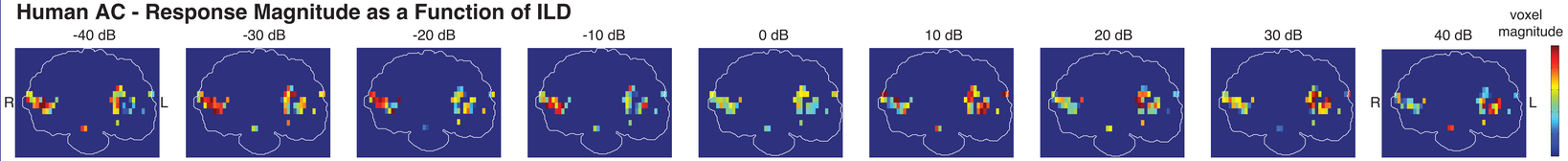
Normalized spike rate at each ILD for each recording topographically illustrates 2 points: 1) nearly all units respond more to contralateral ILDs, and 2) despite this contralateral bias there are still regional differences. Specifically the ventral-rostral areas corresponding to ventral and caudal suprarhinal auditory fields (VAF and cSRAF, respectively) show a decrease in spike rate at extreme ILDs.

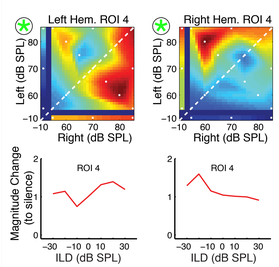


Population Code

When rate level functions (RLFs) are plotted the variety of spike rates at a wide range of ILDs is observed. Despite the variety the population curve reveals a strong bias to contralateral ILDs. Blue lines plot putative left hemisphere responses, obtained by reflecting right hemisphere responses about the midline.

Human AC - Response Magnitude as a Function of ILD



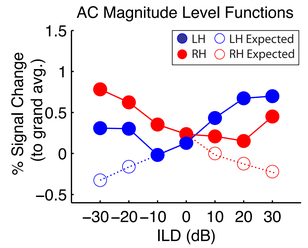


fMRI Response Fields

Exemplar level response areas corresponding to an isolated region of interest (ROI-4), an area located in anterior AC. Both left and right hemispheres are characterized by large response to contralateral ILDs (below the diagonal in LH and above diagonal in RH).

Voxel Magnitude

Normalized voxel strength at a representative coronal slice is modulated by ILD cue. Negative (leftward) ILDs elicit larger responses in right hemisphere compared to positive ILDs. The opposite effect can be observed in left hemisphere.



Cortical Magnitude Level Functions

Across the population both left and right hemispheres displayed a larger magnitude change to contralateral ILDs. Contrary to expectations based on animal physiological recordings, a smaller than expected decrease in magnitude was observed for extreme ipsilateral ILDs. Open circles represent extrapolated data points that might be predicted by electrophysiologic action potential data.

Summary

Despite differences in species and recording technique, both approaches demonstrate a stronger population response to contralateral ILDs, consistent with the opponent-channel model as a mechanism for encoding ILD in cortical populations.

However, human imaging data deviate from the action-potential data, showing greater than expected responses to ipsilateral ILDs.

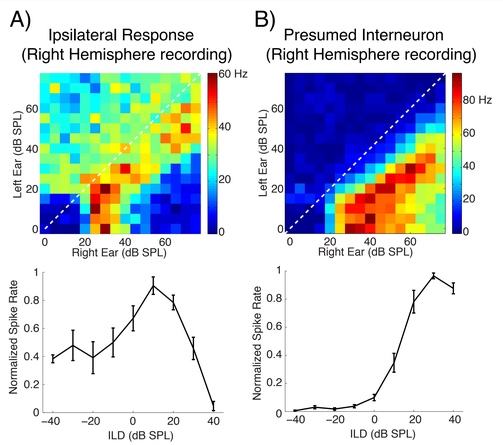
Explanation A: may be a greater proportion of ipsilaterally sensitive neurons in humans (example from multiunit recording)

Explanation B: BOLD will reflect activity across a wider array of neuron types, including interneurons that may be missed by traditional studies that focus on cortical layer IV (example from single unit tetrode recording)

Other potential explanations

- BOLD signal reflects sub-threshold dendritic potentials, both excitatory and inhibitory (Logothetis et al. 2001)

- Sharpening of response due to attentional modulation (Lee and Middlebrooks 2010) could also play a substantial role in the amount of cortical inhibition for both sound localization and identification



Conclusions

Though human and rat auditory cortices are capable of performing vastly different functions, it is important to recognize the similar fundamental neurological components. This is especially important in light of the technical challenges inherent in noninvasively studying the human brain.

Acknowledgements

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