Neurobiology of Hearing (Salamanca, 2012)

Auditory Cortex (1)

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Outline

Lecture 1: Tonotopic organization and stimulus selectivity
   a) Anatomical structure of the mammalian auditory cortex
   b) Tonotopic organization of auditory cortex
   c) Firing patterns and tuning to preferred stimulus

Lecture 2: Temporal processing
   a) Coding of time-varying signals
   b) Temporal-to-rate transformation in A1
   c) Temporal-to-rate transformation outside A1

Lecture 3: Spectral and intensity processing
   a) Spectral processing
   b) Intensity processing

Lecture 4: Spatial and auditory-feedback processing
   a) Spatial processing
   b) Auditory-feedback processing
The Notion of Tonotopic Organization in Auditory Cortex
What is unique about the auditory systems?

1) Longer subcortical pathway
2) Spectrally overlapping, time-varying input signal
3) Sounds entering the ear from anywhere at anytime
4) Hearing-speaking: sensory-motor processing
More spiking synapses in subcortical nuclei

Visual

Auditory

Graded transmission

spiking

Retinal ganglion cell

Vision

Receptor

Primary neuron

Cochlear nuc.

Sup. olive

Inf. colliculus

Thalamus

Cortex

Auditory
Organization of auditory cortex is largely preserved across primate species.

Auditory cortex

New World Monkey
(*Callithrix jacchus* – common marmoset)

Old World Monkey
(*Cercopithecus*)

Human
Overall organization of auditory cortex

Cat
Imig and Reale (1980)

Primates
Morel and Kaas (1992)
Tonotopic organization of auditory cortex: First demonstration in anesthetized cat (at Hopkins!)

Fig. 4. Expt. 2/1/41: right cortex; left cochlea; stimulation of nerve fibers at 6 mm. (basal turn) and 14 mm. (middle turn) from basal end. Note that there are two response areas for the 14 mm. point. See text p. 320 and p. 327. Labels identify sulci. 2 ½ X.
Fig. 5. Expt. 2/5/41; right cortex; left cochlea; nerve fibers stimulated at 1.5, 4, 6, 8, 14 and 19 mm. from the basal end of the spiral. See text p. 321. 2½ X.
Is auditory cortex tonotopically organized?
Lack of an orderly organization in unanesthetized cat

“Standard cortex”

Goldstein et al. (1970), Neural Encoding Lab, BME, JHU
Is there a columnar organization in auditory cortex?
How reliable are anatomical landmarks?

Merzenich et al. (1975)
Auditory cortex is tonotopically organized

Suprasylvian sulcus

iso-frequency axis

Merzenich et al. (1975)
Systematic changes of CF across auditory cortex

Slope = 1 oct/mm

Merzenich et al. (1975)
Tonotopical organization in marmoset auditory cortex

Bendor and Wang (2005)
Tonotopic organization across mammals

Morel and Kaas (1992)
“Why are Evans et al. and our single track penetrations so out of agreement with the orderly representation of the cochlea within AI reported by Merzenich et al.? First and foremost in our view is the different anesthetic state. There is no question that the sorts of anesthetics Merzenich et al. used render many cortical units unresponsive to sound. Further the effect is probably selective so that units with more indirect input pathways are more likely to be affected.” (p.190)

What have we learnt from the old debate?

- Anesthetized
- MGB input
- Multi-unit
- Near threshold
- Single hemisphere
- Unanesthetized
- Cortical response
- Other layers
- Single-unit
- Supra-threshold stimulus
- Averaging across hemispheres
“In this chapter and elsewhere, we have stressed the diversity of the neural coding properties of the units in the auditory cortex. This diversity makes the cortex a difficult region to study and makes it especially unattractive to those who like their science in neat packages. Let us hope that new studies, new techniques, and new findings will move us out of what will someday be called the early phases (or even the dark ages) of neuroscientific study of the cortex.”

**Mysteries of Auditory Cortex**

**Why it’s so silent?**
Because of anesthesia &. non-optimal stimuli!

Onset responses to brief sounds (anesthetized rats)

DeWeese and Zador (2003)

Onset responses to continuous sounds (anesthetized marmosets)

deCharms and Merzenich (1996)
Auditory cortex is capable of sustained firing in awake animals

Wang et. al. (Nature, 2005)
Auditory cortex neurons respond to preferred stimuli with sustained firing and adapt quickly to non-preferred stimuli.

Wang et. al (Nature, 2005)
What is the relationship between firing pattern and stimulus selectivity in auditory cortex?

Auditory cortex neurons respond to preferred stimuli with sustained firing and adapt quickly to non-preferred stimuli.
From a stimulus’ point of view:

“When a sound is heard, a particular population of auditory cortex neurons fire continuously throughout the duration of the sound. Responses of other, less optimally driven neurons fade away quickly after the onset of the sound.” (Wang et al. *Nature* 2005)
From a neuron’s point of view:

Responses of one neuron to entire acoustical parameter space

Acoustic parameter space

Preferred stimulus (sustained firing)

Non-preferred stimuli (onset firing)

Outside RF (no response)

Wang (Hearing Research, 2007)
From a neuron’s point of view:

Responses of one neuron to entire acoustical parameter space

Acoustic parameter space

Wang (Hearing Research, 2007)
Increased stimulus selectivity along ascending auditory pathway

- **Auditory nerve**
- **Inferior colliculus**
- **Thalamus**
- **Auditory cortex**

- **Preferred stimulus** (sustained firing)
- **Non-preferred stimuli** (onset firing)

Wang (*Hearing Research*, 2007)
How responsive is auditory cortex during sleep?  
(unlike under anesthesia!)

Issa and Wang (2008)
Auditory cortex is as responsive to sounds during sleep as during awake state

A

B

Issa and Wang (2008)
However, SWS shows less excitation at low sound levels, ...
..., and less inhibition at high sound levels.
SWS alters auditory processing across sound levels

Issa and Wang (J. Neurosci 2011)
Summary of observations from auditory cortex in awake condition

1) Neurons in auditory cortex are high selective to acoustic stimuli.
   - Each neuron is only responsive to a small region of acoustic
   - As a result, each stimulus only excites a small number of neurons (“spatial sparseness”)

2) Neurons in auditory cortex are also highly responsive (fire plenty of spikes), but only to stimuli they like.
   - “spatial sparseness” does not result in sparse firing (i.e., transient responses)

3) “Selectivity” and “responsiveness” are closely coupled.
   - Stimulus selectivity is a more useful measure than “sparseness” if you want to understand what a neuron actually does.
Suggested readings:

**Tonotopic organization:**


**Firing pattern and stimulus selectivity:**

