Cooling ferret auditory cortex reveals deficits in spatial and non-spatial hearing

Stephen M. Town
Katherine C. Wood
Jennifer K. Bizley
Functional specialization: What vs. Where

A big question in neuroscience is how far is the brain divided into functionally specialized units?

In hearing, it has been suggested that the auditory system branches at the level of auditory cortex into two distinct processing streams specialized for localizing and identifying sounds – also known as the ‘what’ and ‘where’ pathways.

Lomber & Malhotra, 2008; Rauschecker & Scott, 2009; van der Heijden et al. 2019
In ferret auditory cortex, we see interdependent coding (sometimes called “mixed selectivity”) for spatial and non-spatial features of sounds.

We know both primary and non-primary areas are necessary for sound localization (Nodal et al., 2010; Wood et al. 2017), but are these regions also involved in identifying sounds?

Neurons here seem to process ‘what’ and ‘where’ together.

Bizley et al. 2009

Town et al. 2018
To find out, we trained ferrets to discriminate vowel sounds, either in noise or clean conditions (i.e. quiet) and then inactivated auditory cortex during behavior.

To test spatial hearing in the same subjects, we retrained animals to localize sounds, and repeated inactivation.
We also looked at potential interactions between spatial and non-spatial hearing in vowel discrimination, by presenting vowel and noise from either the same or different locations in tests of spatial release from masking.
Reversible inactivation by cooling auditory cortex

To reversibly inactivate auditory cortex during behavior, we used cooling. This reduces the temperature of neurons, and so suppresses spiking activity.

Wood et al. 2017

Cooling loop: Cannula through which cold ethanol flows, allowing heat transfer. Loops are chronically implanted over ferret auditory cortex...
Reversible inactivation by cooling auditory cortex

We implanted cooling loops over the border region between middle and posterior fields of ferret auditory cortex.

This is the region with most predominant tuning to low frequencies that are relevant for vowel sounds.

Loop Temperatures

We cooled both left and right auditory cortex to between 8 and 12°C. (Though anything < 20°C was considered “cooled”)

In sound localization, we also cooled left or right unilaterally
Vowel discrimination in noise

But had no effect on vowel discrimination in clean conditions (this is also seen in Cats [Dewson et al. 1964])
Cooling the same region, in the same animals also impaired sound localization.
Release from masking was weak in control conditions

(maybe not surprising, given spectral differences between vowels and broadband noise)
Spatial release from masking

Release from masking was more obvious in cooling.

This was because cooling impaired performance on co-located noise trials, but not spatially separated trials.
Release from masking was stronger during cooling, but never as effective as removing the noise completely.
Conclusions

Ferret auditory cortex contributes to multiple forms of hearing, suggesting interdependent coding reflects behaviorally relevant neural processing of multiple sound features.

Deficits shown here are not results of general hearing impairment as ferrets could still discriminate vowels in clean conditions and benefit from spatial release from masking.
Vowel discrimination in noise

Two-choice task
- Each trial: Two tokens of a particular vowel
- Rule: Go left for /u/ or right for /e/
- Rewarded with water

Stimuli
- Vowels (/u/ vs. /e/ or /a/ vs. /i/)
- With or without added broadband noise
- Noise (70 dB SPL), generated afresh on each trial
- Presented from both left and right speakers
Spatial release from masking

Variant of vowel discrimination task

Vowels presented from a single speaker (clean) or...

Vowel and noise presented from:
- the same speaker (colocalized)
- different speakers (spatial separation)
Sound Localization

Approach-to-target task

Report the location of a broadband noise burst from one of seven speakers

Speakers arranged in 30° intervals in the frontal hemifield