Sensorimotor signal transmission through AIY interneuron in *C. elegans* during isothermal tracking

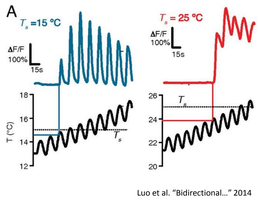
Karen Jiang, Steve Mendoza, Nathaniel Nowak, Leonard Haller, Linsay Ling, Brian Lam, Tim Sherry, and Katsushi Arisaka

UCLA, Department of Physics and Astronomy

INTRODUCTION

Perception and navigation through space requires accurate translation and transmission of **sensory** input to **motor** output, via **interneurons** which process and integrate sensorimotor information

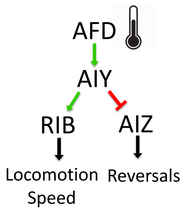
- Model organism *Caenorhabditis elegans* with 302 neurons
- Along a linear temperature gradient, nematodes exhibit **isothermal tracking** and **maximum velocity**



Luo et al. "Bidirectional..." 2014

AFD thermosensory neuron phaselocks with sinusoidal increases in temperature above set point Ts.

Proposed Mechanism:



- While travelling along isotherms, AFD activity **phase locks** with temperature oscillations during head movement
- Steady signal to downstream AIY maintains provides constant input to RIB to maintain **locomotion speed**
- AIY activity will **suppress reversal initiation** by AIZ and turns to maintain linear tracks

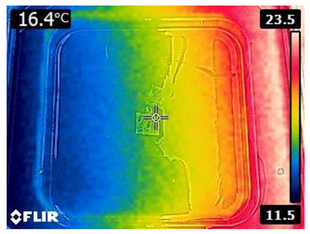
OBJECTIVE

- Confirm AIY as the **gating mechanism** between locomotion speed and reversals
- Observe the role of AFD thermosensory neuron in **informing** and **modulating** AIY signals to other post-synaptic interneurons & motor neurons
- Neuronal imaging without experimenter manipulation, or stimulation greater than what is seen at physiological conditions

EXPERIMENTAL APPROACH

Behavioral Experiments

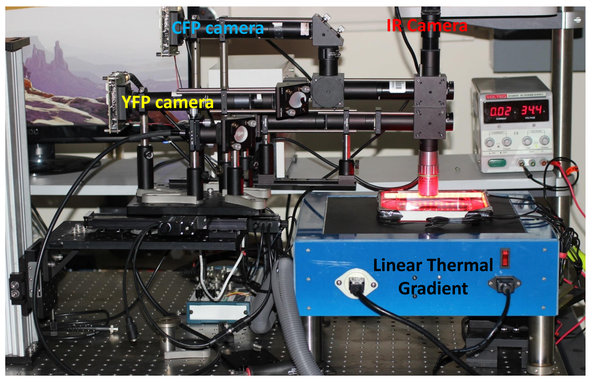
- *Purpose*: Quantify isothermal behavior and obtain velocity statistics
- Placed Wild Type (WT) N2 strain (n = ~25/trial) on gradients of various steepness from 0.02 C/mm to 0.06 C/mm
- Ran behavioral assays for 30 minutes at .33fps with a Canon EOS Rebel T3i camera



Forward Looking Infrared (FLIR) thermal image of linear thermal gradient.

Neuron-Tracking Experiments

- Blue-light insensitive *Lite1(xu7)* mutants with AIY::CAM (Cameleon Ca^{+2} indicator)
- ***Novel*** neuron-tracking epi-fluorescent microscope
- Receive CFP images, YFP images and stage information (neuron position information)



Worm Tracking Epifluorescent Microscope set up with linear thermal gradient

RESULTS

Behavioral Data

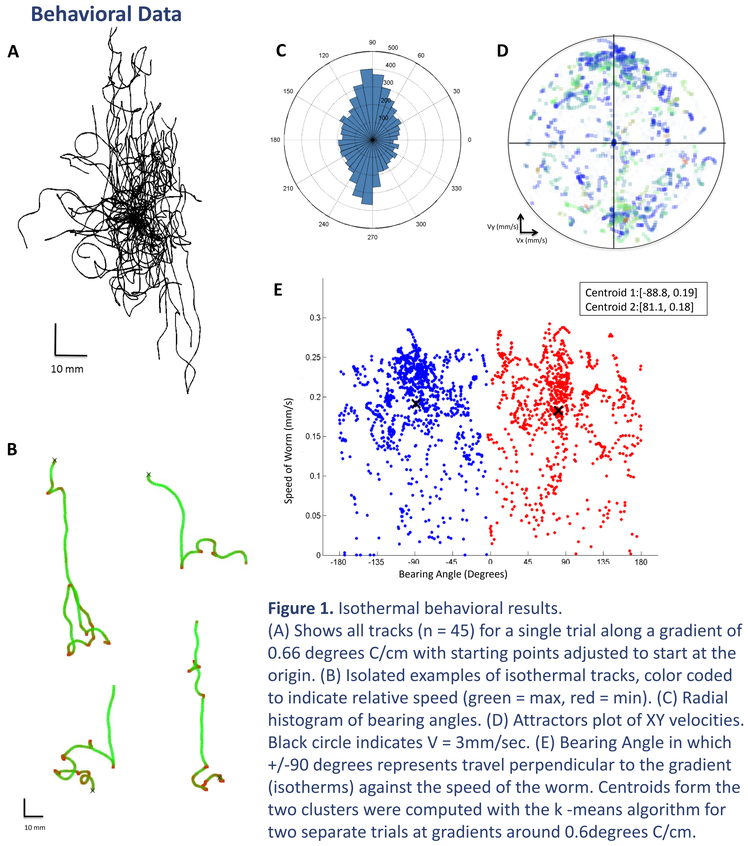
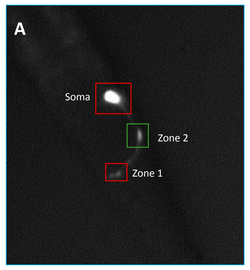


Figure 1. Isothermal behavioral results. (A) Shows all tracks (n = 45) for a single trial along a gradient of 0.66 degrees C/cm with starting points adjusted to start at the origin. (B) Isolated examples of isothermal tracks, color coded to indicate relative speed (green = max, red = min). (C) Radial histogram of bearing angles. (D) Attractors plot of XY velocities. Black circle indicates V = 3mm/sec. (E) Bearing Angle in which +/-90 degrees represents travel perpendicular to the gradient (isotherms) against the speed of the worm. Centroids form the two clusters were computed with the k -means algorithm for two separate trials at gradients around 0.6degrees C/cm.

Preliminary Neuron Data



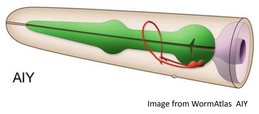
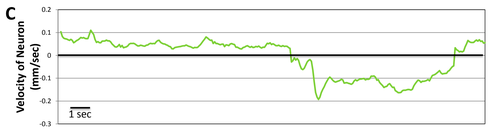
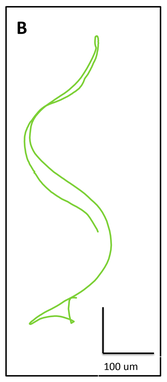


Image from WormAtlas AIY

To obtain a measure of Ca^{+2} activity, Neurite Zone 2 (which contains a high density of Ca+2 channels) shows more robust calcium signals.





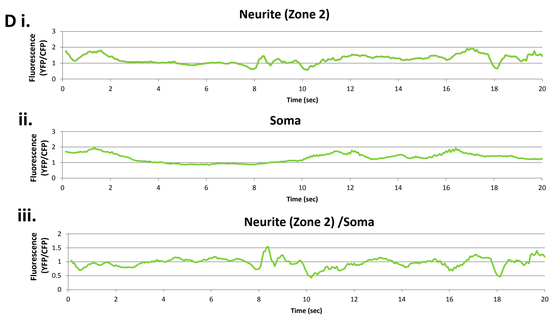


Figure 2. Preliminary results for neuron tracking with novel worm-tracking epifluorescent microscope from single data set at gradient of 0.5degrees C/cm. (A) Static YFP image indicating 3 primary fluorescence zones. (B) Position of neuron obtained from XY stage data during a 20 second isothermal track. (C) Directional velocity of head motion. Negative velocity indicates reversal. (D) Fluorescence signals from process Zone 2 [i] and Soma [ii]. To eliminate overall fluctuations in external light intensity, a ratio between the two fluorescence zones is calculated[iii].

DISCUSSION

During isothermal behavior, *C. elegans* travel at a steady **maximum velocity** informed by their spatial perception of the external thermal environment. This signal to noise ratio S(t) can be modeled by the following:

$$S(t) = A + B(t) + C\sin(\omega t)$$

- **A** is the initial temperature
- **B(t)** is the change in temperature along the direction of motion
- **C** is the amplitude of head motion
- ω is frequency of oscillation
- t is time (sec)

When travelling isothermally, B(t) = 0 and Csin(ωt) = max, so that S(t) is reduced to A + Csin(ωt). Thus, the signal sent downstream to AIY is represented by a sinusoidal function.

Understanding AIY provides a model analogous to the thalamus insofar as gating and processing multiple sensory inputs. Implementing a novel worm-tracking enables visualization of neural activity without experimenter introduced variables.

CONCLUSIONS

We find that during isothermal tracking, nematode worms are travelling at their upper bounds of their velocity spaces. This suggests a **state of attraction**, limiting acceleration and deceleration to minimize energy expenditure.

As of yet, our results from AIY activity are still tentative. We are working to improve our analysis algorithms before drawing definitive conclusions.

FUTURE DIRECTIONS

- Extend data taking time from <1 minute to 10 minutes
- Improve Cameleon fluorescence analysis algorithm
- Increase the field of view for the IR camera to capture full body & extract the nematode's skeleton and center of mass.
- Image AFD along various gradients, as well as on no gradient (control to subtract background activity)

REFERENCES

Clark, Damon A., et al. "The AFD sensory neurons encode multiple functions underlying thermotactic behavior in Caenorhabditis elegans." *The Journal of neuroscience* 26.28 (2006): 7444-7451.

Li, Zhaoyu, et al. "Encoding of Both Analog-and Digital-like Behavioral Outputs by One C. elegans Interneuron." *Cell* 159.4 (2014): 751-765.

Luo, Linjiao, et al. "Bidirectional thermotaxis in Caenorhabditis elegans is mediated by distinct sensorimotor strategies driven by the AFD thermosensory neurons." *Proceedings of the National Academy of Sciences* 111.7 (2014): 2776-2781.

Luo, Linjiao, et al. "Sensorimotor control during isothermal tracking in Caenorhabditis elegans." *Journal of experimental biology* 209.23 (2006): 4652-4662.

ACKNOWLEDGEMENTS

This study is funded through NSF IDBR Program.

Thank you to Undergraduate Research Fellowship Program (URFP) and to Gottlieb and Evers-Manly groups for providing funding.

Special thanks to Alexey Lyashenko for creating our thermotaxis gradients, to the Hallem Lab and Mayra Carrillo for providing samples, and to Michelle Kao, Shirley Cheng, and other members of the Elegant Mind Club.