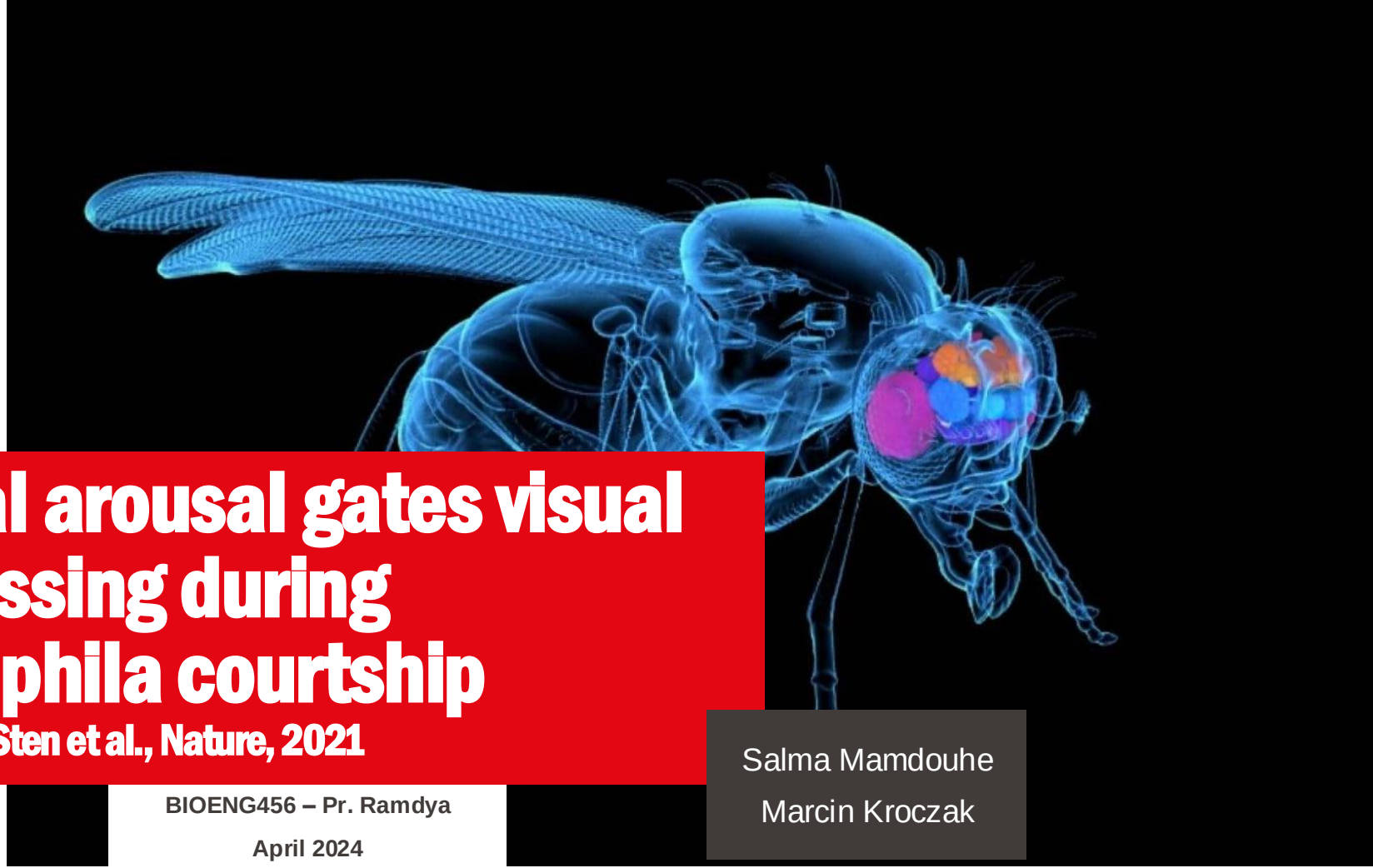

Sexual arousal gates visual processing during Drosophila courtship

Hindmarsh Sten et al., Nature, 2021

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BIOENG456 – Pr. Ramdya

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OUTLINE

Background and Motivation

Experimental Design

Key Findings

Summary

Critique

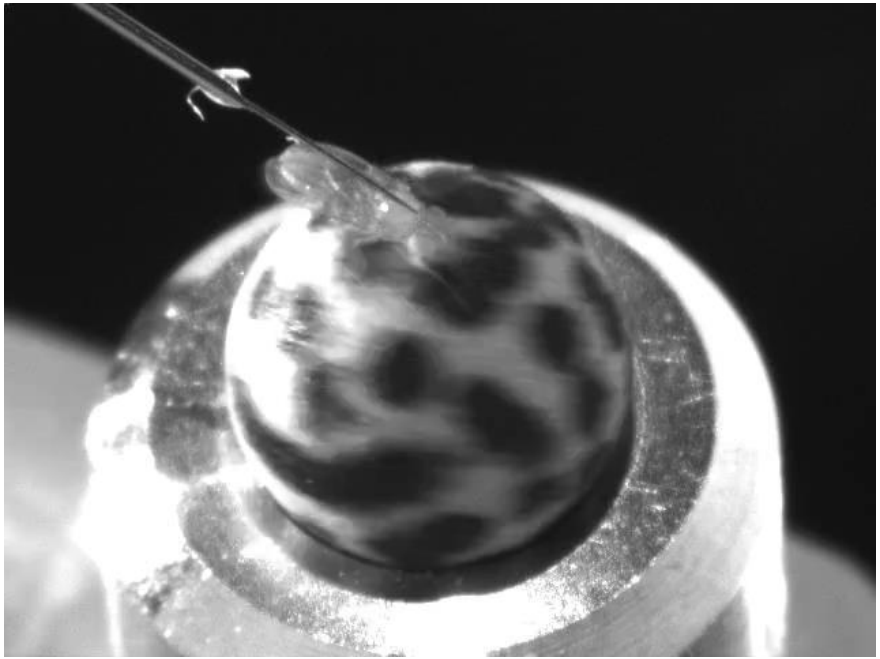
How Internal Arousal Shapes Visual Processing in Drosophila

- Animals rely on **internal arousal states** to regulate behaviors like **mating, feeding, and fighting**.
- These states **modulate sensory processing** to focus on relevant stimuli.
- In **Drosophila**, male courtship behavior is triggered by **P1 neurons**, which respond to **female pheromones**.
- **Courtship Sequence:**
  - **Chasing** the female
  - **Singing** with wing vibrations
- **Artificial activation** of P1 neurons induces courtship even **towards inanimate objects**.

Research Question : How does sexual arousal modify visual processing, turning a female from an **indifferent object** to a **target of desire**?

How Does Sexual Arousal Modify Visual Processing?

- **Key Question:** How does **P1 neuron activation** change how males **perceive a female visually**?
- **Hypothesis:** P1 neurons **increase sensitivity** to **moving targets**, making a female stand out.
- **Focus of the Study:**
  - Examining **LC10a visual projection neurons**
  - Understanding how arousal **transforms perception into persistent pursuit**
- **Before & After Effect:**
  - **Before:** Male **ignores female** (P1 inactive)
  - **After:** Male **actively pursues female** (P1 activated)



Tethered males court a fictive female target. Representative example of a male courting a virtual 'female' target in closed loop during continuous optogenetic activation of P1 neurons. Note frequent unilateral wing-extensions, indicating production of courtship song.

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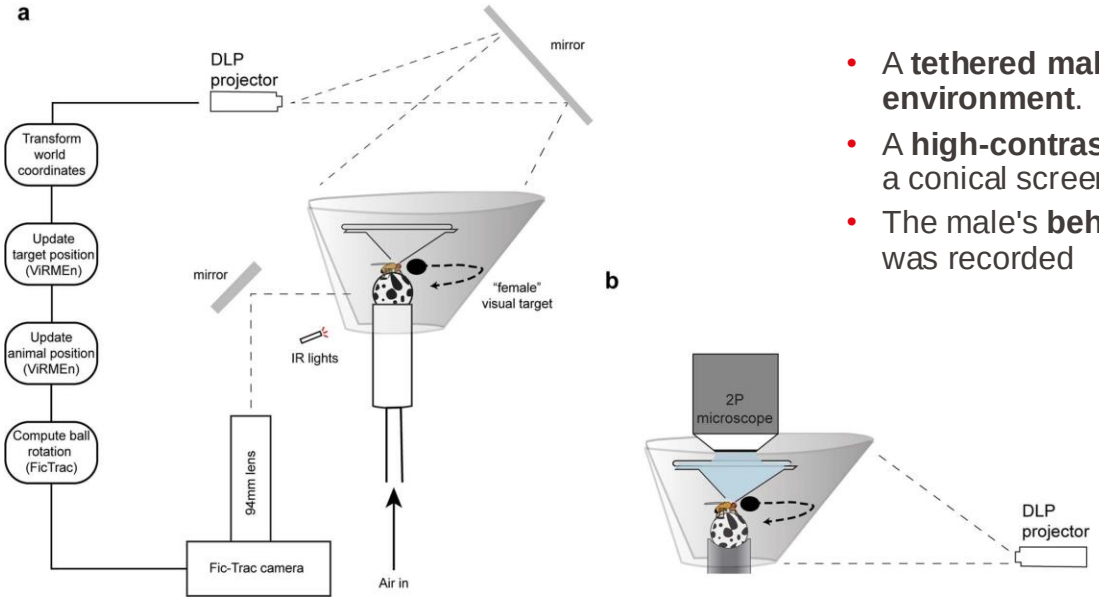
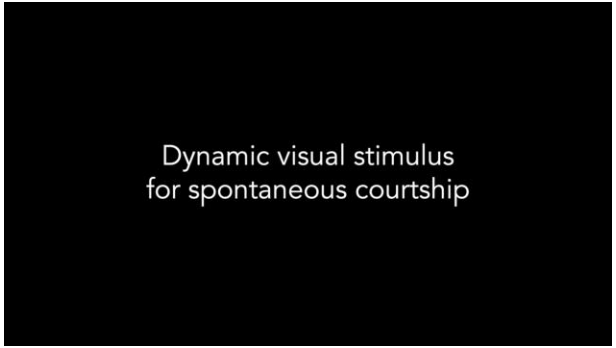
Virtual Reality Setup



- A **tethered male fly** was placed in a **2D virtual environment**.
- A **high-contrast moving dot** simulated a "female" target on a conical screen.
- The male's **behavioral response** (chasing, wing extensions) was recorded

Example of the translating visual stimulus used to drive males to spontaneously initiate courtship. The target traverses a steady arc but appears to advance and recede.



How is Sexual Arousal Induced?

Optogenetics: A technique that uses light to control genetically modified neurons, allowing precise activation or inhibition of specific neural circuits.

- **P1 neurons** were activated using **red light (CsChrimson)** to **mimic sexual arousal**.
- **LC10a neurons** were also stimulated to study **visual motion processing**.

- This allows researchers to **test how each neuron type affects behavior independently**.

P1 neurons:

- A **cluster of sexually dimorphic neurons** in the male Drosophila brain.
- They **trigger and maintain courtship behavior** when activated.
- Respond primarily to **female pheromones** but also regulate **visual perception**.

split-P1 > GCaMP

Schematic of P1 neurons (red) expressing GCaMP in the brain of a male fly with black box denoting approximate imaging region of interest (ROI)

LC10a neurons:

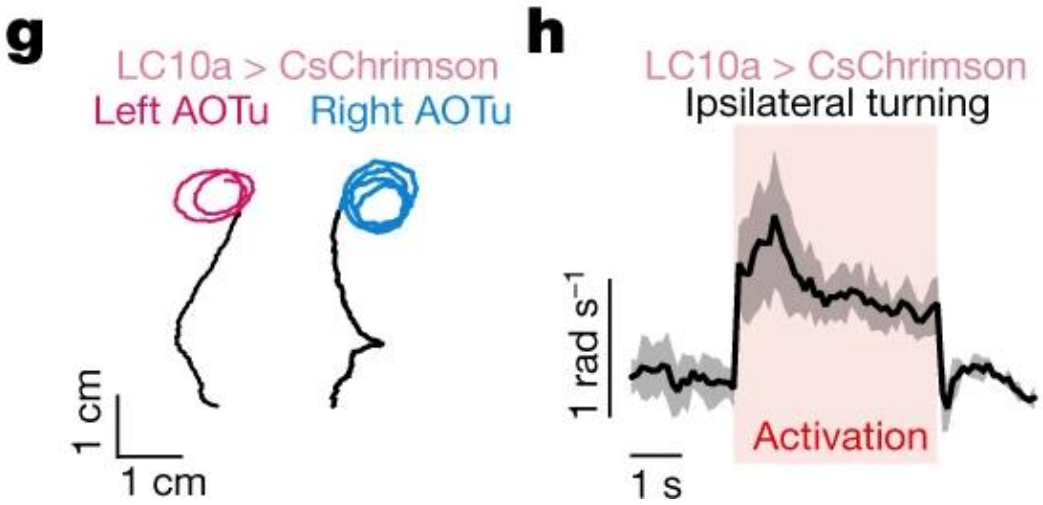
- **Visual projection neurons** that detect **motion** and send signals to motor circuits.
- Important for **tracking moving objects**—in this case, a female fly.
- When activated, they **increase sensitivity to moving targets** and influence **turning behavior**. **Q3**

LC10a > GCaMP

Schematic of LC10a neurons expressing GCaMP with black box denoting approximate imaging ROI.

Optogenetic Activation of LC10a Triggers Turning

- Flies **circle in the direction of the activated LC10a neurons** (left or right).



- Optogenetic activation of LC10a causes flies to turn **ipsilaterally (toward the stimulus).**
- **Increased turning speed** during activation, confirming **LC10a's role in visual tracking**.

AOTu = **Anterior Optic Tubercle**, a brain region in *Drosophila* that plays a role in **visual processing**.

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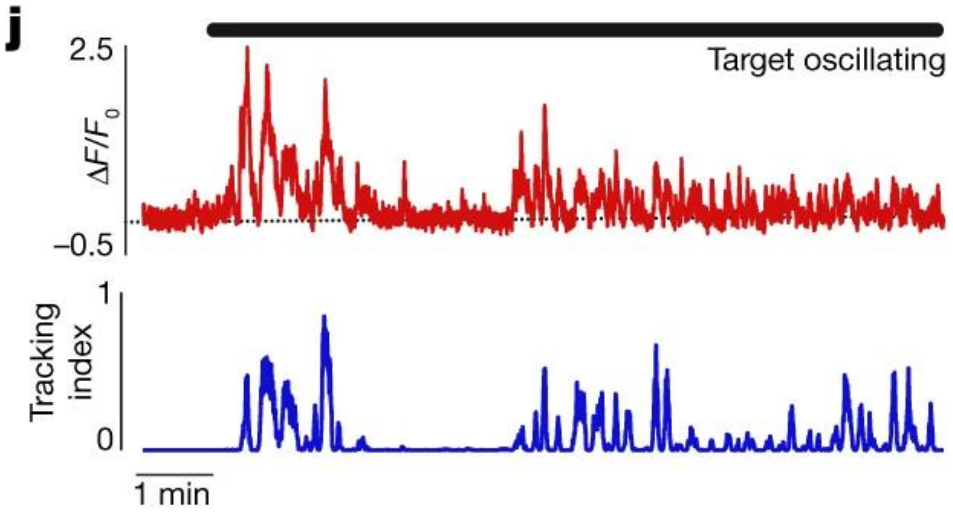
P1 Neural Activity Correlates with Courtship State

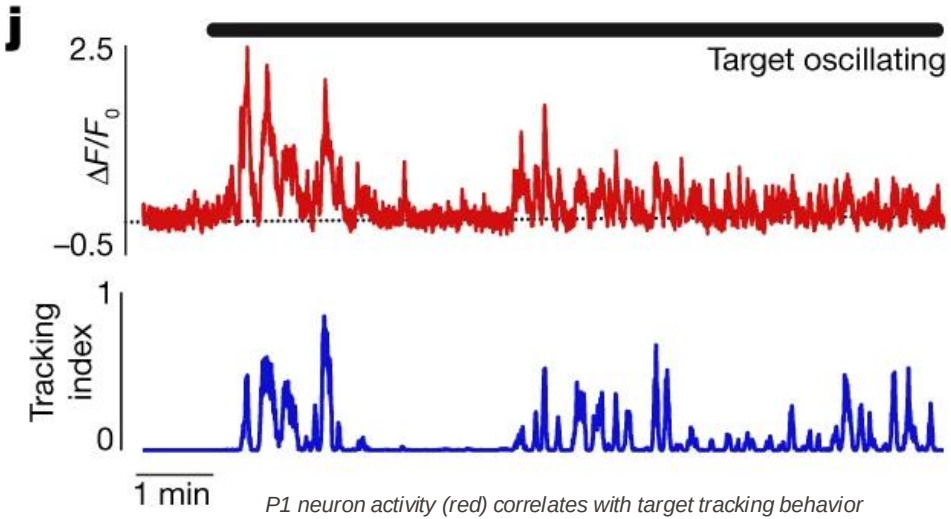
Time-series of P1 activity vs. tracking behavior



- Higher P1 activity = male actively tracks and courts the female (j)

P1 Neural Activity Correlates with Courtship State

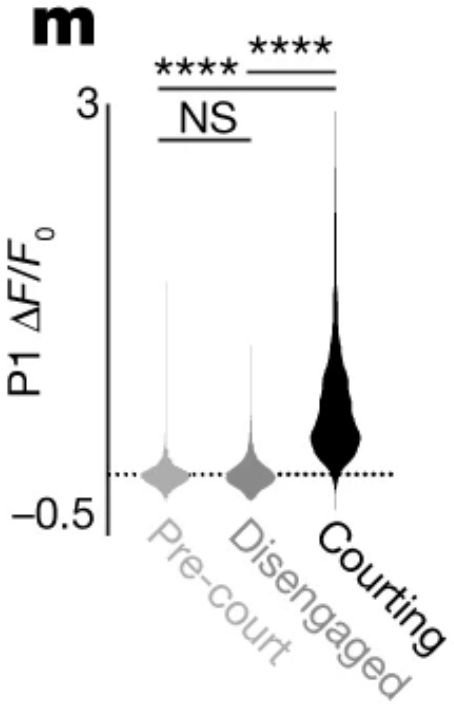
Time-series of P1 activity vs. tracking behavior



P1 neuron activity (red) correlates with target tracking behavior (blue) during oscillating motion.

- Higher P1 activity = male actively tracks and courts the female (j)
- P1 neurons are significantly more active during courtship than in disengaged states (m)

Different behavioral states

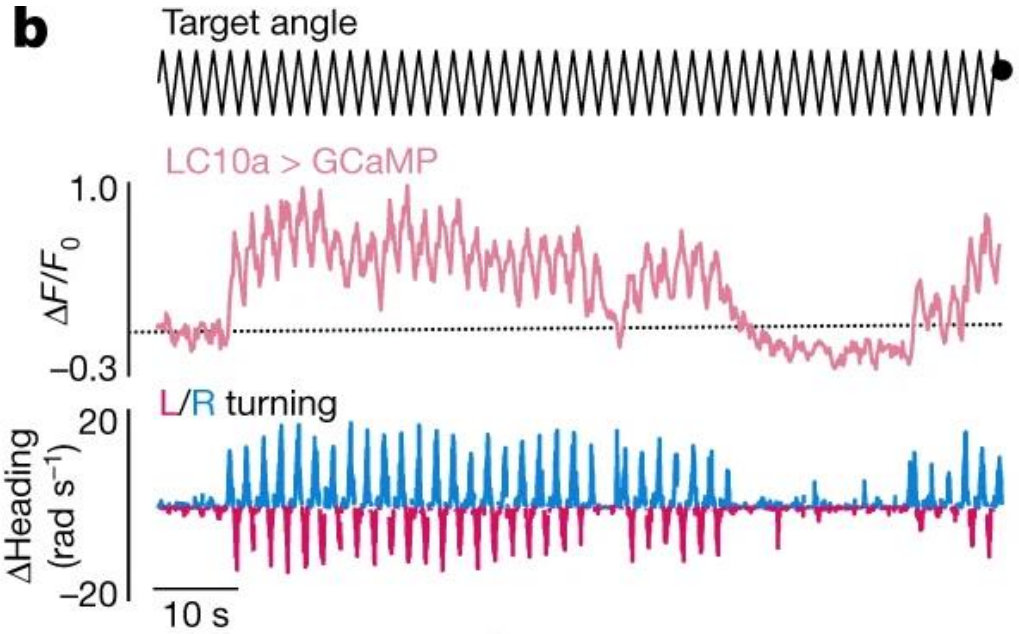


P1 neuron activity is significantly higher during courtship compared to pre-court and disengaged states.

LC10a Neurons Respond to Motion and Guide Tracking Behavior

Q2

- LC10a neurons respond to moving objects, not static images
- Essential for tracking a female's movement during courtship
- LC10a activity correlates with visual motion and turning behavior (b)



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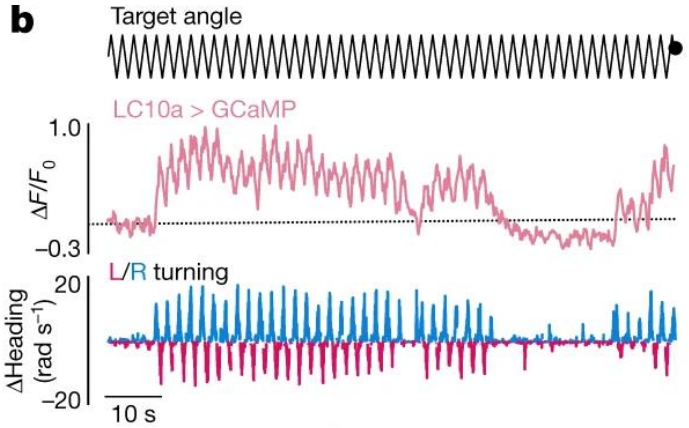

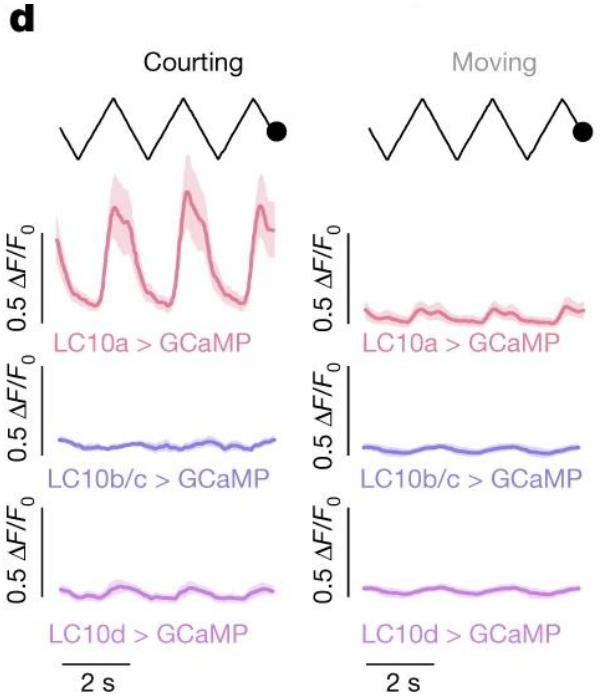

LC10a Neurons Respond to Motion and Guide Tracking Behavior

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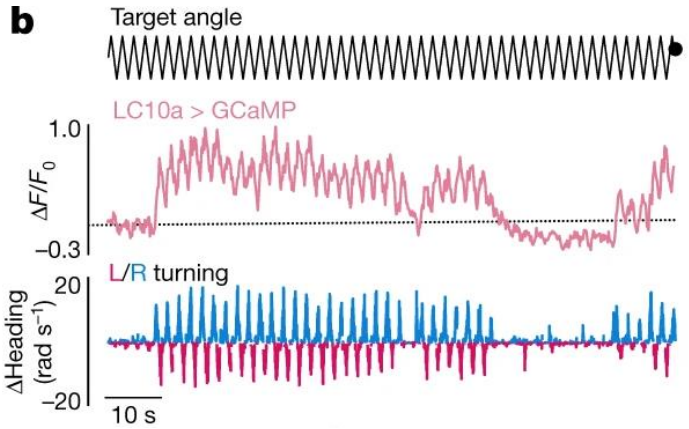
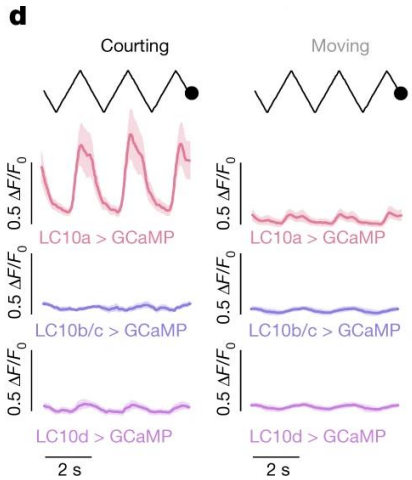
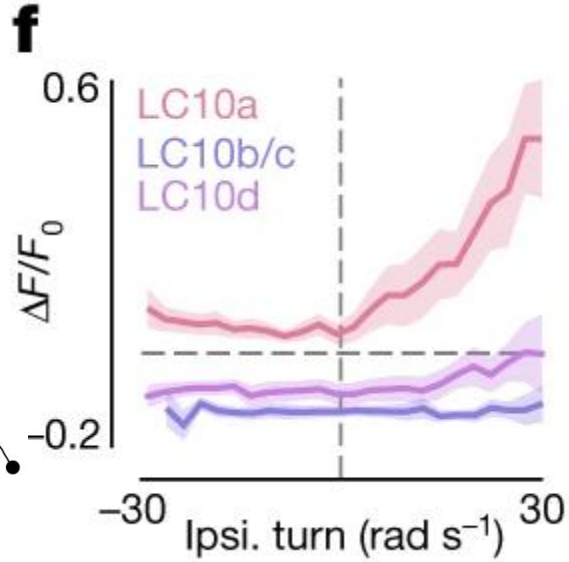
- LC10a neurons respond to moving objects, not static images
- Essential for tracking a female's movement during courtship
- LC10a activity correlates with visual motion and turning behavior (b)
- Stronger LC10a response during courtship vs. general movement (d)
- LC10a is the primary motion detector, while other LC10 neurons show little response (f)



LC10a neurons respond to target motion, driving left (pink) and right (blue) turning.



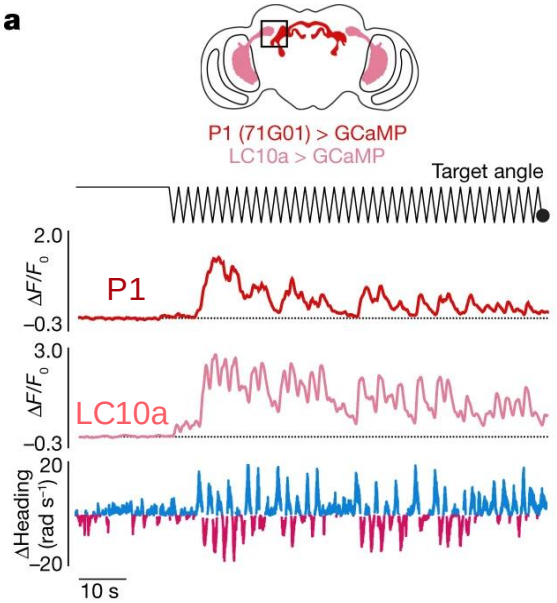
LC10a neurons show stronger activation during courtship than general movement.



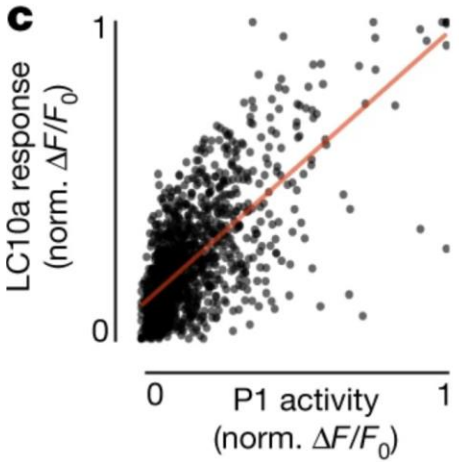
LC10a neurons (red) show increased activity during ipsilateral turns, unlike LC10b/c and LC10d.

P1 Activation Enhances LC10a Visual Responses

- **LC10a neurons detect motion** and play a key role in **tracking moving targets**.
- In the **unaroused state**, LC10a neurons have **low response amplitude** to motion.



Schematic of LC10a and P1 neuron morphology, both expressing GCaMP. Plots below, from top to bottom rows: angular position of the target; functional responses (ΔF/F0) of P1 neurons; functional responses (ΔF/F0) of LC10a; and angular velocity of male.



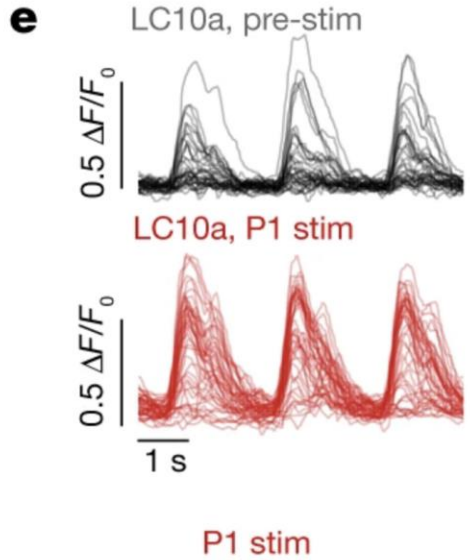
Normalized LC10a responses to each stimulus sweep plotted against normalized average P1 activity in the same time period ($r = 0.68$, $P < 0.00001$, $m = 0.85$, $b = 0.10$).

- When **P1 neurons are activated**, LC10a neurons become **more responsive to visual motion**.
- This suggests that **P1 neurons increase visual gain**, making the fly more **sensitive to moving stimuli**.

P1 Neurons Gate Visual Motion Processing in LC10a Neurons

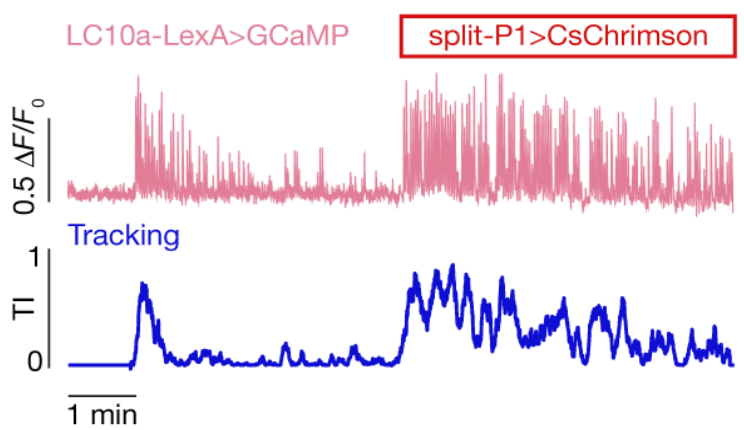
Q4

Responses (ΔF/F0) of LC10a neurons



Spontaneous Courtship

P1 Activation



Example of tracking index and the activity of LC10a neurons in a male before and during optogenetic activation of P1 neurons expressing CsChrimson.

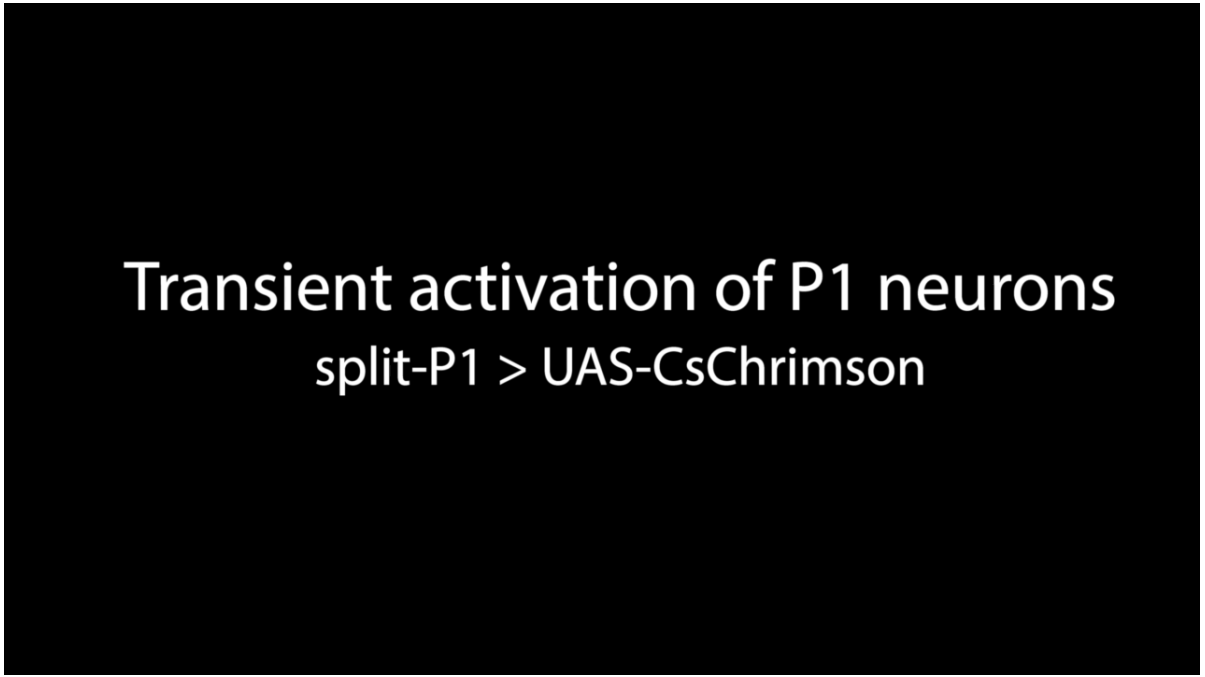
- **LC10a response gain increases when P1 neurons are active**, enhancing motion perception.
- This increase in visual sensitivity helps **males track females more efficiently**.

- **Without P1 activation, motion tracking is weak**, confirming that **sexual arousal is necessary for persistent pursuit**.
- **P1 neurons do not directly encode motion** but **modulate LC10a activity to prioritize visual tracking**.

P1 Activity Enhances LC10a Visual Responses

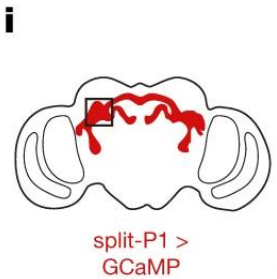
Q2

Q4



Transient activation of P1 neurons drives sustained courtship. Representative example of a male presented with a simple, repeating visual target before and after P1 neurons are optogenetically activated. Blue line indicates the integrated path of the male.

- This video shows how **males track a visual stimulus persistently** after P1 activation, supporting the idea that **P1 enhances visual processing**.

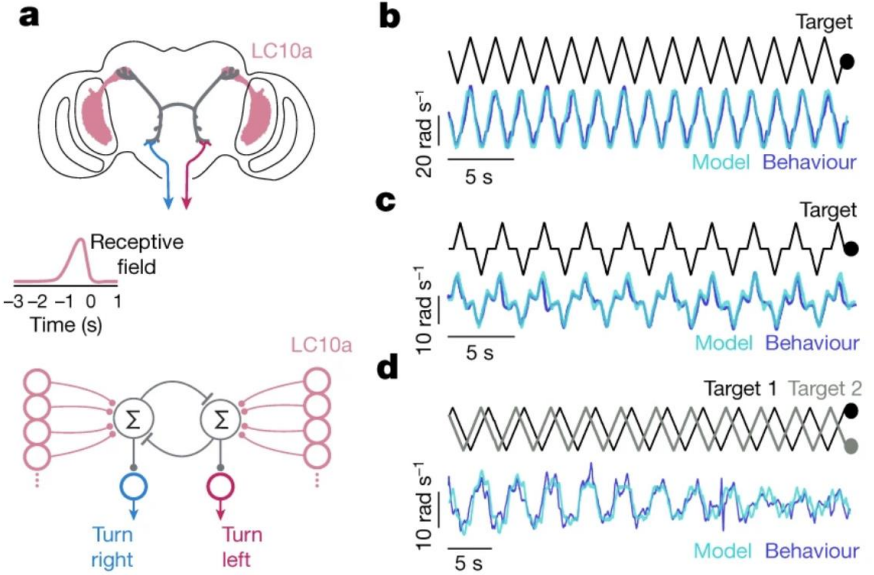


Schematic of P1 neurons (red) expressing GCaMP in the brain of a male fly with black box denoting approximate imaging region of interest (ROI)

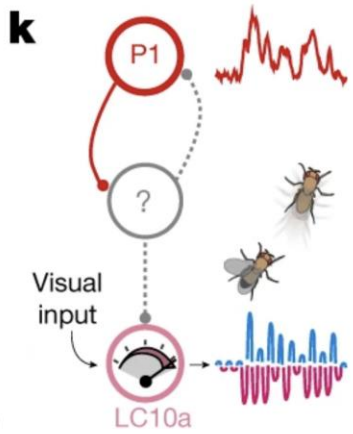
Network Model: P1 Neurons Improve Behavior Prediction

Q5

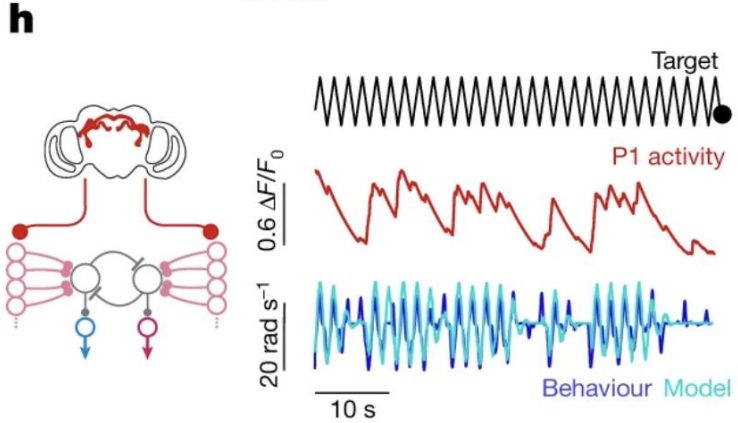
- The model predicts turning, but without P1, it lacks flexibility (a-d)
- Adding P1 neurons improves model accuracy by modulating tracking (h)
- P1 neurons integrate internal state with visual input to optimize pursuit (k)



LC10a neurons control left and right turning in response to visual stimuli (a). Panels (b-d) show the model predicting fly behavior, where movement closely follows the oscillating target.



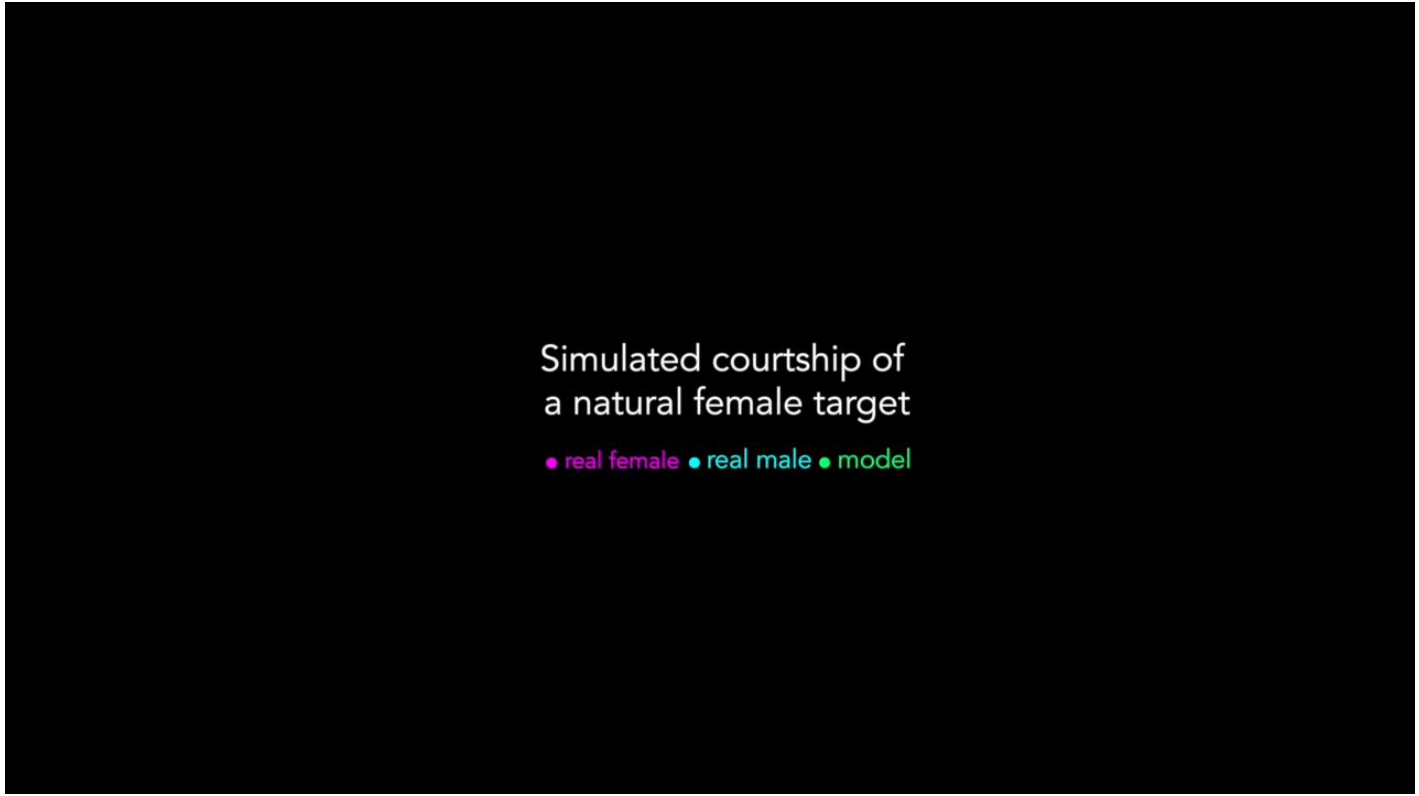
P1 neurons enhance LC10a activity, modulating visual tracking based on arousal.



P1 neuron activity (red) fluctuates in response to a moving target. The behavior model (blue) closely follows actual fly movement, showing that P1 neurons enhance visual tracking.

Model Prediction

- Able to build a model that accurately predicts the mating behavior of flies



An LC10a network model predicts the behaviour of freely courting males.

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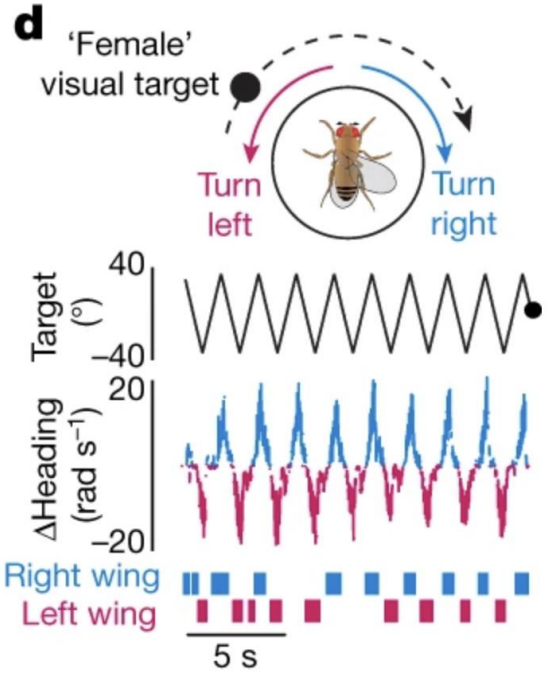
Key Findings: How P1 Neurons Modulate Visual Processing

- **Q1:** P1 activity correlates with the persistence and intensity of courtship behavior.
- **Q2:** LC10a neurons respond to small, moving objects, crucial for tracking a female.
- **Q3:** Optogenetic activation of LC10a neurons causes flies to turn toward the activated side.
- **Q4:** P1 activation increases LC10a response amplitude, enhancing motion sensitivity.
- **Q5:** Adding P1 activity to the model improves prediction of persistent tracking behavior.
- **Q6:** A P1-like system in robotics could improve selective attention to moving objects.

Answer : P1 neurons **transform** a female from an **indifferent object to a target of desire** by **enhancing visual processing** in LC10a neurons, making the male more responsive to motion and driving persistent courtship behavior.



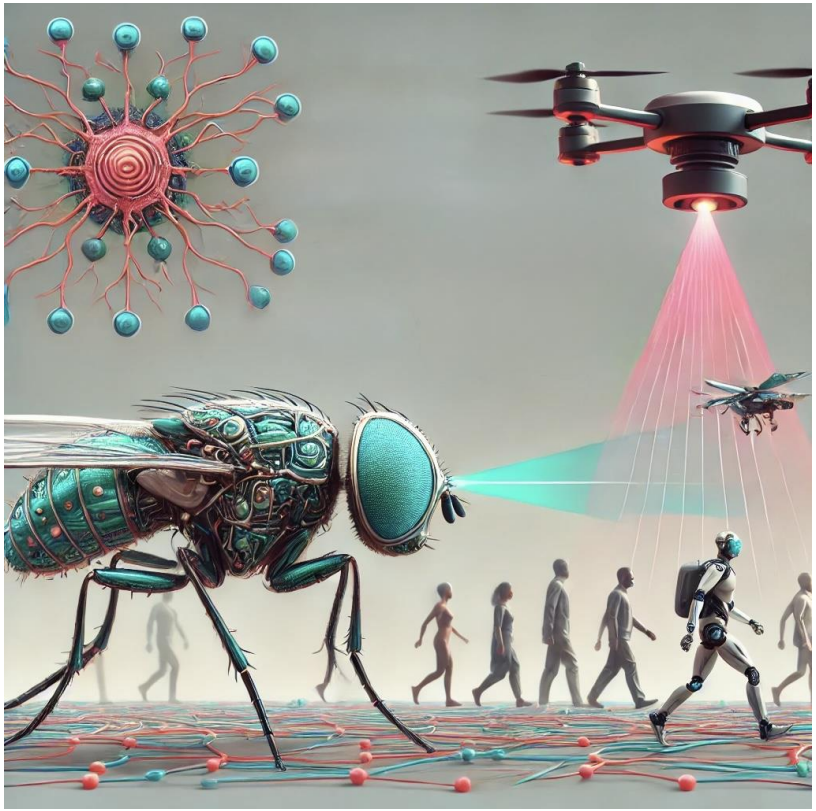
A male fly tracks a moving visual target by turning left or right. Changes in heading direction (ΔHeading) correspond to alternating unilateral wing extensions (blue for right, pink for left).

How P1-Like Systems Could Improve Robotics & AI

Q6

Marcin

- Adaptive Attention – Robots could prioritize important objects in dynamic environments
- Contextual Decision-Making – Instead of treating all stimuli equally, AI could amplify relevant inputs (like P1 enhances LC10a)
- Self-driving cars – Adjust attention to moving pedestrians vs. stationary objects
- Drones – Improve target tracking under variable conditions
- AI vision systems – Detect emotionally relevant objects or faces in human-robot interaction



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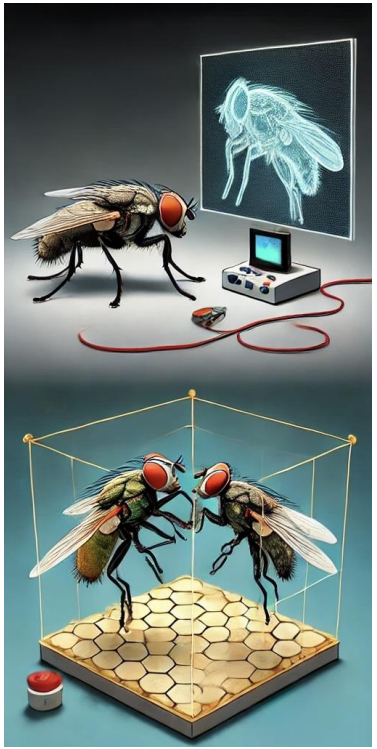
Does a 2D Virtual Setup Capture Natural Courtship?

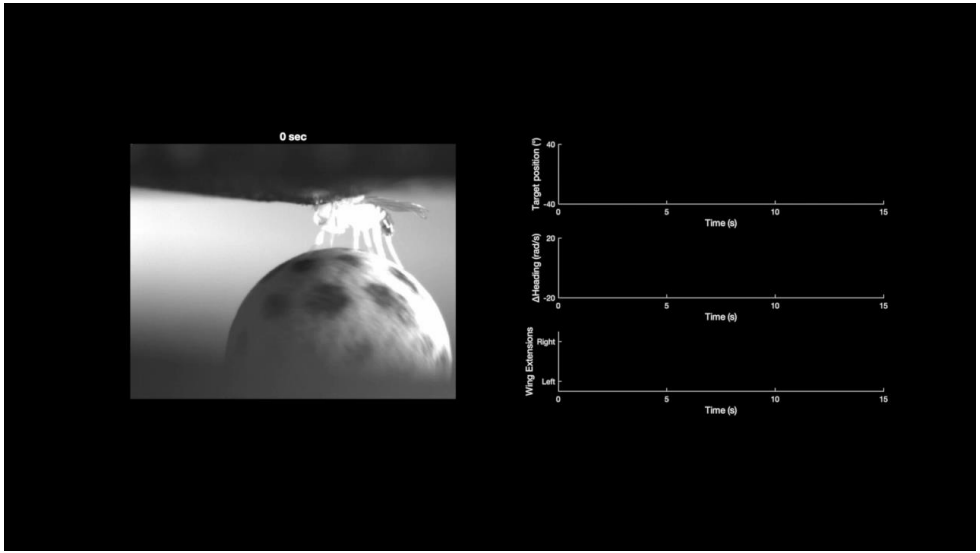
- Flies court in 3D environments, but the study used a high-contrast 2D dot as a female substitute
- Real female flies emit pheromones that strongly influence male courtship
- P1 neurons respond to both visual and pheromonal inputs, so testing only visual cues may oversimplify the system
- In real courtship, males adjust their behavior based on female responses (e.g., courtship escalation or retreat)
- The virtual setup does not allow these natural feedback interactions, possibly overestimating the role of visual tracking alone



Would the same results hold if males were placed with real females in a more complex setting?

Future Experiments & Expanding the Study

- Test P1 Activation in Free-Moving Flies, 3D natural setting
- Explore Cross-Species Comparisons
- Apply Findings to AI & Robotics



A male fly spontaneously initiates courtship toward a moving visual target. The trajectory and unilateral wing extensions are shown. The male does not turn before the stimulus appears.

Q&A