

A gyroscopic control loop for active target vision

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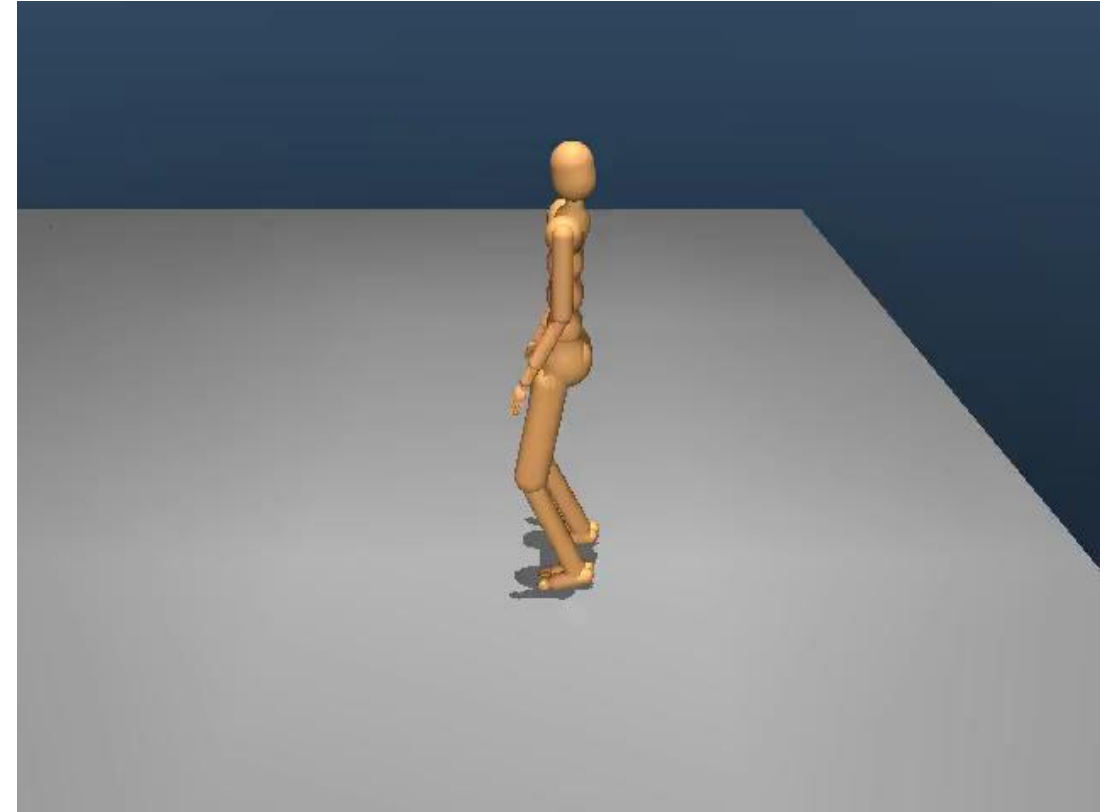
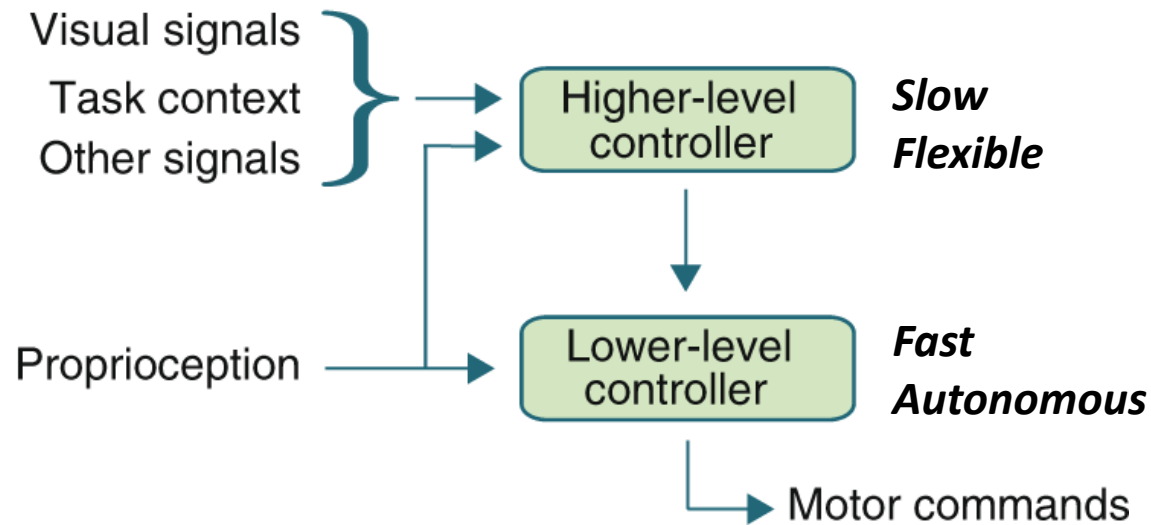
AFOSR FA9550-23-1-0401 (8/23–7/26)



Outline

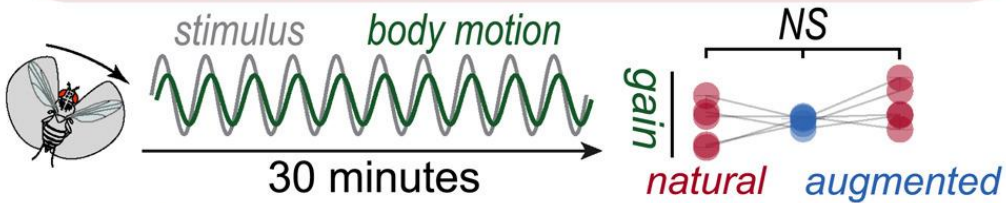
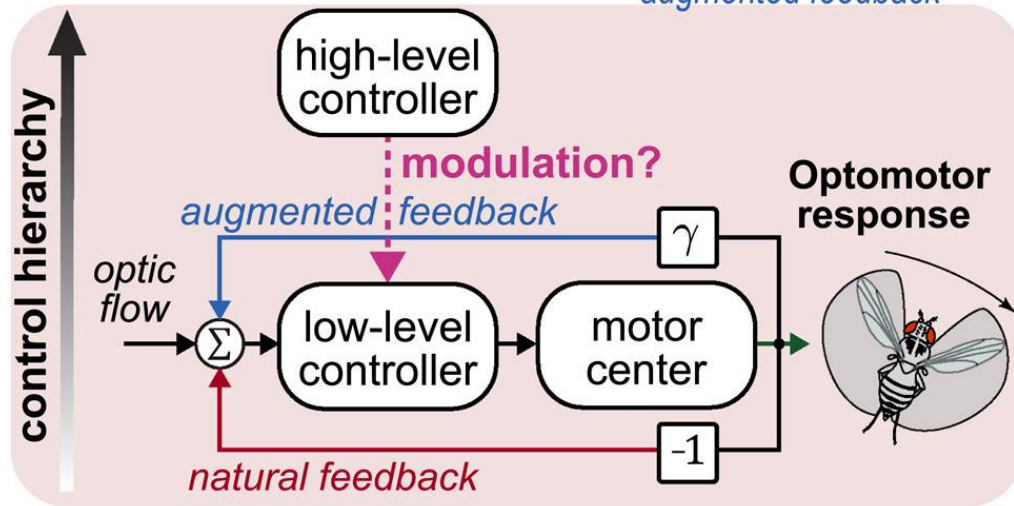
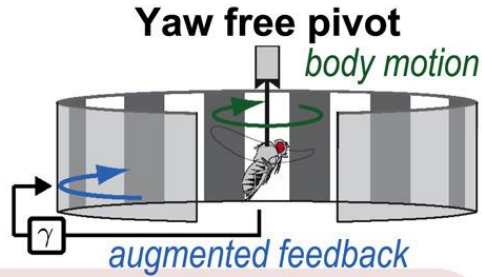
- **Background**
- Recent progress

Neuroscience and AI/robotics research have converged on a hierarchical structure for motor control

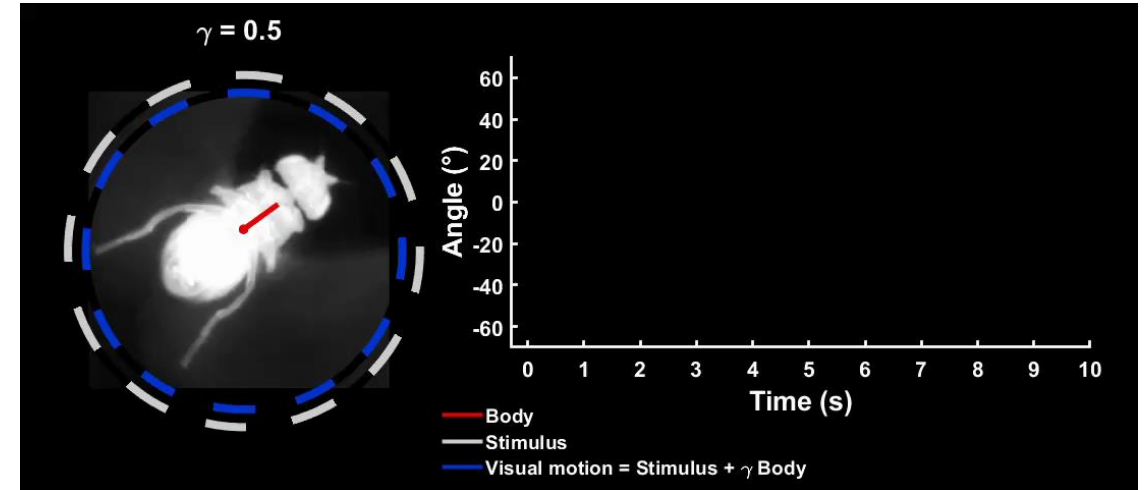


The optomotor response is autonomous

How flexible is the optomotor response (OR) in augmented reality?



The OR does not adapt to augmented reality

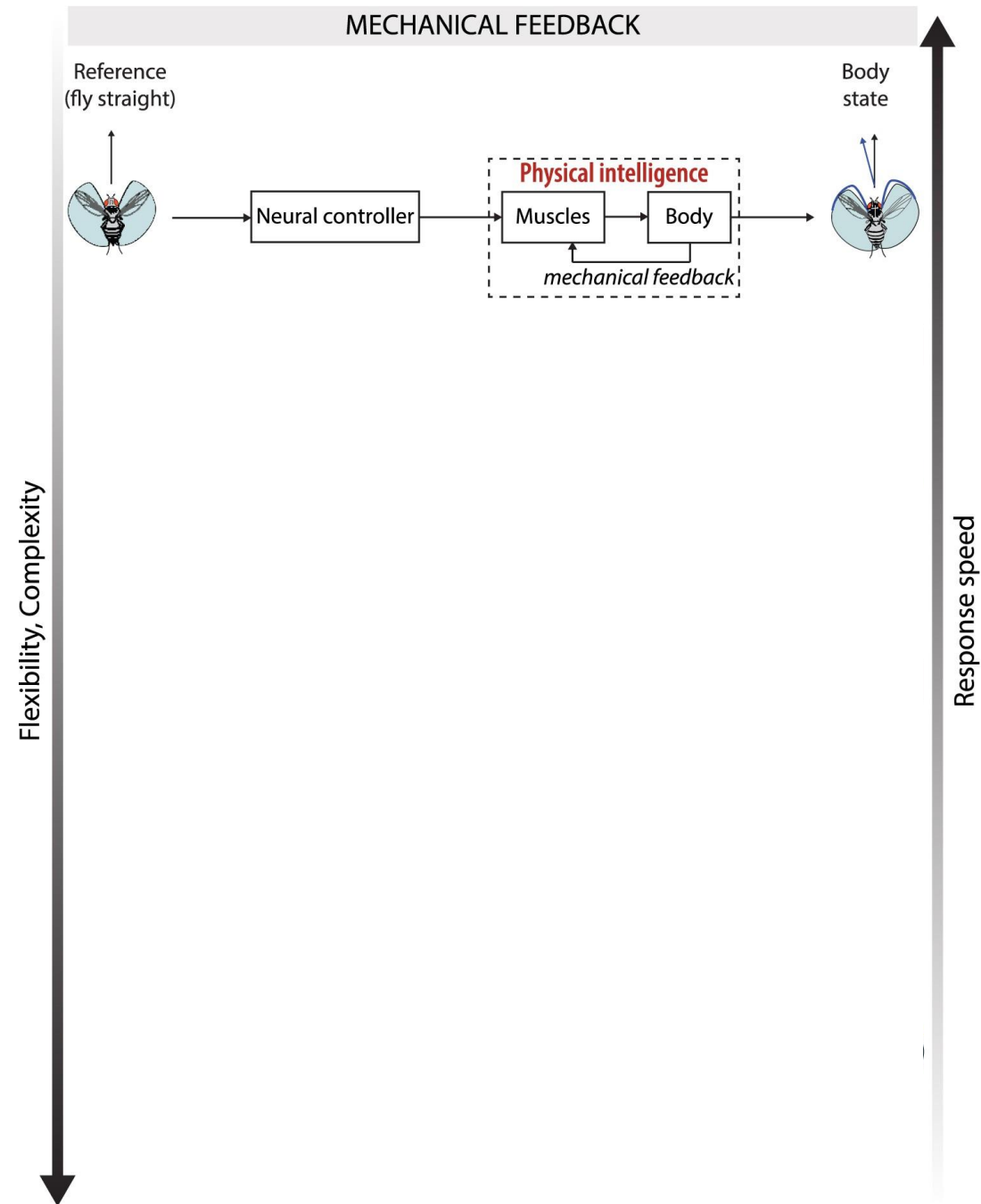


Locomotion control strategies

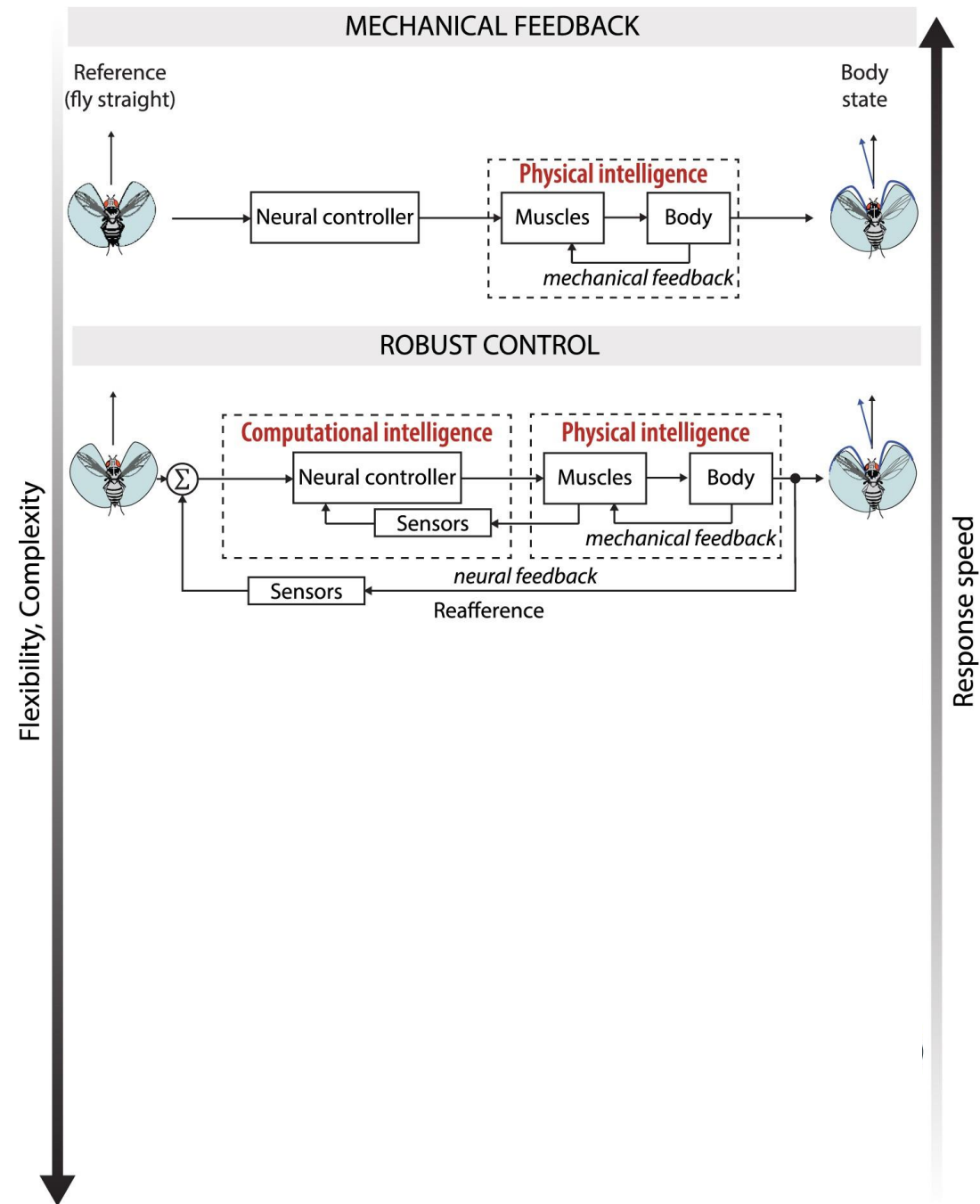
Flexibility, Complexity

Response speed

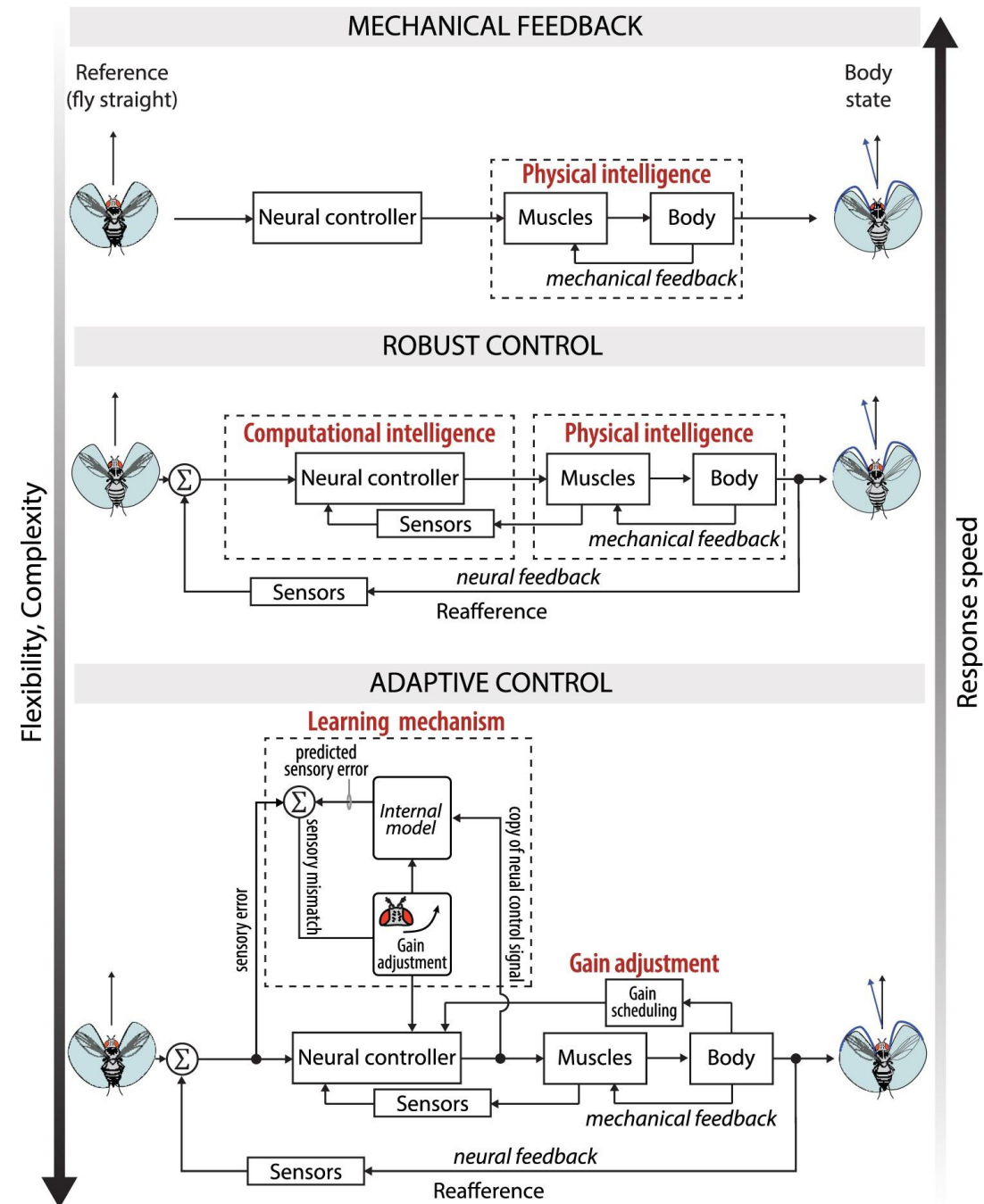
Locomotion control strategies

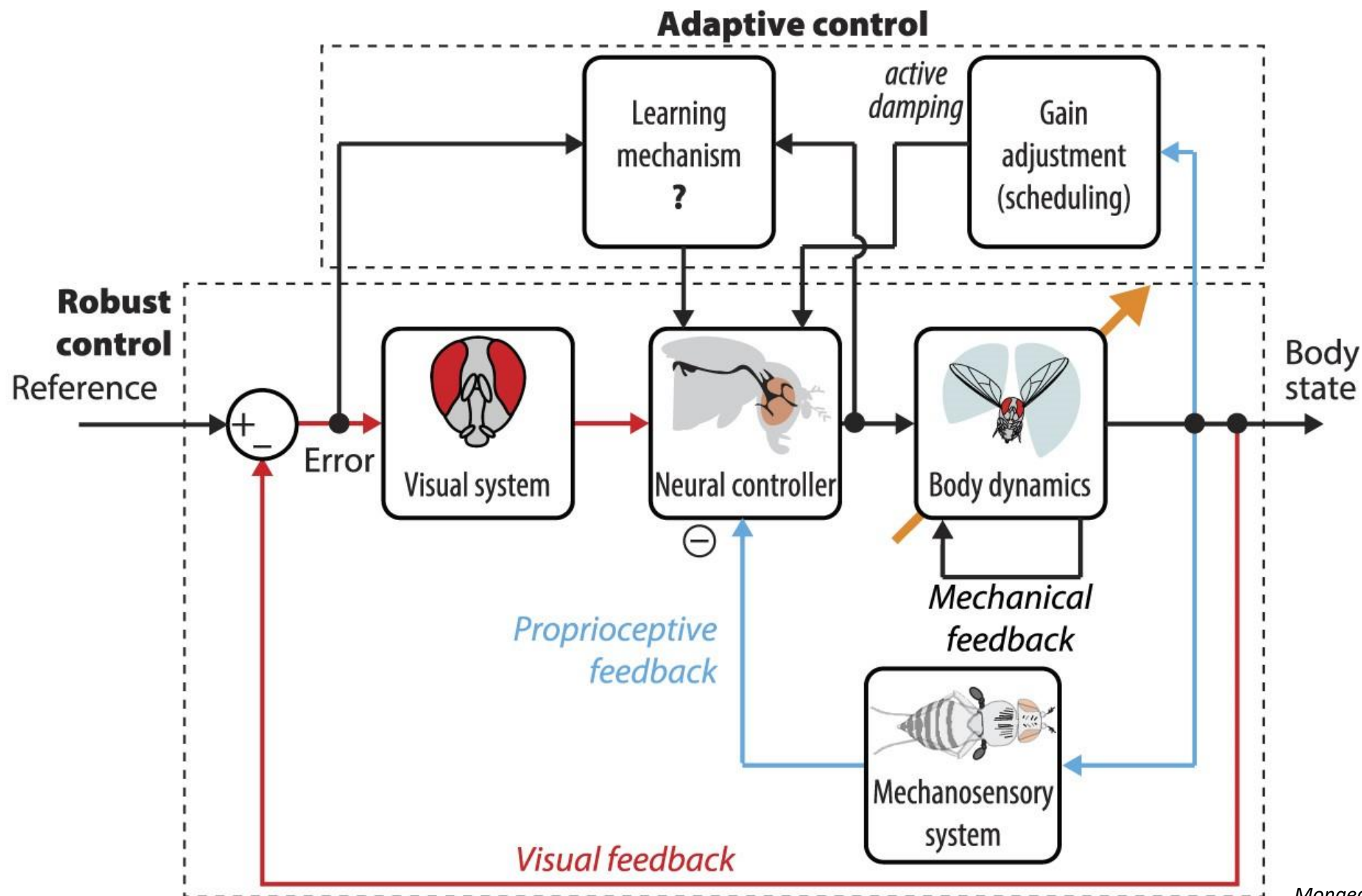


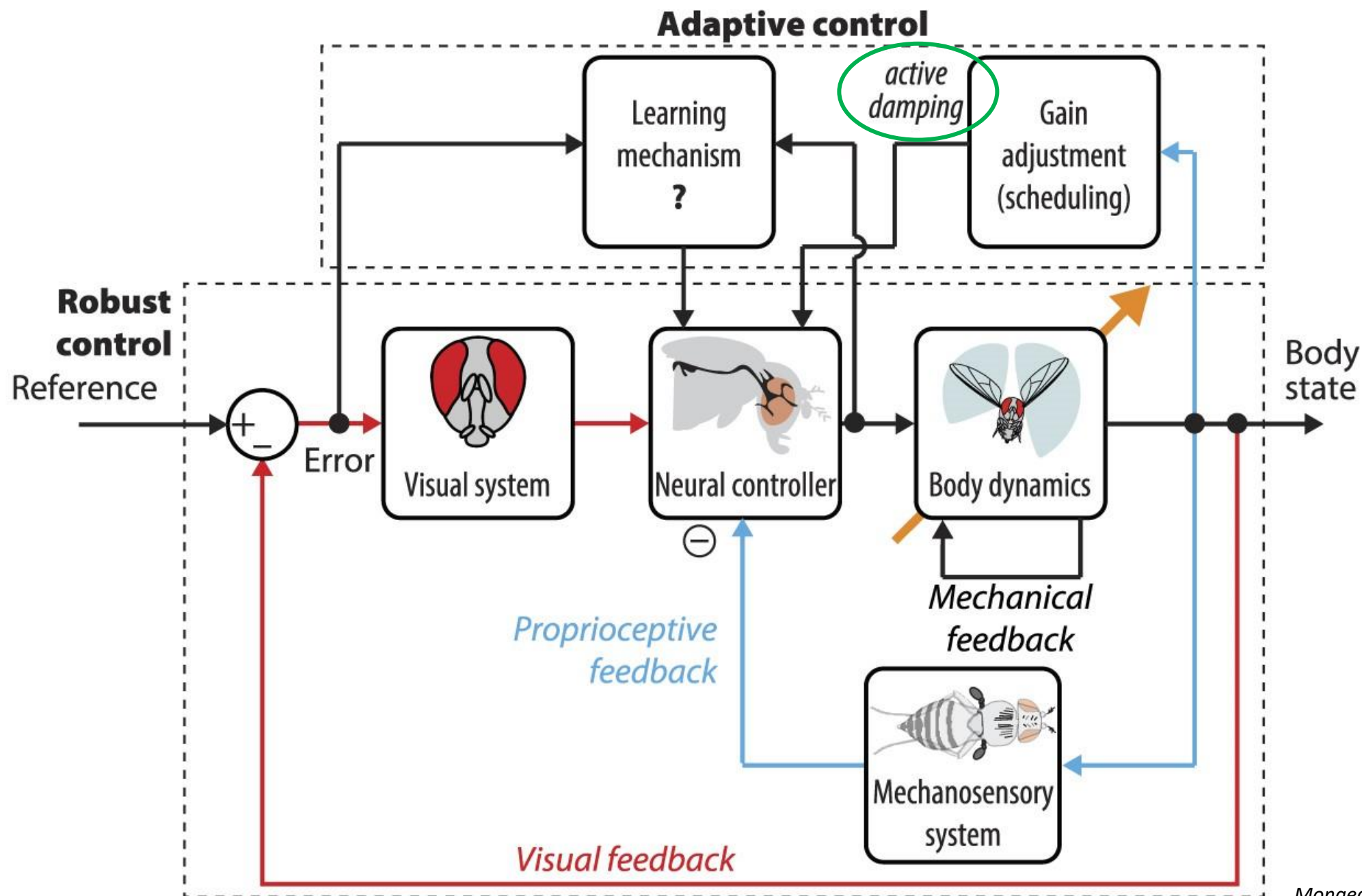
Locomotion control strategies



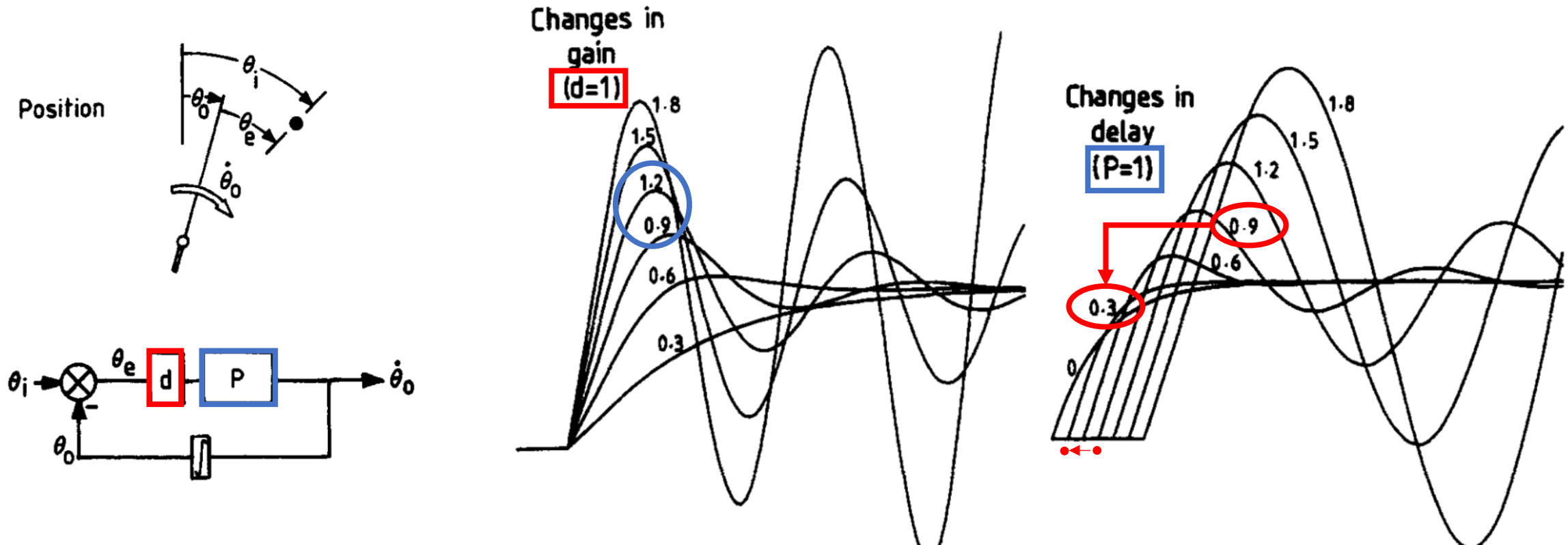
Locomotion control strategies







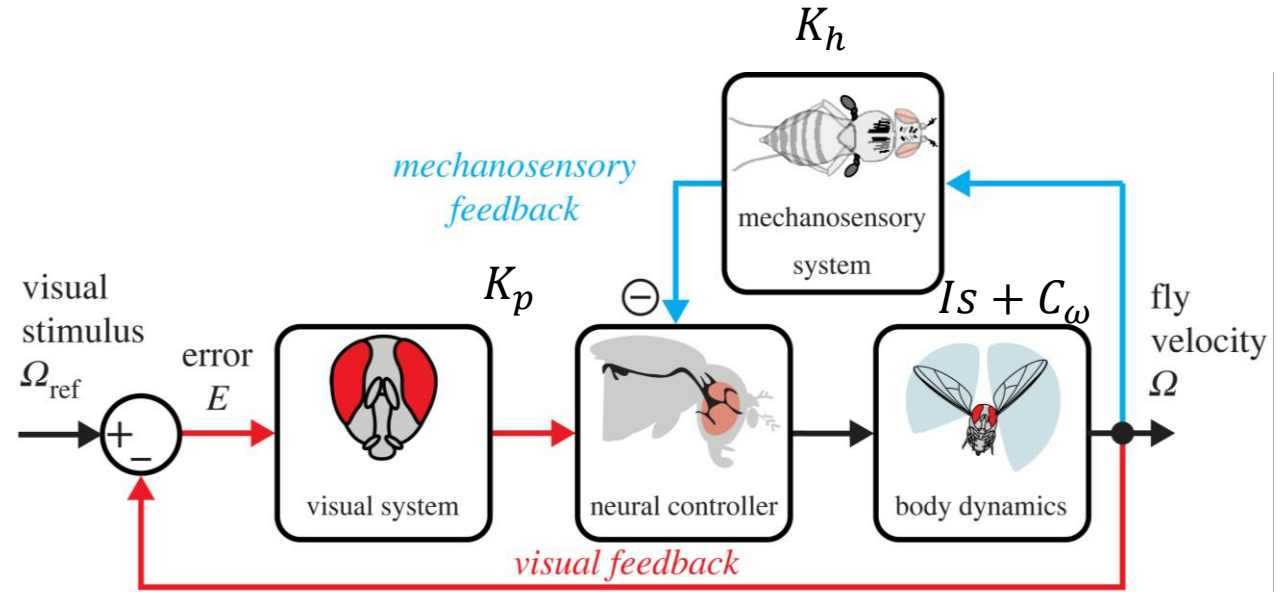
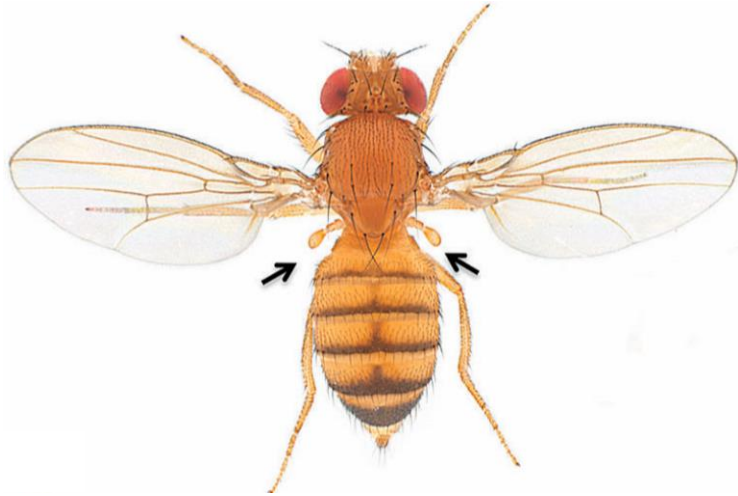
A control theoretic basis for active damping



- High performance visual flight control is fast (short delay) and sensitive (high gain)
- Optomotor control is sensitive, gain approaches 1, so can easily reach instability

Does proprioceptive feedback contribute to active damping for high performance object tracking?

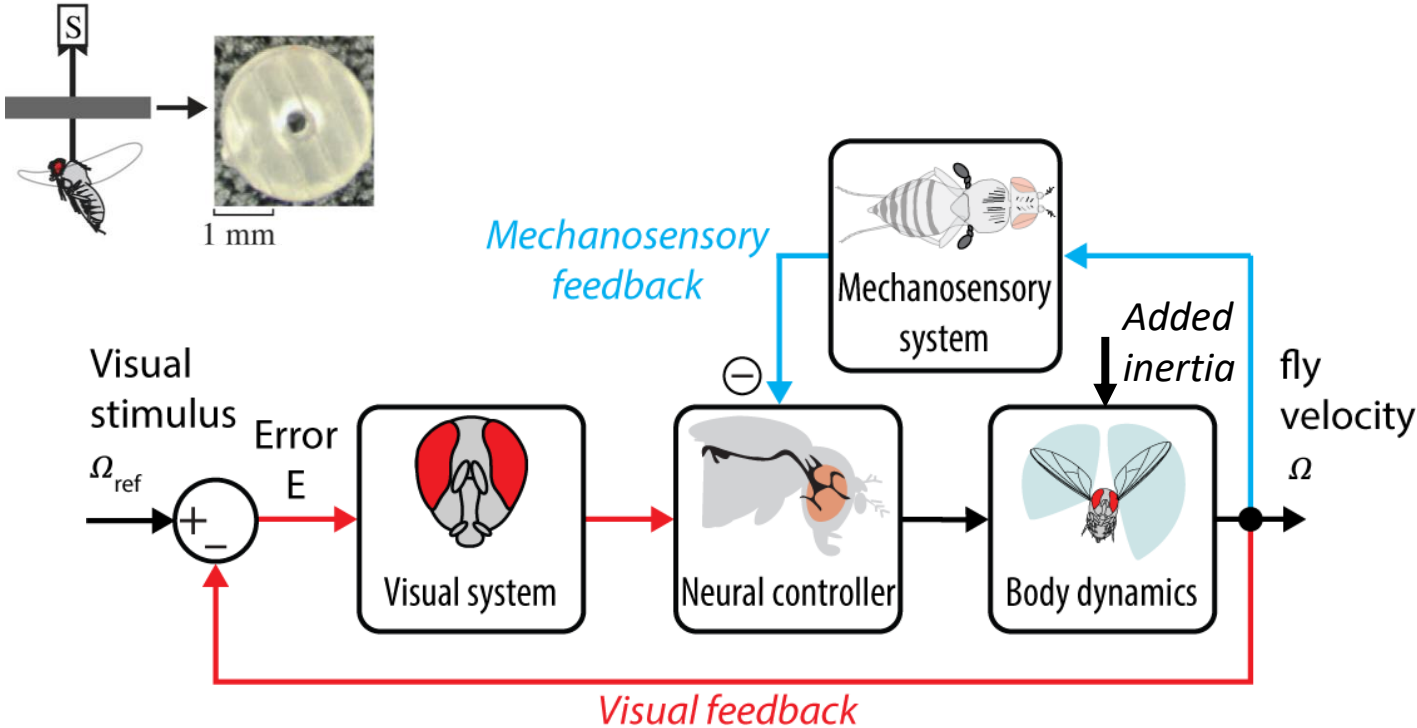
Active damping through inner-loop proprioceptive feedback



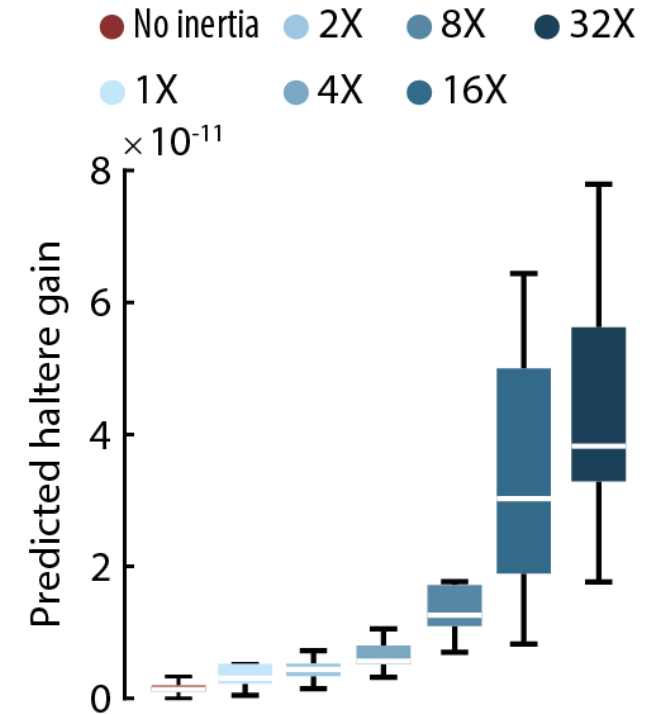
$$G(s) = e^{-st} \frac{K_p}{Is + (\underbrace{C_\omega}_{\text{passive}} + \underbrace{K_h}_{\text{halteres}})}$$

Hypothesis: halteres increase damping

fly with added inertia

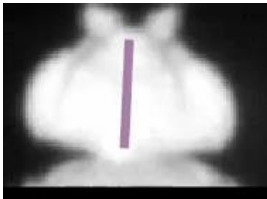


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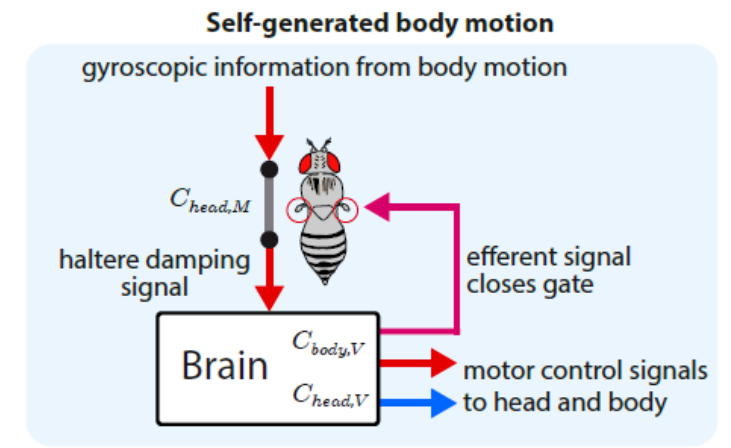
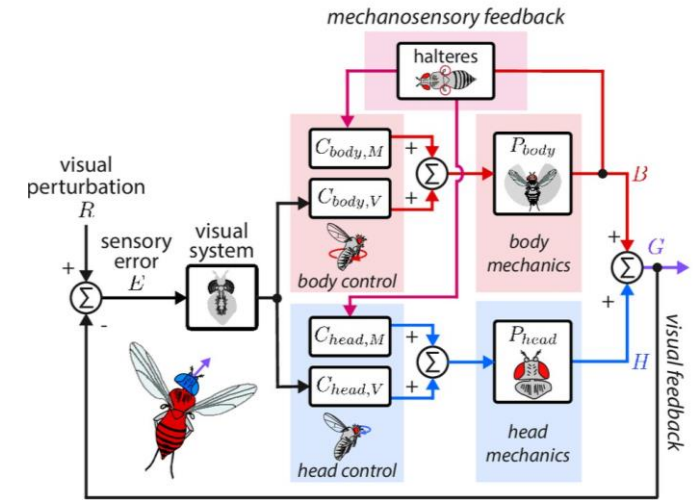
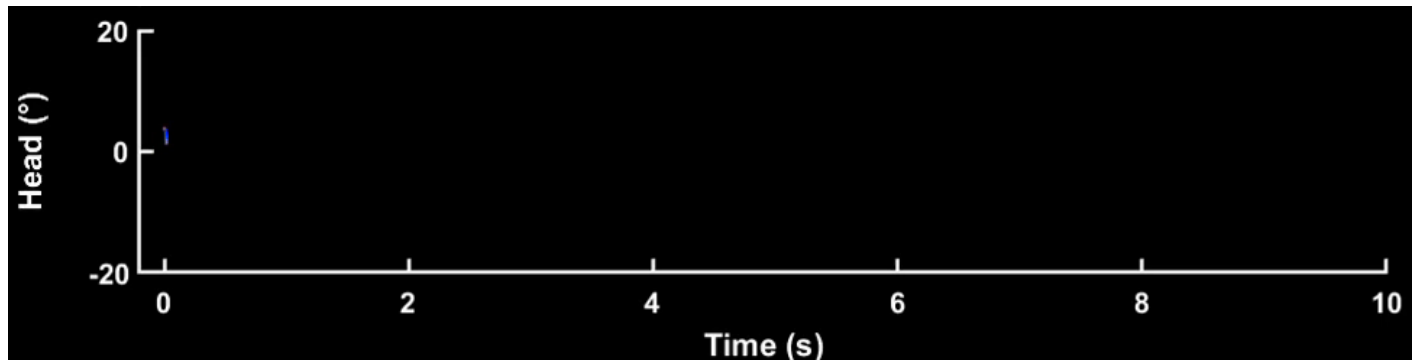
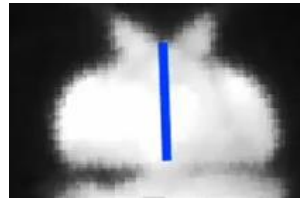


Proprioception damps out head movements

Body-fixed



Body-free



Proprioception gates visual object fixation in flying flies

Highlights

- Flies rigidly tethered in virtual reality flight steer to center a vertical bar

Authors

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RESEARCH ARTICLE



Nested mechanosensory feedback actively damps visually guided head movements in *Drosophila*

Benjamin Cellini, Jean-Michel Mongeau*

Department of Mechanical Engineering, Pennsylvania State University, University Park, United States

SCIENCE ADVANCES | RESEARCH ARTICLE

BIOPHYSICS

Flies trade off stability and performance via adaptive compensation to wing damage

Wael Salem¹, Benjamin Cellini¹, Heiko Kabutz², Hari Krishna Hari Prasad², Bo Cheng¹, Kaushik Jayaram², Jean-Michel Mongeau^{1*}

Article

Motor neurons generate pose-targeted movements via proprioceptive sculpting

<https://doi.org/10.1038/s41586-024-07222-5>

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Benjamin Corko^{1,2}, Igor Siwanowicz², Kari Close¹, Christina Christoforou¹, Karen L. Hibbard¹, Mayank Kabra¹, Allen Lee¹, Jin-Yong Park¹, Si Ying Li^{1,3}, Alex B. Chen^{1,4}, Shigehiro Namiki^{1,5}, Chenghao Chen^{1,6}, John C. Tuthill¹, David D. Bock^{1,7}, Hervé Rouault^{1,8}, Kristin Branson¹, Gudrun Thirke¹ & Stephen J. Huston^{1,9,10}



Flying *Drosophila* stabilize their vision-based velocity controller by sensing wind with their antennae

Sawyer Buckminster Fuller^{a,1}, Andrew D. Straw^b, Martin Y. Peek^c, Richard M. Murray^d, and Michael H. Dickinson^e

^aSchool of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138; ^bInstitute for Molecular Pathology, 1030 Vienna, Austria; ^cHoward Hughes Medical Institute Janelia Farm Research Campus, Ashburn, VA 20147; ^dDivision of Engineering and Applied Sciences, California Institute of Technology, Pasadena, CA 91125; and ^eDepartment of Biology, University of Washington, Seattle, WA 98195

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PROCEEDINGS B

royalsocietypublishing.org/journal/rspb

Flies adaptively control flight to compensate for added inertia

Wael Salem, Benjamin Cellini[†], Eric Jaworski and Jean-Michel Mongeau



J. R. Soc. Interface (2012) **9**, 1685–1696

doi:10.1098/rsif.2011.0699

Published online 21 December 2011

The influence of sensory delay on the yaw dynamics of a flapping insect

Michael J. Elzinga^{1,*}, William B. Dickson² and Michael H. Dickinson³

The Journal of Experimental Biology 209, 1617–1629
Published by The Company of Biologists 2006
doi:10.1242/jeb.02166

Task-level control of rapid wall following in the American cockroach

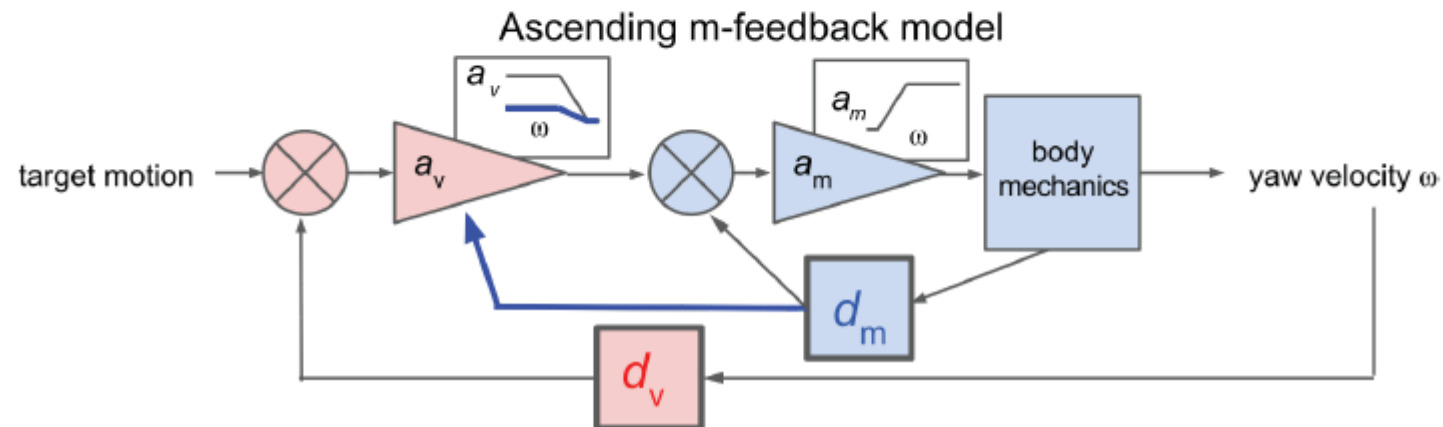
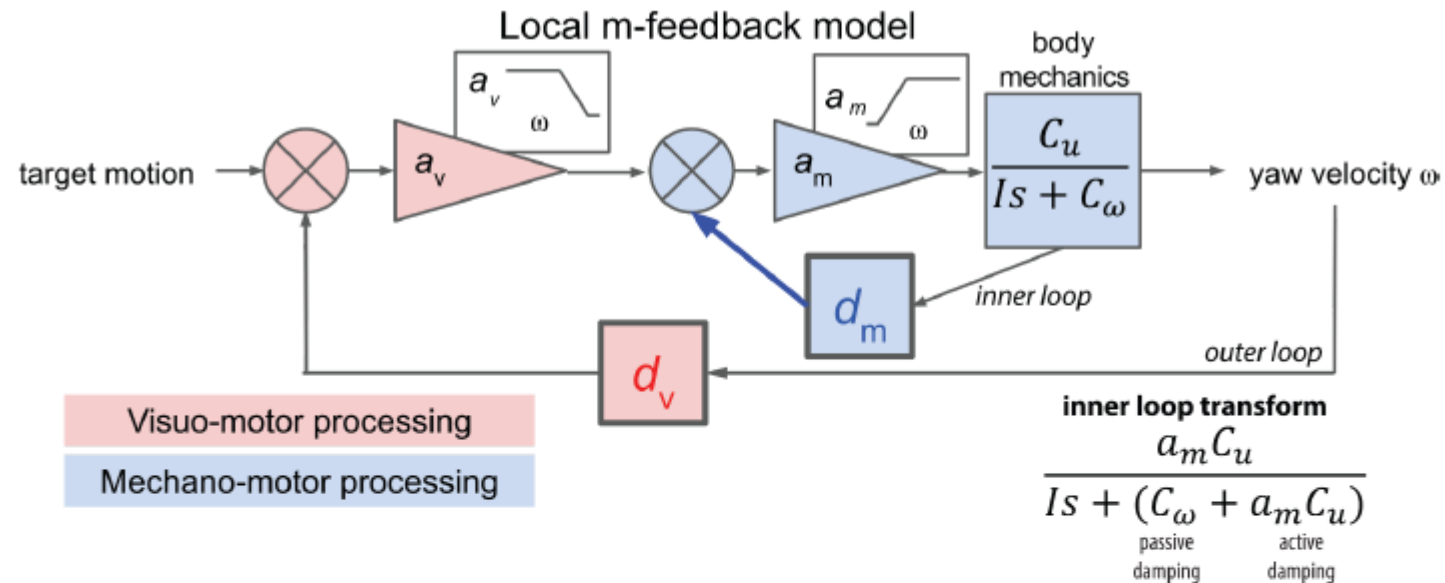
N. J. Cowan^{1,*}, J. Lee¹ and R. J. Full²

¹Department of Mechanical Engineering, Johns Hopkins University, Baltimore, MD 21218, USA and ²Department of Integrative Biology, University of California at Berkeley, Berkeley, CA 94720, USA

*Author for correspondence (e-mail: ncowan@jhu.edu)

Active damping of visually guided movement via mechanosensory feedback
may be a general principle across biological taxa

Alternative control models for damping of visuomotor responses

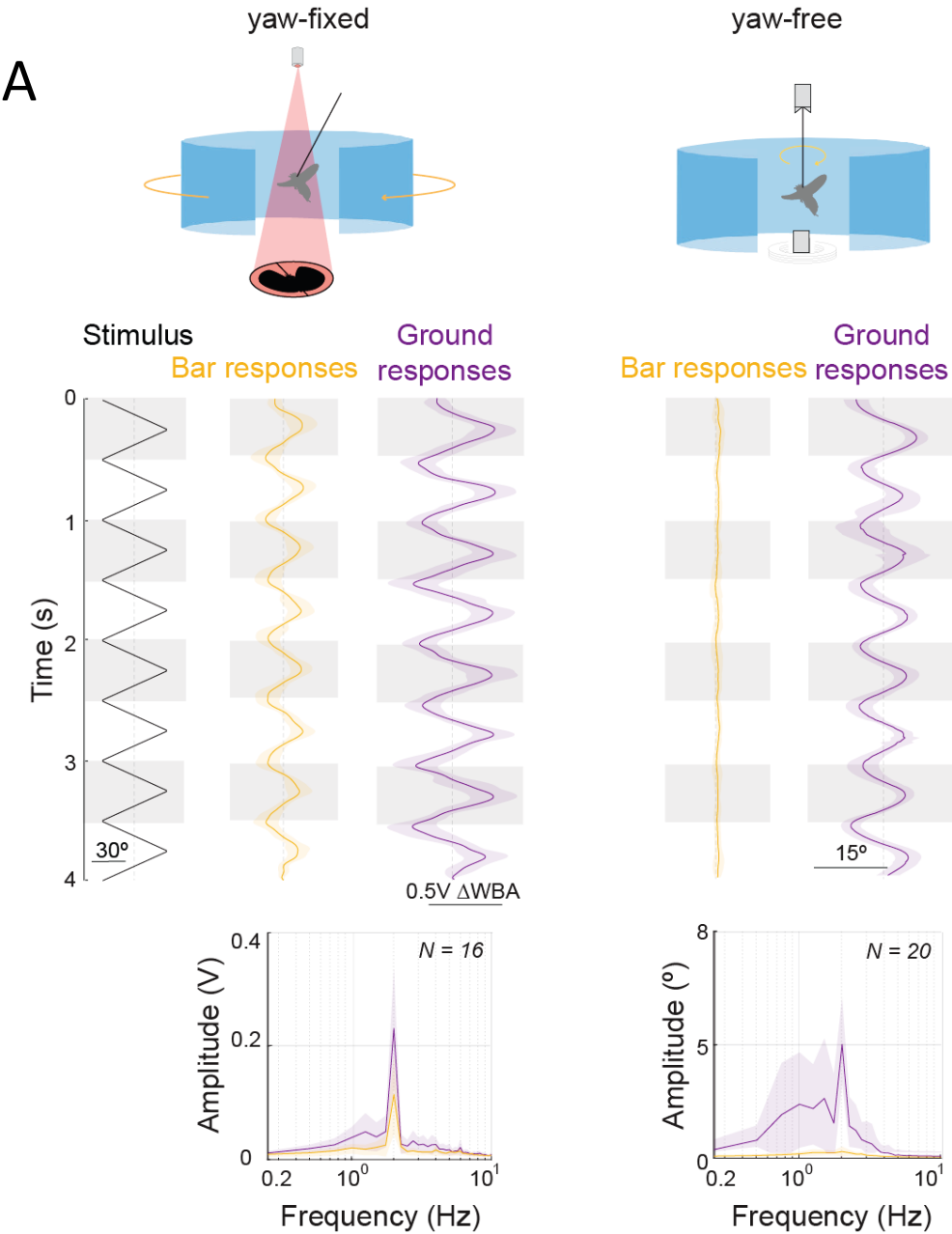
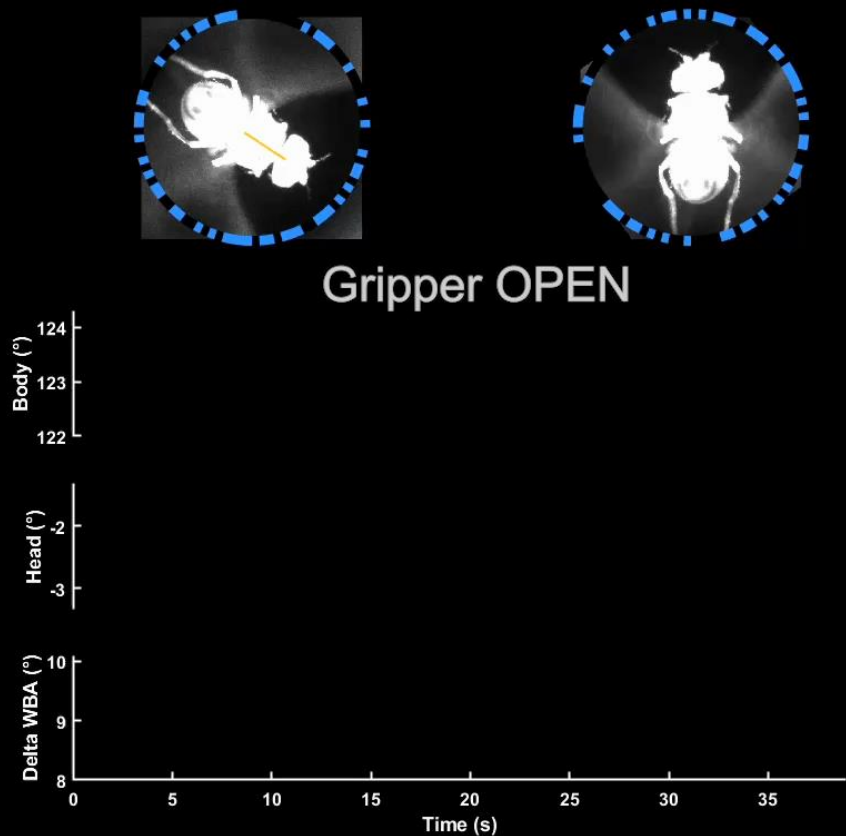


Outline

- Background
- **Recent progress**

Objective 1: test hypothesis that gyroscopic feedback actively damps visual object tracking behavior

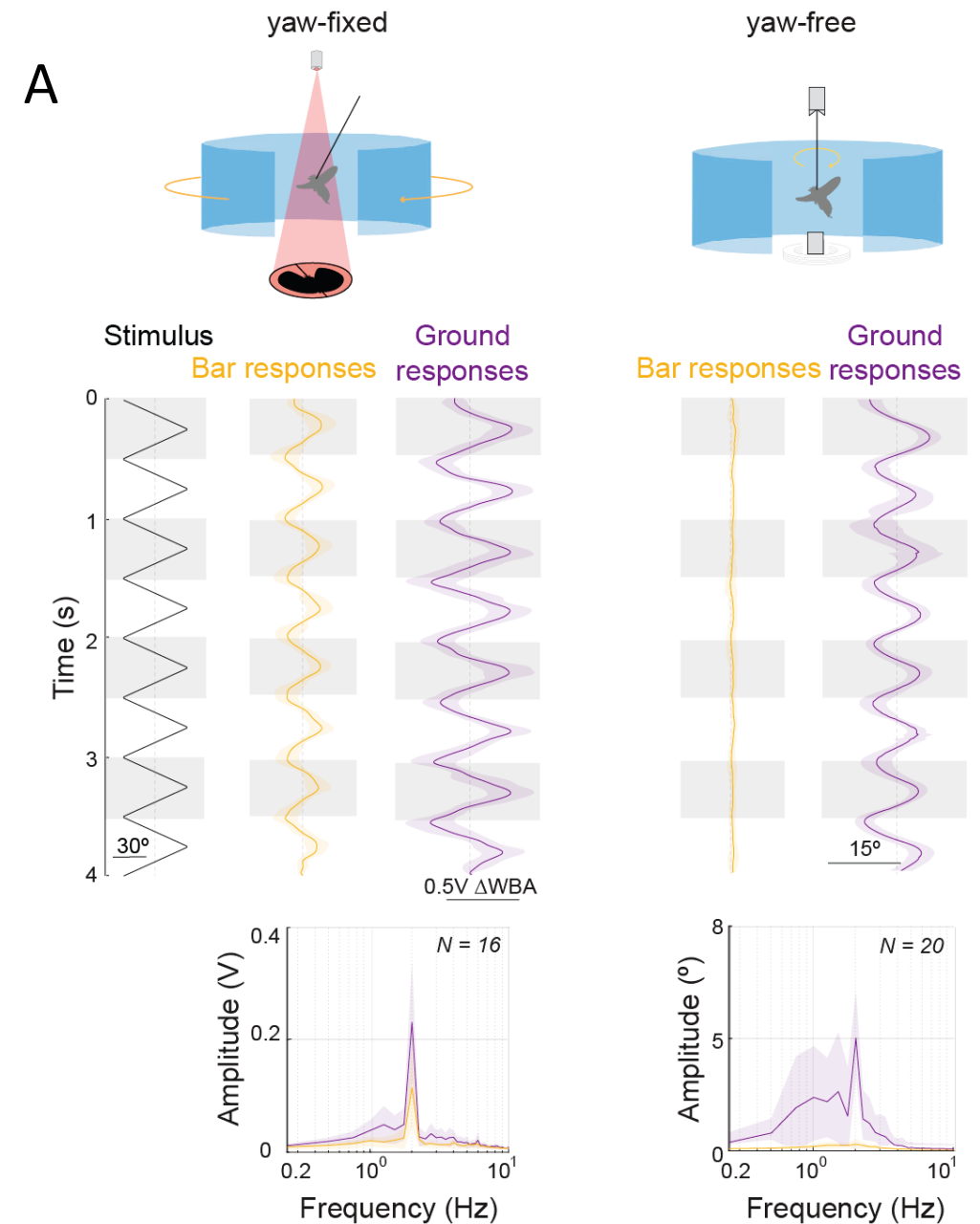
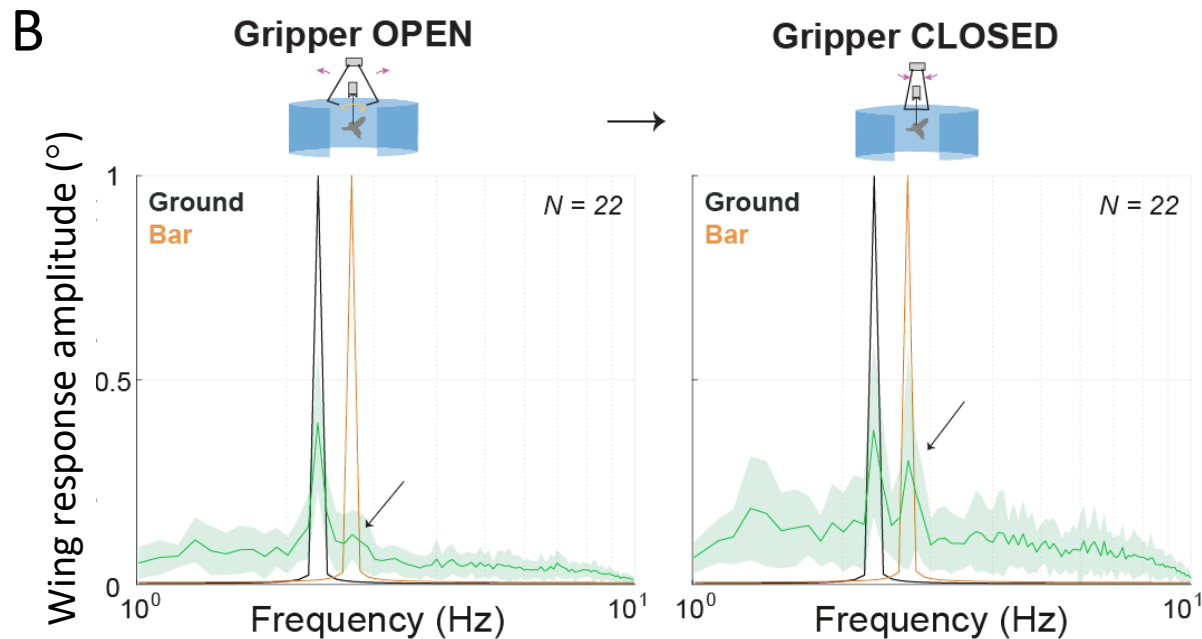
Approach: (i) compare yaw-fixed to yaw-free responses to bar/ground motion, (ii) use mechanical gripper to fix body dynamics within subjects



Objective 1: test hypothesis that gyroscopic feedback actively damps visual object tracking behavior

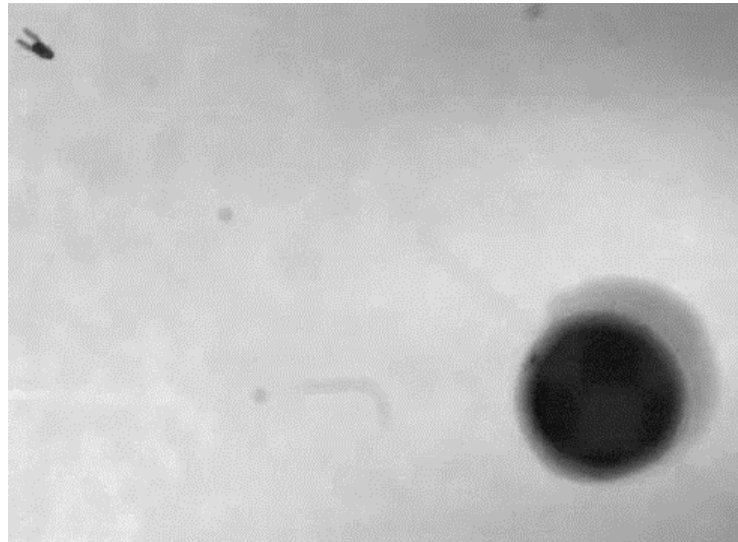
Approach: (i) compare yaw-fixed to yaw-free responses to bar/ground motion, (ii) use mechanical gripper to fix body dynamics within subjects

Results: fixing body movement, disabling gyroscopic signals, induces high gain visual tracking of a narrow bar (disables active damping)



Determining mechanisms of visual attention switch

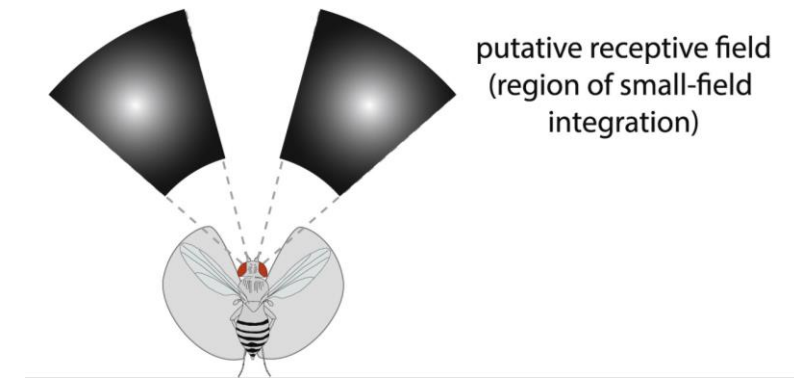
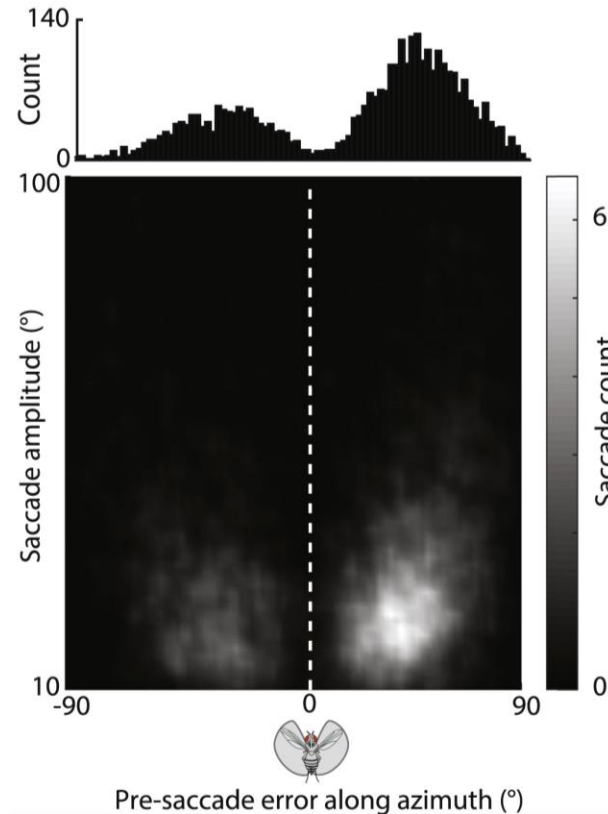
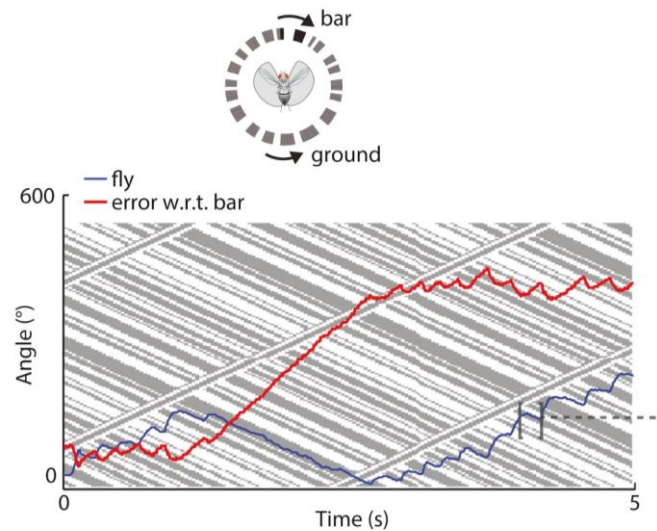
- Actively turning toward a feature of interest, e.g., a landing site, requires a switch in attention

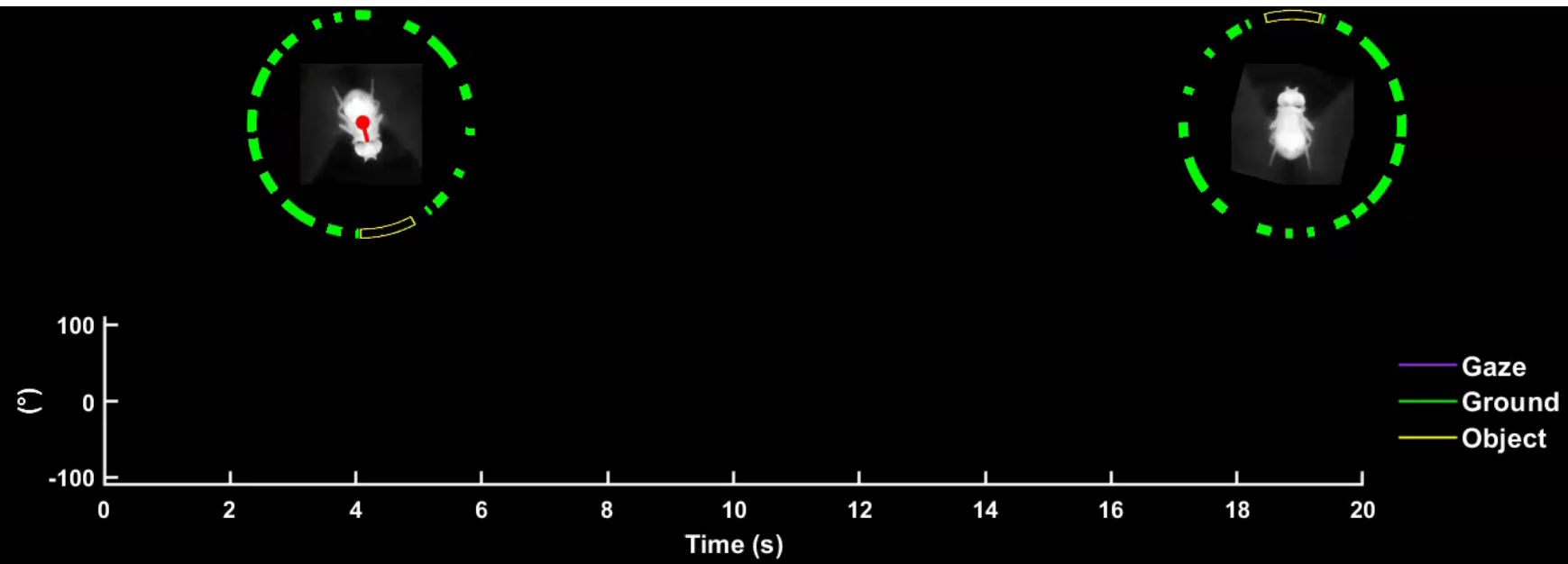


Van Breugel et al., 2012

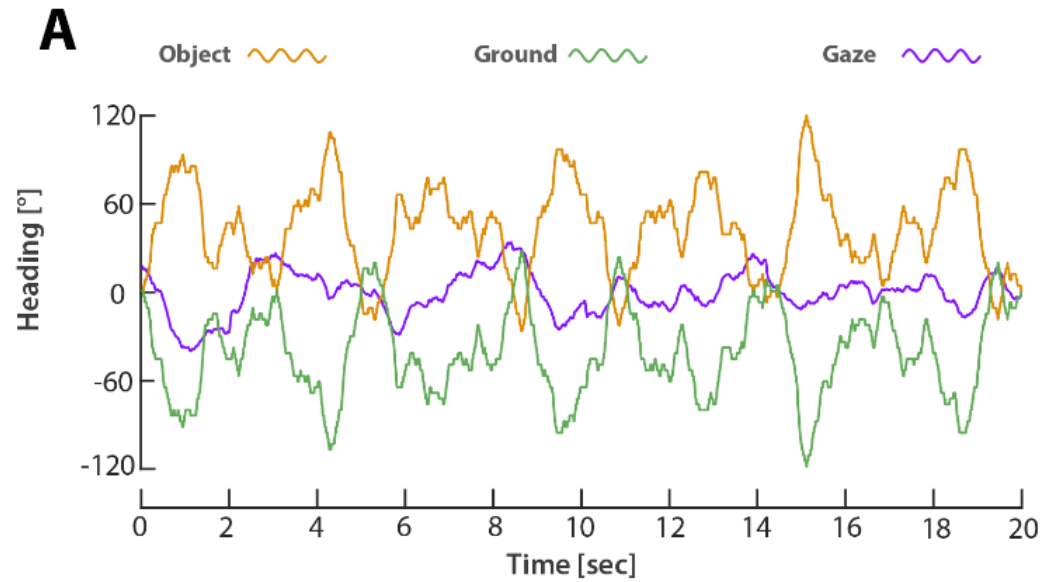
Attention switching

- Actively turning toward a feature of interest, e.g., a landing site, requires a switch in attention
- Dynamics of attention switching in flies remain poorly understood

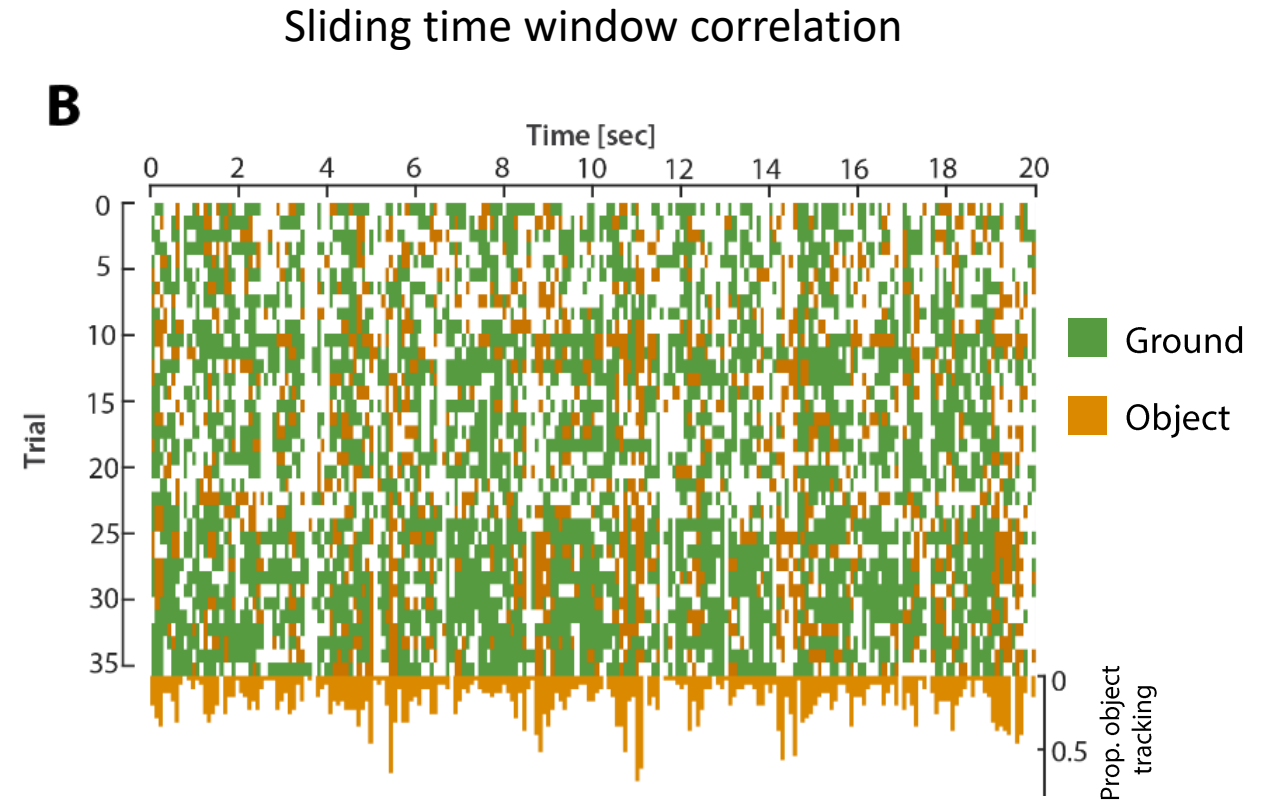
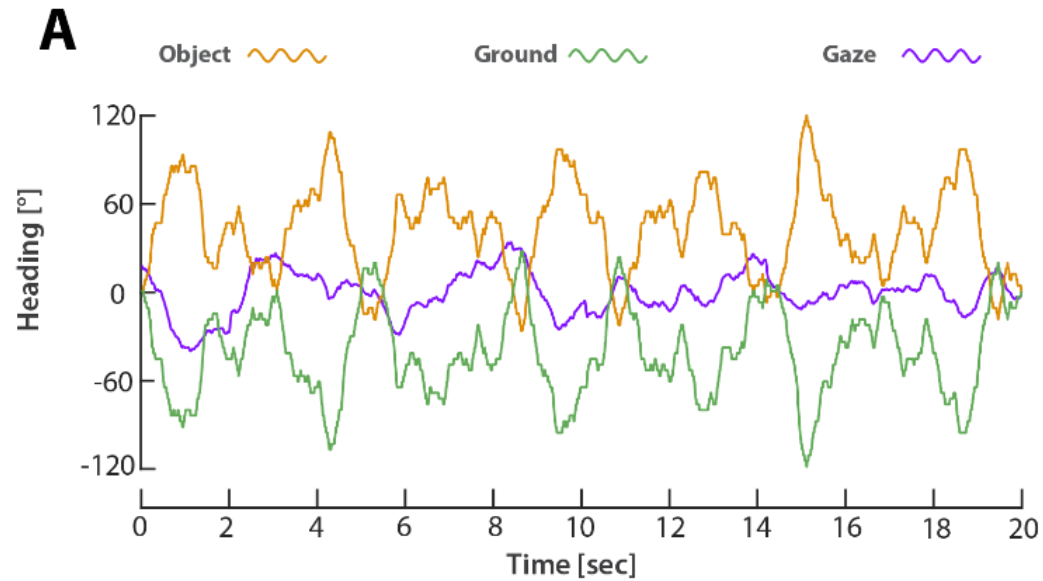




Flies rapidly switch attention

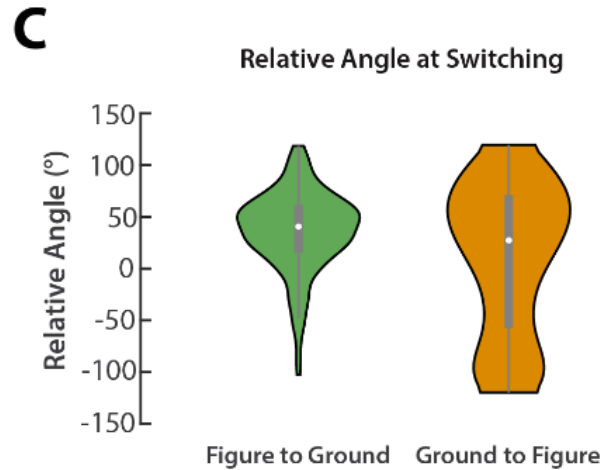


Flies rapidly switch attention



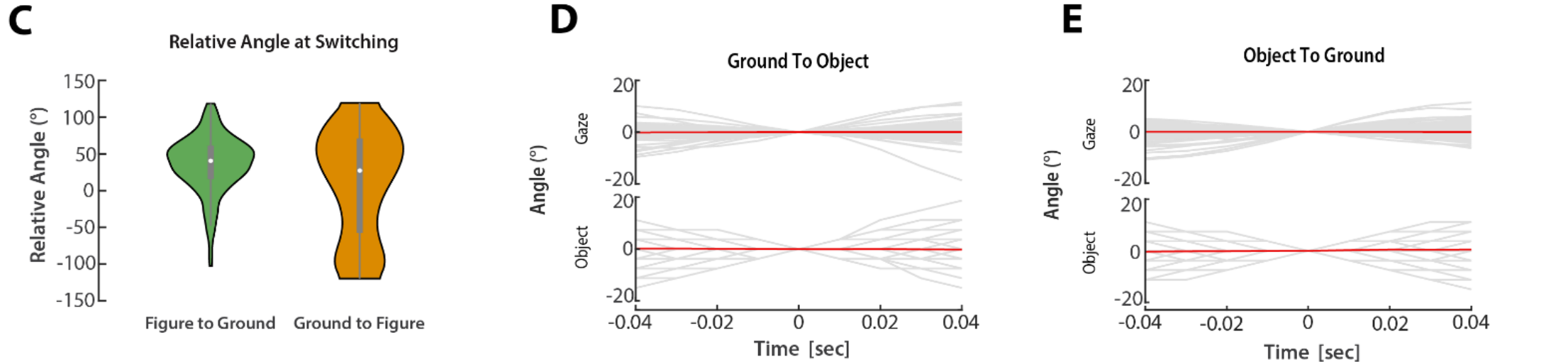
$n = 7$ flies, 5 trial each

Object position triggers a switch in attention



Object position triggers a switch in attention

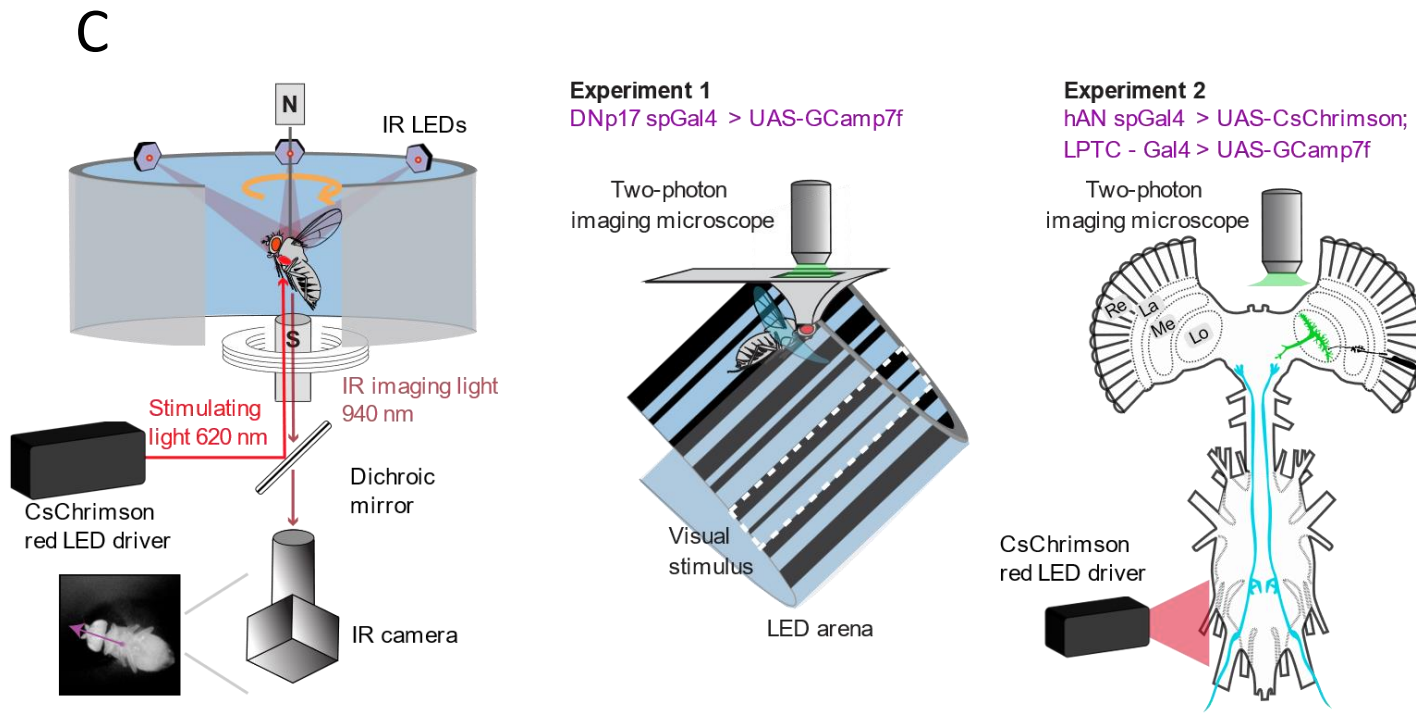
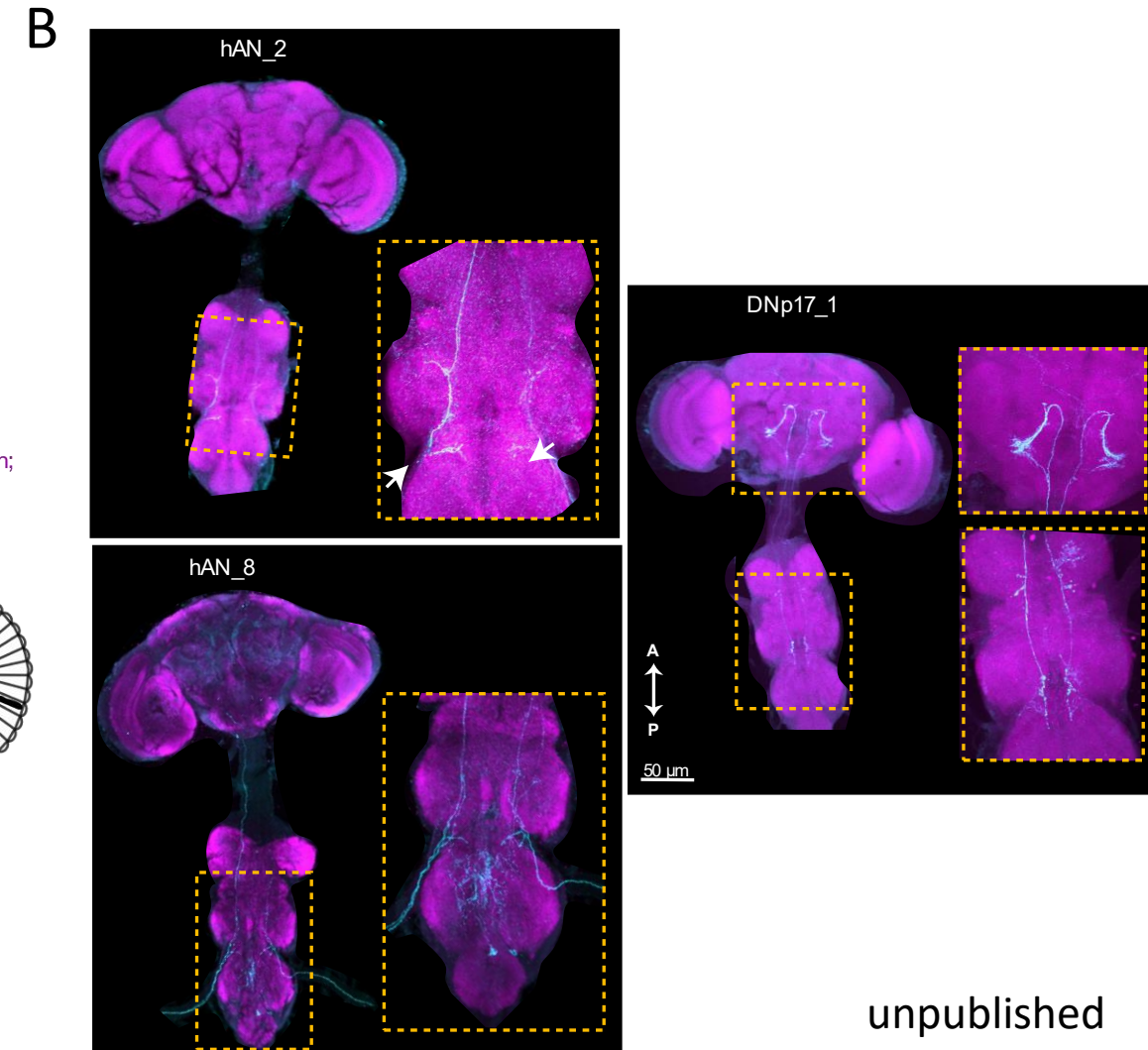
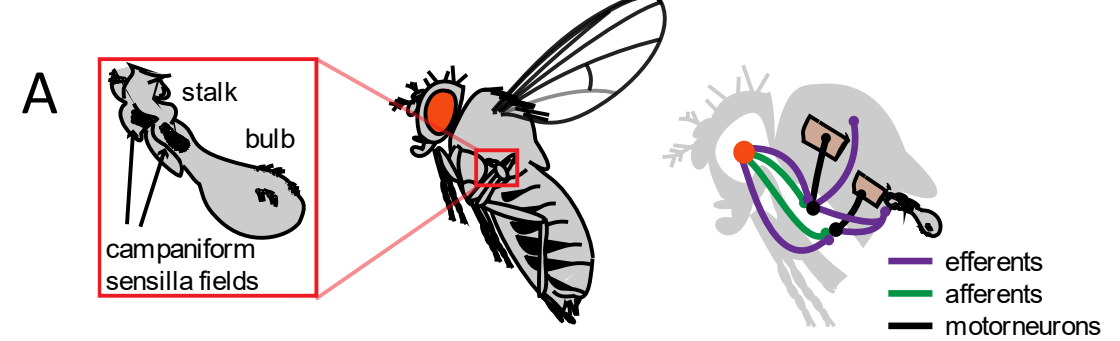
Gaze & object trajectory at switching



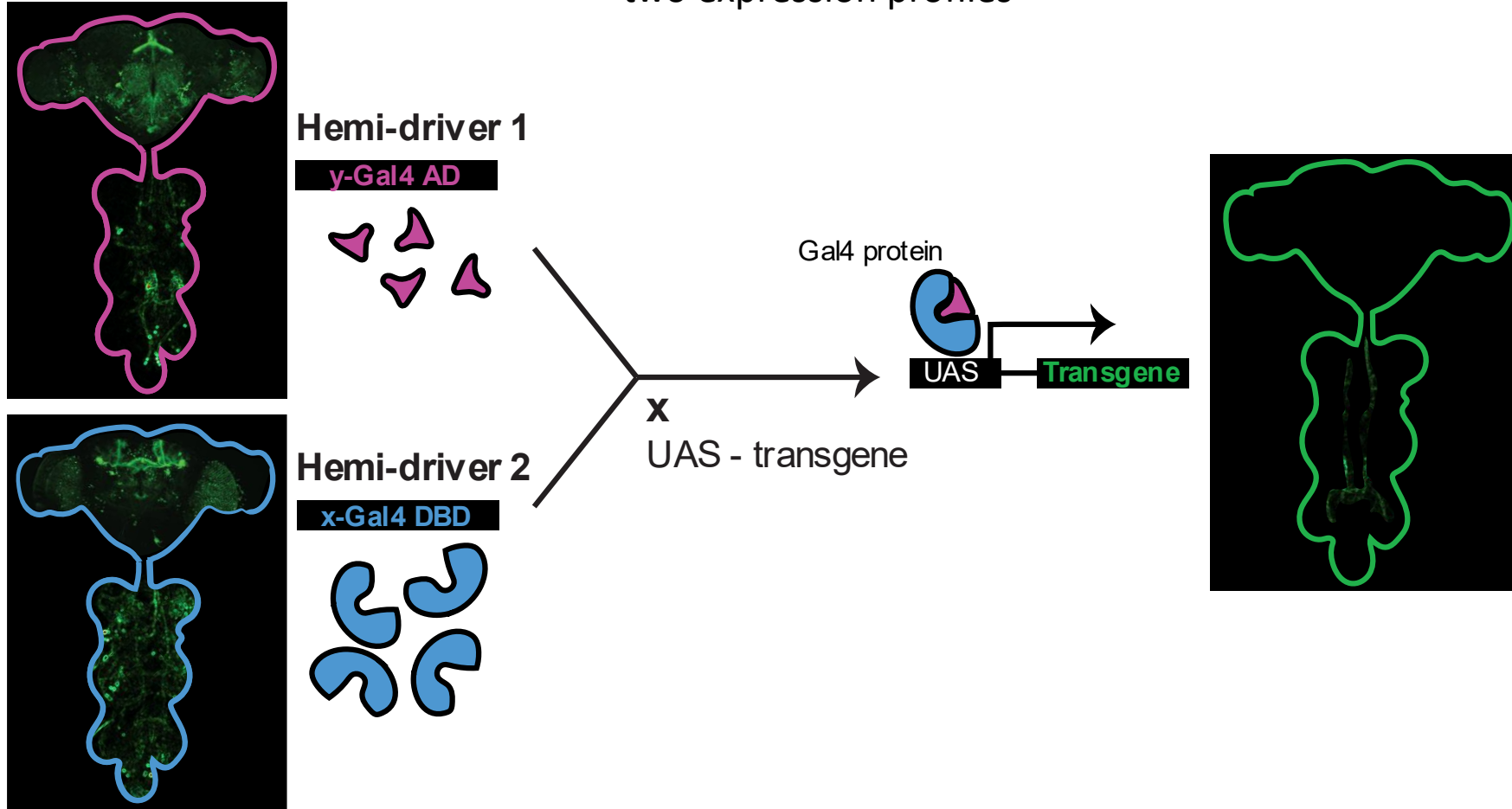
Objective 2: experimentally manipulate signaling between the haltere sensory paths and pre-motor visual processing

Approach: (i) use *intersectional genetics* to isolate fly lines that label single pairs of haltere-visual neurons, (ii) perturb the function of these neurons, (iii) test the effect on *active damping of object tracking*

Results: connectome-based screen of > 100 intersection crosses generated 12 highly viable new reagents to test (3 examples)



intersectional genetics
labels the intersection of
two expression profiles



Objective 3: test hypothesis that visual ecology (visual conditions where a species lives) influences visual tracking strategies

Approach: compare species from visually sparse desert environments with species from visually cluttered environments



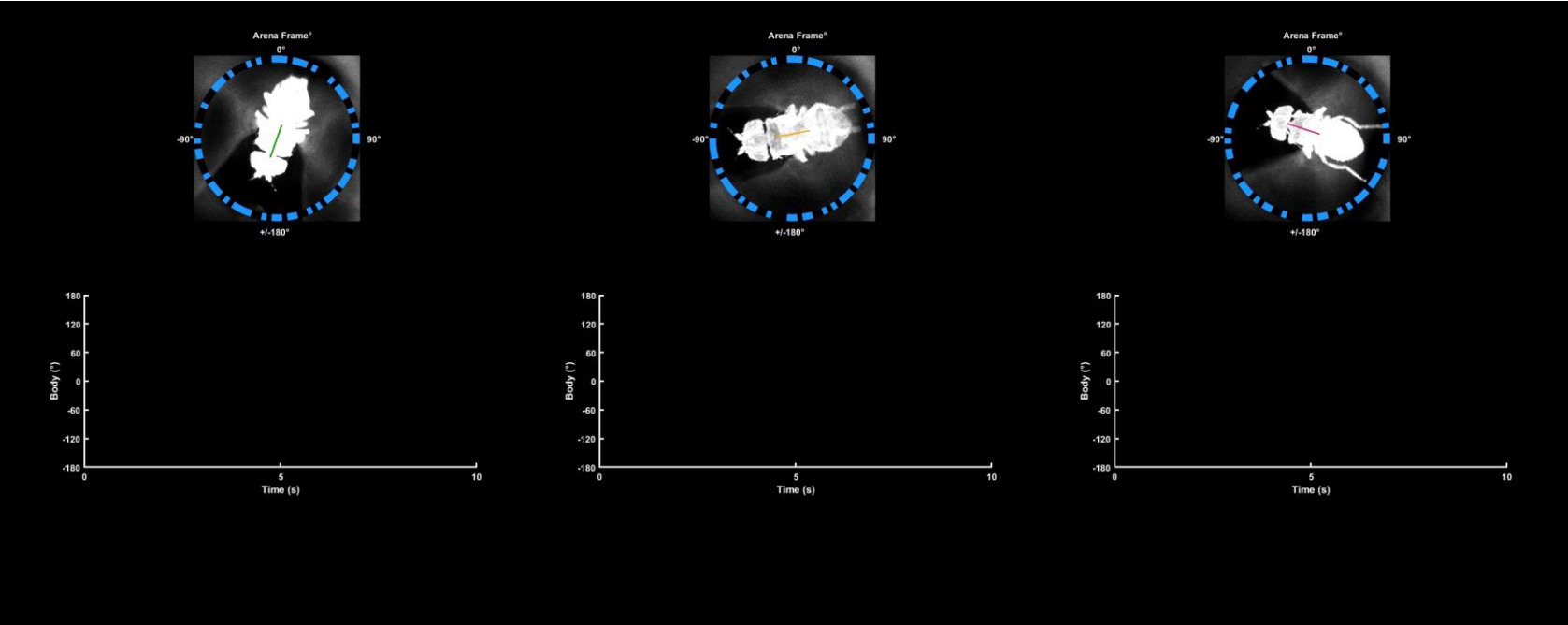
D. melanogaster



D. moj. baja



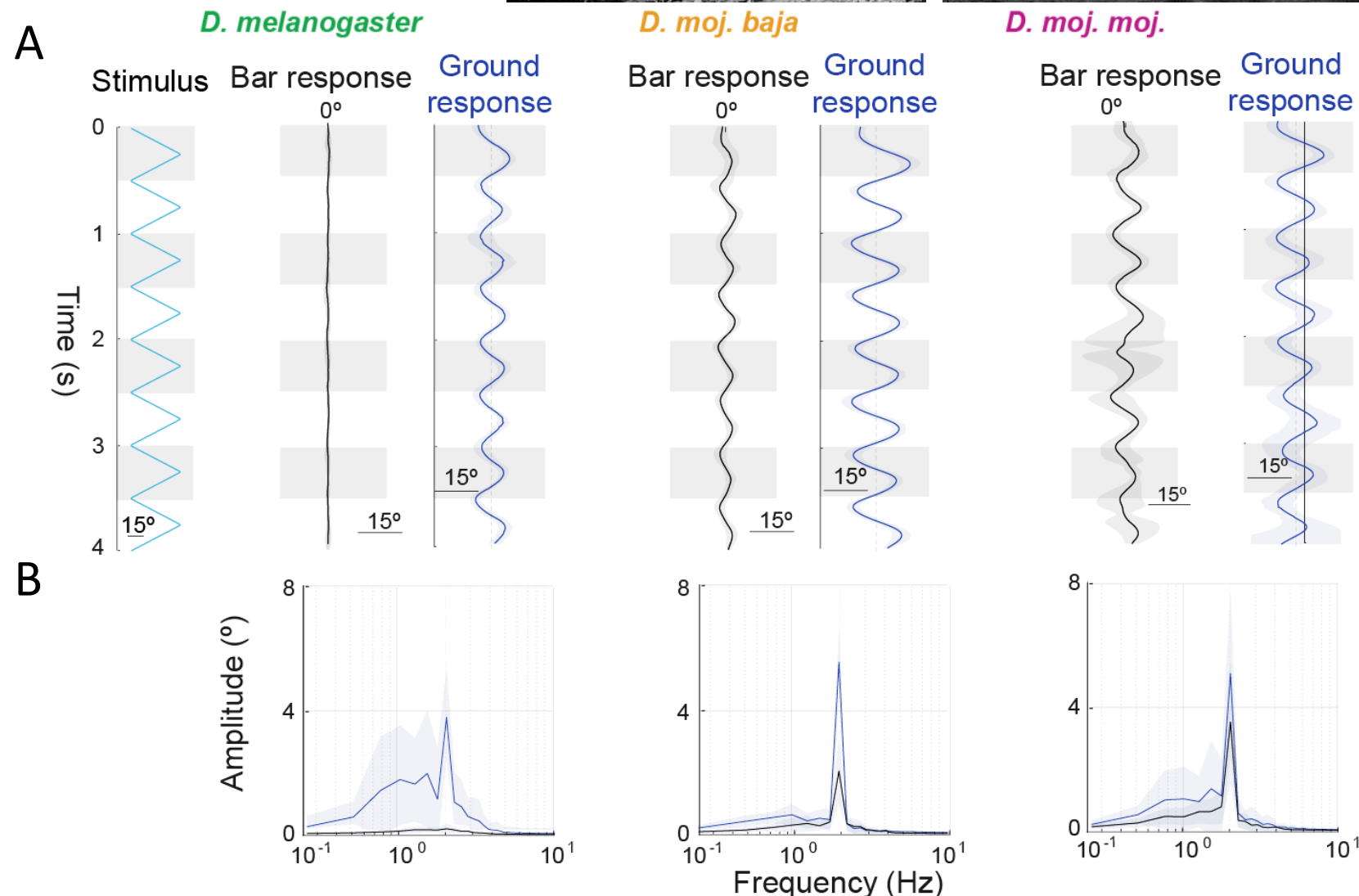
D. moj. moj.



Objective 3: test hypothesis that visual ecology (visual conditions where a species lives) influences visual tracking strategies

Approach: compare species from visually sparse desert environments with species from visually cluttered environments

Results: species from visually cluttered environments smoothly track the ground and saccade to track objects; species from visually sparse desert (also African savannah, not shown) show strong smooth fixation dynamics: “fixate-and-saccade” tracking strategy





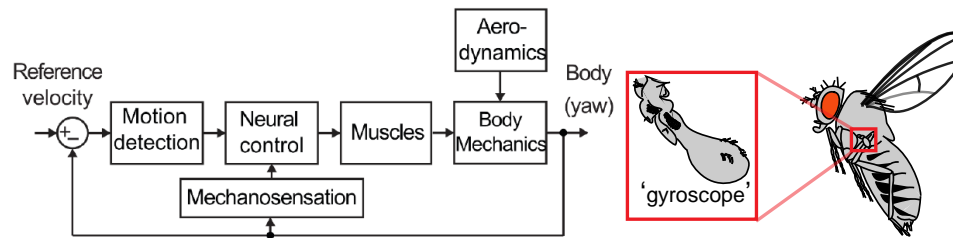
A Gyroscopic Control Loop for Active Target Vision

Mark Frye, Dept. of Integrative Biology and Physiology, UCLA



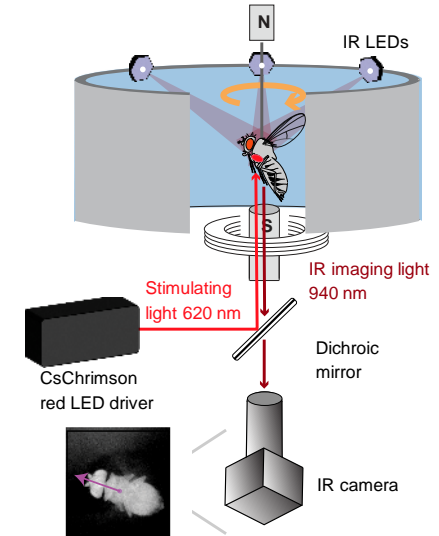
Objectives:

- 1) To formalize the behavioral interactions between mechanosensory feedback and visual tracking
- 2) To discover the functional cellular circuits that implement mechanosensory control of active target vision



Technical Approach:

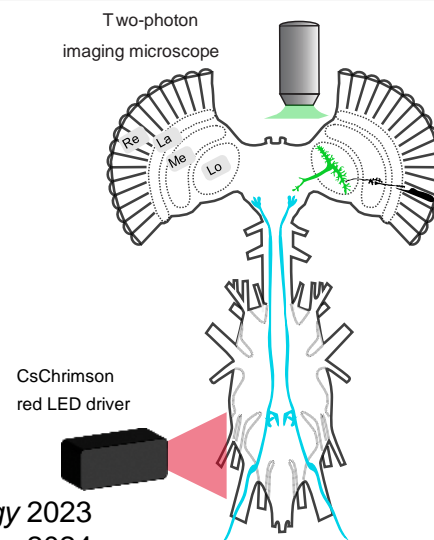
- Compare object tracking during yaw-fixed and yaw-free closed loop flight
- Use optogenetics to “read” sensory information from, and “write” sensory commands to haltere-visual integration neurons
- Compare visual control across species adapted to visually sparse desert and cluttered city environments



Accomplishments:

- Showed that gyroscopic signals in flight are required for object tracking
- Genetically labeled pairs of neurons projecting between haltere and visual centers
- Showed that visual tracking strategies vary with differing visual landscapes

Current Biology 2023
Current Biology 2024



DoD Benefit:

Generate bio-inspired algorithms for adaptive flight control by fusing multi-sensor signals, and lay the groundwork for the development of intelligent aerial systems that adapt to varied visual terrain for target pursuit with robust visual stability

