TDLC Sensorimotor Network

Feldman
Poo
Tallal
Benasich

THE COMPUTATIONAL BRAIN

Sejnowski
Bell
Auditory Perceptual Learning and Plasticity

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Hearing is More Than Sensing Sounds

It involves constructing a model of the world:

- What objects do the sounds correspond to?
- Where are they?
- What do they mean?

“Look man, you can listen to Jimi, but you can't hear him. There’s a difference man. Just because you're listening to him doesn't mean you're hearing him.”

- Sidney Deane in ‘White Men Can’t Jump’
The Nature of Sound

• Changes in (air) pressure that have characteristic properties such as amplitude and frequency

• Pure tones are sinusoids when pressure change plotted against time

• More complex sounds can be described in terms of a sum of sinusoids

• Frequency relates to pitch; amplitude relates to loudness

• Pitch and loudness are psychological properties; frequency and amplitude are physical properties
Describing Physical Features of Sounds
Speech Signals

- Spectrogram shows frequency against time, intensity shown by darkness
- “Joe took father’s shoe bench out”
From Ear to Brain

• Outer ear (pinnae and ear canal): amplifies certain frequencies, important for locating sounds

• Middle ear (includes malleus, incus, stapes): converts airborne vibrations to liquid-borne vibrations

• Inner ear (includes cochlea): converts liquid-borne sounds to neural impulses
From Ear to Brain

- 4-5 synapses from ear to cortex
- Medial geniculate nucleus projects to primary auditory cortex (A1)
- A1 is surrounded by secondary auditory cortex
- Neural signals ascend and descend in the pathway
From Ear to Brain: Tonotopic Organization

Saenz & Langers, 2014
## Comparisons Between the Auditory and Visual Systems

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<tr>
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<th>Auditory system</th>
<th>Visual system</th>
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<td><strong>Thalamo-cortical route</strong></td>
<td>Medial geniculate nucleus projects to primary auditory cortex</td>
<td>Lateral geniculate nucleus projects to primary visual cortex</td>
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<td><strong>Organizing principle of early neural processing</strong></td>
<td>Tonotopic organization (orderly mapping between sound frequency and position on cortex)</td>
<td>Retinotopic organization (orderly mapping between position on retina and position on cortex)</td>
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<td><strong>Temporal and spatial sensitivity</strong></td>
<td>Temporal &gt; Spatial</td>
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<td><strong>Functional specialization of feature processing</strong></td>
<td>Less well documented in the auditory domain</td>
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<td><strong>Higher-order context-dependent pathways</strong></td>
<td>Evidence for separate auditory pathways for “what” versus “where”/“how”</td>
<td>Evidence for separate visual pathways for “what” versus “where”/“how”</td>
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Feature Processing in Auditory Cortex

Evidence from single-cell recordings:

• Less evidence that different auditory features (loudness, pitch, tempo, timbre) are processed by different regions, compared to vision

• Neurons in A1 may be tuned to pure tones, but in secondary areas may respond to a range of frequencies or changes in frequency
Feature Processing in Auditory Cortex

Neurons tuned to amplitude and locations, too
How Do Listeners Deal With Variability?

• Categorical perception: continuous changes in inputs are mapped onto discrete percepts
• Percepts may be mapped onto abstract representations that specify nature of acoustic signal (e.g. voicing, timing, phonemes, syllables)
• Could also be mapped onto units of articulation (i.e. understanding what other people are saying by figuring out how I could say it) - motor theory of speech perception
Perceptual Learning

• Prior experiences can increase perceptual sensitivities to differences.
• Perception is malleable even in adults.
• Changes often require extensive training and practice.
• The type of practice impacts the development of changes.
• What changes during learning has been debated for over 100 years.
What Changes?

William James’s two processes of perceptual learning:

1) Words drag percepts apart.

2) Small differences remind us of larger differences.
Perceptual Learning As Cued Recall

EVENT A

EVENT B

BEFORE

EVENT A+

EVENT B+

AFTER
What Changes?

Ivan Pavlov’s cortical theory of perceptual learning:

“...the excitatory process which is originally widely spread in the cerebral part of the analyser is gradually overcome by internal inhibition, excepting only the minutest part of it which corresponds to the conditioned stimulus.” - Pavlov, 1927
Perceptual Learning As Distractor Suppression

EVENT A
BEFORE
EVENT A-
AFTER

EVENT B
EVENT B-
U.S.A. VS. Israel

Perceptual Template Model

Reverse Hierarchy Theory
Perceptual Learning as Selective Attention

EVENT A

EVENT B

BEFORE

EVENT A-

EVENT B-

AFTER
Reverse Hierarchy Theory

Reverse Hierarchy Theory: visual system hierarchies of areas and cell types
Perceptual Learning As Reconfiguration

EVENT A

EVENT B

BEFORE

EVENT A'

EVENT B'

AFTER
What Changes With Perceptual Learning?

OLD SCHOOL

- Long-term memories
- Stimulus representations

“NEW” SCHOOL

- Selective attention
- Levels of processing
What Changes in Brains During and After Auditory Perceptual Learning?

OLD SCHOOL

- Long-term memories (beyond A1)
- Stimulus representations (A1)

“NEW” SCHOOL

- Selective attention (Prefrontal?)
- Levels of processing (beyond A1)
Auditory Plasticity

- Learning about sounds changes auditory processing.
- These changes can be seen in neurophysiological recordings from auditory cortex.
Brain Regions Involved in Auditory Plasticity

Suga, 2008
Brain Regions Involved in Auditory Plasticity

Augmentation

- Prefrontal cortex
- Cholinergic b. f.
- Non-ACh

Auditory cortex
- MGBv
- MGBm PIN
- IC

Somato. cortex

Assoc. cortex
- Amygdala

- TRN

- Tone burst (CS)
- Ele. leg-stim. (US)

Paired or unpaired CS & US

Behavioral responses

Suga, 2008
Brain Regions Involved in Auditory Plasticity

Scheich et al. 2011
Brain Regions Involved in Auditory Plasticity

Scheich et al. 2011
Brain Regions Involved in Auditory Plasticity

Burwell and Amaral, 1998
When a sound is unfamiliar, hippocampal lesions speed auditory learning, amplify auditory cortical plasticity, and disrupt generalization.

Brain Regions Involved in Auditory Plasticity

- Hippocampus
- Entorhinal cortex
- Peri/Postrhinal cortex

Burwell and Amaral, 1998
When a sound is unfamiliar, hippocampal lesions speed auditory learning, amplify auditory cortical plasticity, and disrupt generalization.

Brain Regions Involved in Auditory Plasticity
Feature Processing in Auditory Cortex

Neurons tuned to amplitude and locations, too
Spectro-Temporal Receptive Field Plasticity

• Auditory cortical neurons respond differentially to acoustic features - receptive fields describe this response profile.

• Training experiences are associated with the retuning of receptive fields (RF).

• RF changes include shifts in the selectivity of responding, generalized increases in responsiveness, and the development of new sensitivities.
Evoked Potential Plasticity

• Predictable EEG deflections follow perceptible changes in the auditory environment

• N1-P2 amplitude reflects
  ➢ the intensity of the sound
  ➢ the amount of acoustic change

• Training and sound exposure can both enhance P2 peak amplitude
Event-Related Spectral Perturbation Plasticity

Wisniewski et al., 2014
What Changes in Brains During and After Auditory Perceptual Learning?

**ANIMALS**
- Excitatory tuning (in A1 and nearby)
- Inhibitory responses (in A1)

**HUMANS**
- “Late” evoked responses (in Frontal)
- Oscillations (in Frontal/Parietal)
When Do Auditory Circuits Change?

Perceptual acuity naturally varies, but often greater resolution is advantageous. What constrains increases in resolution?
When Do Auditory Circuits Change?
Cumulative Effects On Capacity

- **Dynamic equilibrium**
- **Prolonged mismatch**
- **Dynamic equilibrium**

**Manifestation of plasticity**
- **Negative mismatch: demand > supply**
- **Positive mismatch: demand < supply**

**Demand on (use of) functional supply**

**Time**

**Maximum function**
- Flexibility: Functional supply supports a range of functioning, but is optimized (black line) to a level of demand that is integrated over some unknown time period.
Can Software Adapt To Unknown Needs?

Is your current curriculum adapting to each student's exact needs? Our software solutions do just that.

• No, it does not, but adaptive learning technologies don’t either.

• Scheduling training regimens based on student errors works (sometimes), because it funnels students toward a goal and increases time on task.
Things to Think Through

Can early learning experiences derail/enhance brain development?

What sorts of changes are desirable/possible?

How might one assess whether changes are progressing in a desired way?

In what ways do learning-related changes vary across species and brain regions?