Cortical Synaptic Plasticity Improves Sensory Perception

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Departments of Otolaryngology and Neuroscience/Physiology
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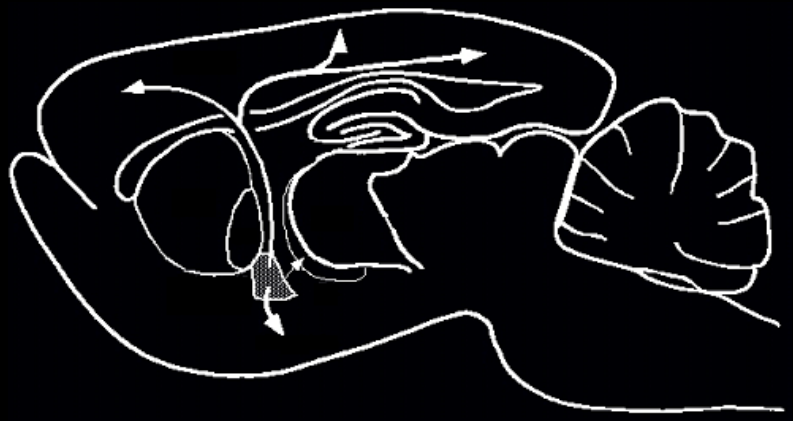
Neuroplasticity

Neuroplasticity

Sensory experience

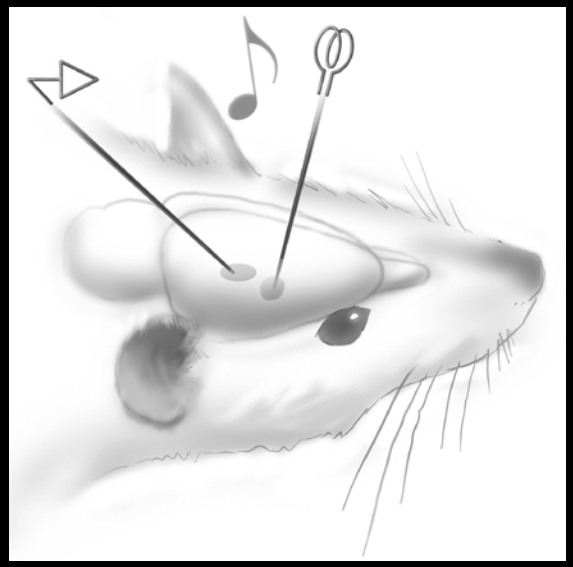
Internal state

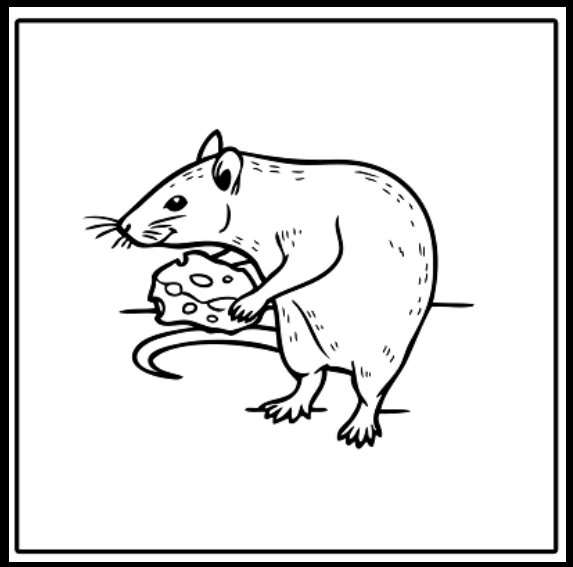


Cortical Plasticity: Our Approach

Rat primary auditory cortex

Electrophysiology and behavior





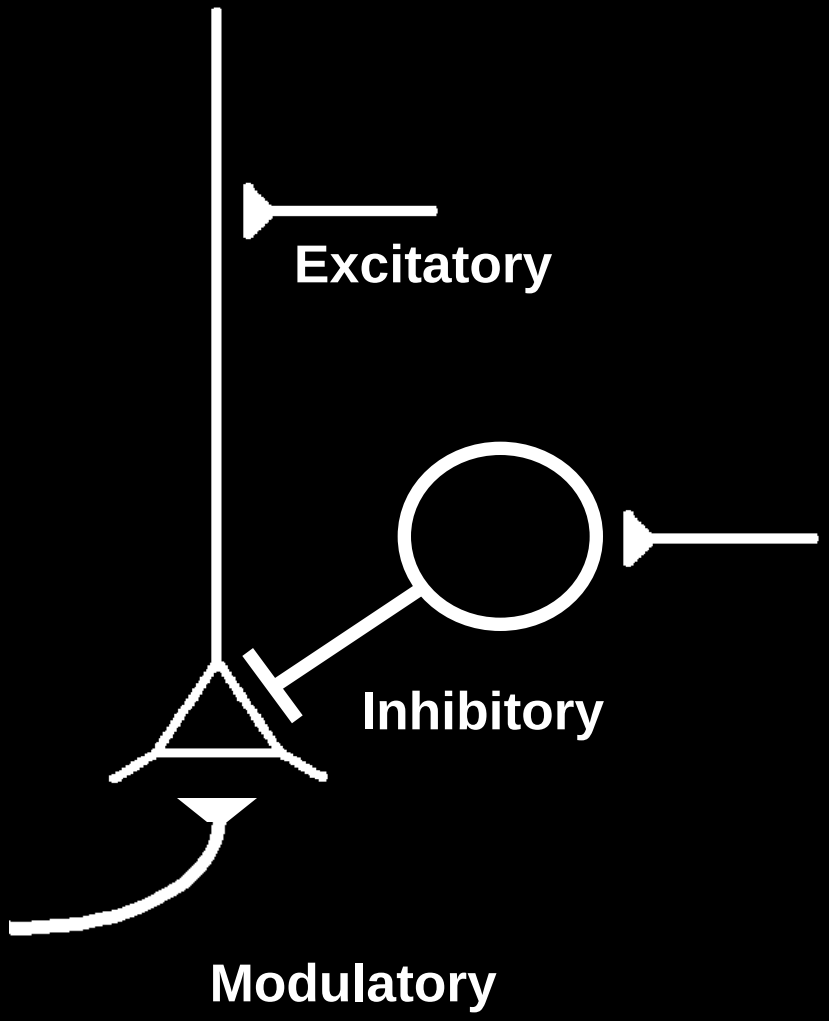
Questions

How are synapses modified *in vivo*?

How does cortical synaptic plasticity alter perception?

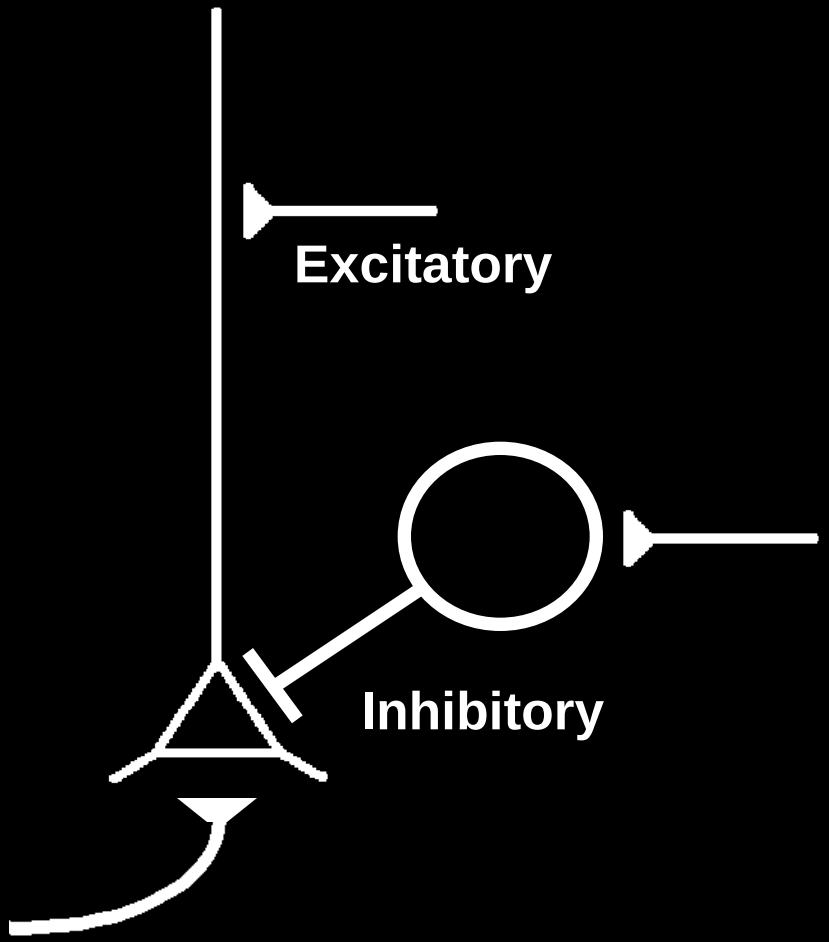
synapse ⟶ network ⟶ behavior

Synaptic Input to Cortical Neurons



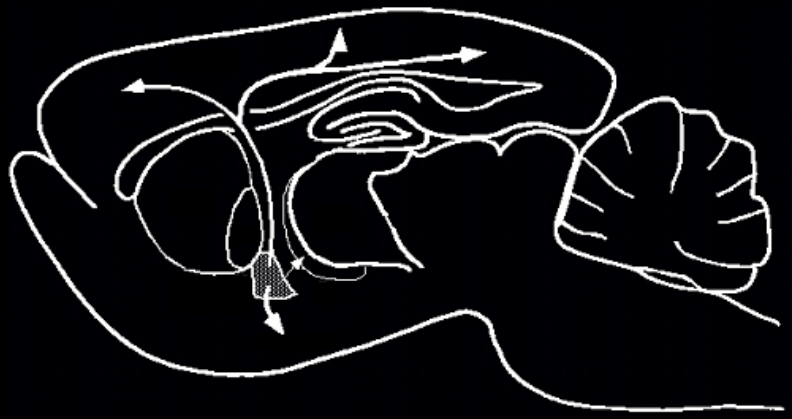
- Cortical neurons receive three main synaptic inputs:
  - **excitatory**
  - **inhibitory**
  - **neuromodulatory**

Synaptic Input to Cortical Neurons

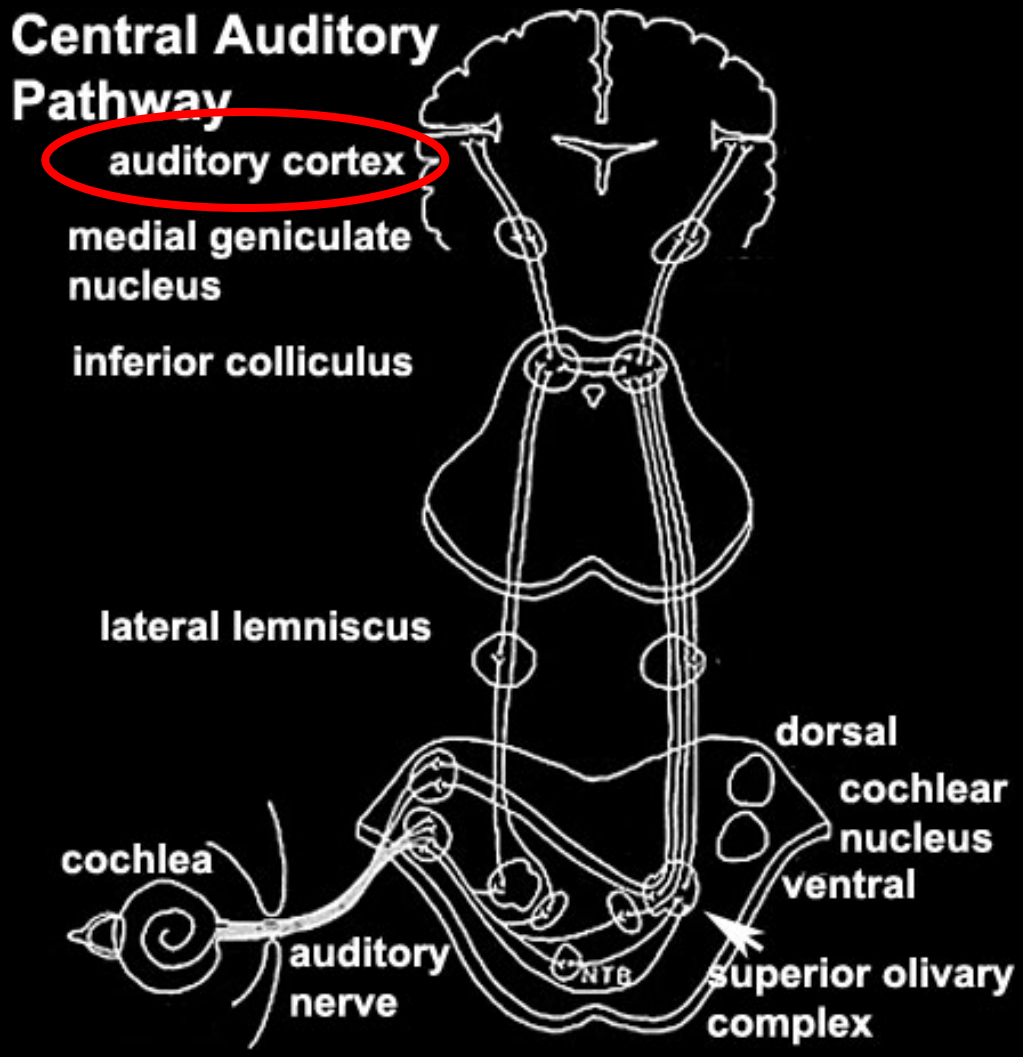


Sensory experience

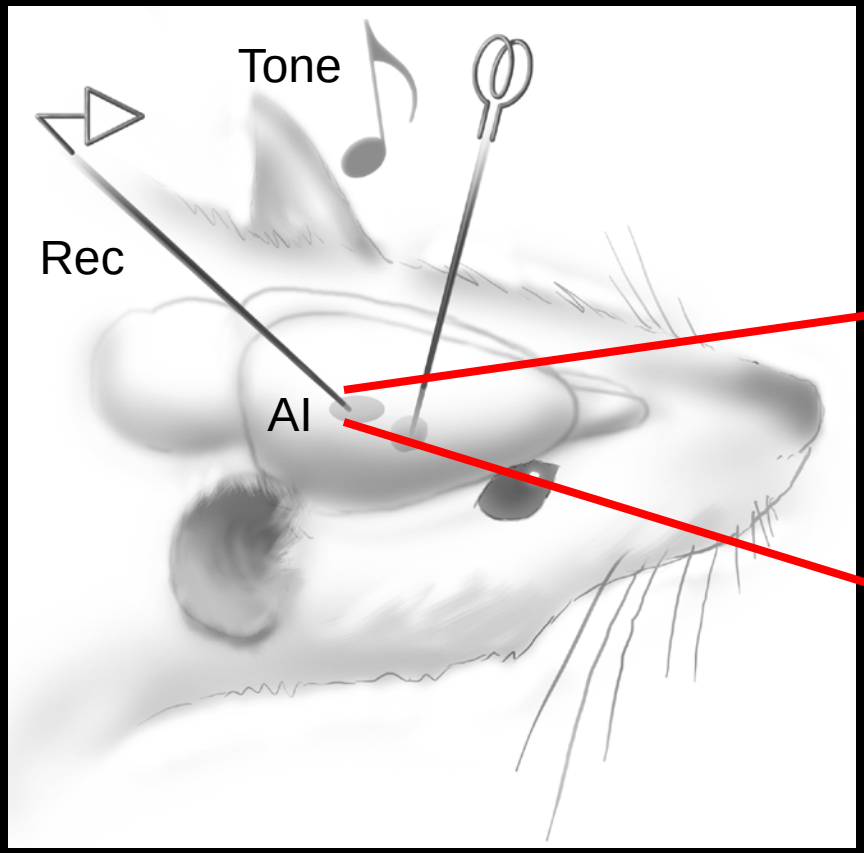
Internal state

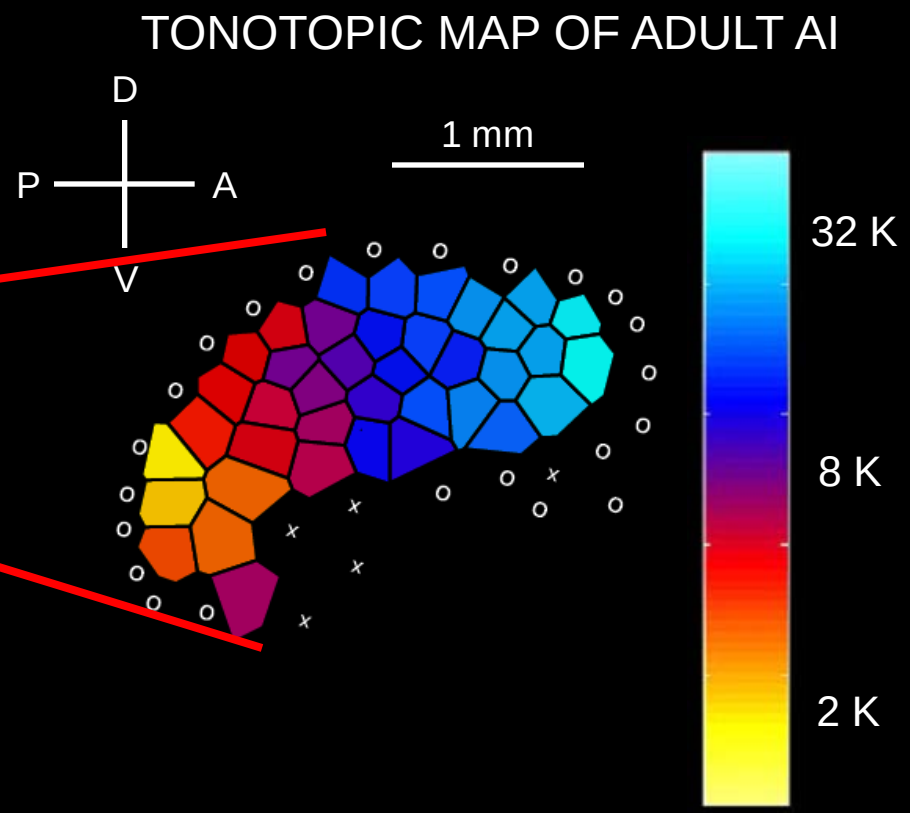


The Mammalian Auditory System



Tonotopic Organization of Adult Rat AI





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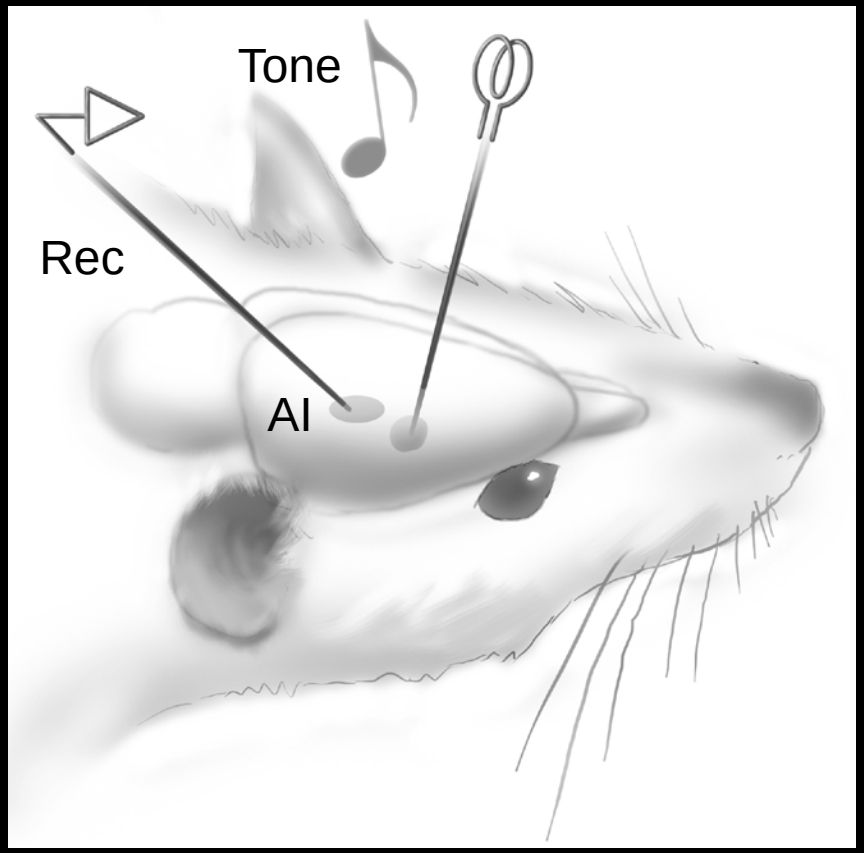
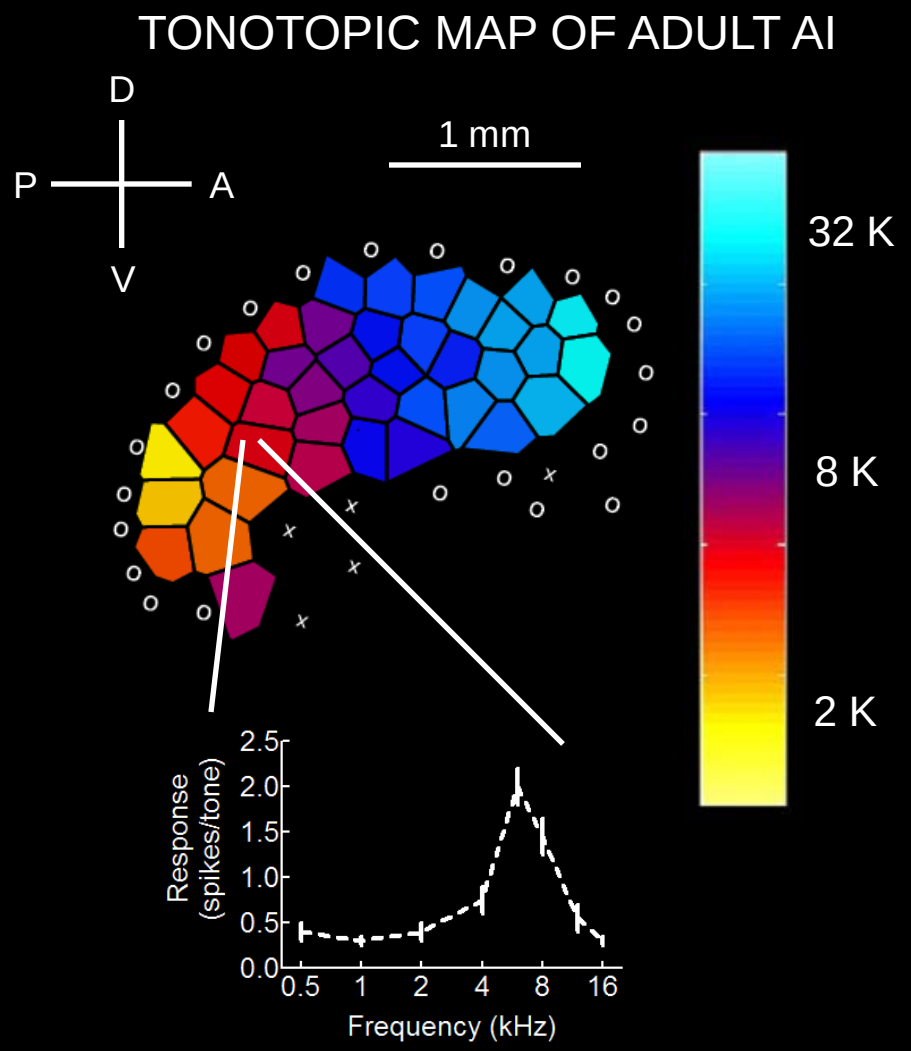
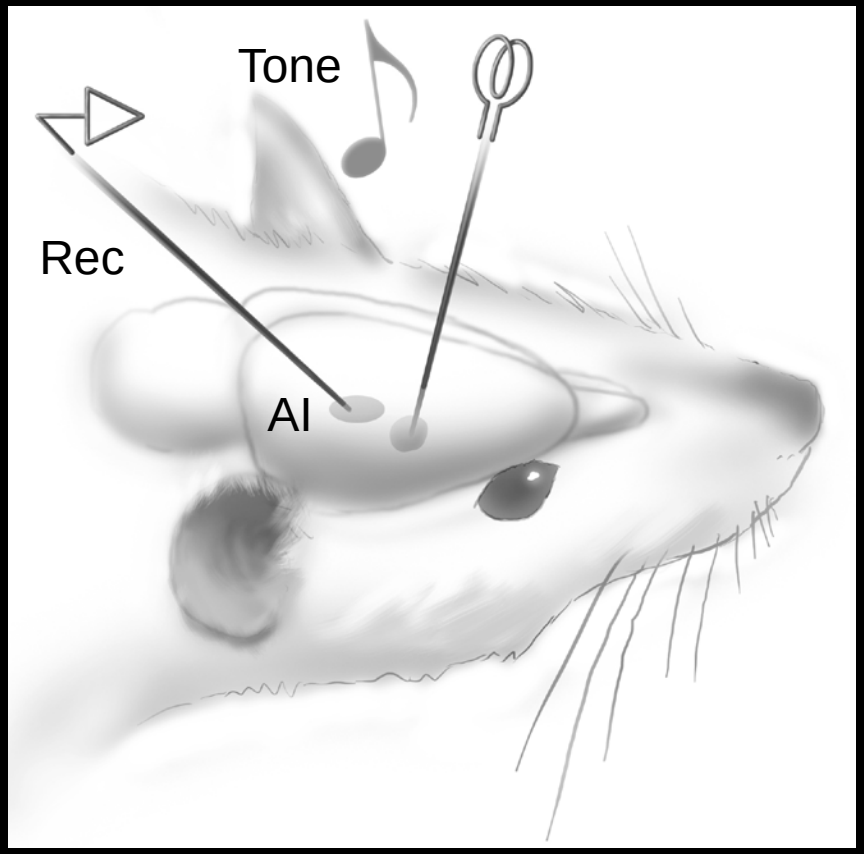
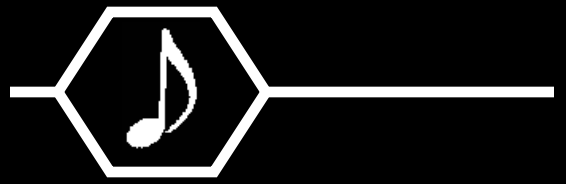




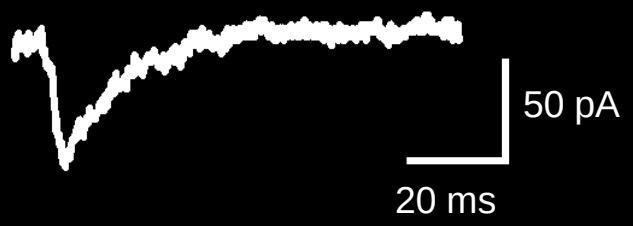
Methods: In Vivo Voltage-Clamp



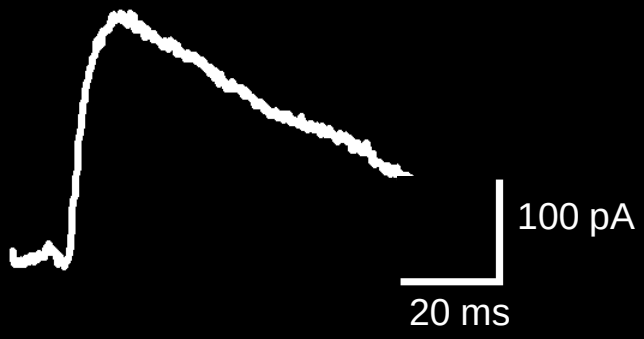
SENSORY STIMULATION (TONE)



SYNAPTIC EXCITATION (-70 mV)



SYNAPTIC INHIBITION (0 mV)



Balance of Excitation and Inhibition

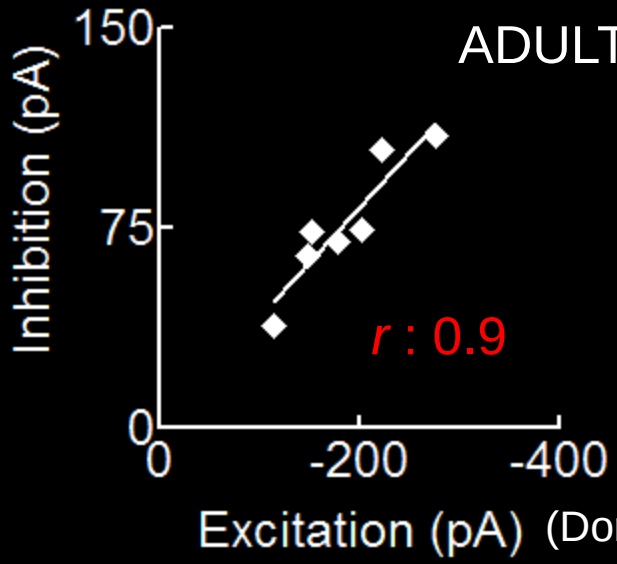
Whole-cell recording (adult rat cortex)

“Synaptic tuning curve”

(Dorrn et al., Nature 2010)

Balance of Excitation and Inhibition

Whole-cell recording (adult rat cortex)

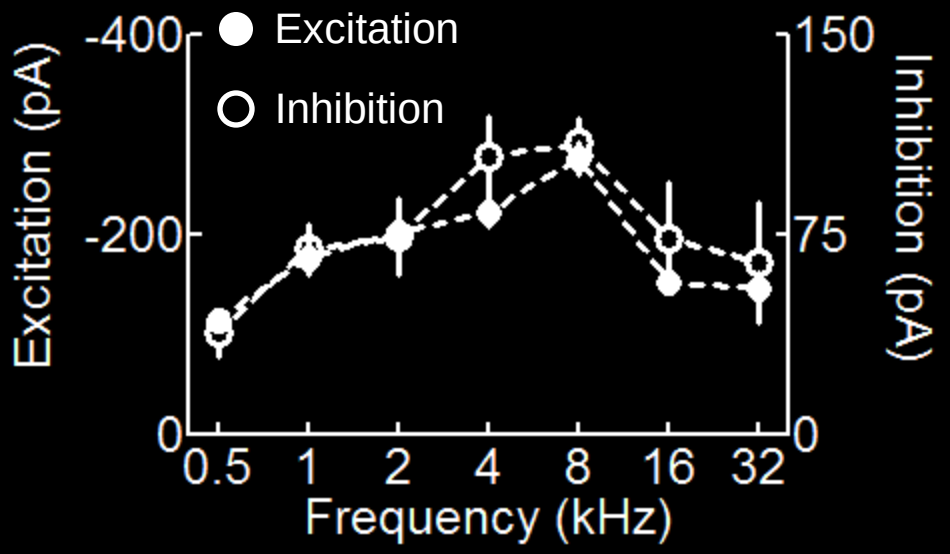


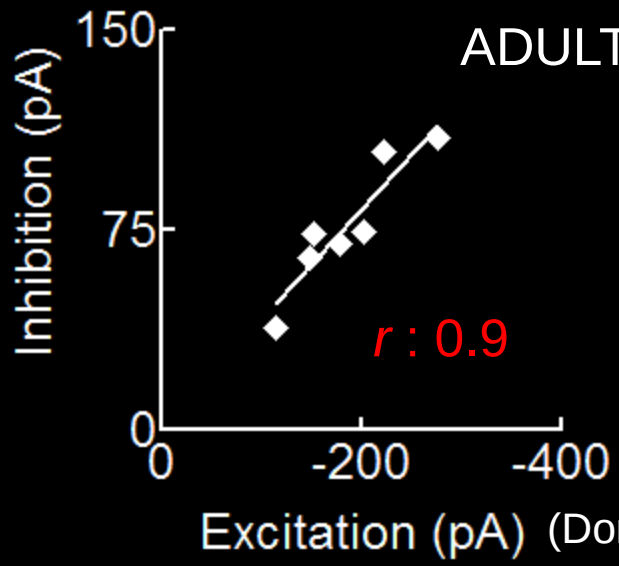
"Synaptic tuning curve"

(Dorrn et al., Nature 2010)

Balance of Excitation and Inhibition

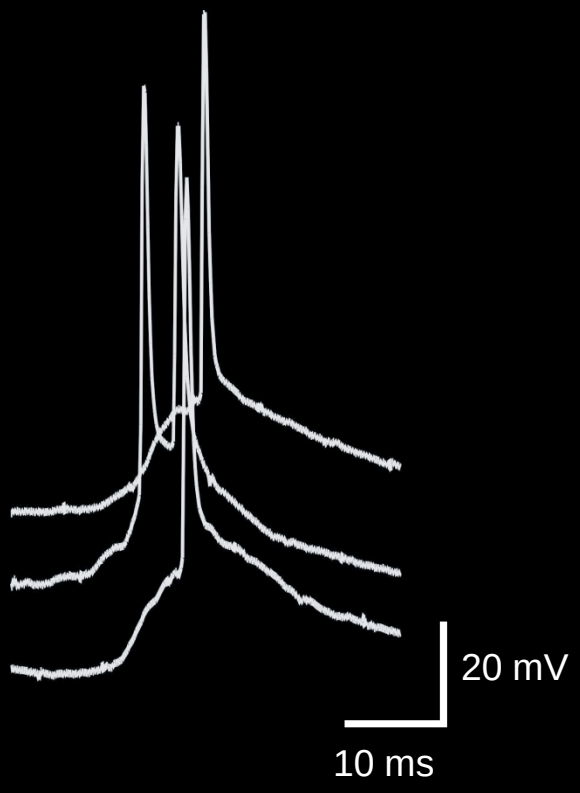
Whole-cell recording (adult rat cortex)



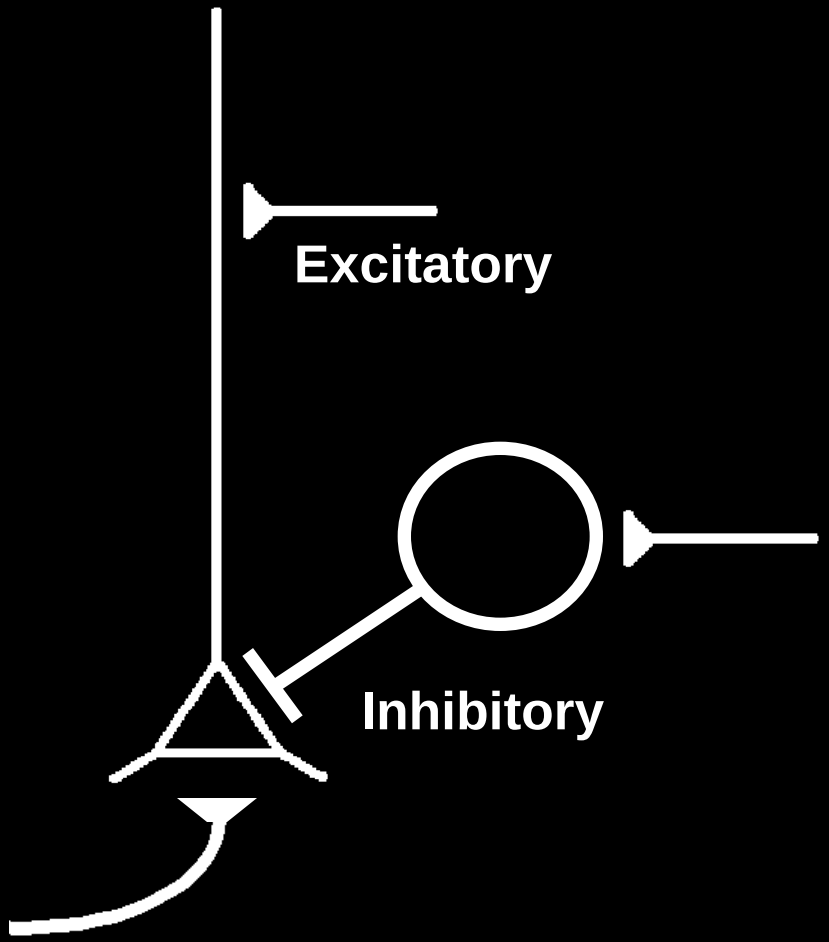


(Dorrn et al., Nature 2010)

"Synaptic tuning curve"

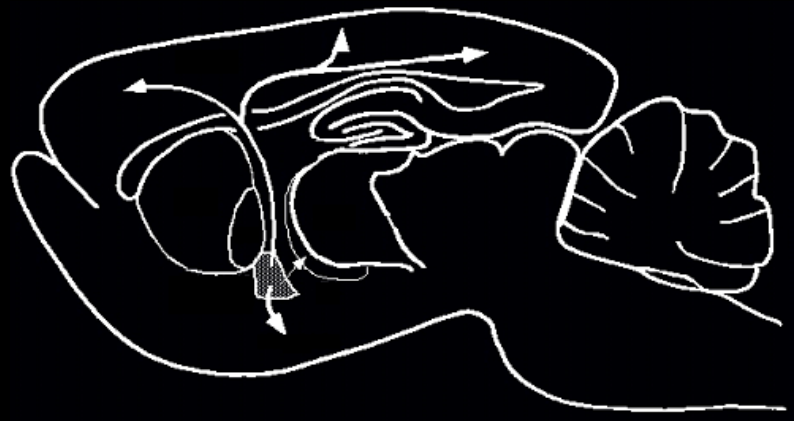


Neuromodulation Is Required for Plasticity



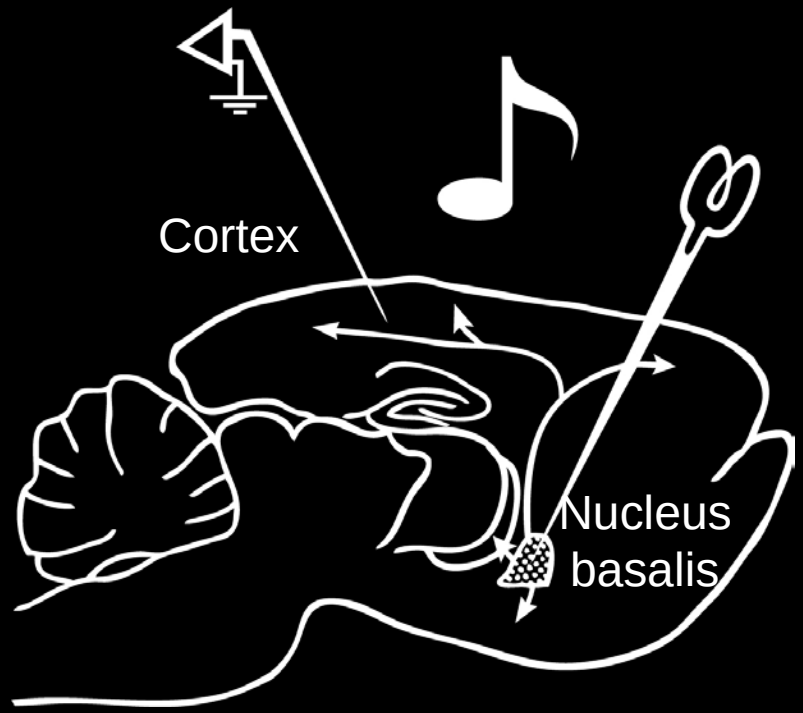
Sensory experience

Internal state

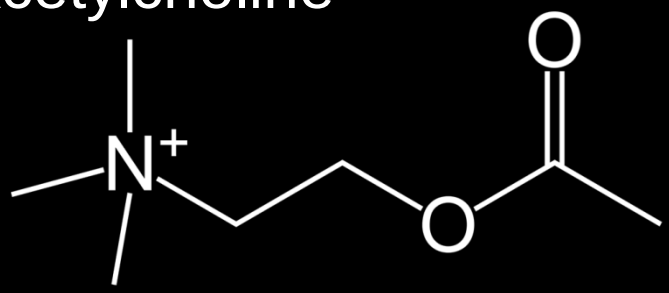


Nucleus Basalis Stimulation

Nucleus basalis is major source of cortical acetylcholine



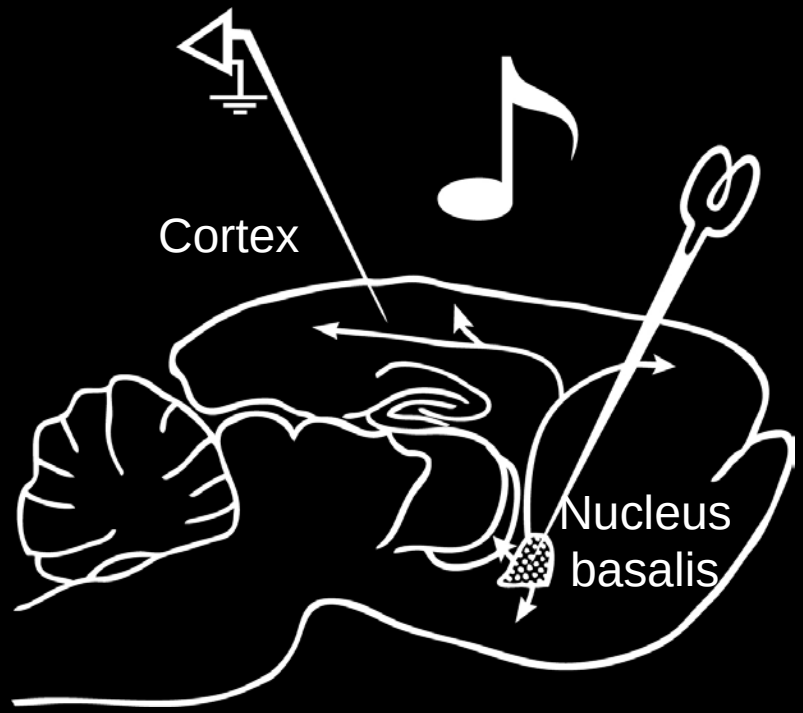
Acetylcholine

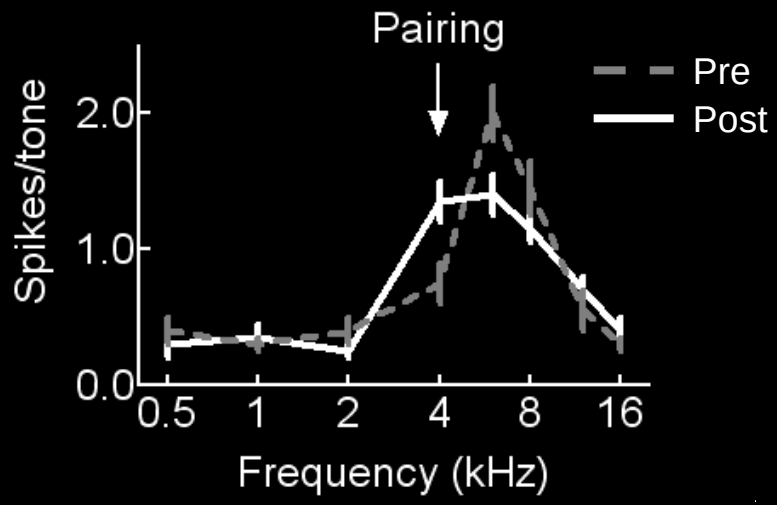


Involved in attention, arousal, and learning

Nucleus Basalis Pairing

Nucleus basalis is major source of cortical acetylcholine





Bakin & Weinberger PNAS 1996

Involved in attention, arousal, and learning

Nucleus Basalis Pairing

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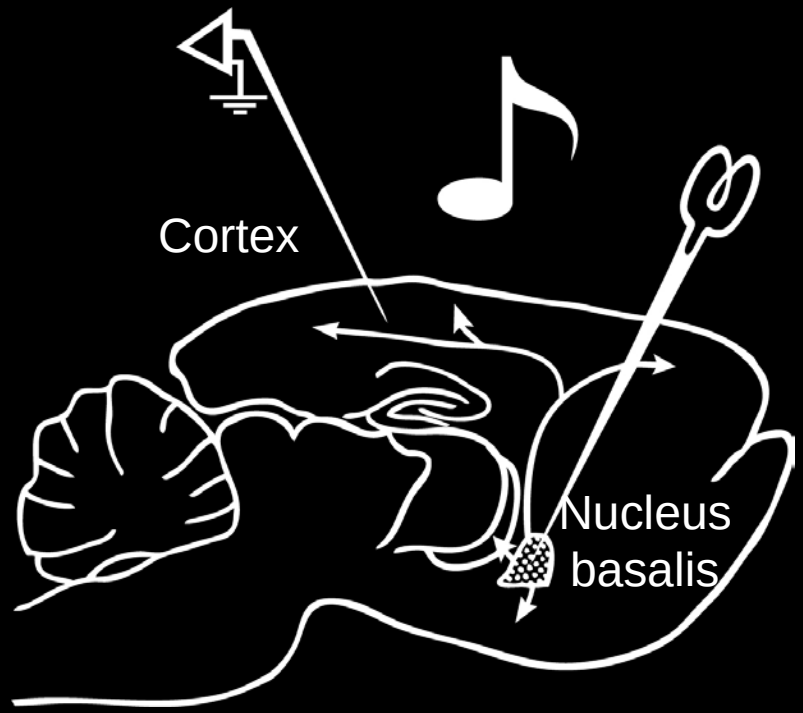
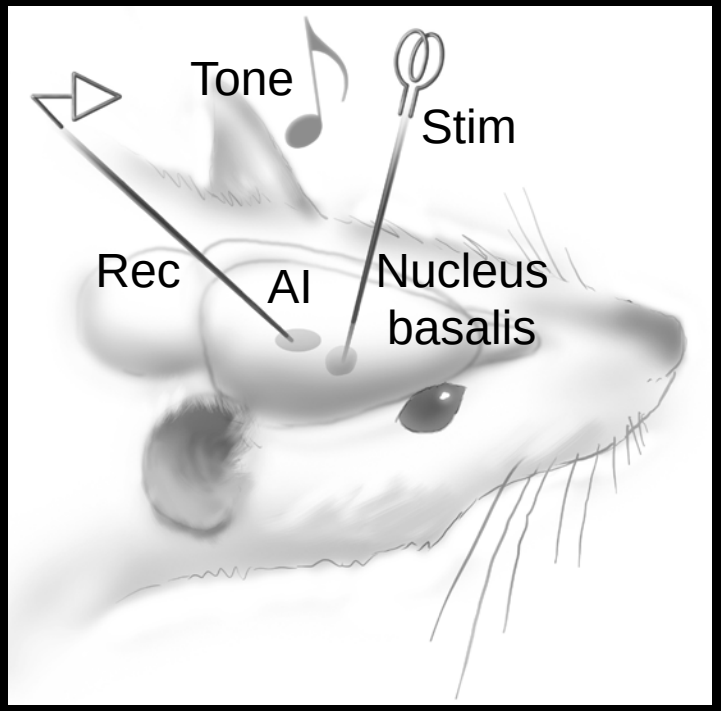




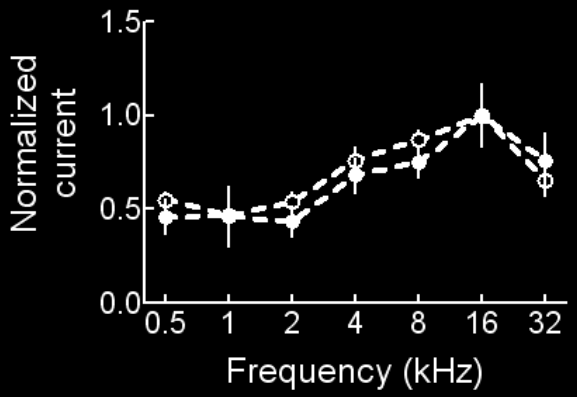
Nucleus basalis stimulation enables adult cortical plasticity

Involved in attention, arousal, and learning

(Bakin & Weinberger, PNAS 1996,
Kilgard & Merzenich, Science 1998,
Froemke et al., Nature 2007,
Froemke, Carcea et al., Nature Neuroscience 2013)

Experiment: Nucleus Basalis Pairing

STEP ONE
Map frequency tuning
(5-10 minutes)

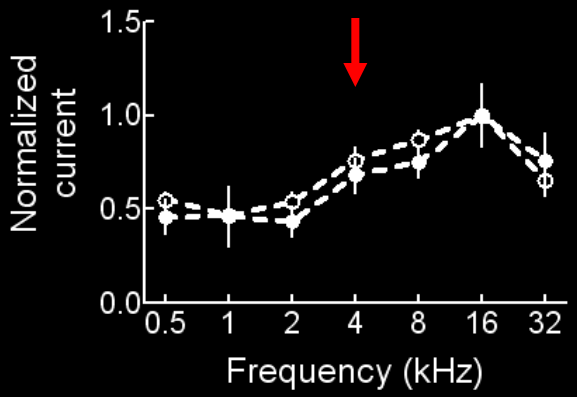


STEP TWO
Nucleus basalis pairing
(3-5 minutes)

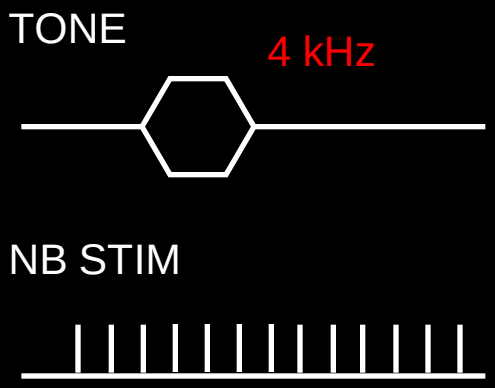
STEP THREE
Map frequency tuning
(10+ minutes)

Experiment: Nucleus Basalis Pairing

STEP ONE
Map frequency tuning
(5-10 minutes)



STEP TWO
Nucleus basalis pairing
(3-5 minutes)



STEP THREE
Map frequency tuning
(10+ minutes)

Experiment: Nucleus Basalis Pairing

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Map frequency tuning
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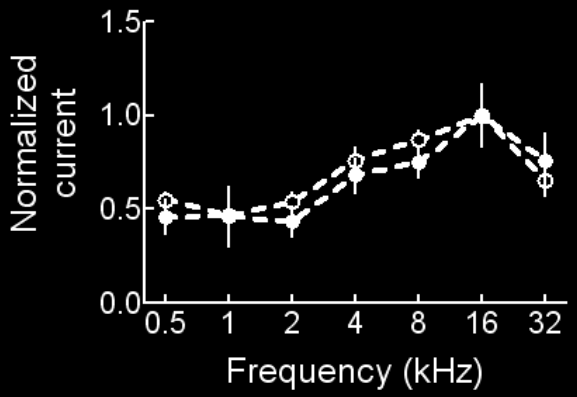
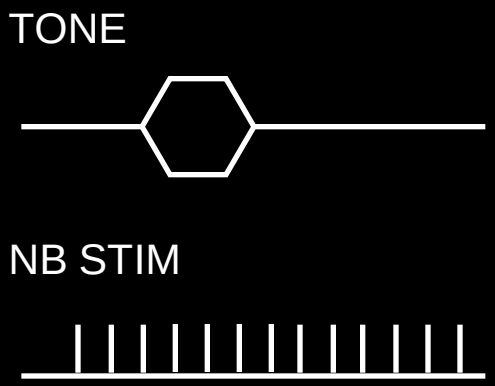
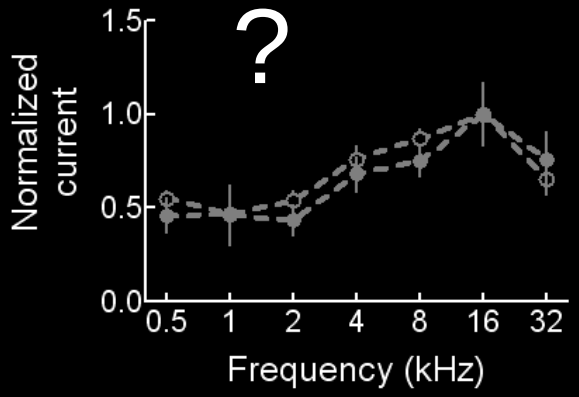


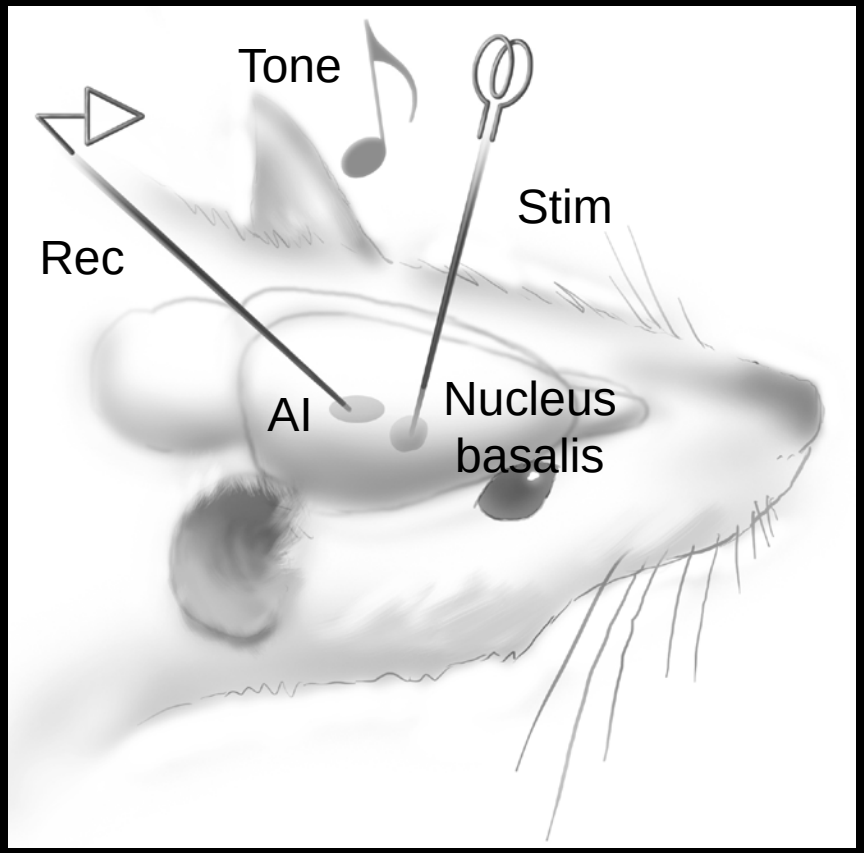
STEP TWO
Nucleus basalis pairing
(3-5 minutes)

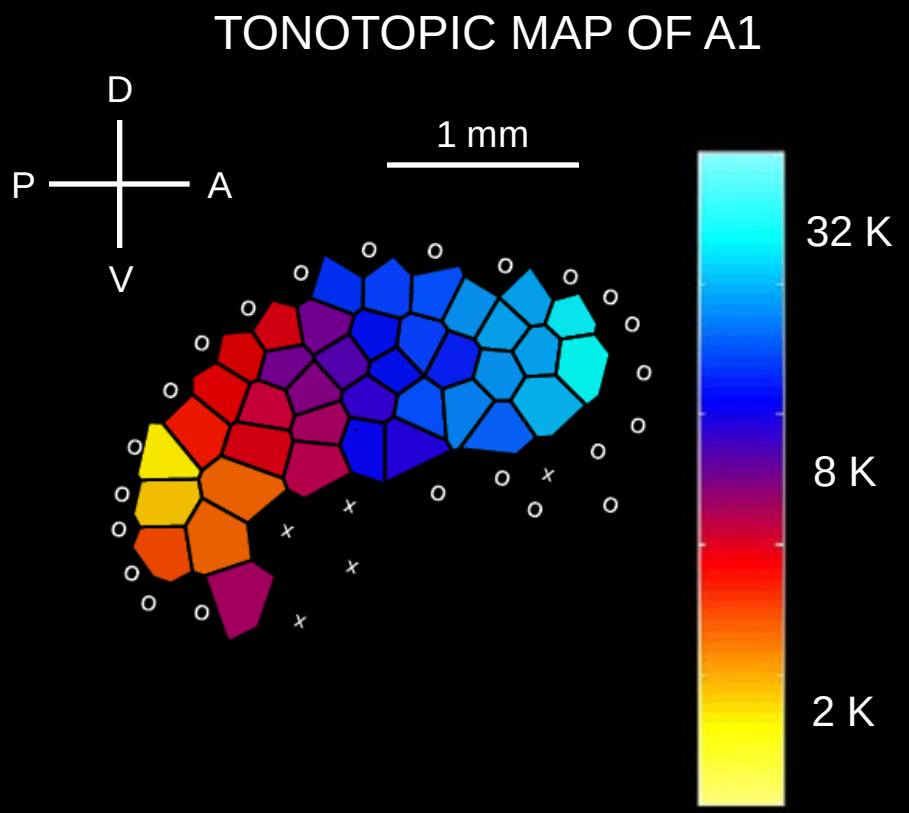


STEP THREE
Map frequency tuning
(10+ minutes)



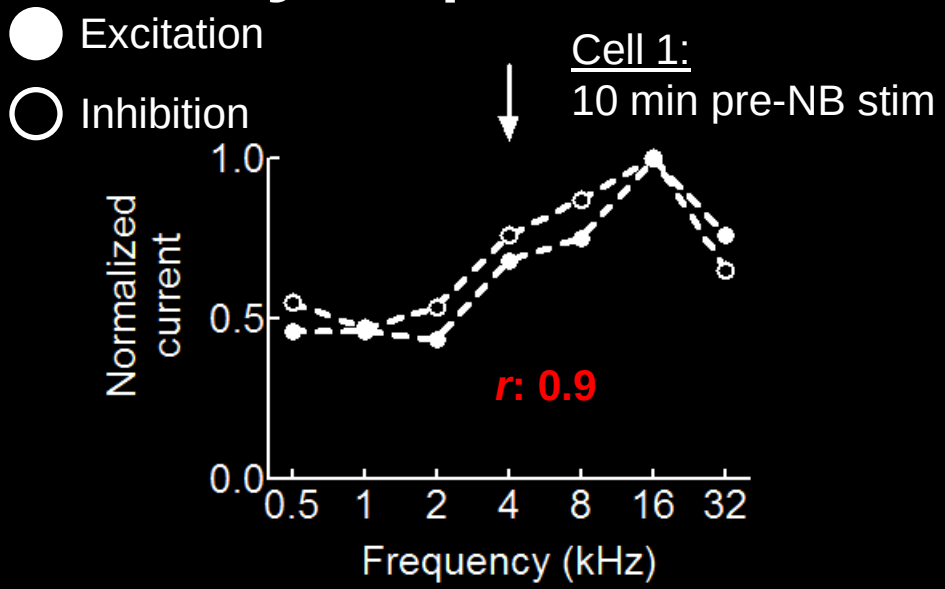
Multiple Consecutive Recordings





Neighboring cells have similar tuning

Plasticity and Rebalancing of Synaptic Excitation & Inhibition

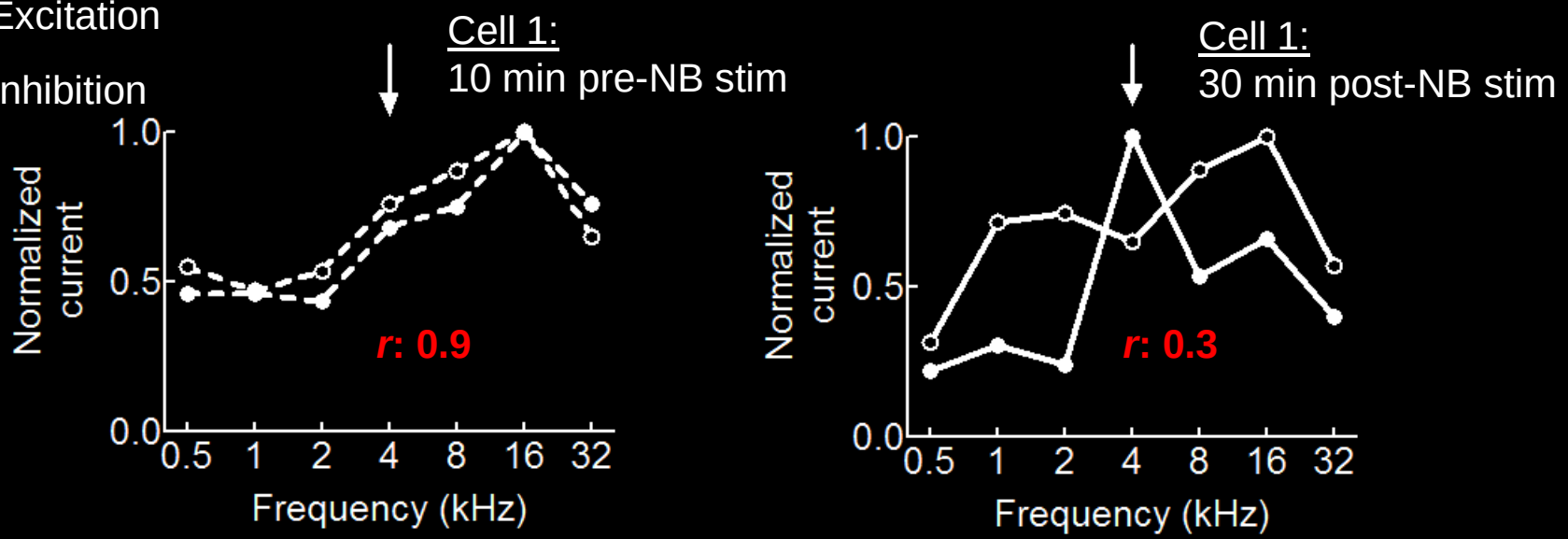


(Froemke et al., Nature 2007)

Plasticity and Rebalancing of Synaptic Excitation & Inhibition

Excitation

Inhibition



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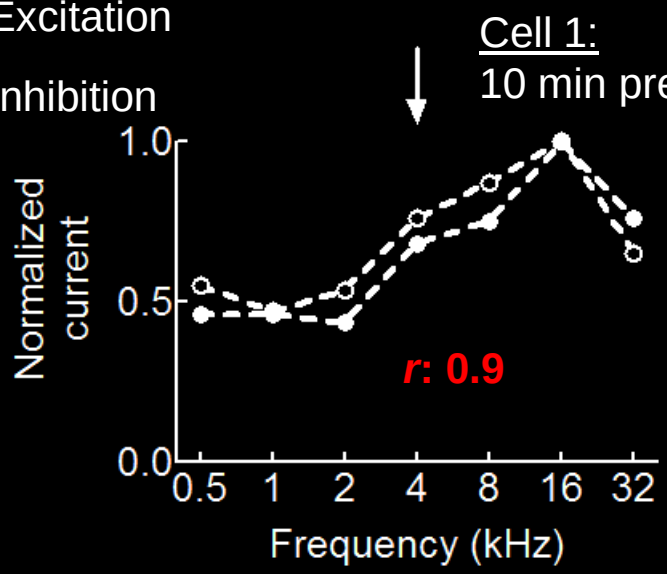
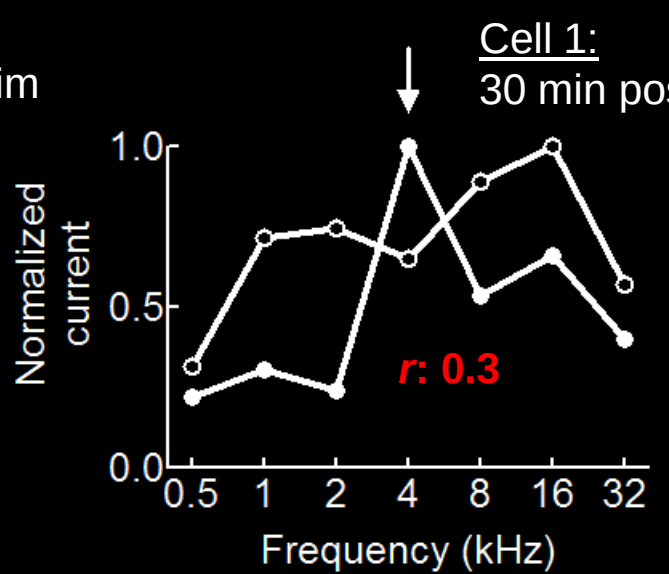
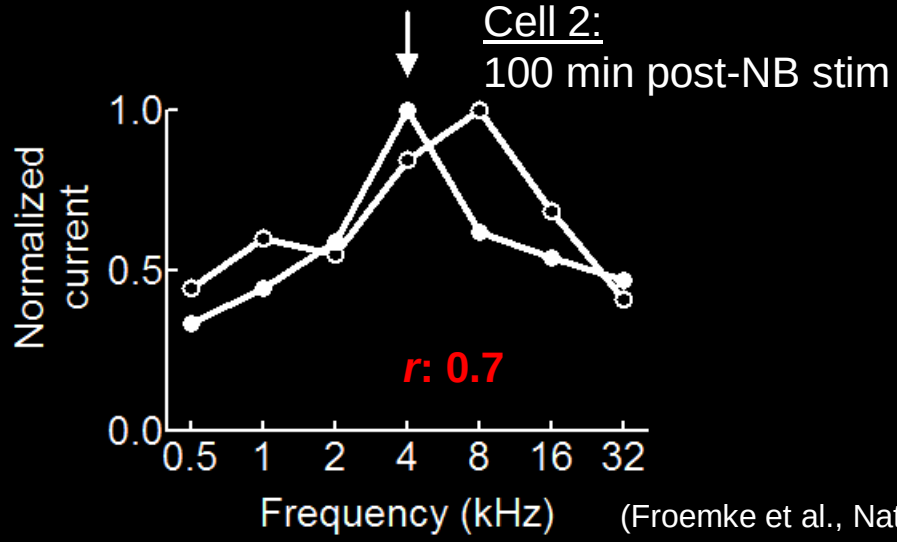
Plasticity and Rebalancing of Synaptic Excitation & Inhibition

Excitation

Inhibition





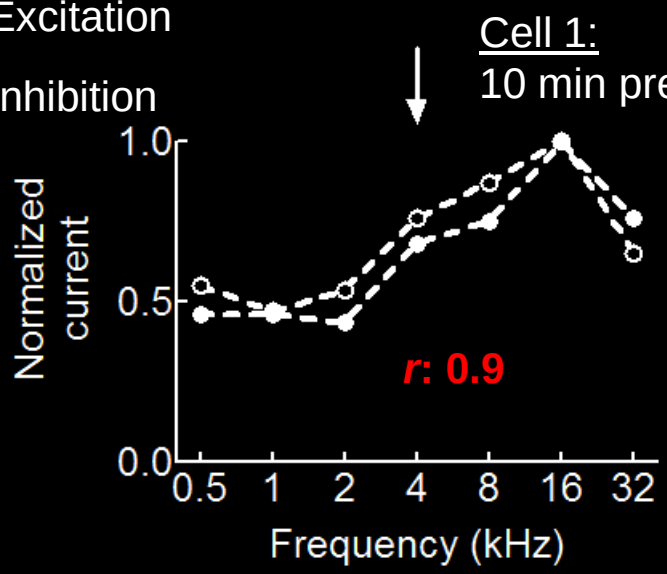


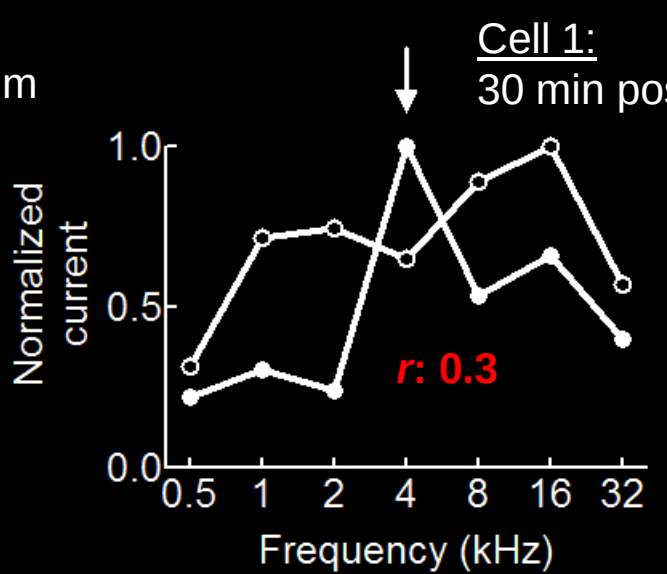
(Froemke et al., Nature 2007)

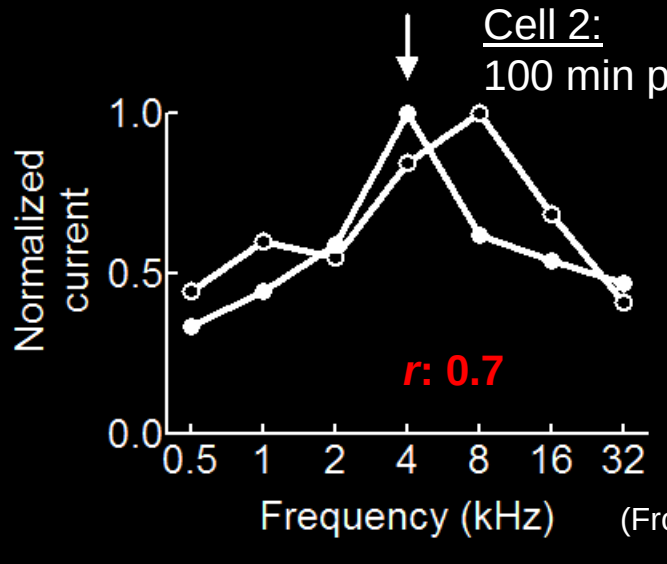
Plasticity and Rebalancing of Synaptic Excitation & Inhibition

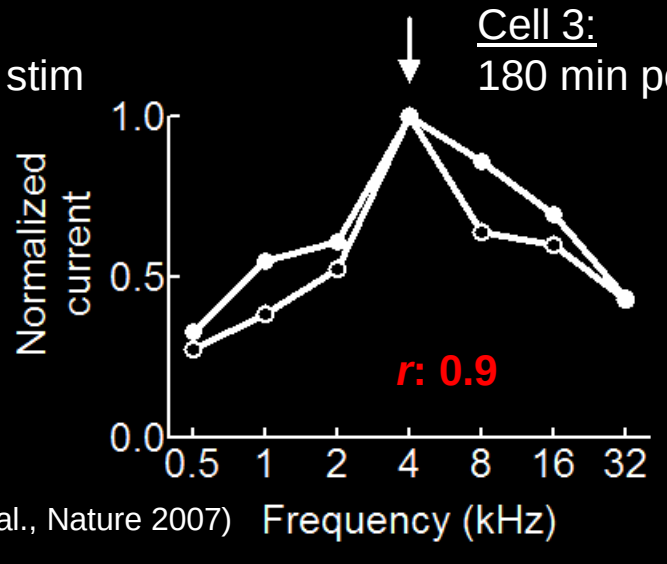
Excitation

Inhibition



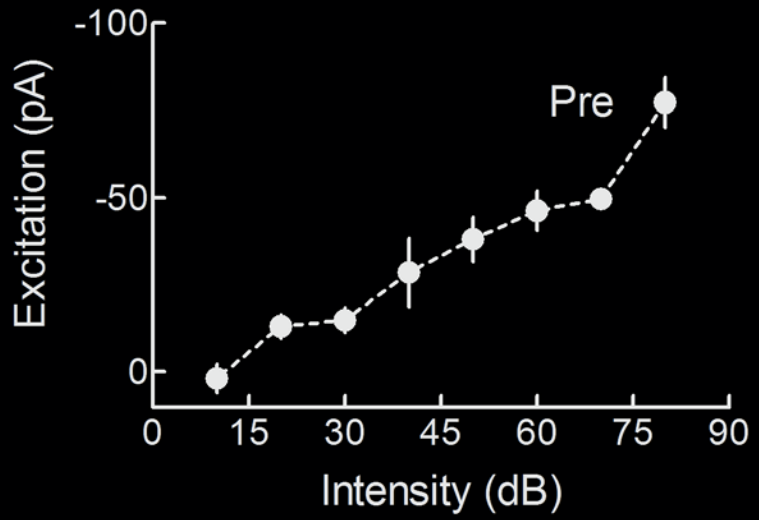






(Froemke et al., Nature 2007)

Long-Term Modification of ‘Loudness’ (Intensity) Tuning



(Froemke, Carcea et al., Nature Neuroscience 2013)

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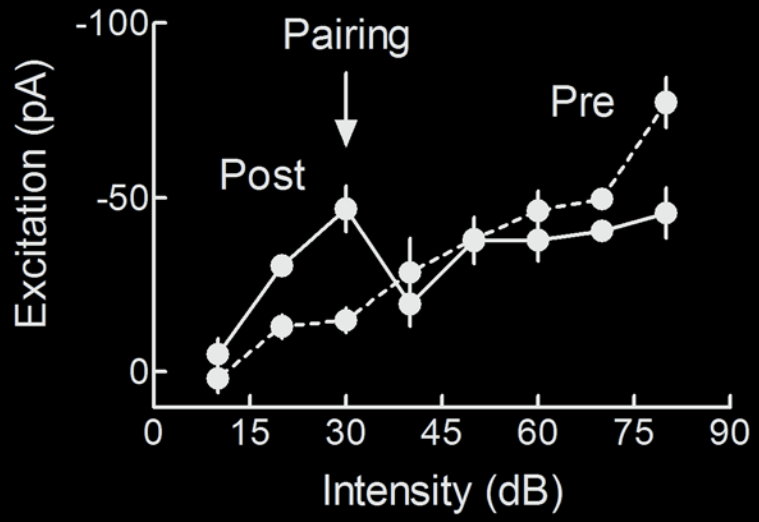

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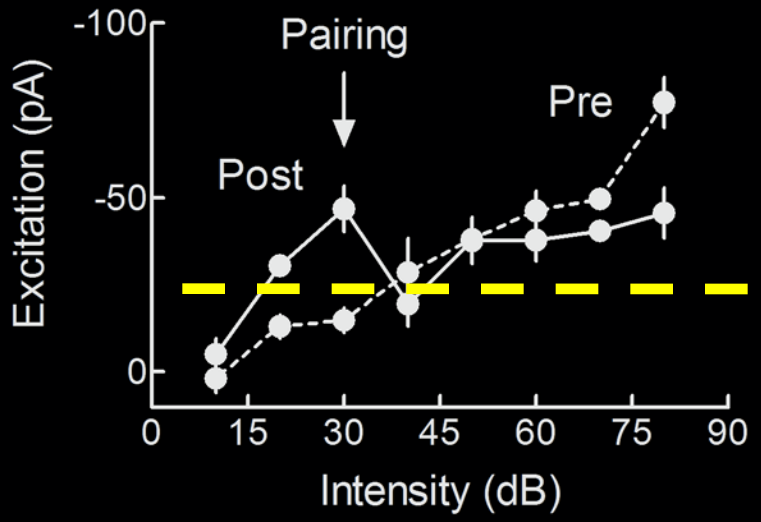


Perceptual Threshold?

(Froemke, Carcea et al., Nature Neuroscience 2013)

Outline

- Neuromodulation enables adult plasticity
- Behavioral effects of cortical plasticity
- Oxytocin, maternal behavior, and cortical plasticity

Ioana Carcea

Raquel Martins

Bianca Jones

Mariela Mitre

Behavioral Task:
Sound Detection & Recognition

Non-target (foil) tones:
do nothing.

Behavioral Task:
Sound Detection & Recognition

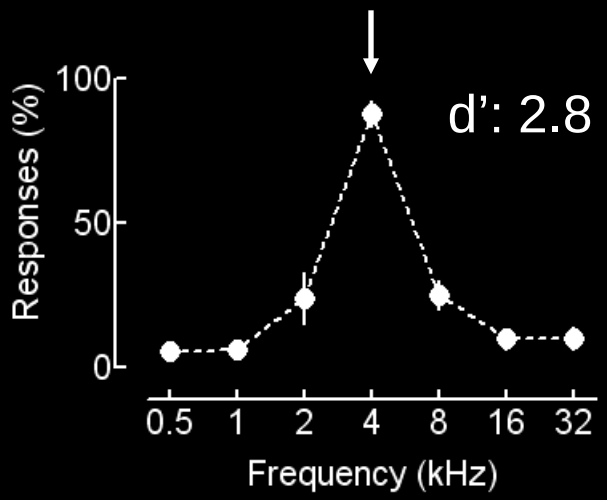
Non-target (foil) tones:
do nothing.

Target tone:
nosepoke.

Correct response:
reward!

Behavioral Task: Sound Detection & Recognition

EASIER TASK (1 octave)



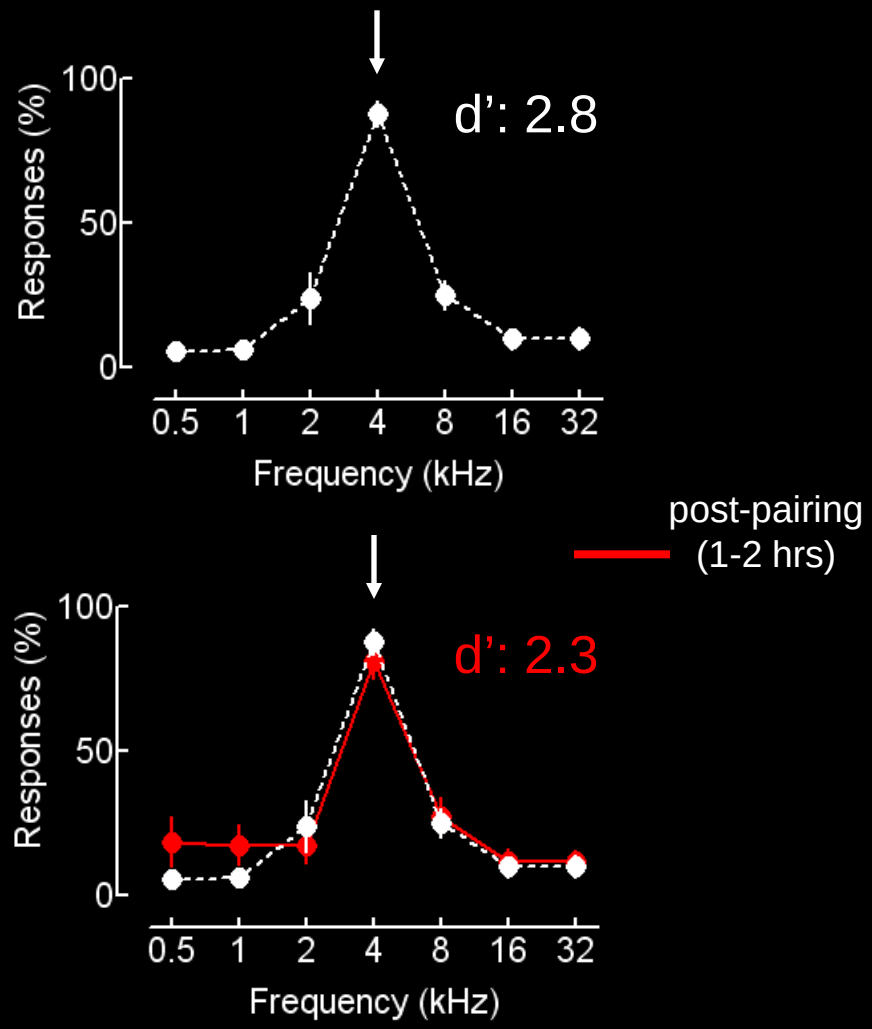
HARDER TASK (0.16 octaves)

(Froemke, Carcea et al., Nature Neuroscience 2013)

Behavioral Task: Sound Detection & Recognition

EASIER TASK (1 octave)

HARDER TASK (0.16 octaves)



(Froemke, Carcea et al., Nature Neuroscience 2013)

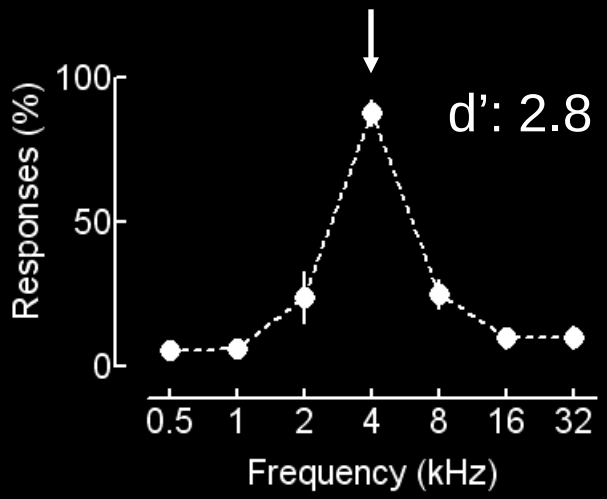
Behavioral Task:
Sound Detection & Recognition

Suddenly make task harder:

‘foil’ tones are more similar to ‘target’

Behavioral Task: Sound Detection & Recognition

EASIER TASK (1 octave)



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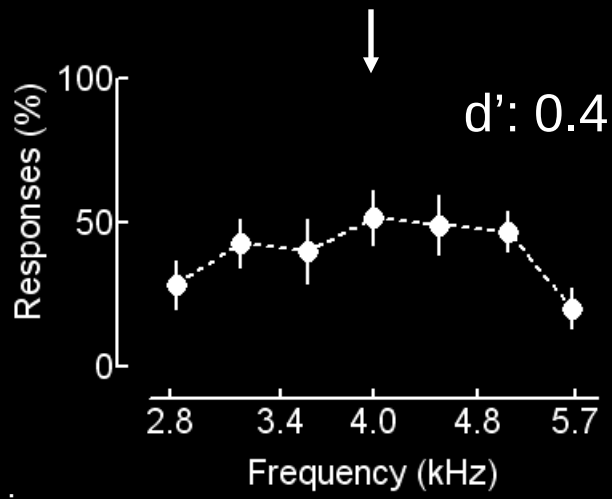
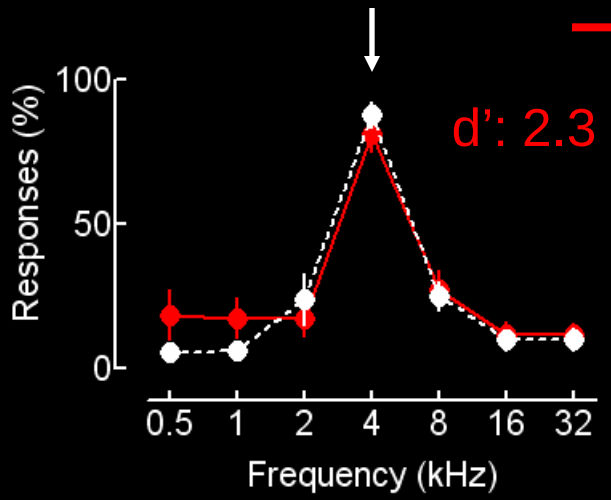


post-pairing (1-2 hrs)

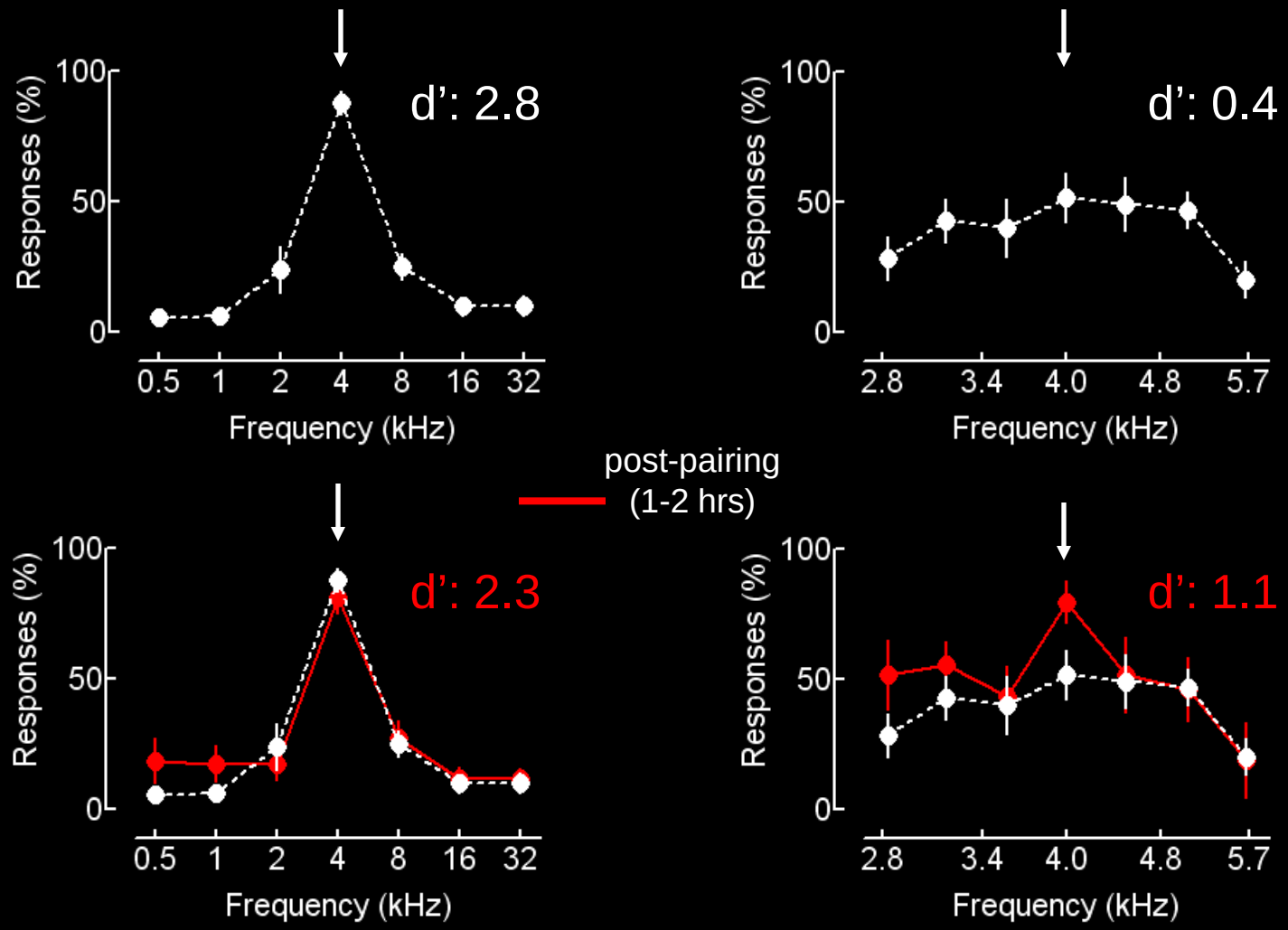


(Froemke, Carcea et al., Nature Neuroscience 2013)

Behavioral Task: Sound Detection & Recognition

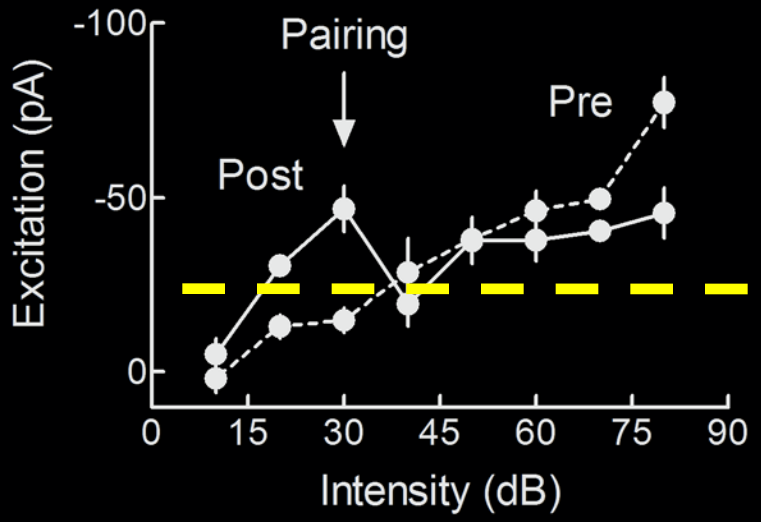
EASIER TASK (1 octave)

HARDER TASK (0.16 octaves)



(Froemke, Carcea et al., Nature Neuroscience 2013)

Long-Term Modification of ‘Loudness’ (Intensity) Tuning



Perceptual Threshold?

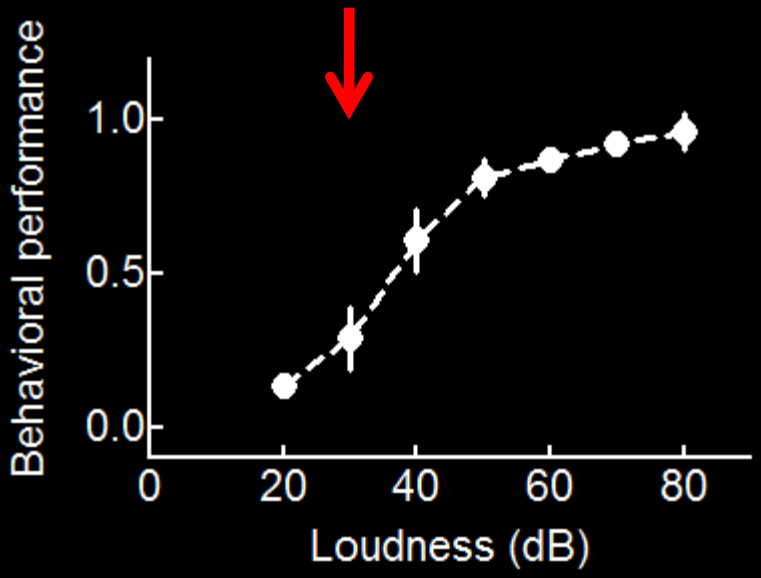
(Froemke, Carcea et al., Nature Neuroscience 2013)

Behavioral Task:
Sound Detection & Recognition

Volume is also varied

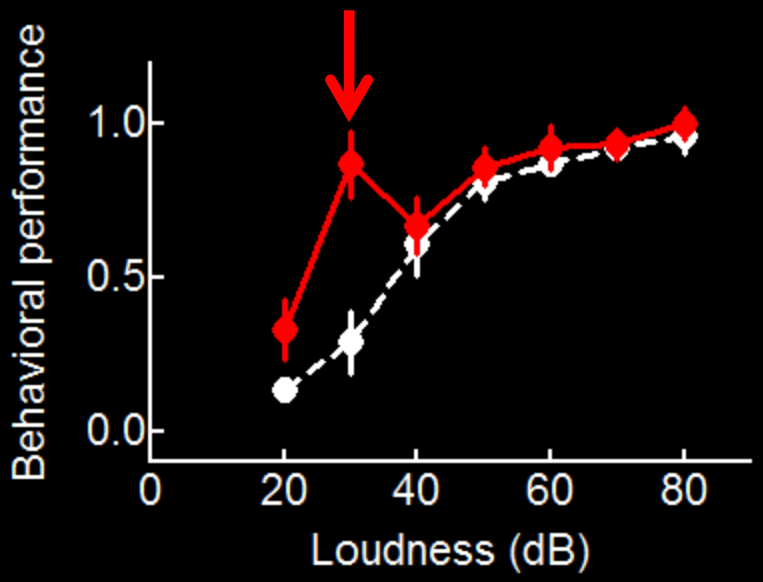
4 kHz is rewarded at all volumes

Behavioral Task: Sound Detection & Recognition



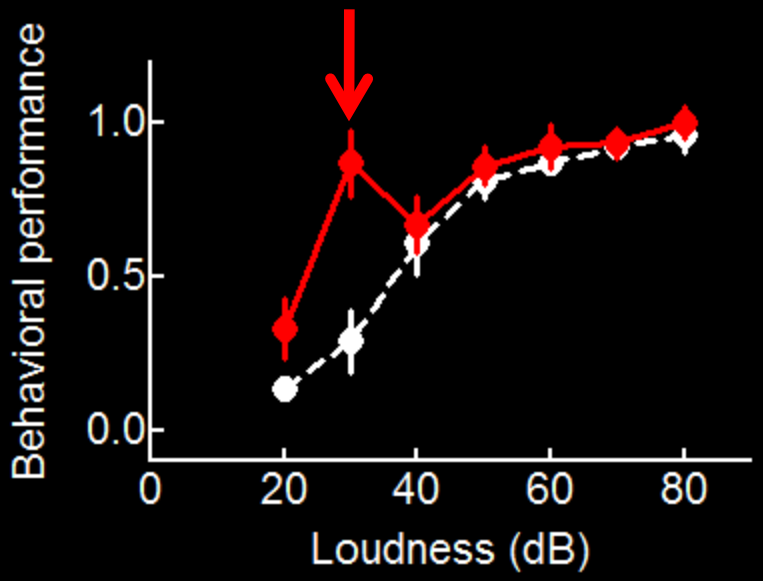
(Froemke, Carcea et al., Nature Neuroscience 2013)

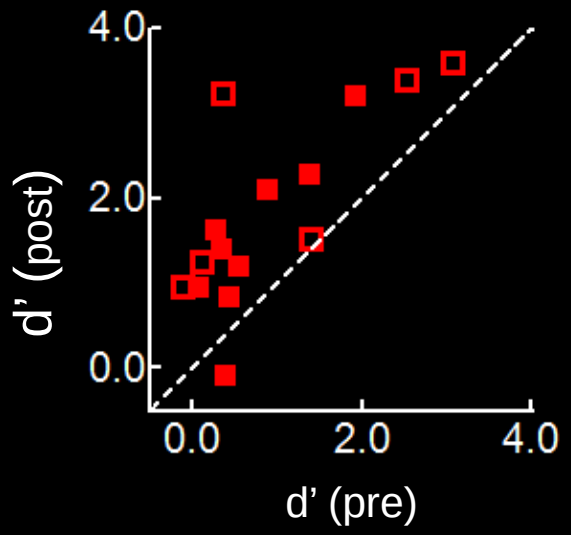
Behavioral Task: Sound Detection & Recognition



(Froemke, Carcea et al., Nature Neuroscience 2013)

Behavioral Task: Sound Detection & Recognition





(Froemke, Carcea et al., Nature Neuroscience 2013)