Multisensory integration by descending neurons in hawkmoths

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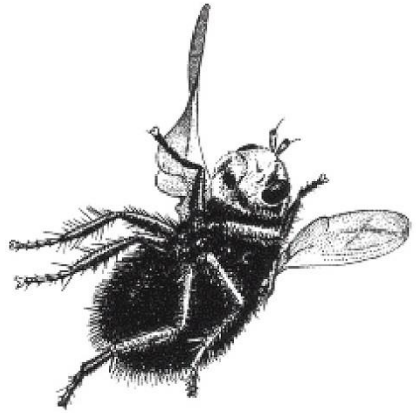


ncbs

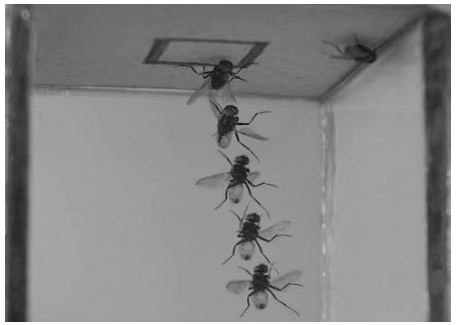
Behavioural coordination in flying insects

PI: Sanjay P. Sane

National Centre for Biological Sciences, Bangalore. India

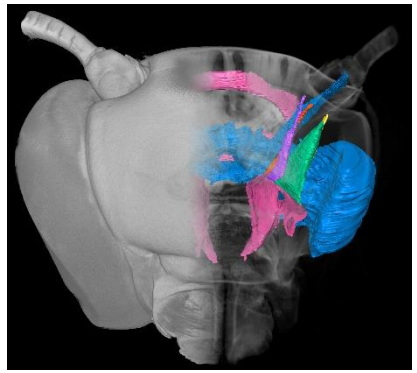
Problem/Objective

- Examining the structures of simple and complex insect behaviours.
- Understanding the neural and mechanical basis of how behavioural modules are coordinated.
- Investigating the sensory and motor apparatus of diverse behavioural modules.



Technical Approaches

- Intracellular / extracellular electrophysiology of descending neurons in hawkmoths.
- Electromyography
- Electron microscopy
- Neuroanatomical techniques
- X-ray Microtomography (MicroCT)
- High-speed videography with machine learning
- Field ecology
- Modelling and Simulations



Accomplishments (2016-2020)

- Comprehensive characterization of >200 descending neurons in hawkmoths using intracellular electrophysiology.
- Characterization of antennal mechanosensory and motor circuits and control theoretic modelling of their positioning behaviour.
- Characterization of head stabilization apparatus and behaviour.
- Role of mechanosensory cephalic hair in flight initiation and long distance flight.
- Multiple behavioural studies on freely flying moths and flies and analysis of their landing behaviours on vertical and inverted surfaces
- Generated an Electron microscopy, MicroCT facility and a large low-flow wind tunnel at NCBS.
- MicroCT datasets of internal anatomy of hawkmoth flight, antennal and neck musculature.

DoD benefits / Deliverables

- Basic understanding of the neural circuits underlying reflexes and other rapid responses.
- Basic knowledge of neural basis of multisensory integration, using hawkmoths as a model system.
- Understanding of kinematics of flapping wings in generation of diverse aerial maneuvers for flapper applications

- **21 research papers and reviews** (Nature communications, eLife, J Exp Biol, J Comp Neurol, Science Advances, Current Biology etc.)
- **AFOSR funded conference** on “Multisensory integration in flight’
- Upcoming issue on “Multisensory integration in flight’ in Biology Letters.

AFOSR funded research topics

Hawkmoths *(Daphnis nerii)*

- *Electrophysiological studies of multisensory integration by descending neurons*
- *Role of cephalic hair in flight initiation and its mechanosensory encoding*
- *Mechanisms of head stabilization and gaze control*
- *Antennal mechanosensory feedback and its role in flight*
- *Multimodal mechanisms of mate recognition*

Diverse flies *(Drosophila melanogaster, Musca domestica, Hermetia illucens, Sarcophaga dux etc)*

- *Mechanics of the wing hinge and its role in flight*
- *Biomechanics of the fly thorax*
- *Eco-physiology of long-distance flights*
- *Odor and visual tracking of objects*

Wasps *(Trichogramma spp.)*

- *Miniaturization of nervous systems and flight apparatus*

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Wasps *(Trichogramma spp.)*

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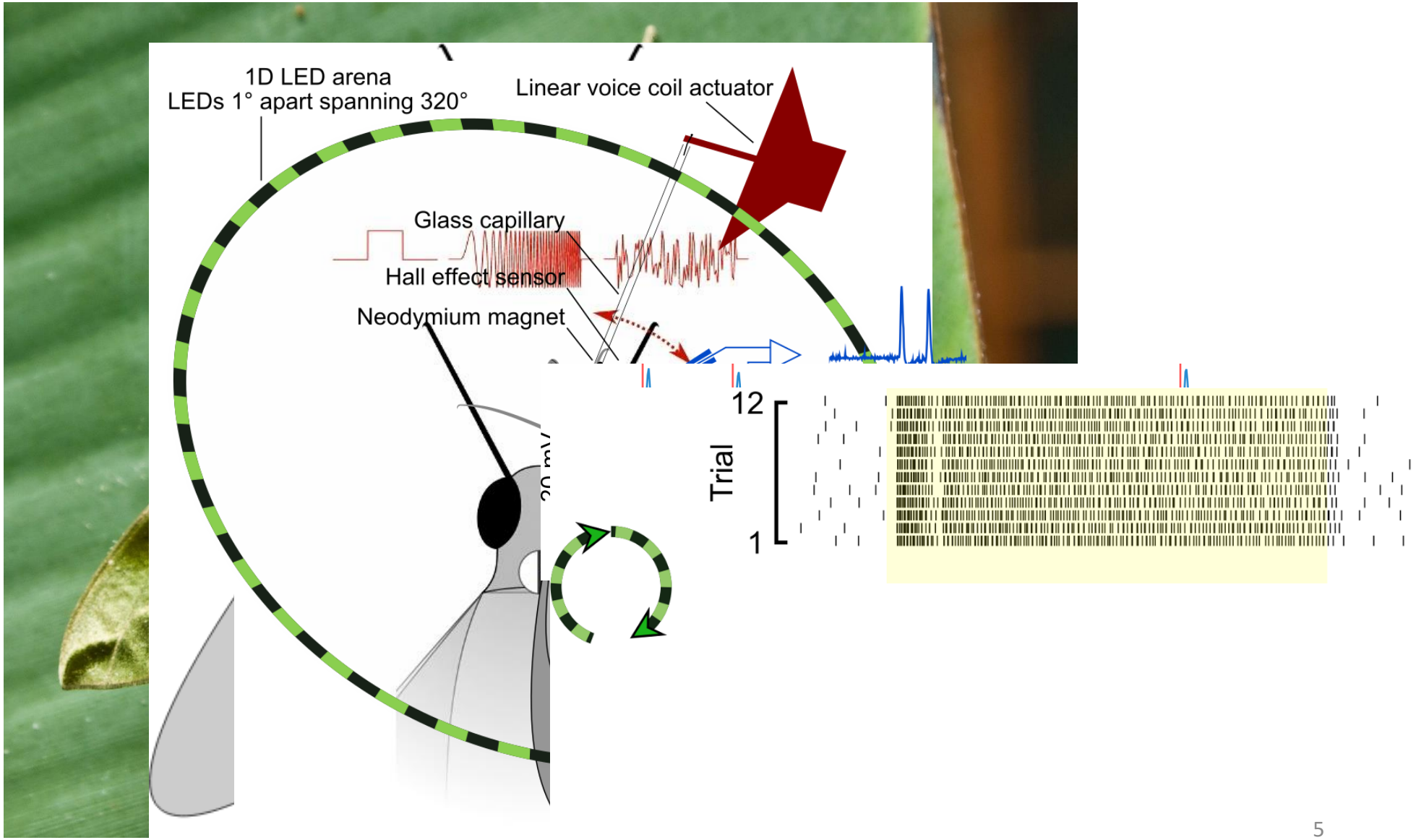
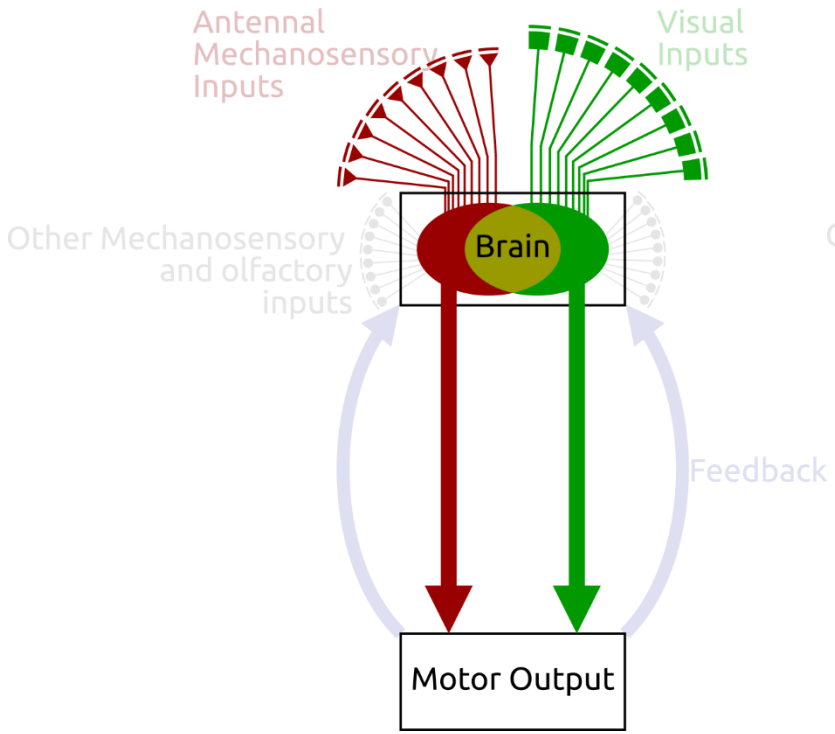
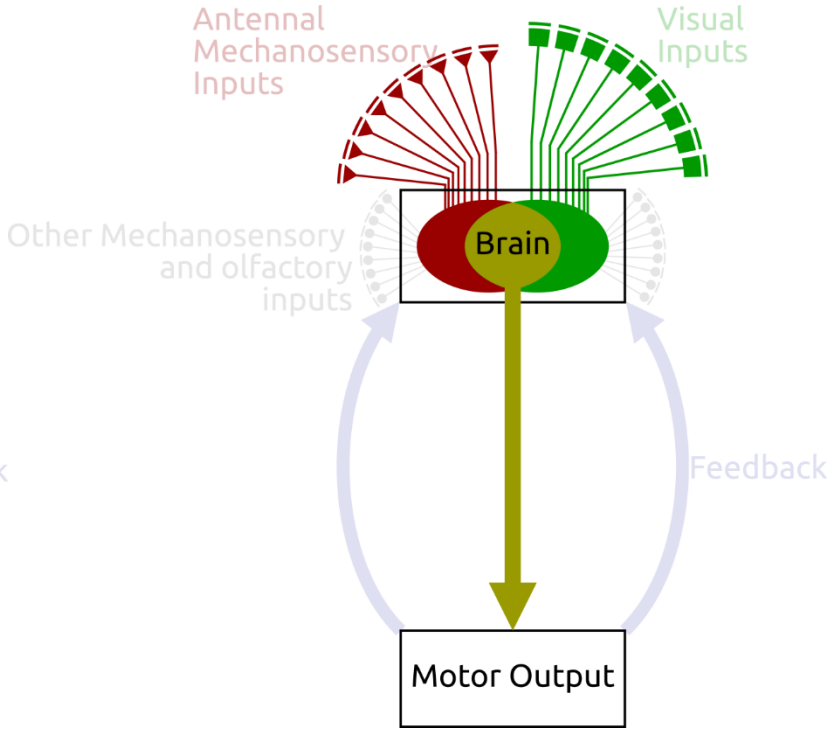
Multisensory integration by descending neurons

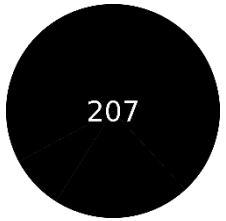


Several descending neurons respond to both mechanical and visual stimuli





Descending neurons recorded:



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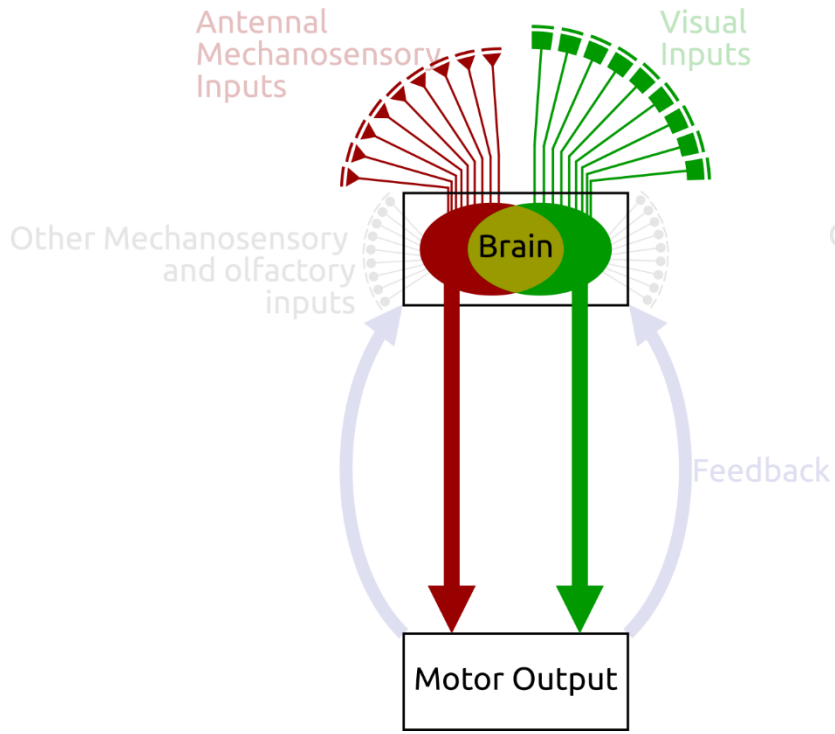

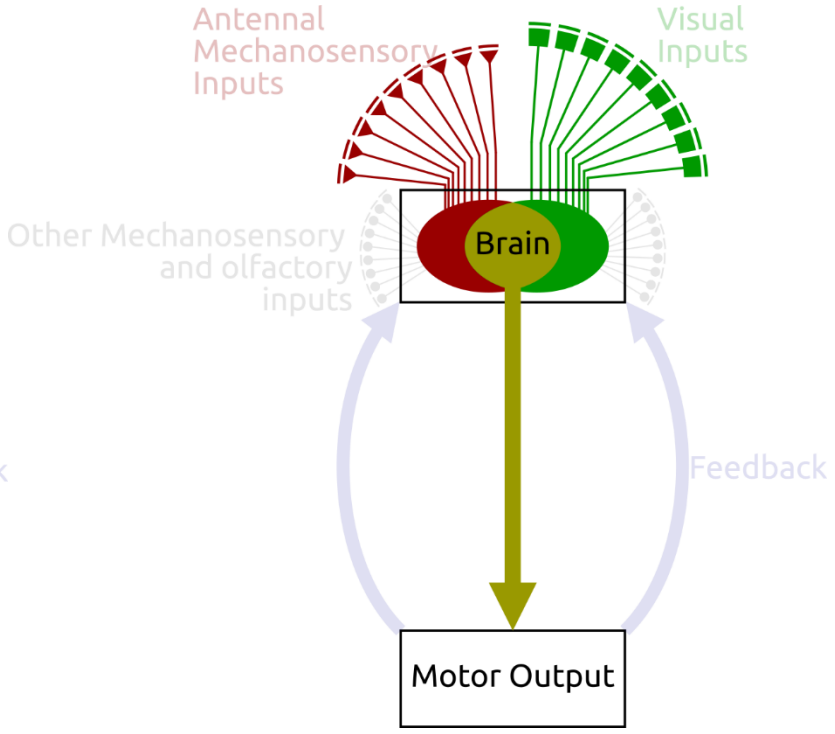

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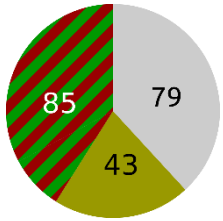
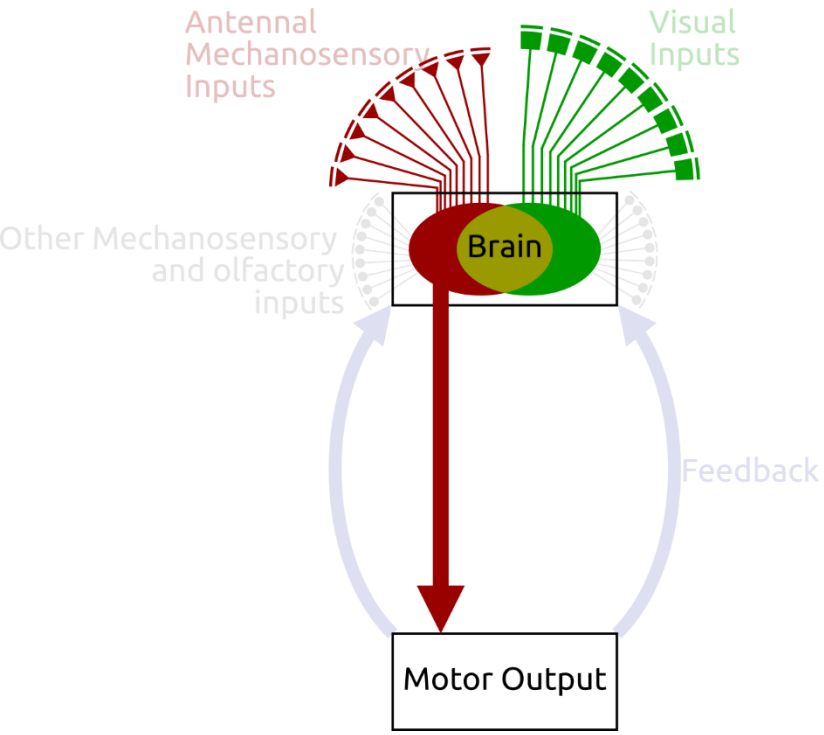
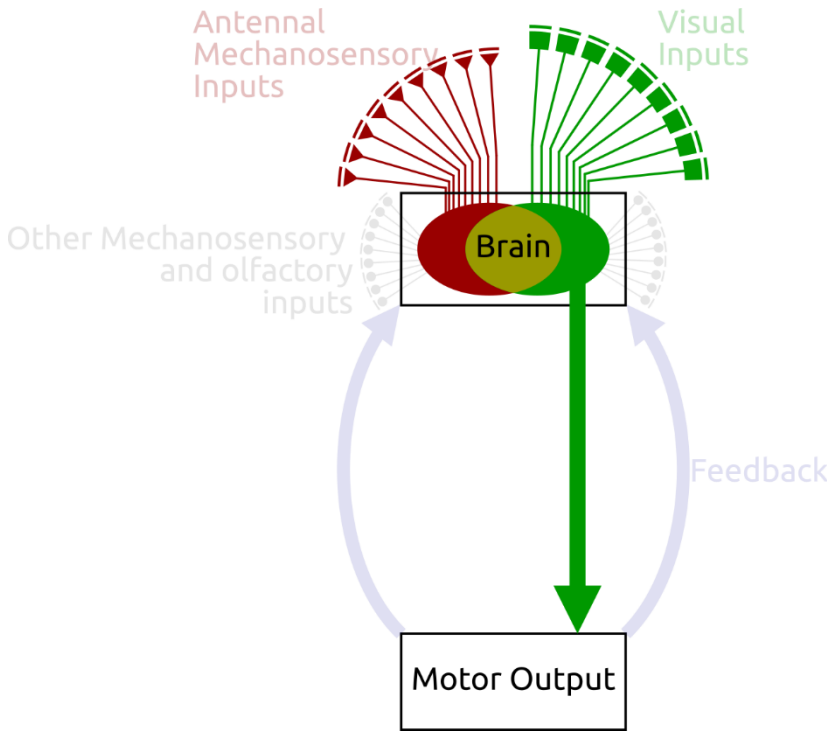
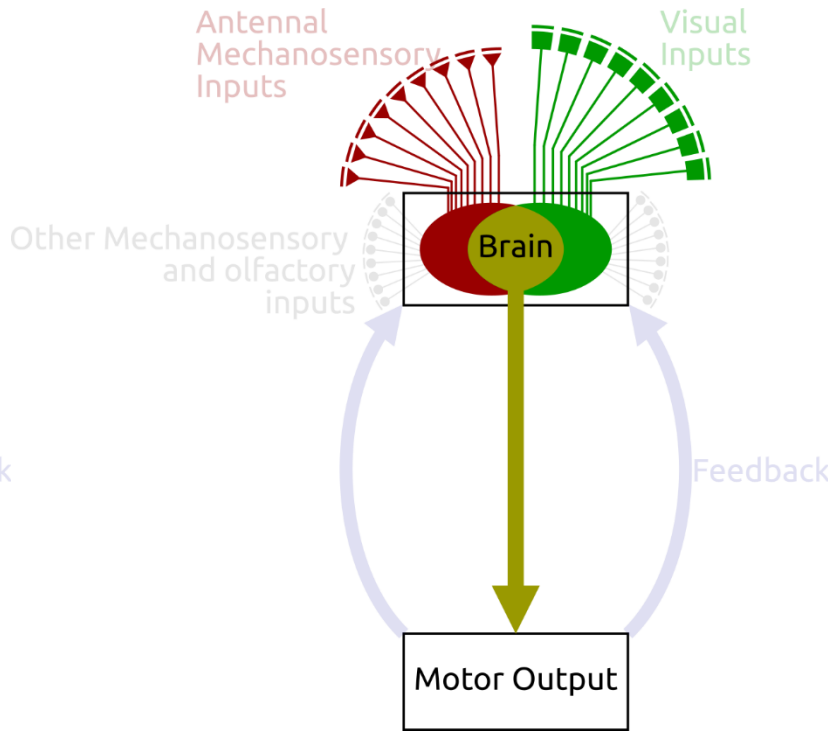


- Unimodal descending neurons responding to either visual or antennal mechanosensory stimuli
- Multimodal descending neurons responding to both visual and antennal mechanosensory stimuli
- Other neurons – random/constant/sparse firing not responding to stimuli provided

Several descending neurons respond to both mechanical and visual stimuli







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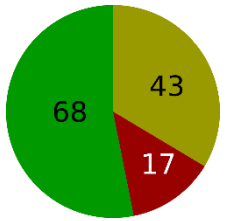
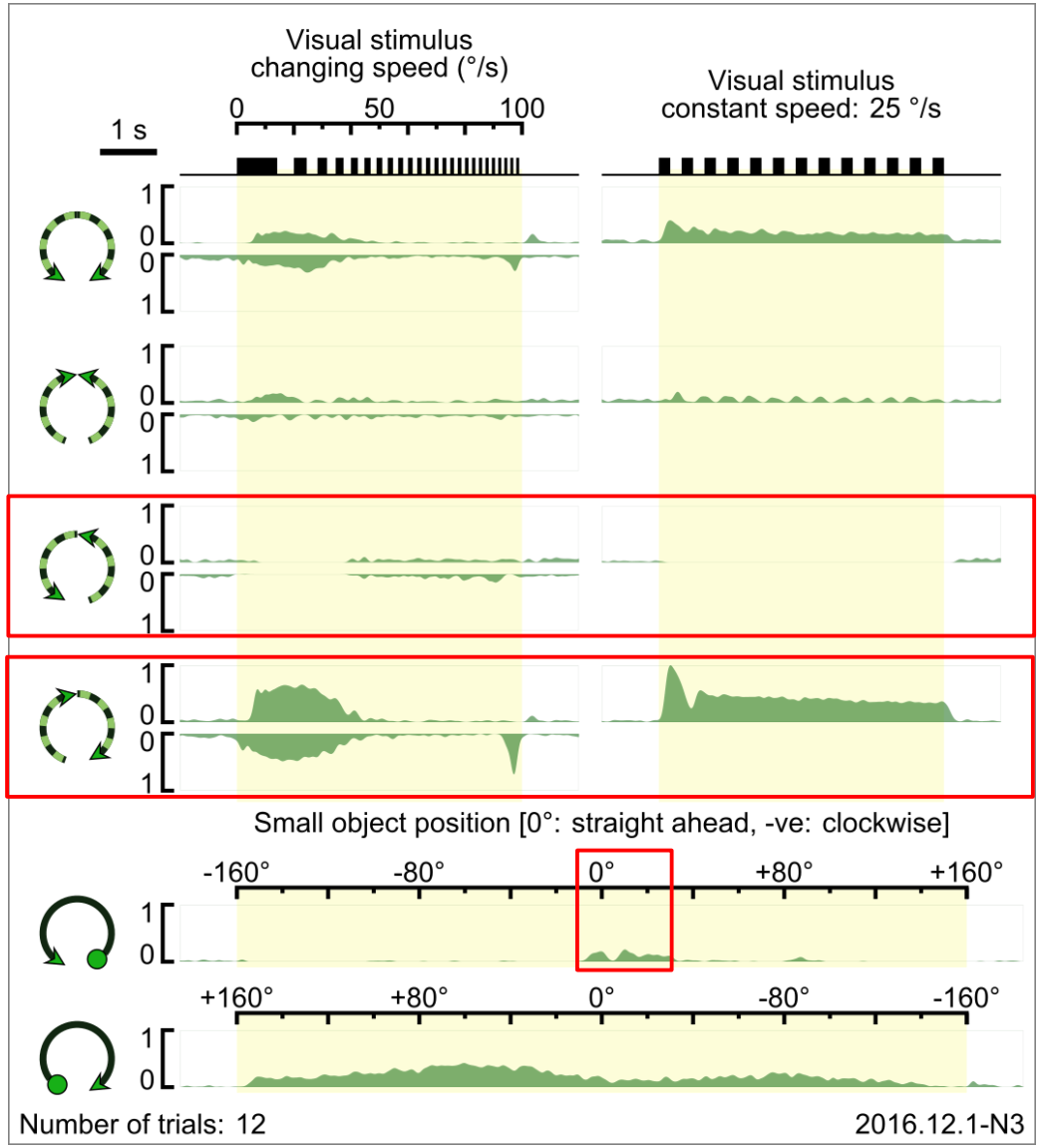
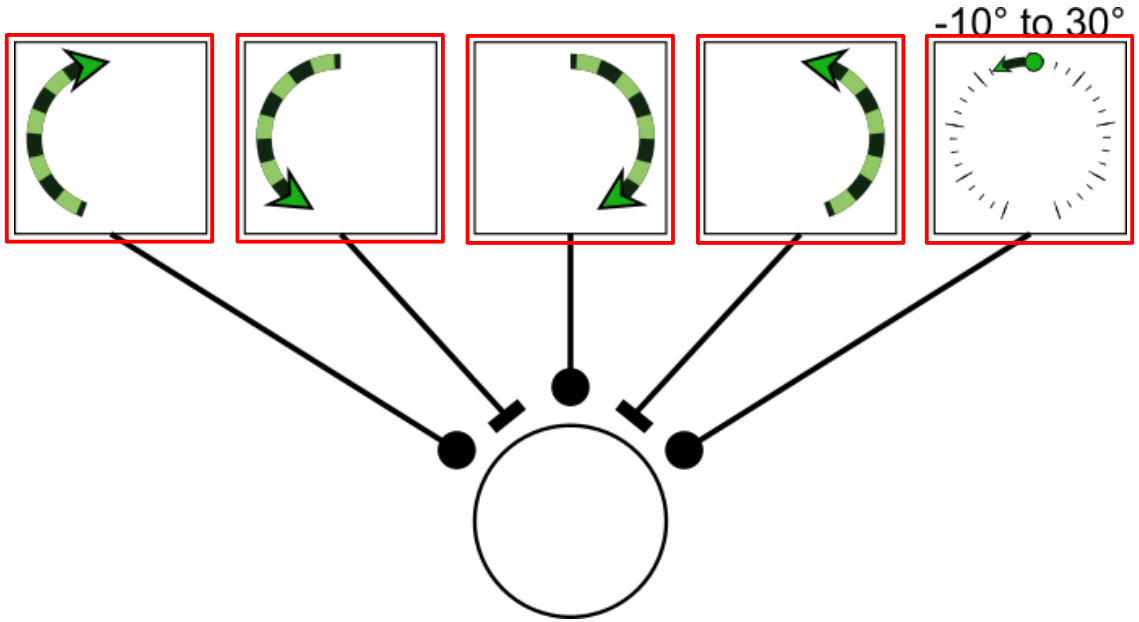


- Unimodal descending neurons responding to antennal mechanosensory stimuli
- Unimodal descending neurons responding to visual stimuli
- Multimodal descending neurons responding to both visual and antennal mechanosensory stimuli

Minimal circuits

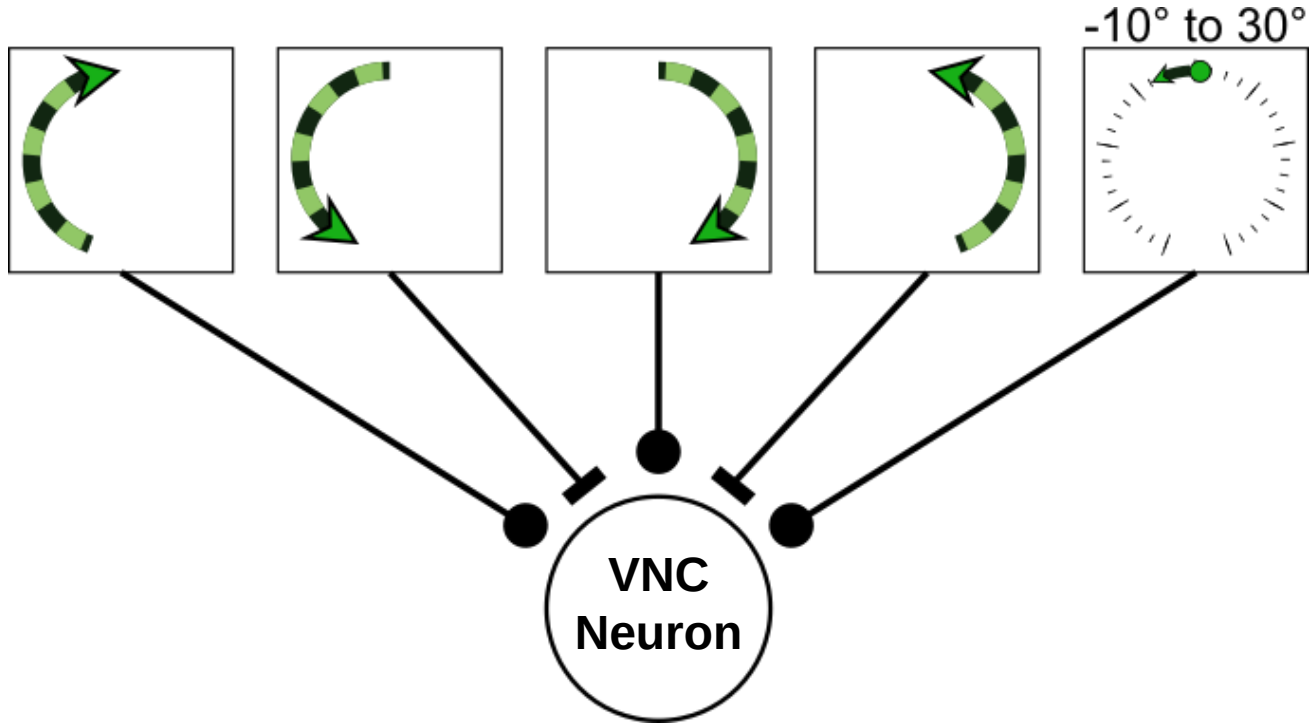
A qualitative way to represent and classify neurons





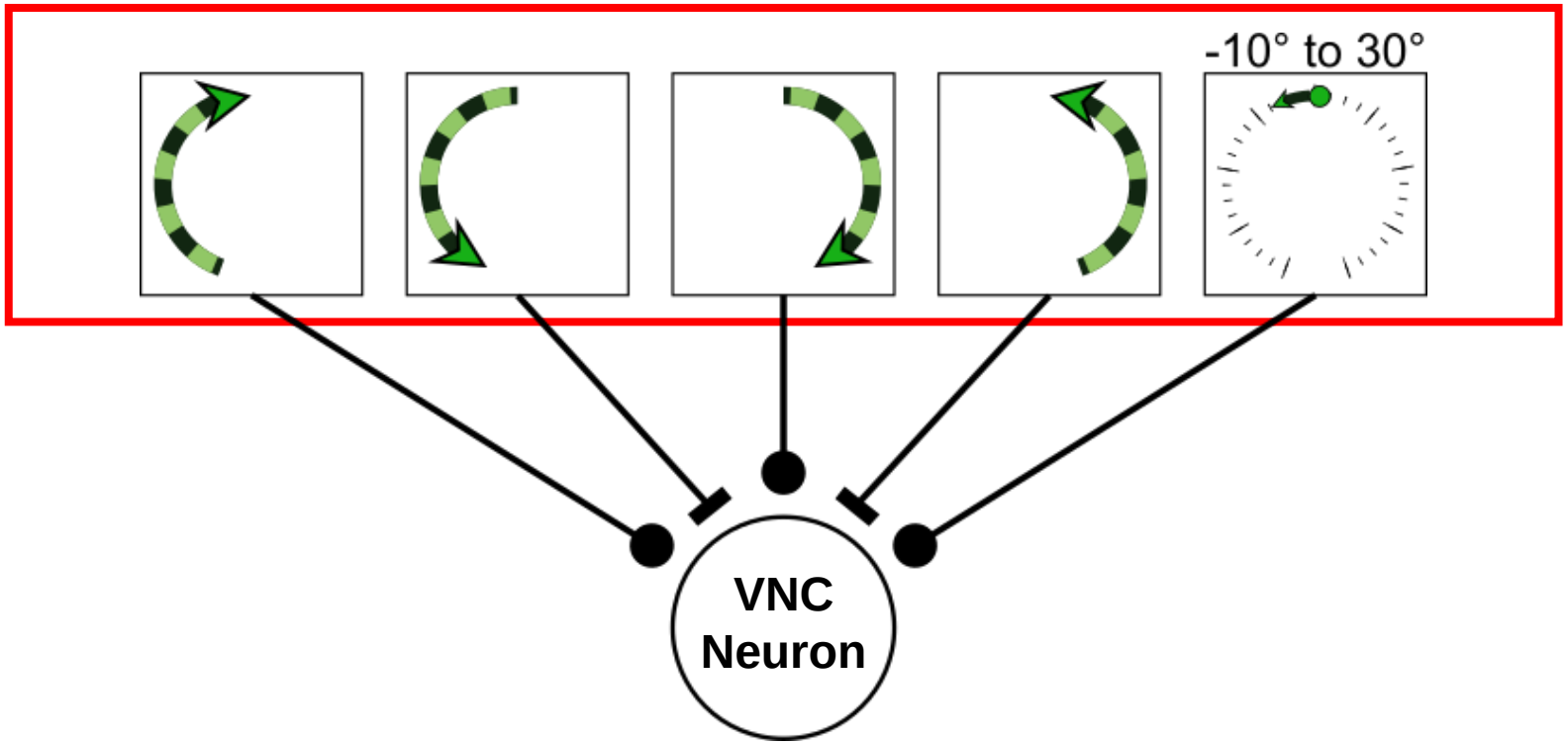
- ***Responds to wide and small field motion***
- ***Strong excitation to counterclockwise rotation***
- ***Strong inhibition to clockwise rotation***

Objects and Operations



Objects and Operations

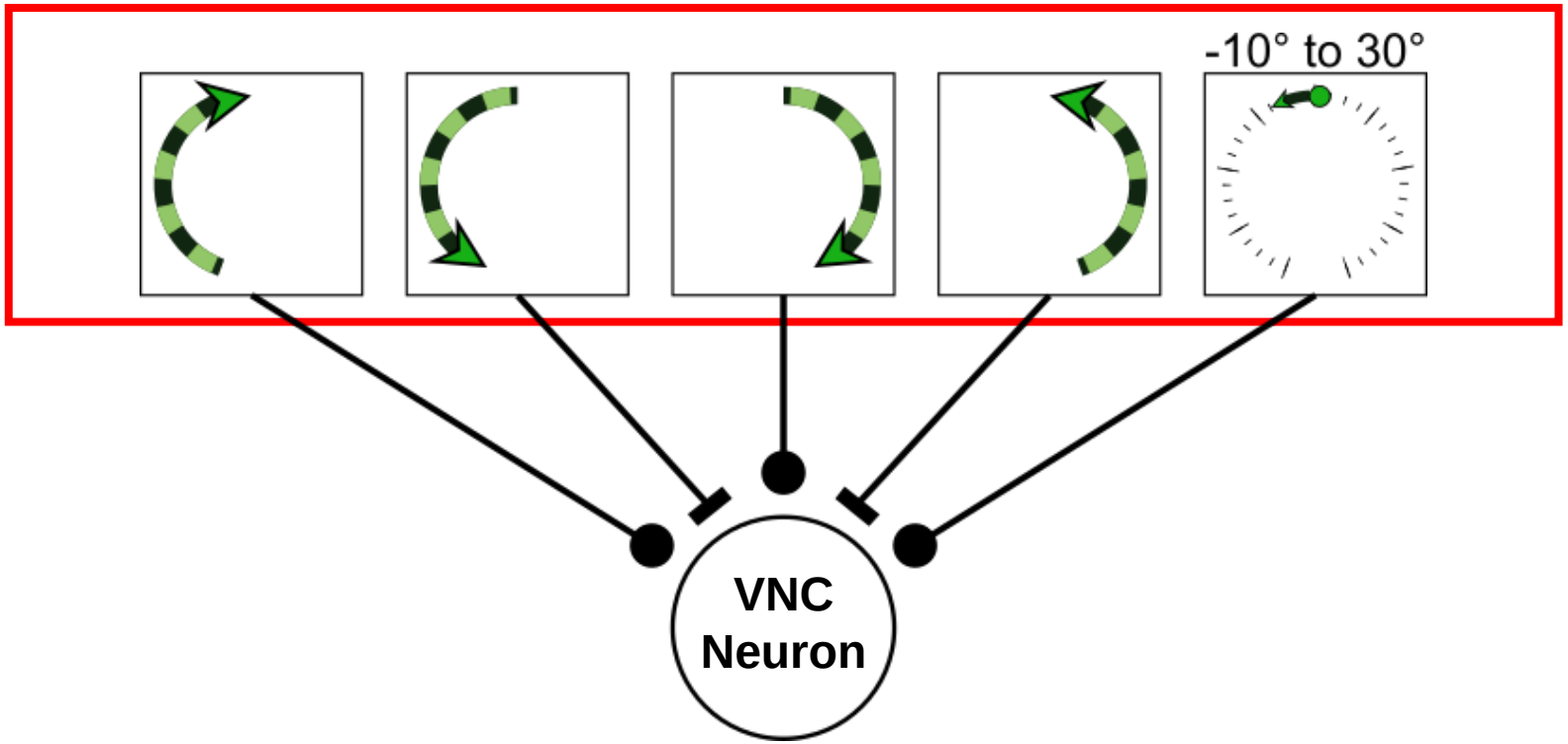
Stimulus: What the neurons see?



Objects and Operations

Stimulus: What the neurons see?

- *Fictive backward left wide field*
- *Fictive forward left wide field*
- *Fictive backward right wide field*
- *Fictive forward right wide field*
- *Small object fictive clockwise*
- *Small object fictive counterclockwise*



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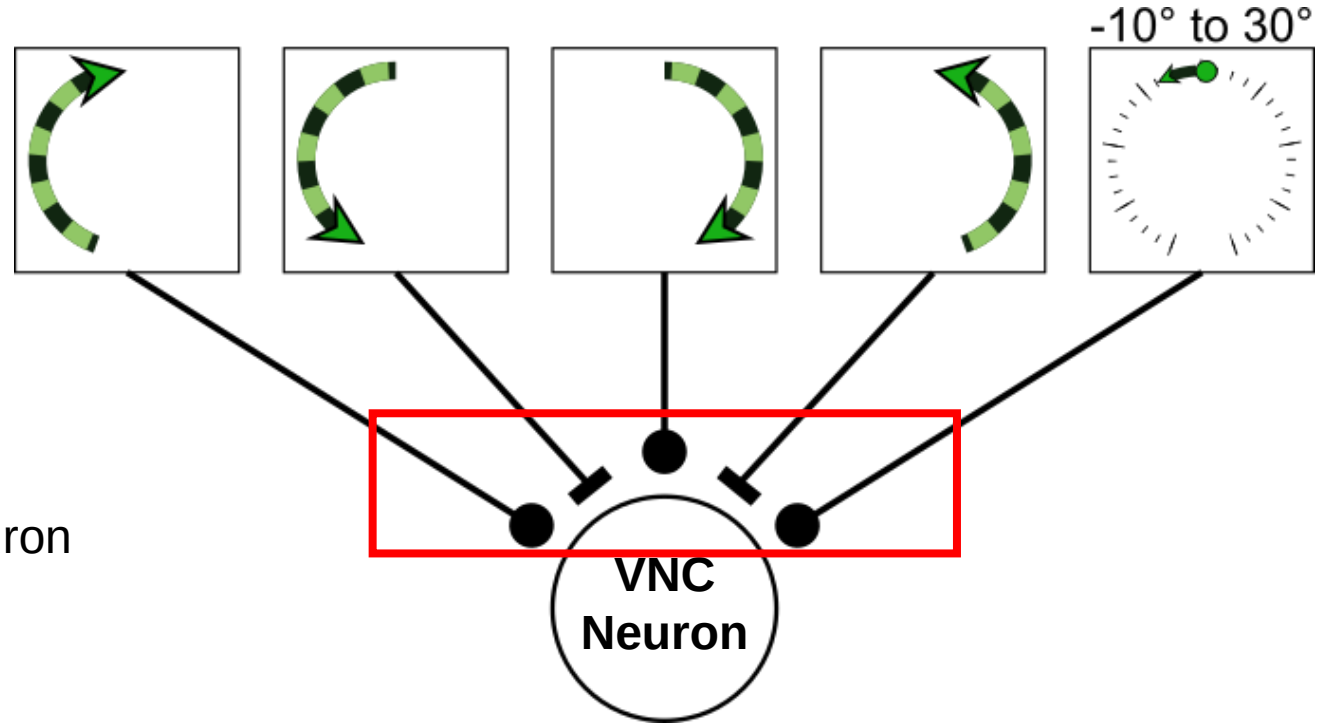
Operation: How they influence the VNC neuron



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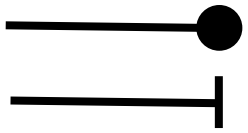
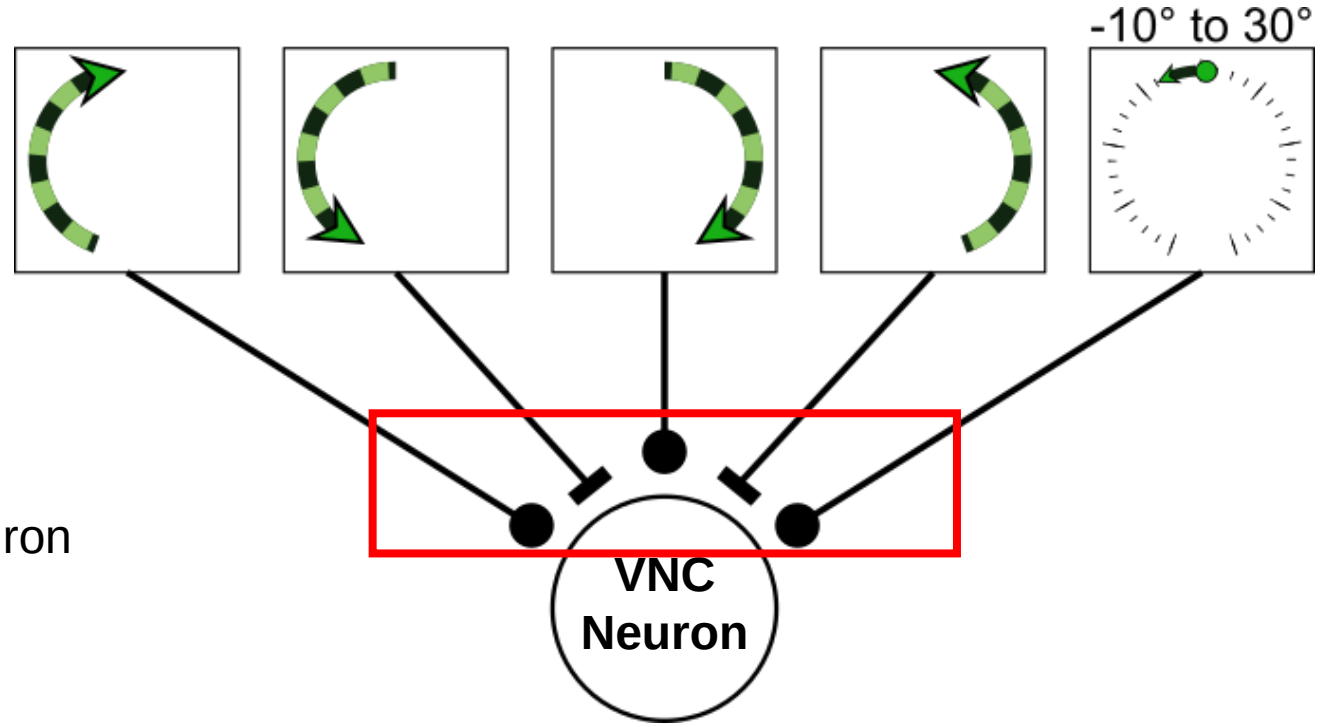


Excitation

Inhibition



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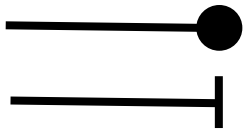
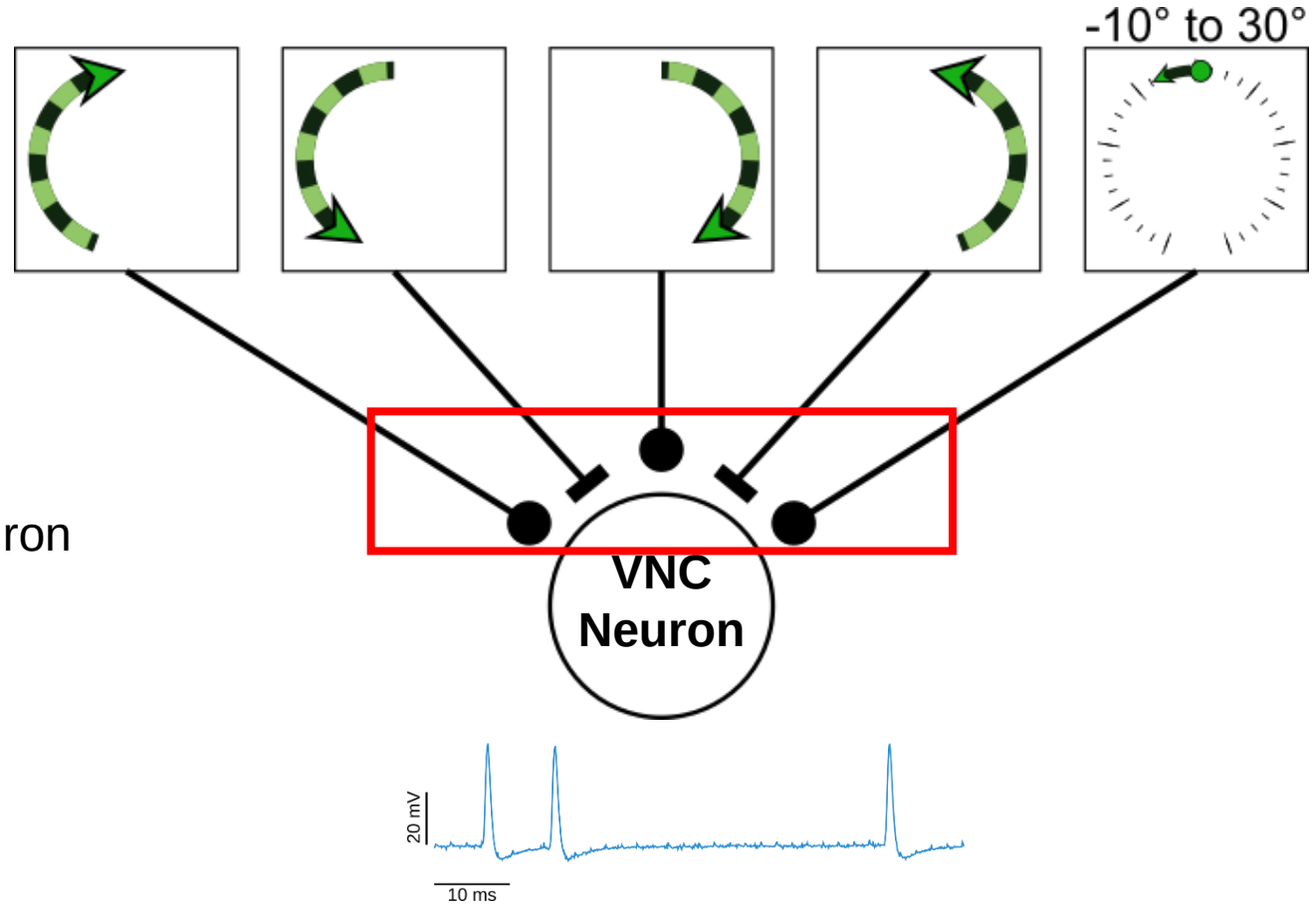


Excitation

Inhibition

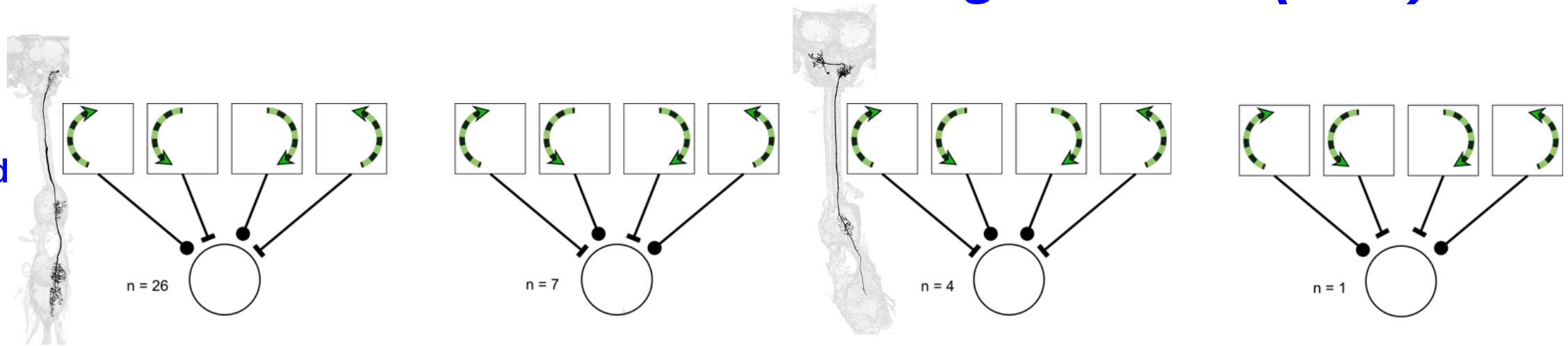
Response: Our recordings



These models can be algorithmically determined and simulated

Minimal circuits of Visual Descending Neurons (DNs)

Wide-field neurons



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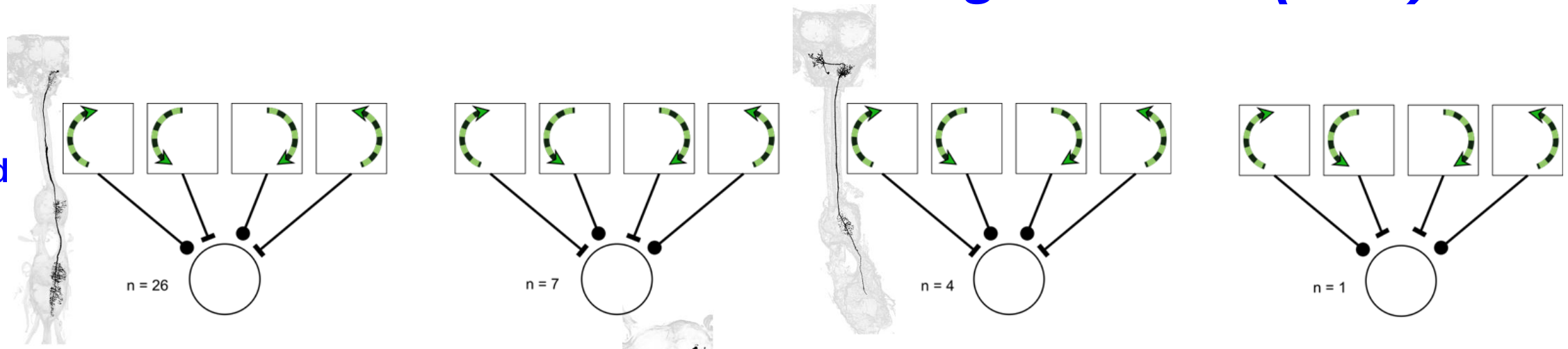
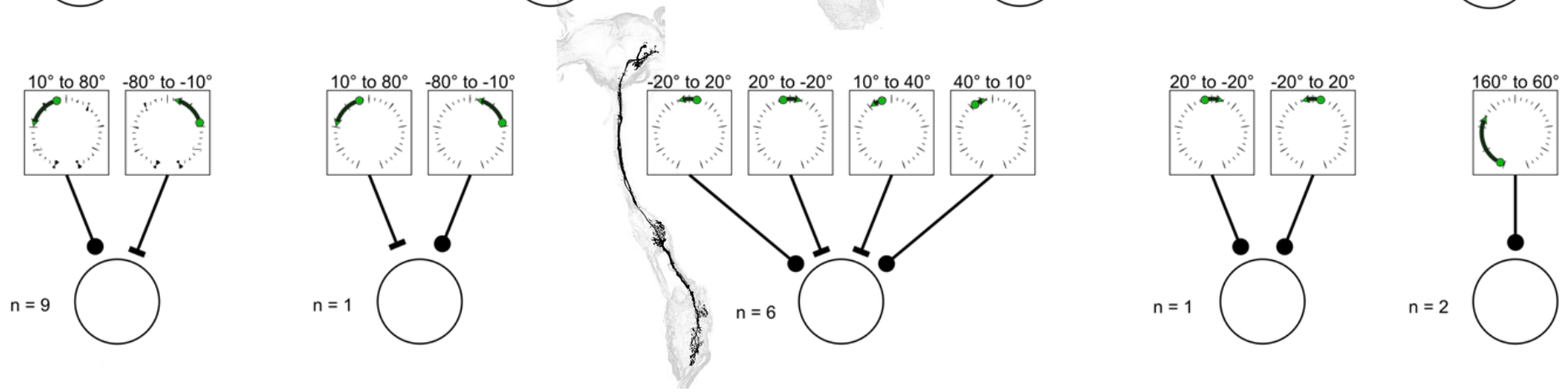


Small-object neurons



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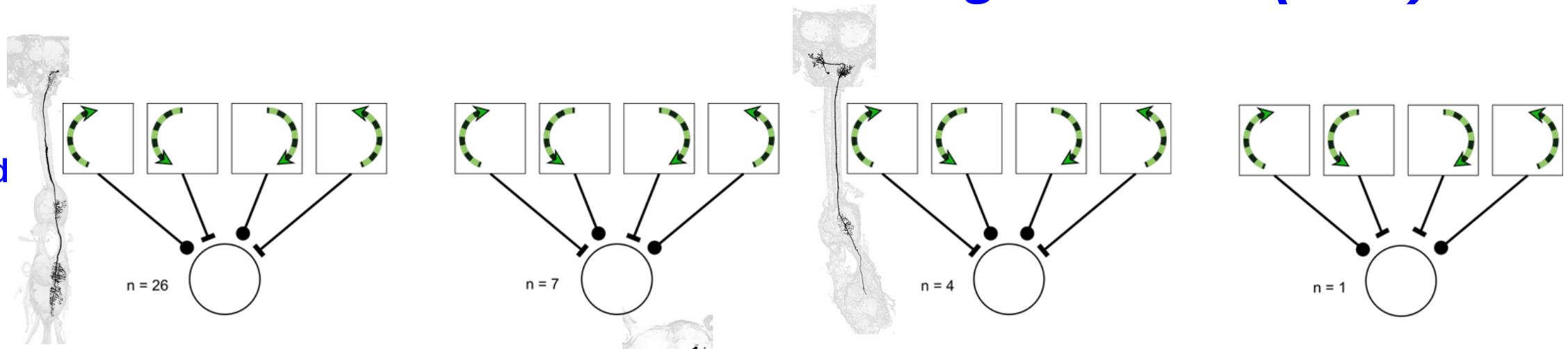

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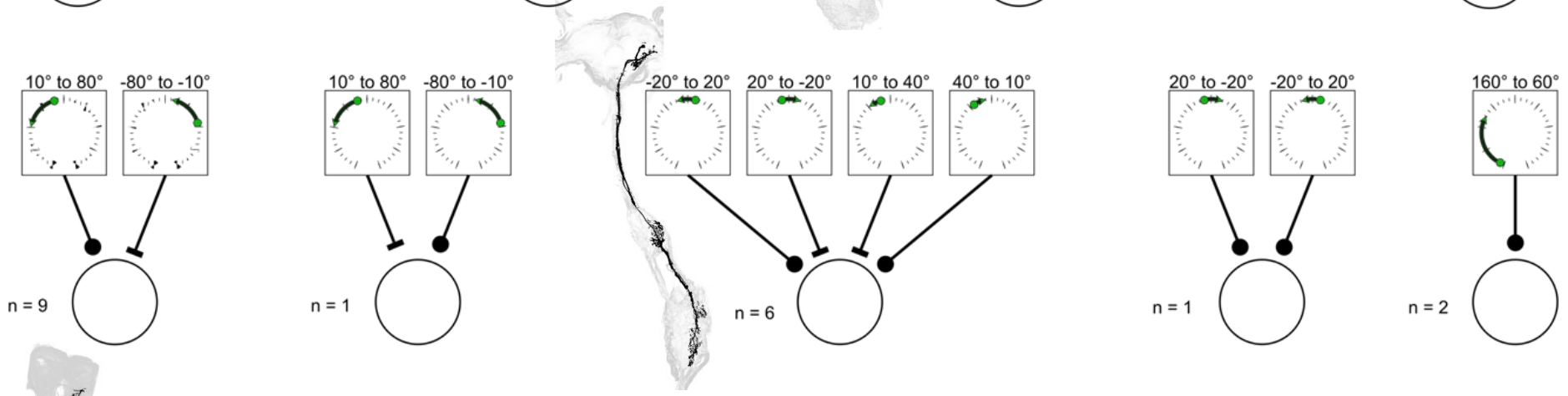
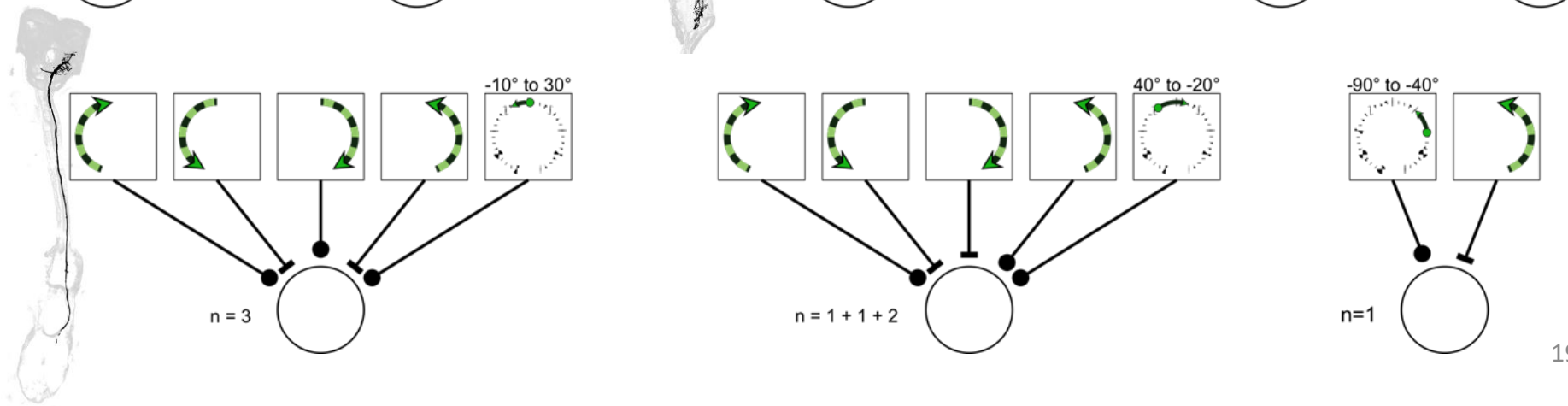
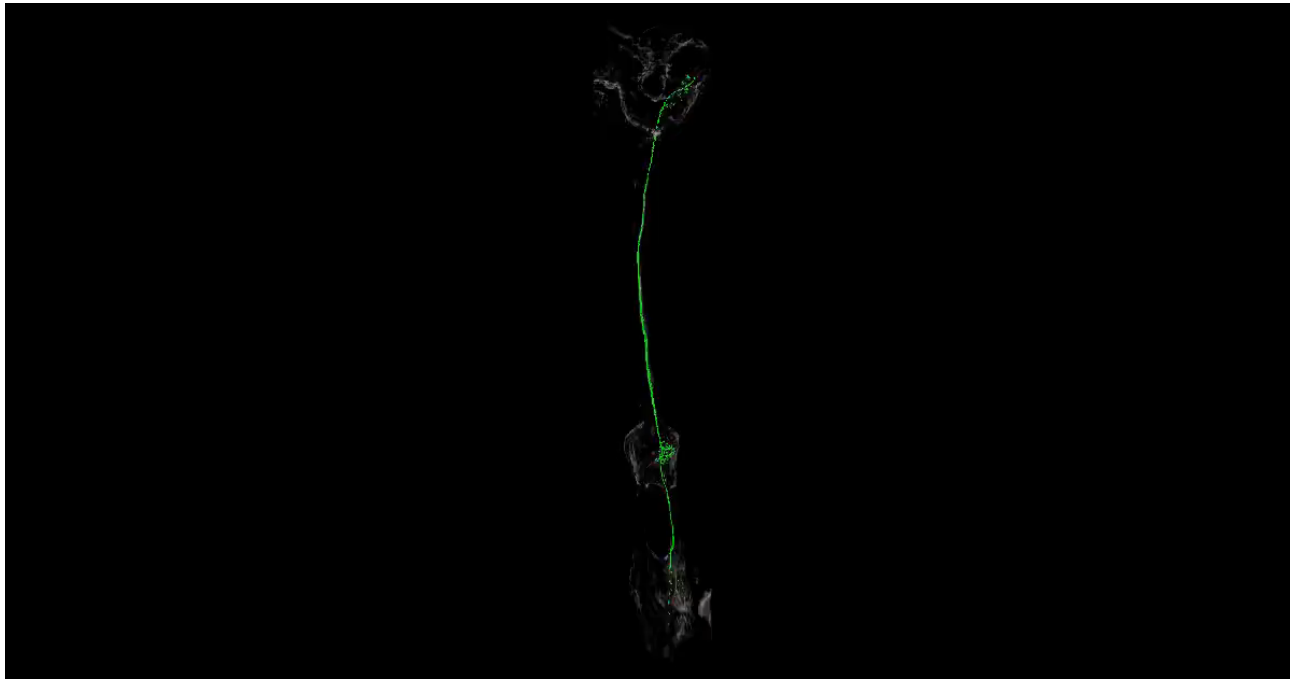
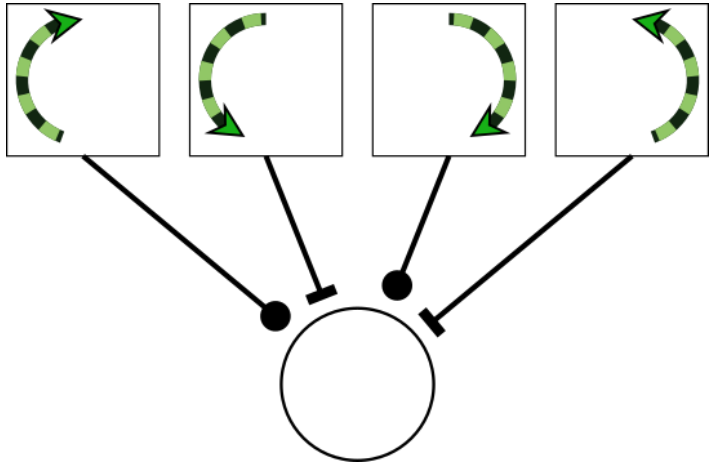


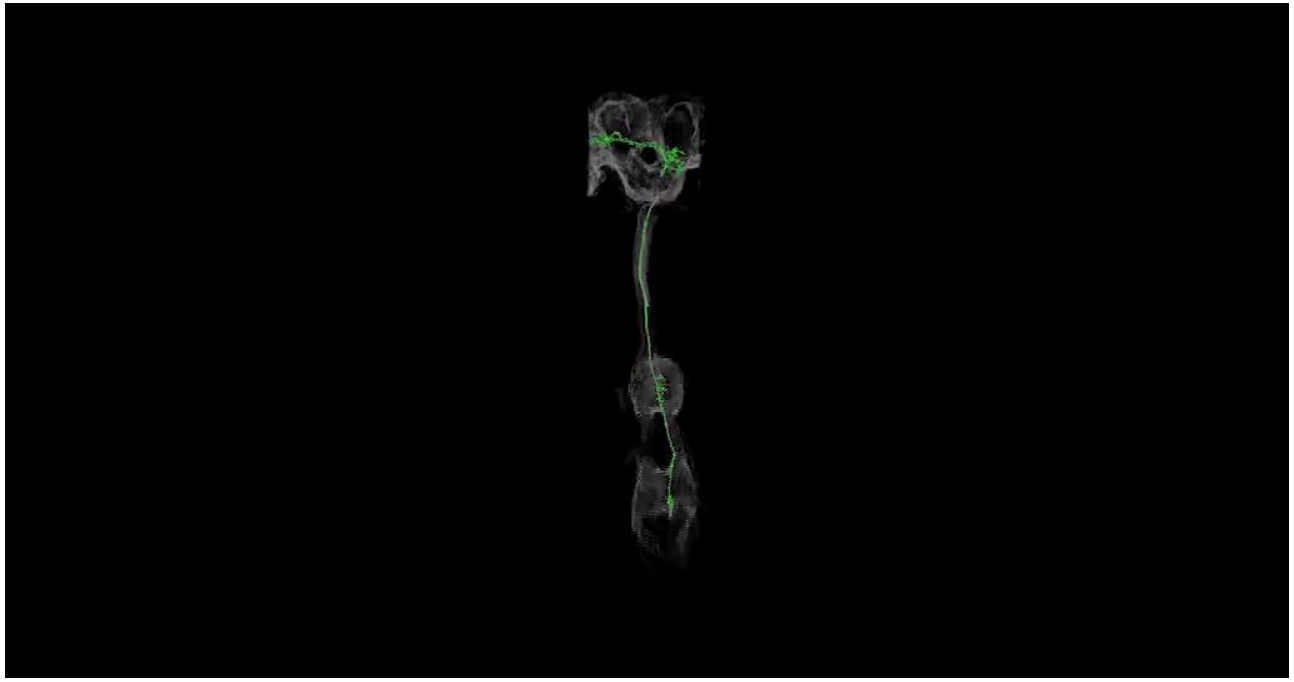
Wide-field and small-object neurons



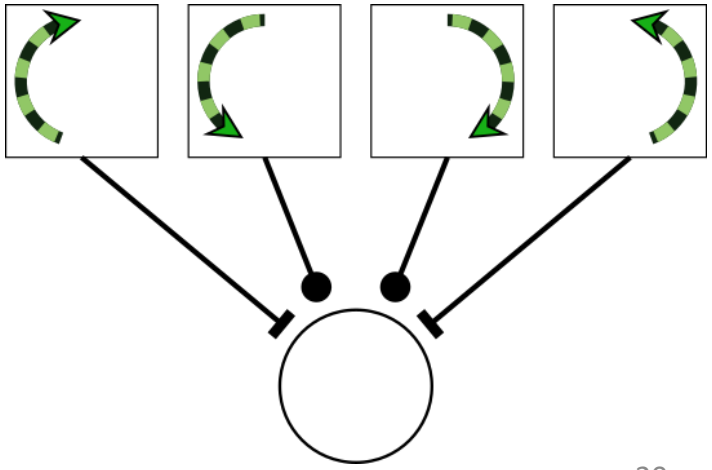


Ipsilateral Neuron
Wide-field sensitive

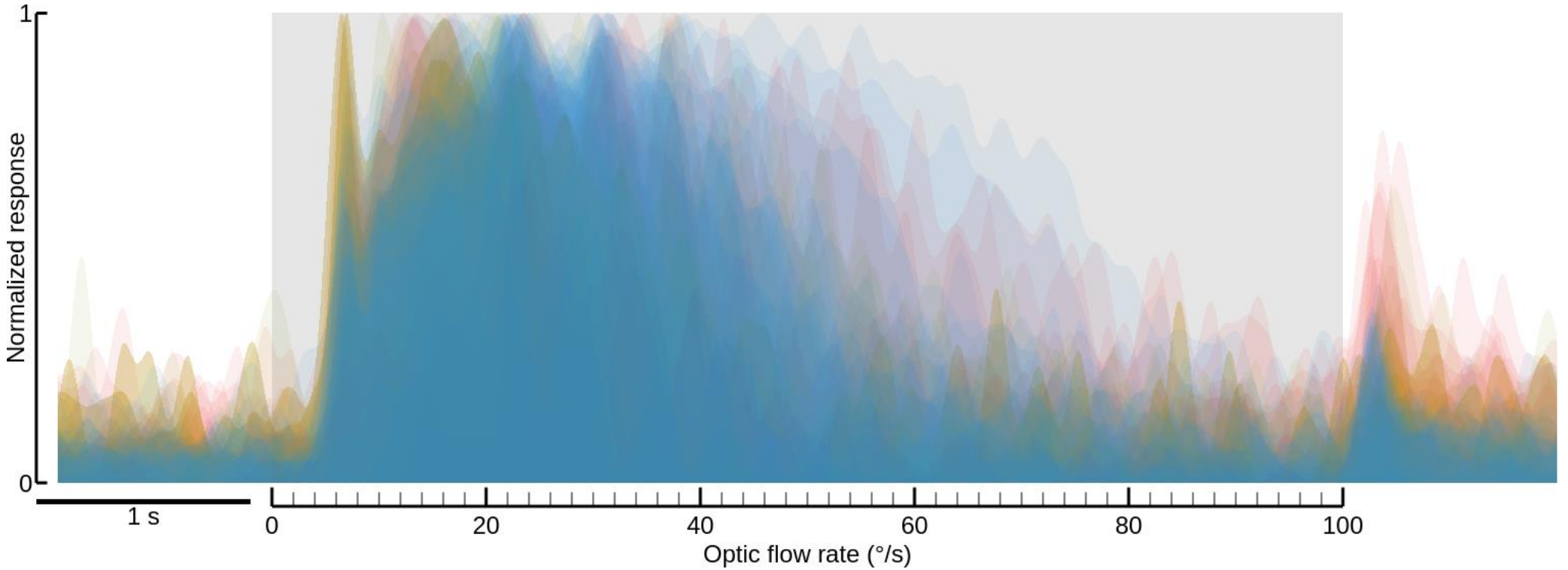




Contralateral Neuron
Wide-field sensitive

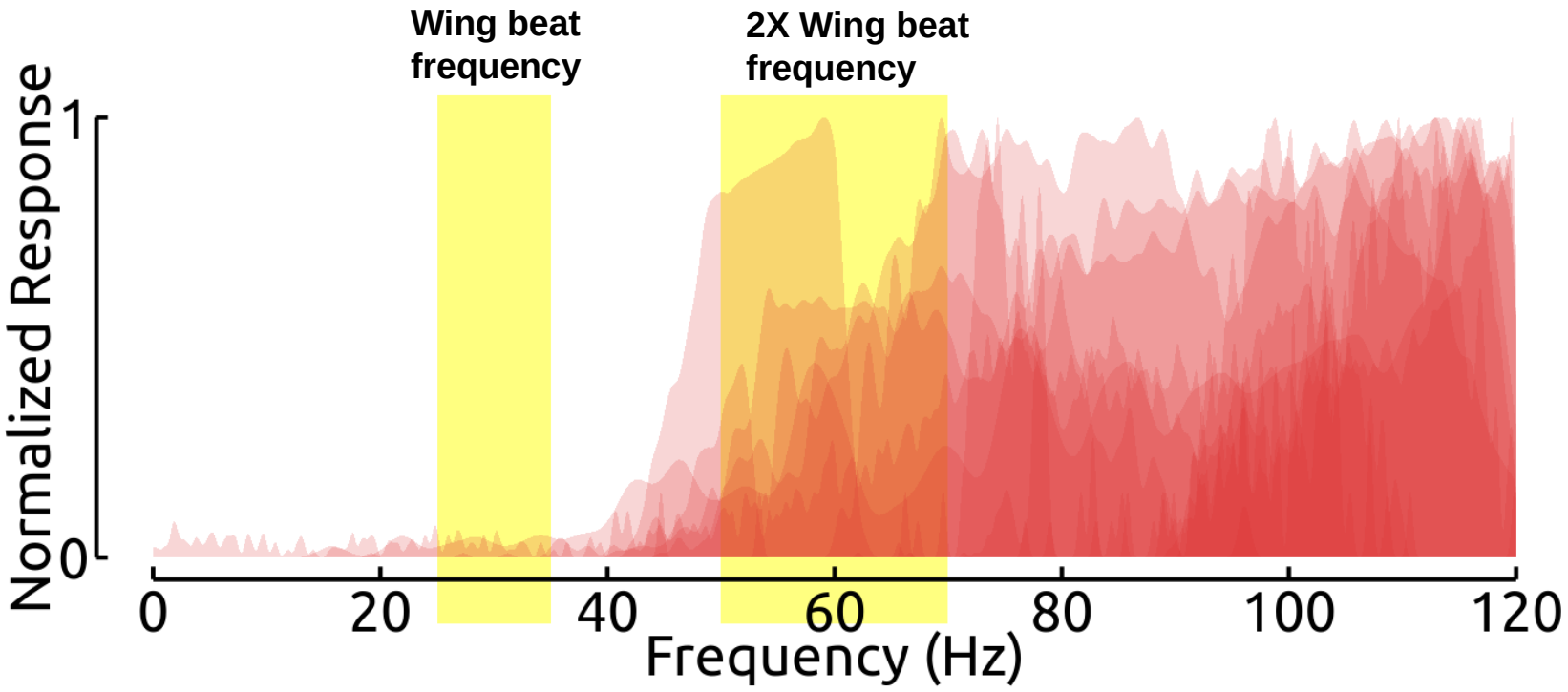


Responses of DNs that transduce only visual stimulus taper after ~60°/s:
Low-pass properties of visual-only DNs



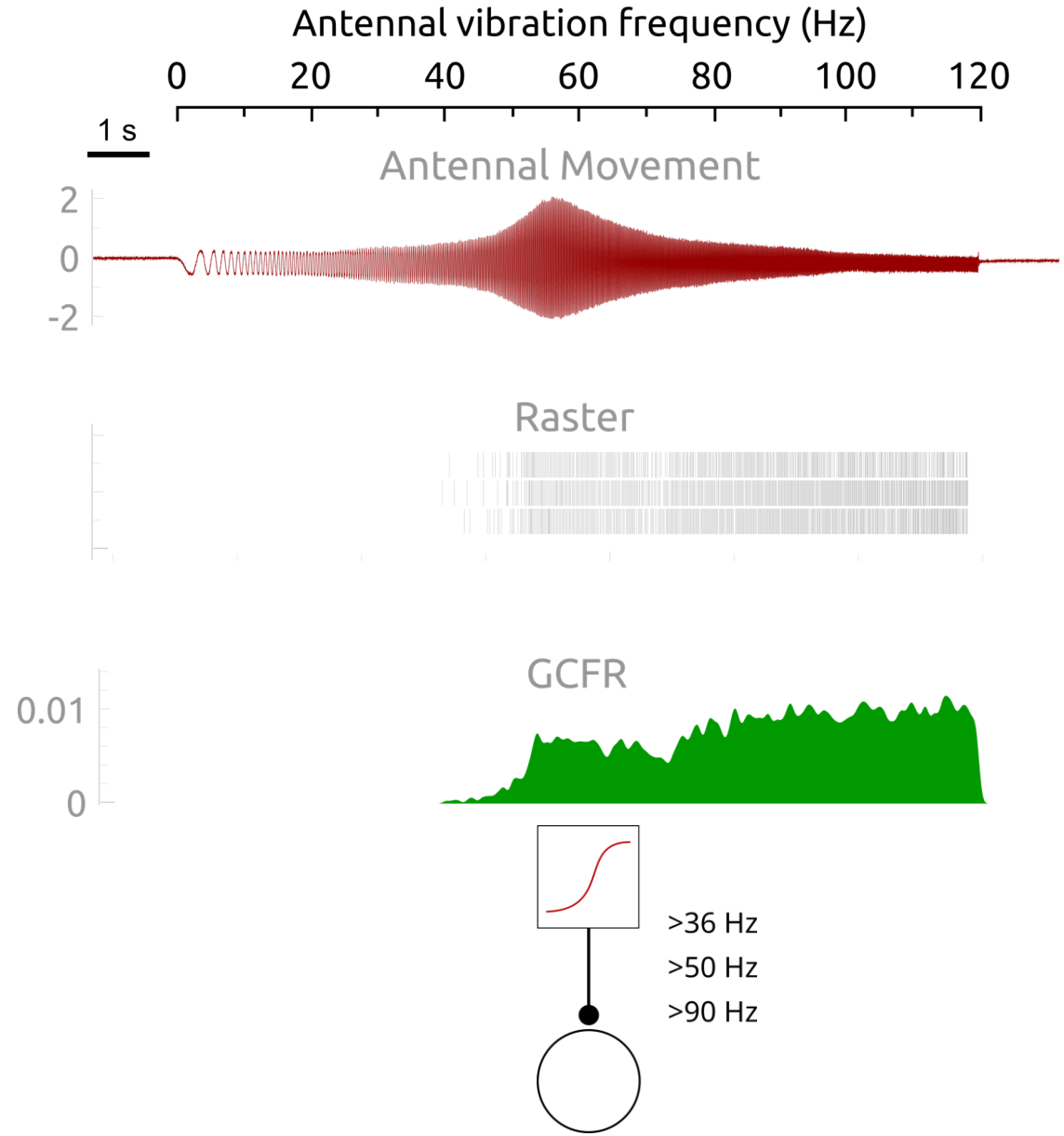
N = 45

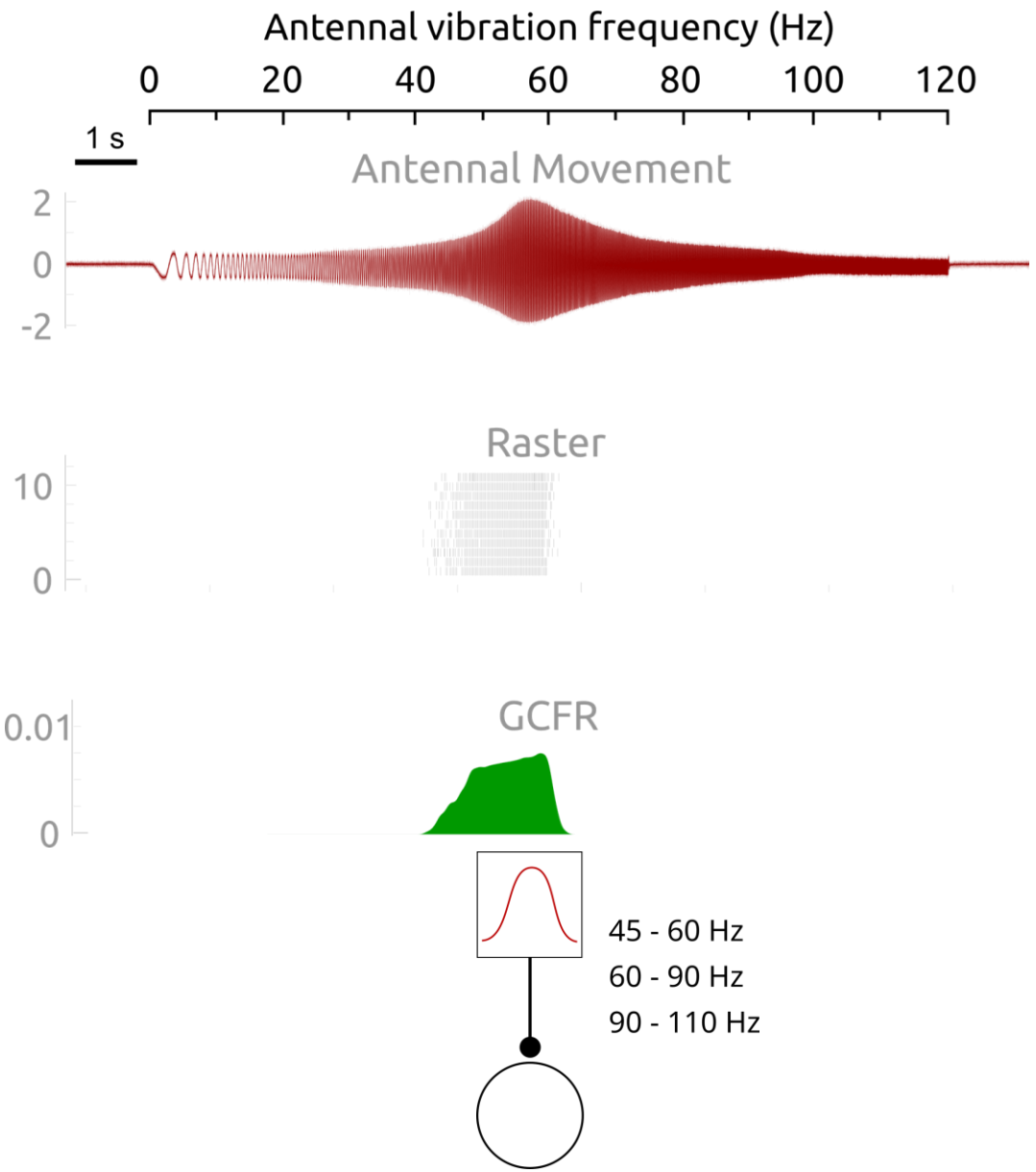
DNs that transduce only antennal mechanosensory stimuli respond to frequencies > 40 Hz:
High-pass properties of mechanosensory-only DNs



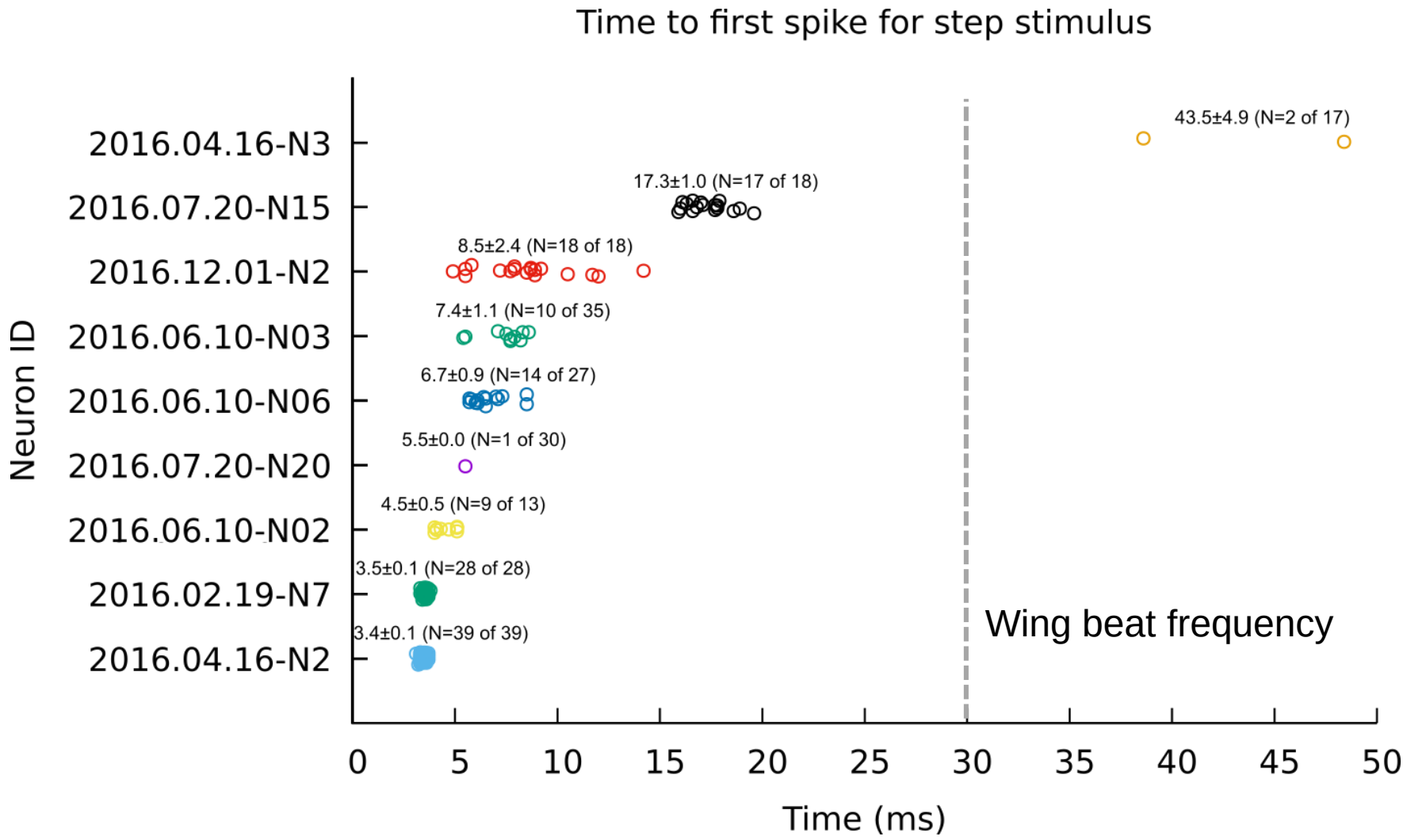
N = 16

Minimal circuits of antennal mechanosensory Descending Neurons

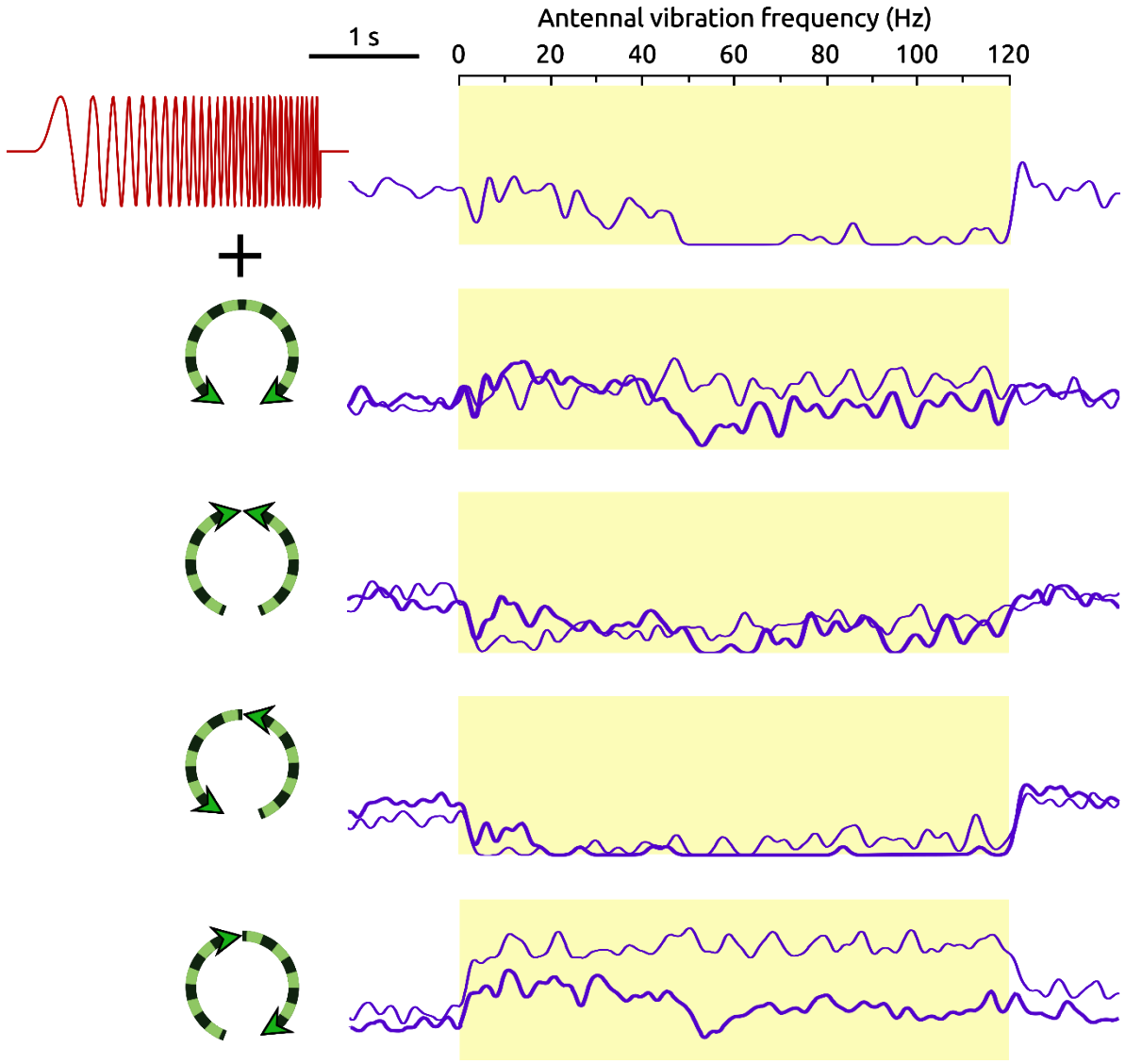




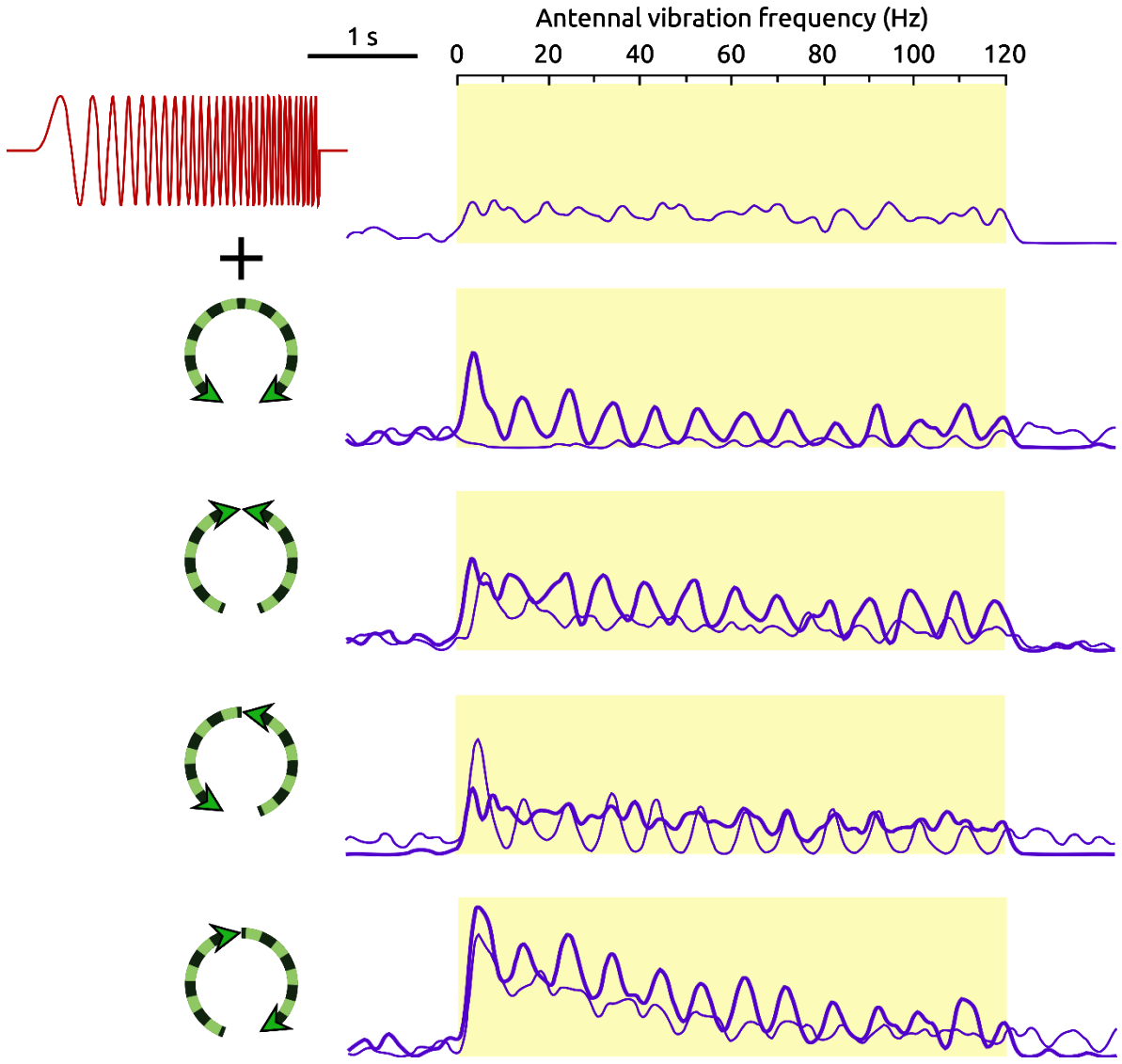
DNs that transduce only antennal mechanosensory inputs have low latency, low jitter and high fidelity



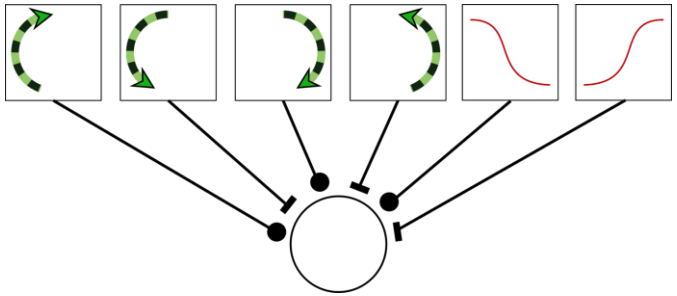
Multimodal DNs combine antennal mechanosensory and visual stimuli

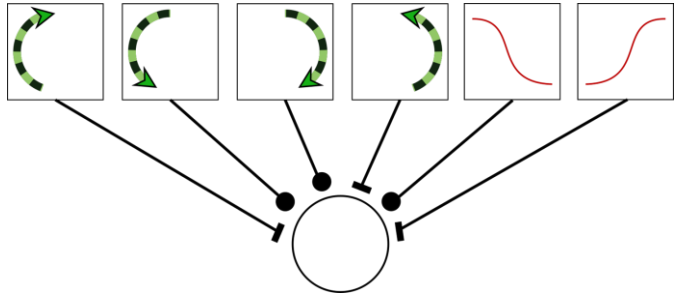


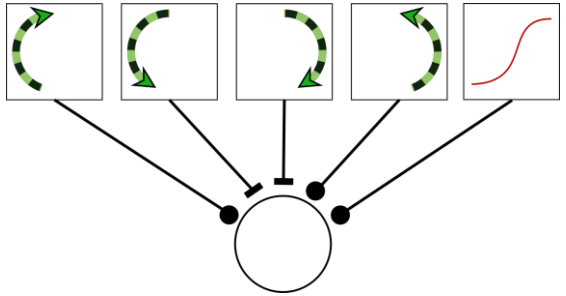
Antennal mechanical stimulus can modulate DNs response to visual stimulus

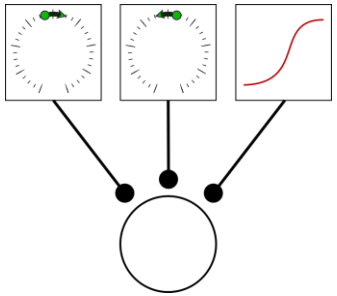


Minimal circuits for Multimodal Descending neurons





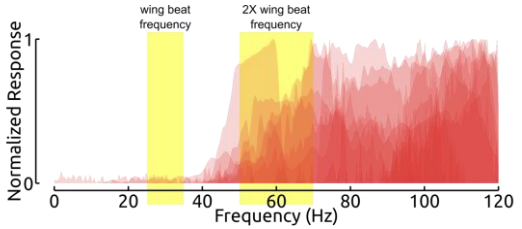


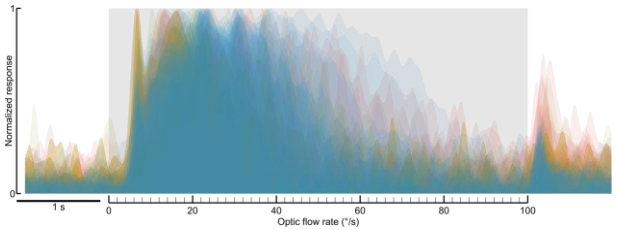


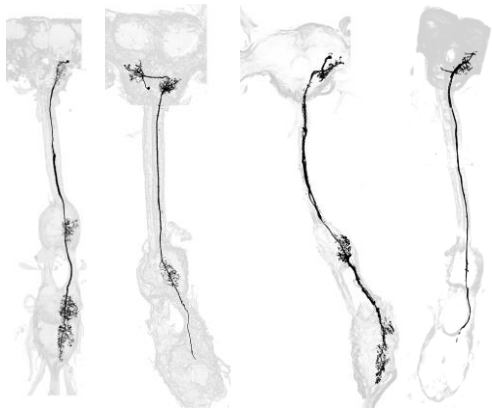
Summary

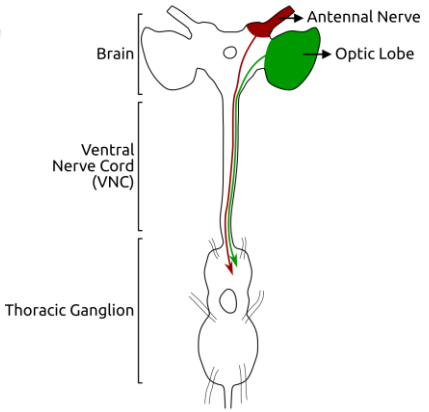
Visual and mechanosensory transduction occurs in different frequency bands.

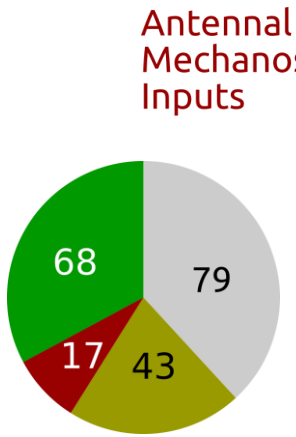
Hypothesis: Slower maneuvers depend heavily on visual feedback. Rapid turns depend heavily on mechanosensory feedback

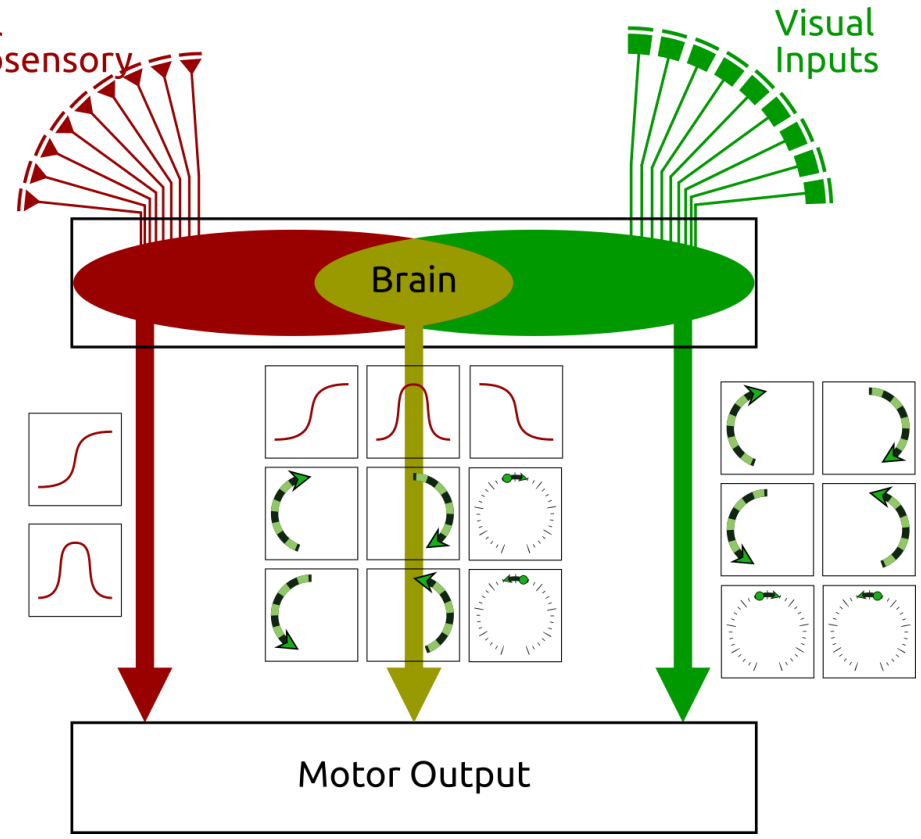


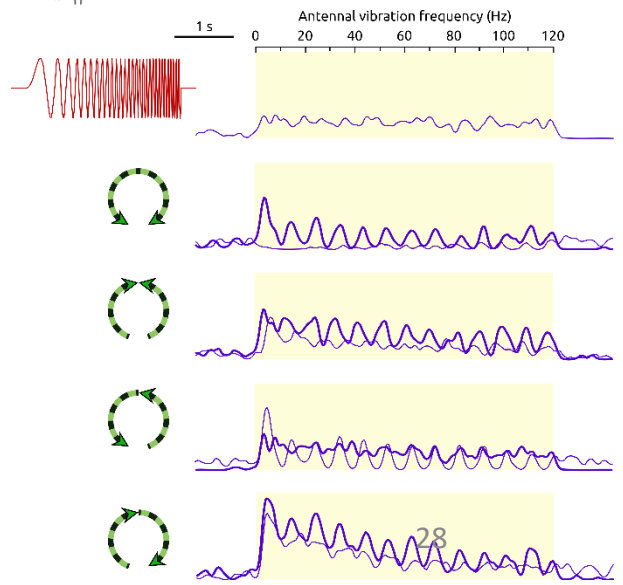












Summary

Visual interneurons are organized into wide-field sensitive, object-sensitive and "objects against wide-field" sensitive neurons.

Clear bandwidth separation in visual vs. mechanosensory cues:
Mechanosensory transduction occurs at rapid timescales/ high frequencies
Visual transduction occurs at slower timescales/lower frequencies

This bandwidth separation is also evident at the behavioural level in head stabilization (Chatterjee et al, in prep) and flight stabilization assays (Dahake et al, eLife 2018)

Mechanosensory cues can alter the gains in visual coding

Acknowledgements

Central Imaging Facility

Mechanical Workshop

Funds:

NCBS

Air Force Office of Scientific Research

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