Adaptive Processing of Sound Location

www.auditorybrain.com/downloads

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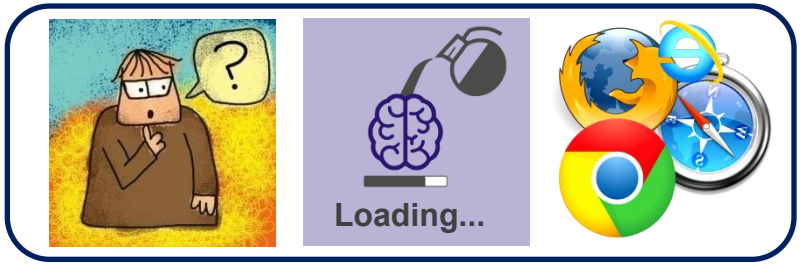

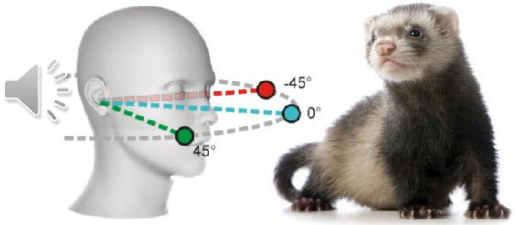

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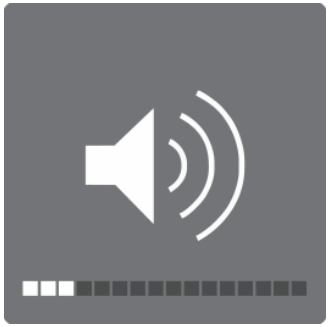
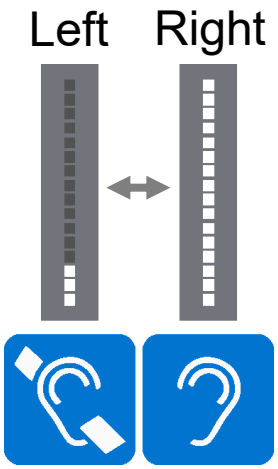
How does the brain learn to use abnormal auditory input?

Learn to rely more on intact sensory inputs

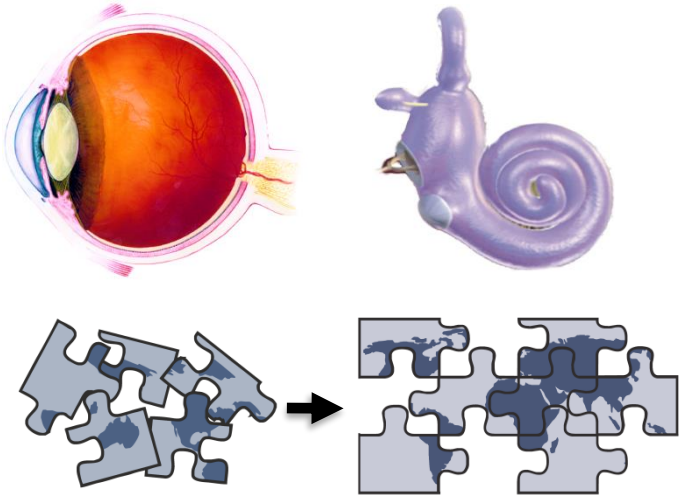
Learn to use abnormal sensory inputs

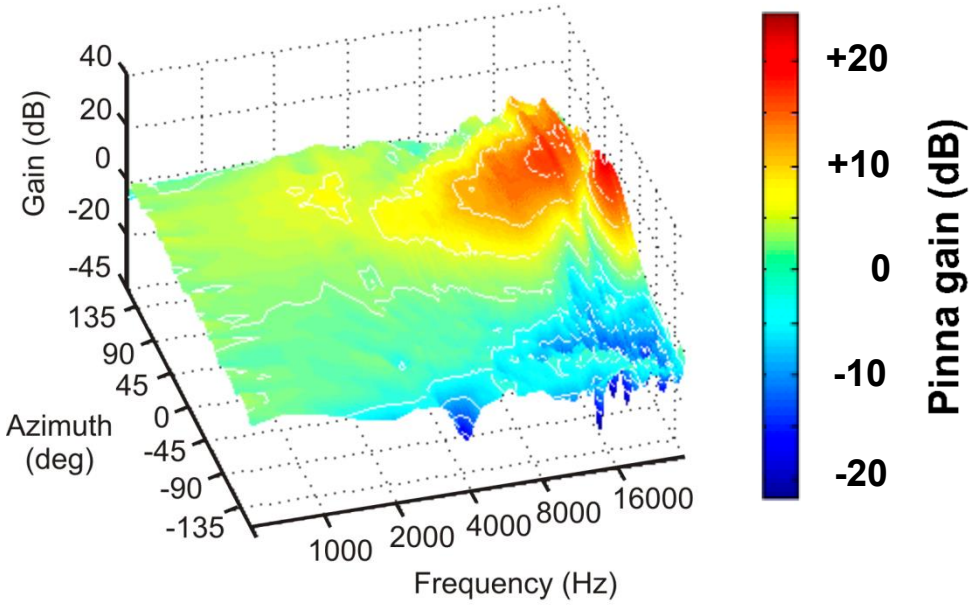





BBC TWO

Sound localization requires integration of multiple cues





Binaural cues

ITDs ILDs Spectral

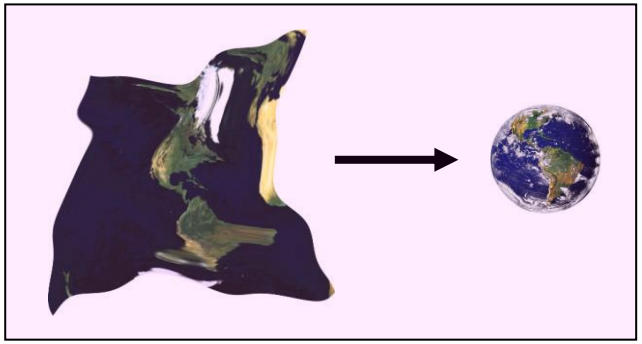
Adapting to changes in auditory spatial cues

How does sound localization adapt to a developmental hearing loss in one ear?

Remapping

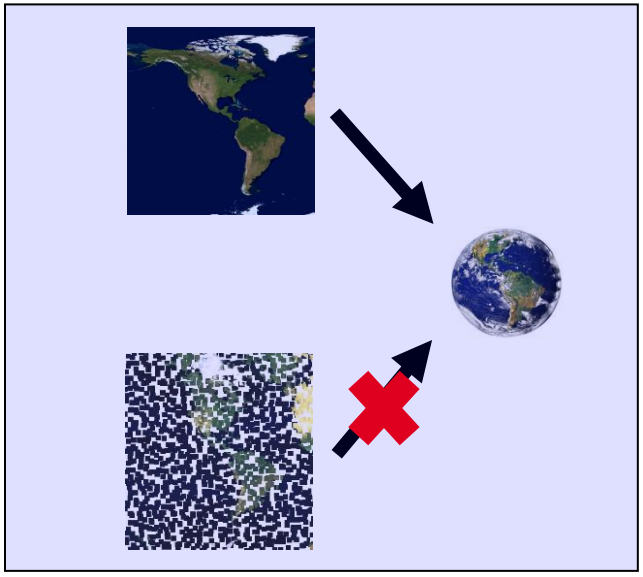
1. Learn to **use** the abnormal cues by remapping cue values onto correct locations

e.g. Knudsen et al. (1984) *J Neurosci,* Gold & Knudsen (2000) *J Neurosci*

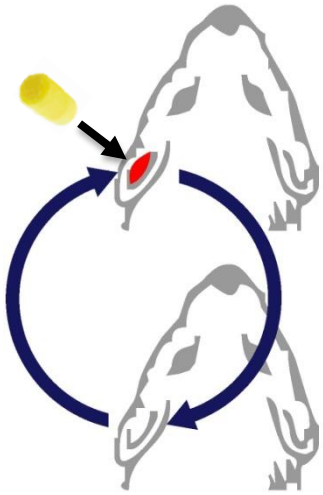


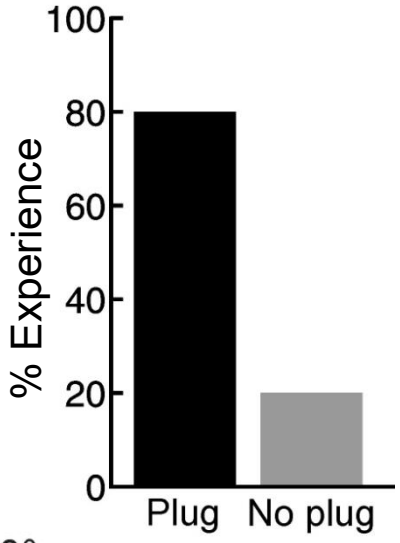
Reweighting

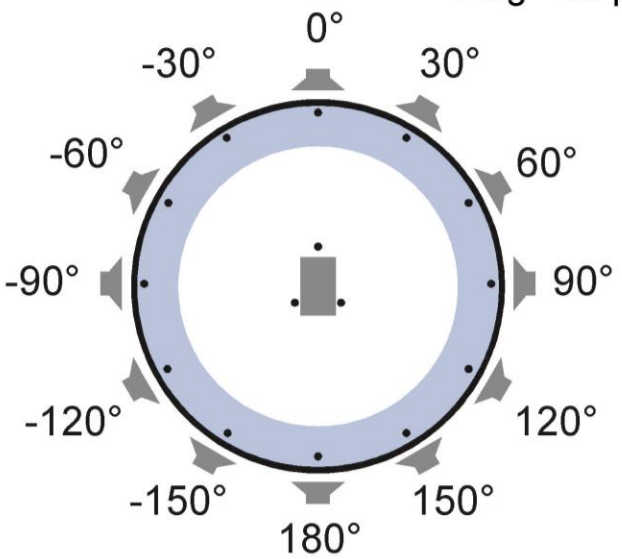
2. Learn to **ignore** abnormal cues by increasing the relative weight given to cues that remain unchanged



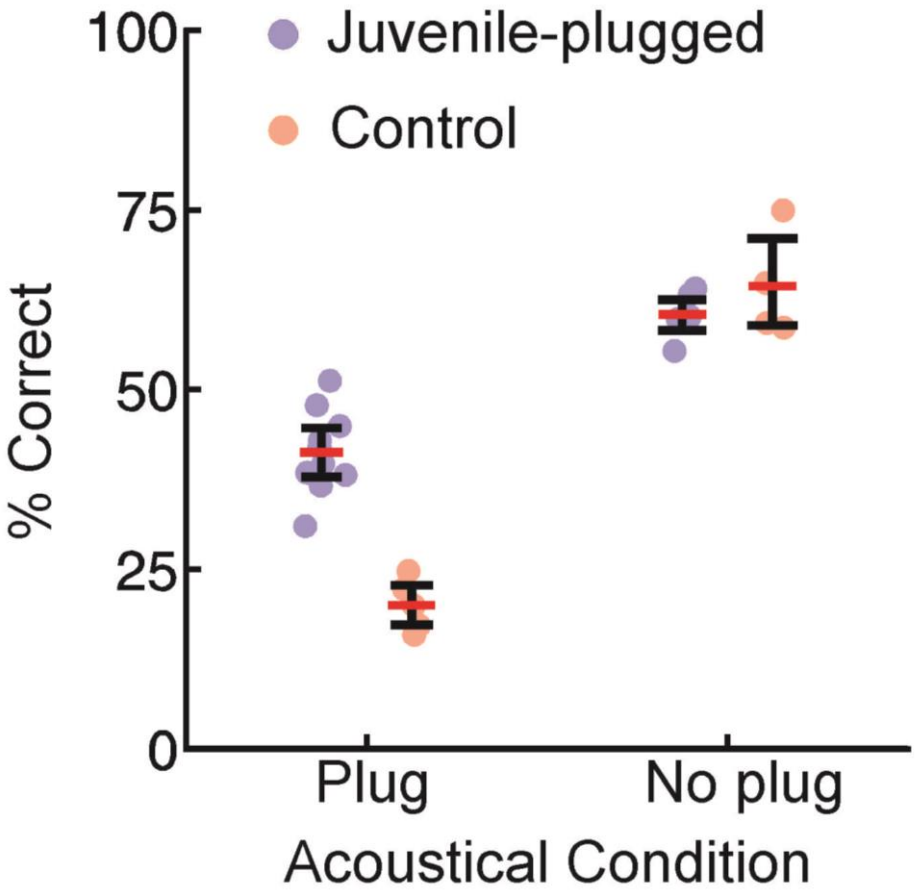
Sound localization behaviour adapts to an earplug







Stimuli: **Flat-spectrum, 200ms, 56-84 dBSPL**



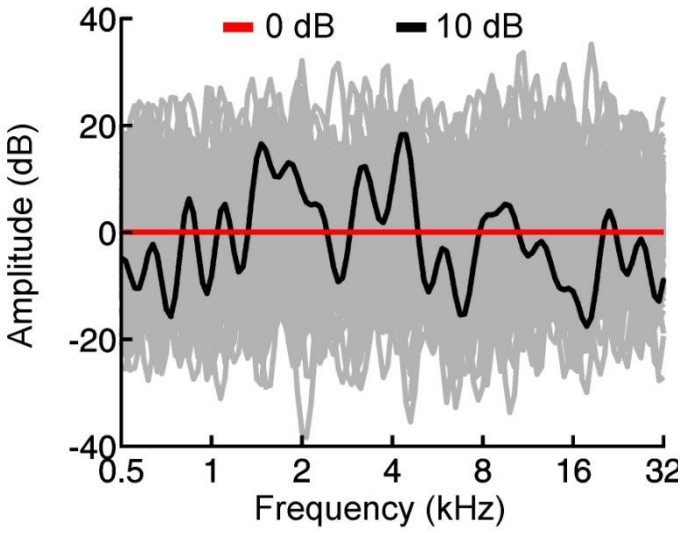
Juvenile-plugged ferrets adapt to an earplug but localize sounds **even better** when the earplug is removed

Learning to rely more on monaural spatial cues

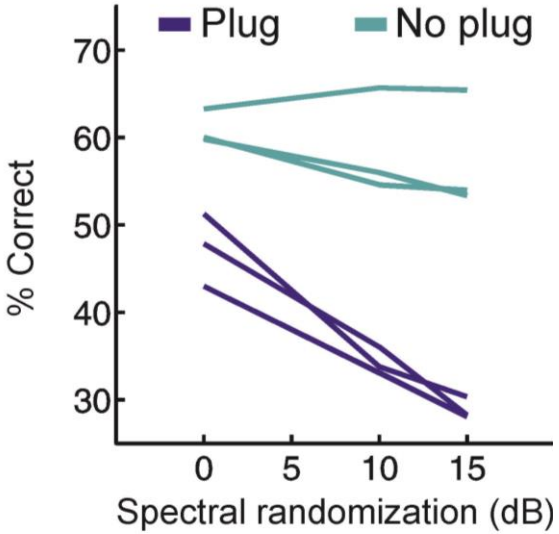
- Varying the sound spectrum across trials impairs monaural localization

Wightman & Kistler (1997) *JASA*, Kumpik et al. (2010) *J Neurosci*

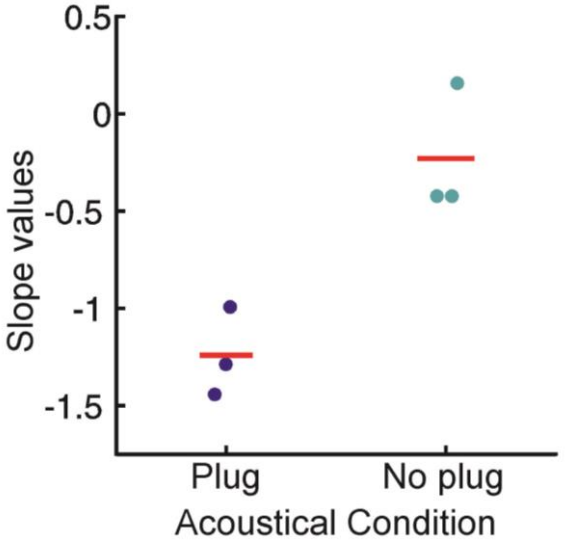
Randomization (10dB)



Regression



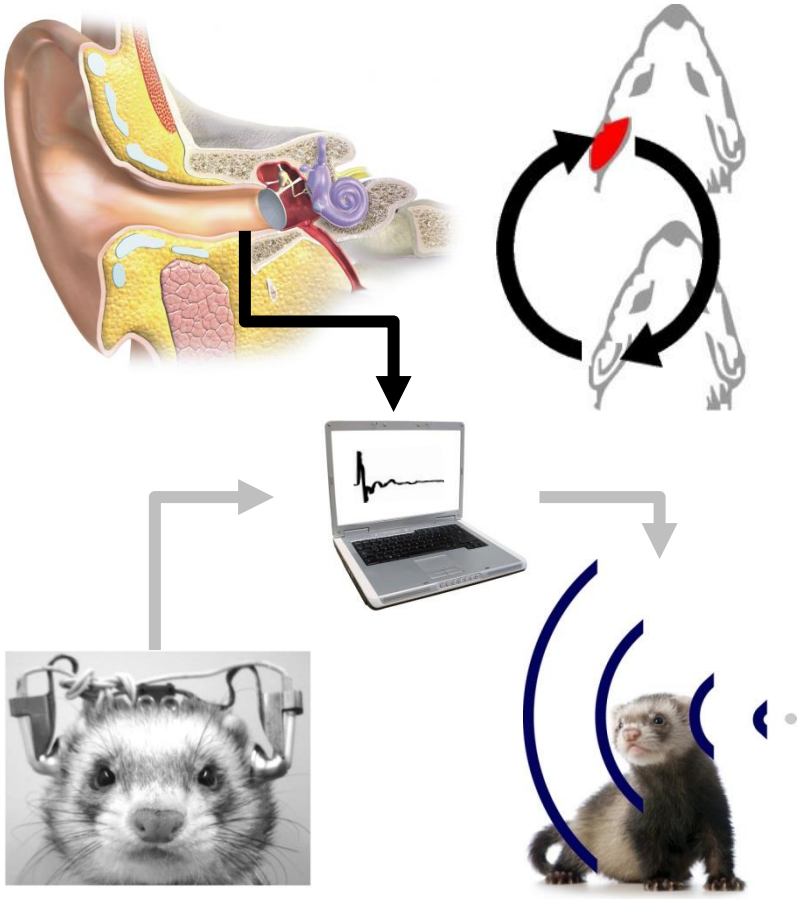
Slopes



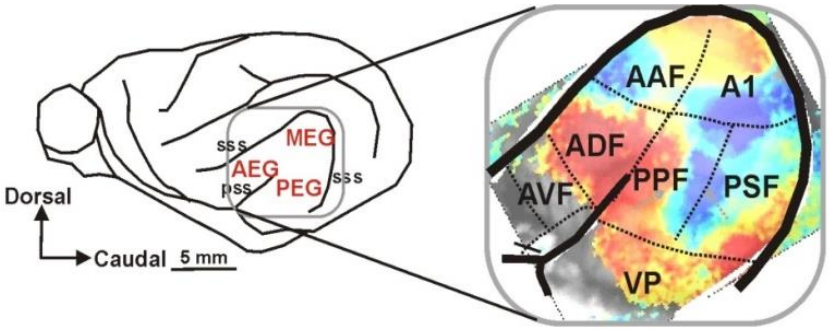
Juvenile-plugged ferrets learn to rely more on monaural spatial cues, but **only** when wearing an earplug

Cue reweighting in primary auditory cortex

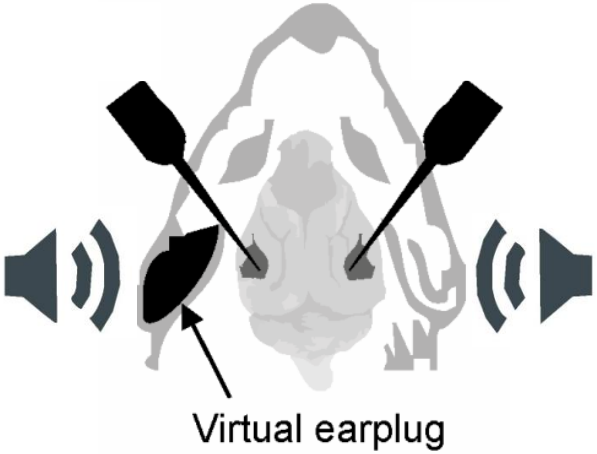
Virtual acoustic space techniques



Bilateral A1 recordings



Bizley & King (2009)



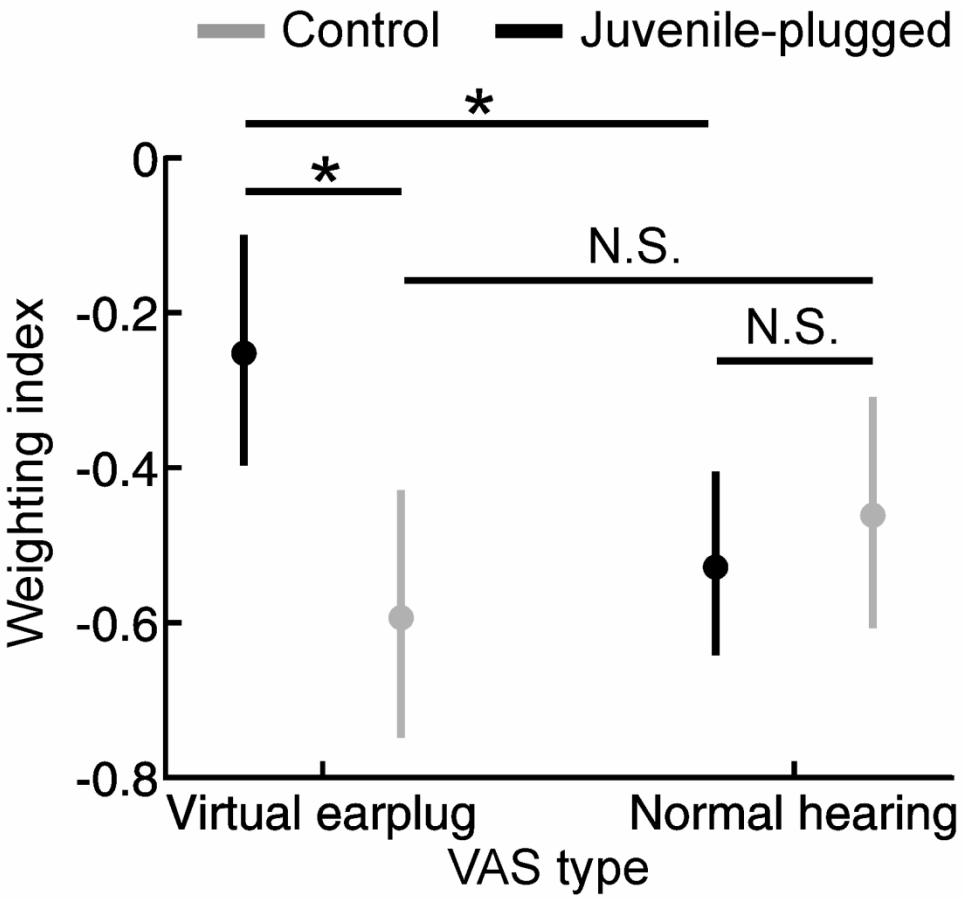
Relative to controls, juvenile-plugged animals should be **more** sensitive to the **intact** cues and **less** sensitive to the **altered** cues, but **only** in the presence of a virtual earplug

Cue reweighting in primary auditory cortex

- We measure sensitivity using the mutual information (MI) between spike counts and individual spatial cues

Weighting Index (WI)

$$WI = \frac{MI_{Intact} - MI_{Altered}}{MI_{Intact} + MI_{Altered}}$$



Reweighting of spatial cues in primary auditory cortex is context-dependent and parallels that seen behaviourally

Context-dependent reweighting of auditory spatial cues

Summary

1. Ferrets adapt to a developmental hearing loss in one ear by learning to rely more on their good ear

2. Neurons in primary auditory cortex show corresponding changes in their activity patterns (so not just a cognitive coping strategy)

3. When the hearing loss is reversed, ferrets locate sounds normally

Conclusions

Adaptation to hearing loss does not necessarily prevent you from learning to use normal hearing whenever it is available

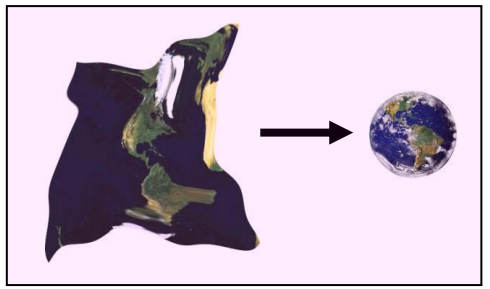
The auditory system can learn and maintain different processing strategies and switch between them depending on which sensory conditions are experienced

Keating et al. (2013) *Curr Biol*

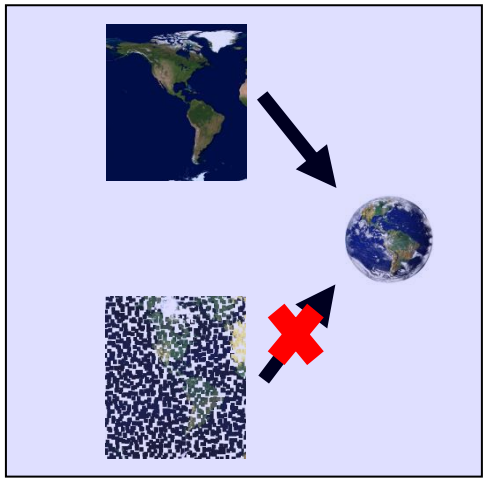
Why do we see different adaptive mechanisms?

How does the brain adapt to a developmental hearing loss in one ear?

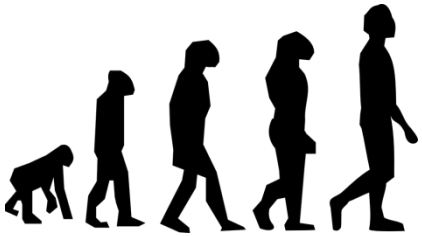
1. Learn to **use** abnormal cues by remapping cue values onto correct locations

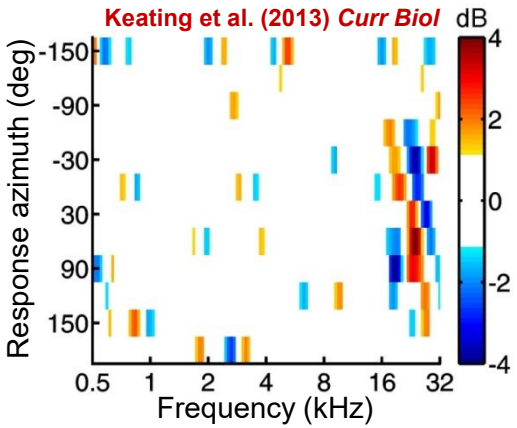


2. Learn to **ignore** abnormal cues and instead rely on cues that remain unchanged



Why do we see different mechanisms?

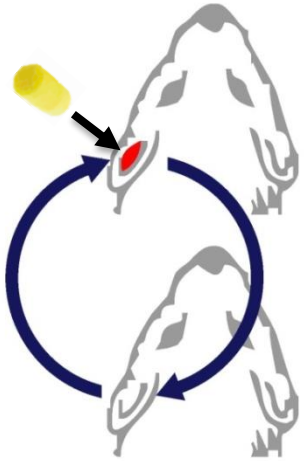




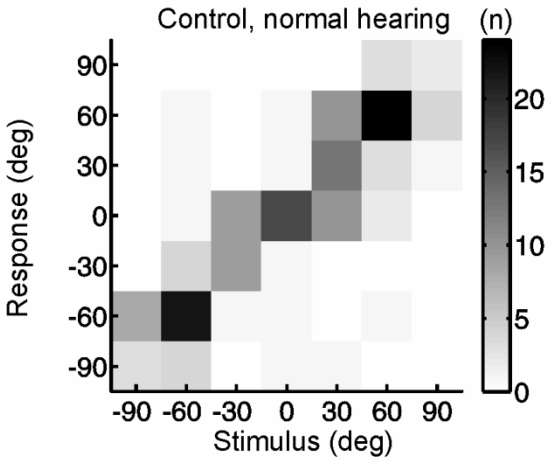
Research Question:

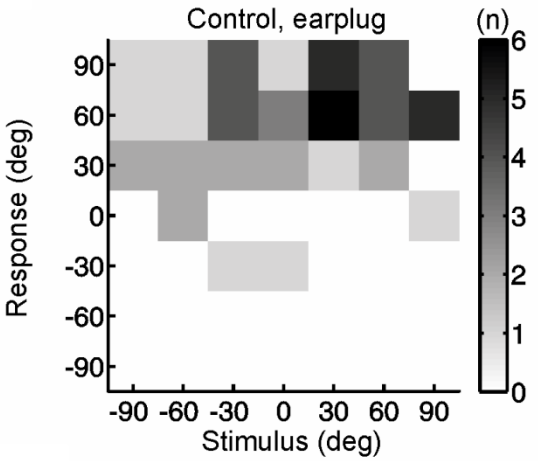
Can ferrets reared with a unilateral hearing loss locate sounds if we take away their spectral cues?

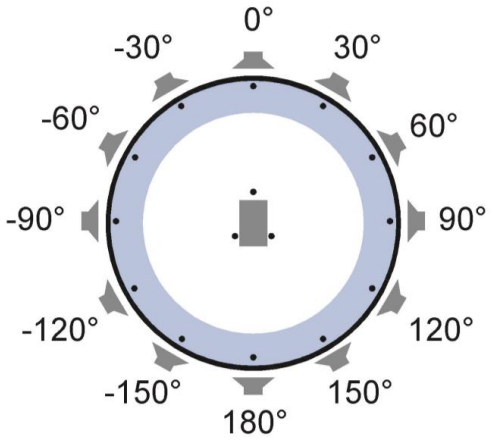
Behavioural adaptation to abnormal binaural cues

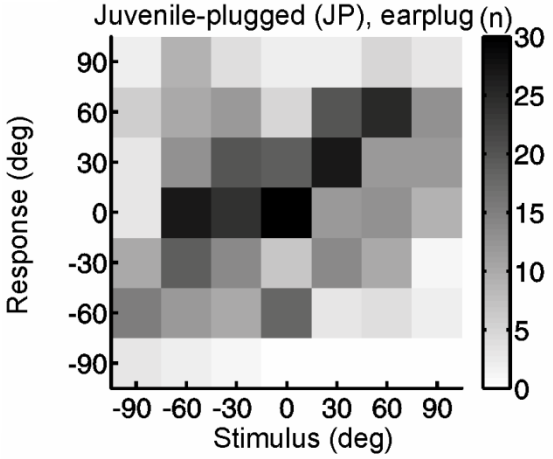


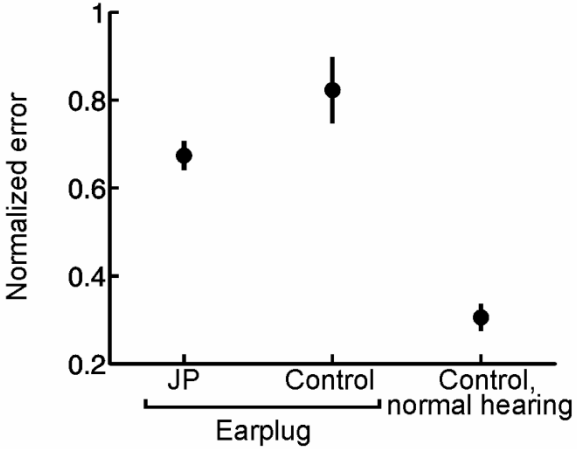
Stimuli: high-frequency narrowband, 200ms











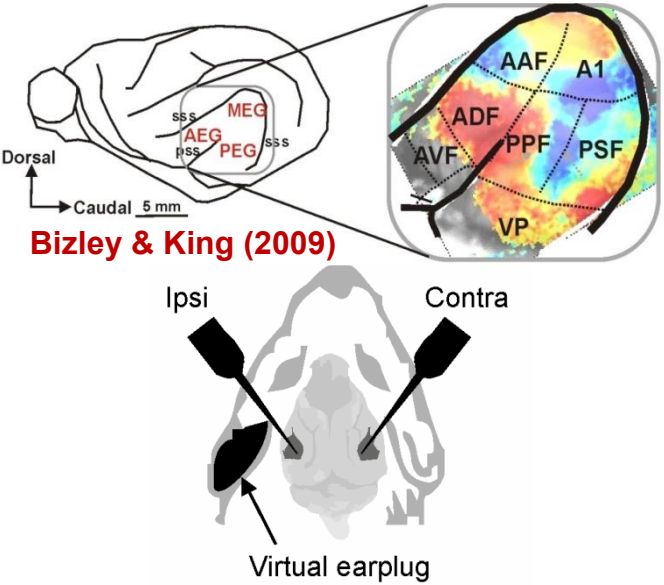
Juvenile-plugged ferrets possess a second adaptive mechanism that does not require spectral cues

Adaptive processing of Interaural Level Difference in A1

- In ferrets, ILDs are the primary cue for localizing high-frequency narrowband sounds

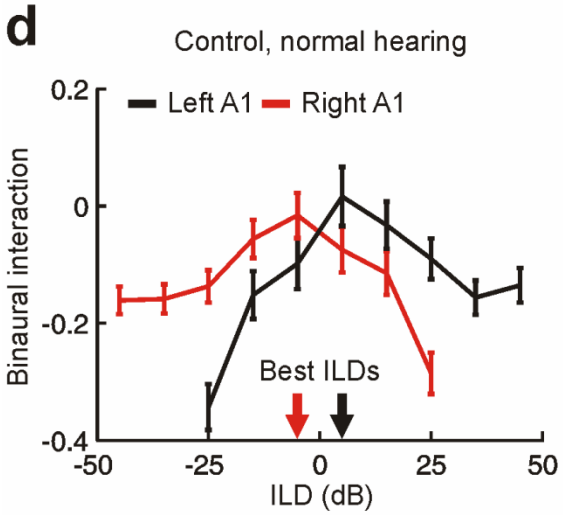
Keating et al. (2014) *EJN*

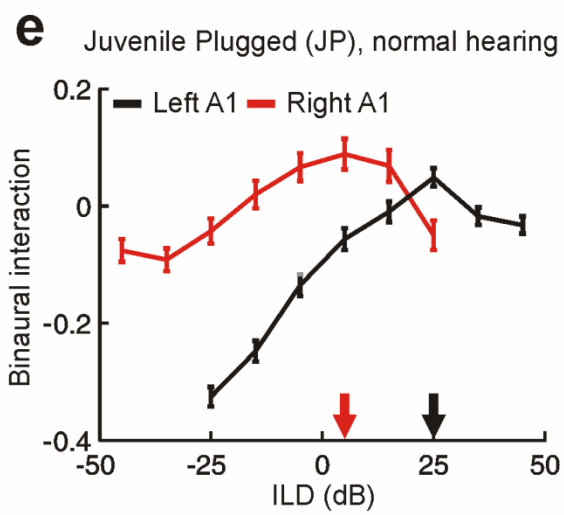
Bilateral A1 recordings

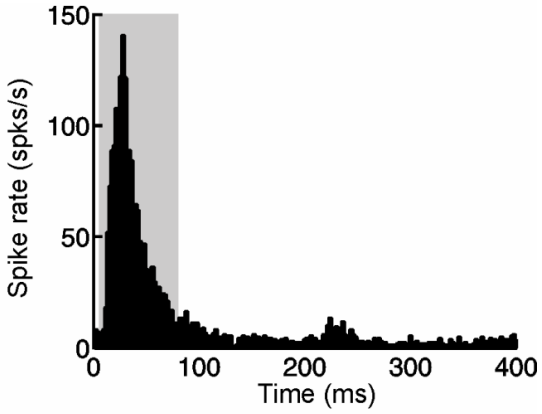


Bizley & King (2009)

ILD sensitivity







Adaptive shifts in ILD tuning are seen bilaterally in primary auditory cortex of juvenile-plugged ferrets.

This second adaptive mechanism is very similar to how barn owls adapt to unilateral hearing loss.

Multiple adaptive processes enable adaptation

Summary

1. Ferrets that experience a developmental hearing loss in one ear can learn to locate sounds correctly using abnormal binaural cues

2. Adaptive changes in neural activity are seen bilaterally in primary auditory cortex of juvenile-plugged ferrets

3. Neural activation patterns suggest that the brain compares the activity of neurons within each hemisphere to locate sounds

Conclusions

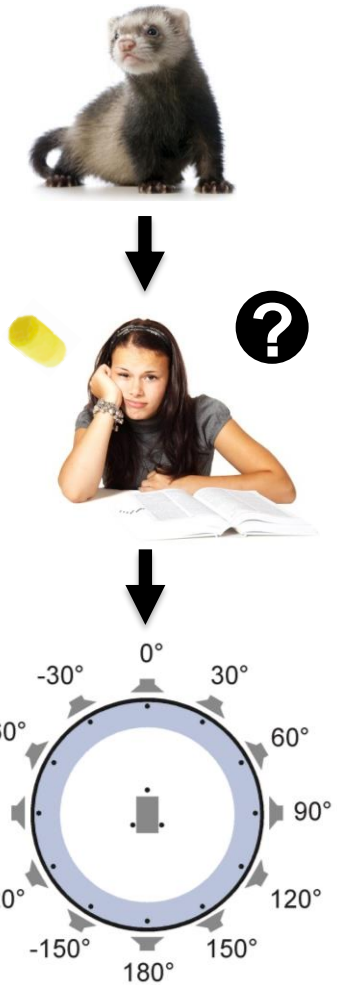
Complementary adaptive processes contribute to the developmental plasticity of spatial hearing

i. **Flexibility may help maintain accurate spatial hearing in diverse environments**

ii. **Different species may be more similar than was previously thought**

Keating et al. (2015) *Nat Neurosci*

What does this tell us about adult plasticity in humans?



Stimuli: 100ms, 56-84 dBSPL, tones or noise, interleaved

Feedback only given for noise stimuli with flat spectra

If adult humans wear an earplug in one ear for prolonged periods of everyday life (~1 week), sound localization adapts using only one adaptive process

Kumpik et al. (2010) *J Neurosci*

Normal hearing

Training with earplug in one ear (1 hour sessions)

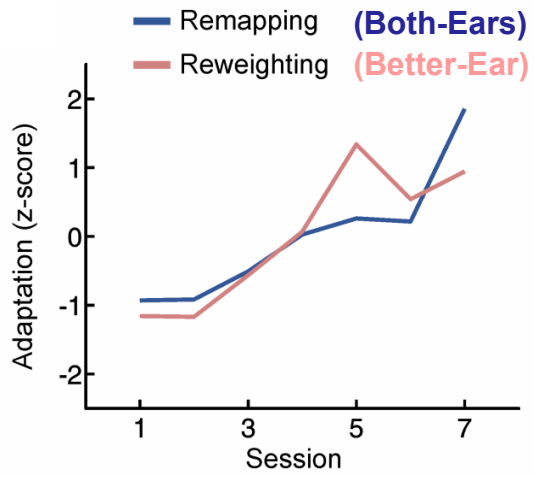
Questions

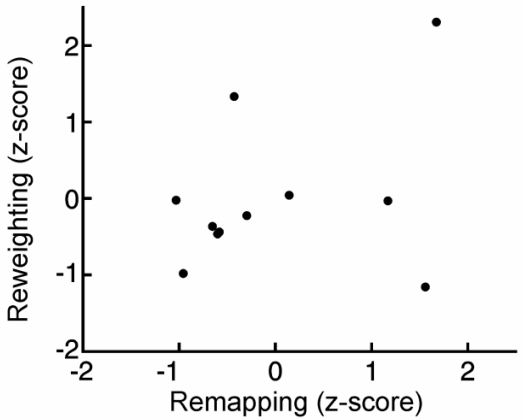
1. Can adult humans adapt to an episodic hearing loss in one ear?
2. Does adaptation involve multiple adaptive mechanisms?
3. How do different forms of adaptation emerge over time?

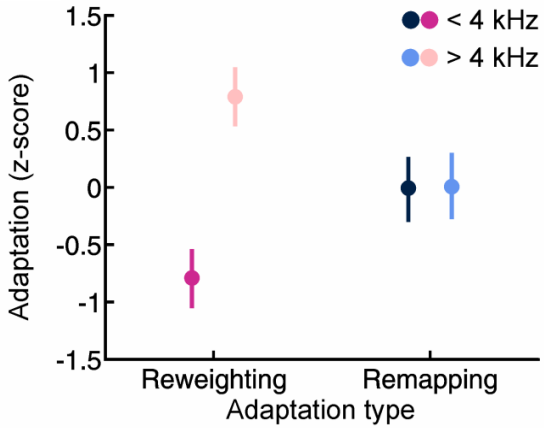
Independence of cue remapping and cue reweighting

Independent processes **Effect of frequency**

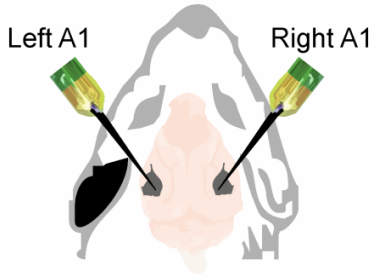
Adult Human Behaviour

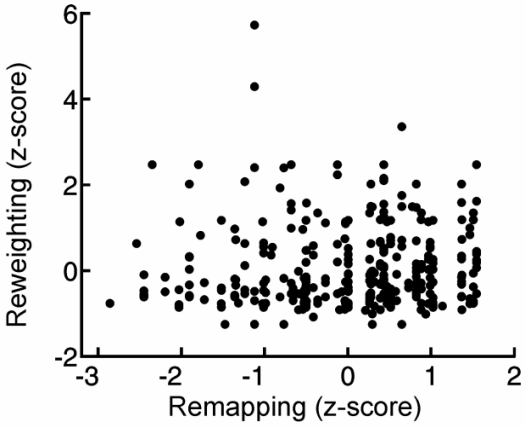


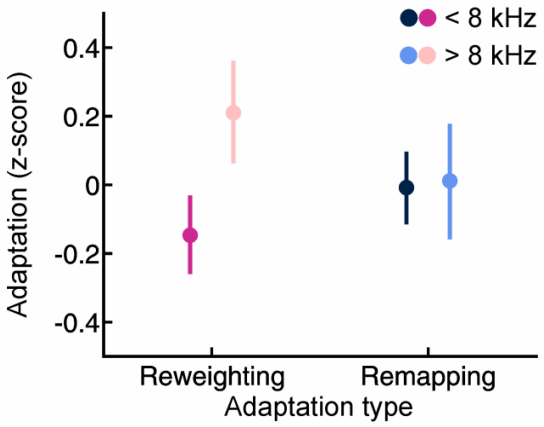




Developmental Ferret Neurophysiology







Different forms of adaptation emerge independently in subjects and neurons, which may be because each adaptive process depends on frequency in a different way

Multiple adaptive processes throughout the lifespan

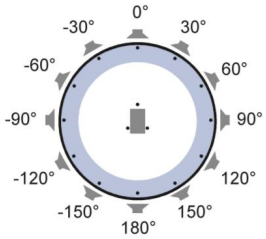
Summary

1. Behavioral training enables adult humans to adapt to a unilateral hearing loss better and faster

2. Different forms of adaptation are seen at different frequencies, and involve different sets of neurons

3. Individuals differ in how they adapt to hearing loss

Keating et al. (2016) *eLife*



Conclusions

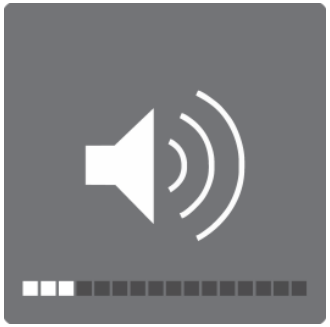
Different forms of adaptation are observed across the lifespan and across different species

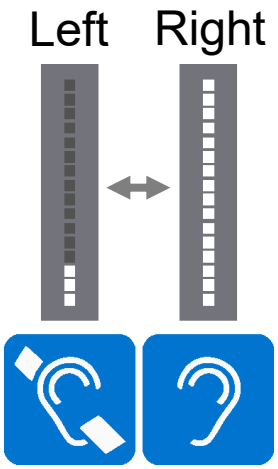
In addition to restoring auditory input, rehabilitation strategies might include training that helps people fully unlock the potential of whatever hearing they have available

Complex real-world problems enable adaptive flexibility

Learn to rely more on intact sensory inputs

Learn to use abnormal sensory inputs





Concluding thoughts

1. When sensory impairments affect some sensory inputs more than others, multiple adaptive processes may help the brain adapt

2. This is helpful because sensory input changes dramatically across different environments

Adaptive flexibility and movie reviews...

Context

3

6

How good was it really?