Magnetosensitivity Trends in *Caenorhabditis elegans* behavior under 2D Environmental Conditions

Angela Rose David, Angela Du, Cynthia Chen,
Lanya Abdul, Marcela Caldera, and Katsushi Arisaka

UCLA, *Elegant Mind Club* @ Department of Physics and Astronomy

Elegant Mind Club UCLA

http://www.elegantmind.org

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ABSTRACT

- The Vidal-Gadea et al. (2015) study has observed that in temperate soil habitats, the starved free-living nematode species Caenorhabditis elegans will migrate vertically downwards with respect to the Earth's magnetic field vector, driven by biochemical impulses via AFD sensory neurons.
- However, as the only published study to draw such conclusions, we cannot conclusively rely on its findings to understand *C. elegans* motion.
- Our paper will observe the natural motor patterns of C. elegans in response to an artificial geomagnetic field and analyze their activity using two-dimensional worm-tracking software in conjunction with MatLAB.
- By reproducing the study's experiment, we intend to not only verify its contents but to demonstrate the extent to which magnetosensitive neuron activity can influence behavioral patterns in organisms, especially when affected by external stimuli. In doing so, we hope to further explore the relationship between geomagnetism and its corresponding effect on living systems, especially in terms of energy and the flow of information.

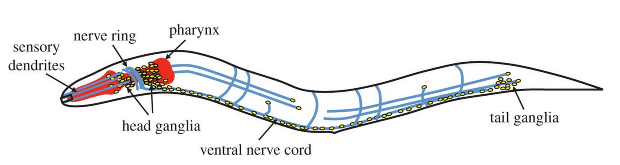
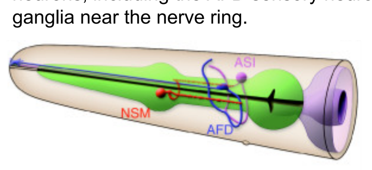


Figure 1. Overview of the *C. elegans* nervous system. The majority of neurons, including the AFD sensory neurons, are located in several ganglia near the nerve ring.



Neuron	Gene name	Function
AFD	*gcy-8**	Thermosensory
ASI	*daf-7**	Chemosensory
NSM	*eat-4*	Serotonergic
AVA	*glr-1*	Glutamatergic
PDE	*cat-1*	Dopaminergic
DVB	*unc-25*	GABAergic
DA9	*unc-17*	Cholinergic
ALM	*mec-2*	Mechanosensory

Figure 2. Depiction of adult head, highlighting the serotonergic neuron NSM in red, the two sensory neurons, AFD in blue and ASI in purple, the pharynx in green, and the anterior end of the intestine in gray. The corresponding table lists the major genes observed and their known primary function.

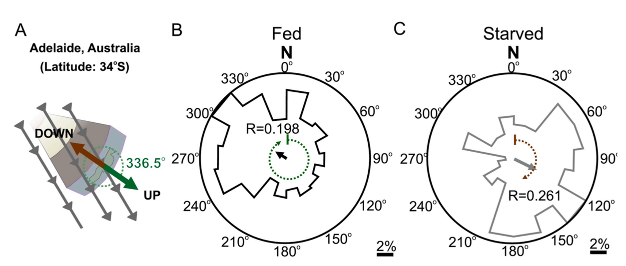


Figure 3. In investigating the magnetic orientation of worms from distinct geographical locations such as Adelaide, Australia, the study observed the above patterns. Plots for well-fed (B) and starved (C) worms are shown, with the local angle relative to the up and down direction in green and brown dashed arches respectively. According to the plots, starved worms migrate southward, most likely in search of food, whereas well-fed worms climb upwards, prompted by AFD neuron detection of the geomagnetic field.

INTRODUCTION

- To better understand neural networks within the human brain, researchers have studied *Caenorhabditis elegans* as a biological model for comparison. Biochemical activity in these worms' brains in response to certain external conditions, such as geomagnetism, mimic similar neurological pathways in humans, highlighting the potential for higher level cognition in their behavioral responses to environmental stimuli.

- **Past research:** Vidal-Gadea et al. found that starved *C. elegans* often orient themselves in a southward direction with respect to the geomagnetic field vector when searching for a nutrition source (2015), implying the following:
  1. *C. elegans* can detect and respond to the Earth's magnetic field via sensory neurons.
  2. They consciously migrate at angles to the observed magnetic field, creating the optimal vertical orientation for feeding

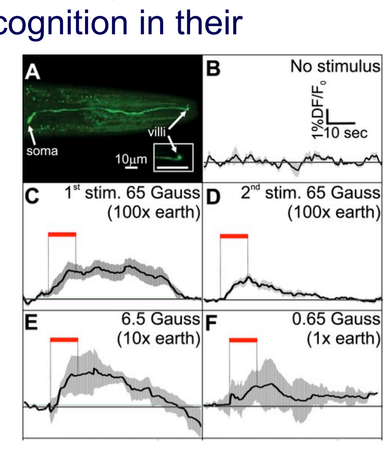


Figure 4. The Vidal et al. study demonstrates significant calcium activity in the AFD sensory neurons of worms exposed to varying levels of magnetic stimuli. For example, AFD neurons responded when the magnetic stimuli was reduced to 6.5 (E) and 0.65 Gauss (F).

- While we are limited in our magnetosensitivity observations of *C. elegans* due to the complexity of multicellular behavioral and biological systems, our experiment intends to set the framework for patterns of two-dimensional motor activity in animals, at least in terms of exposure to specific magnitudes along the Earth's gravitational field.

OBJECTIVES

Our aim is to replicate the Vidal-Gadea et al. experiment by tracking the *C. elegans* movement in a two-dimensional setup similar to the organism's natural environment. We hope that by inducing familiar geomagnetic conditions, we can more accurately define *C. elegans*' migration patterns and identify whether their behavior demonstrates magnetosensitivity to environmental stimuli.

HYPOTHESIS

Based on previous knowledge of C. elegans behavior and consequent experimental analysis, we will invalidate the findings of the 2015 Vidal-Gadea et al. study by showing that typical worm burrowing - at least in terms of feeding patterns - tends to diverge at a wide angle in two directions, forming a conical-shaped trend as opposed to the observed single uniform pattern depicted in the study.

CONCEPTUAL DIAGRAM

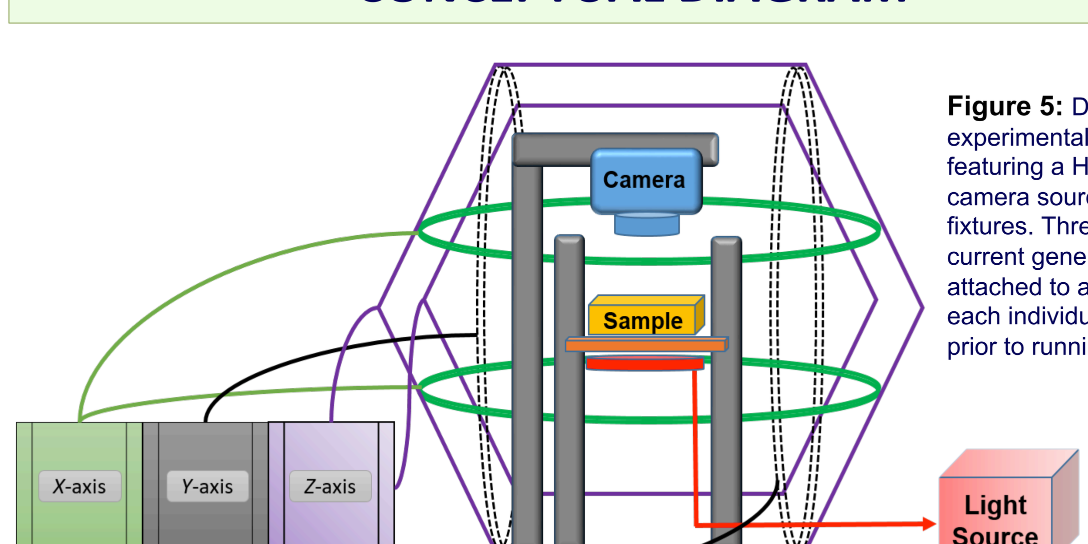


Figure 5: Diagram of experimental hardware, featuring a Helmholtz cage, camera source, and light fixtures. Three separate current generators were attached to a respective axis, each individually calibrated prior to running trials.

MATERIALS AND METHODS

- **Bio sample:**
  - 10cm rectangular agar plate filled with 2% agar solution
    - ➢ Solution made of 1.00 g agar and 50-mL distilled water
  - 20-30 Adult, starved *C. elegans* (N2 wild-type strain)
    - ➢ Incubated at 20.4˚C
- **Hardware:**
  - Gaussmeter
  - 1 m^3 Helmholtz cage
  - Red LED light fixture
  - One Canon 60D camera
  - Three electromagnetic current generators
- **Software:**
  - NEMO
  - MatLab
  - Worm Tracker
  - Magic Lantern Time-Lapse

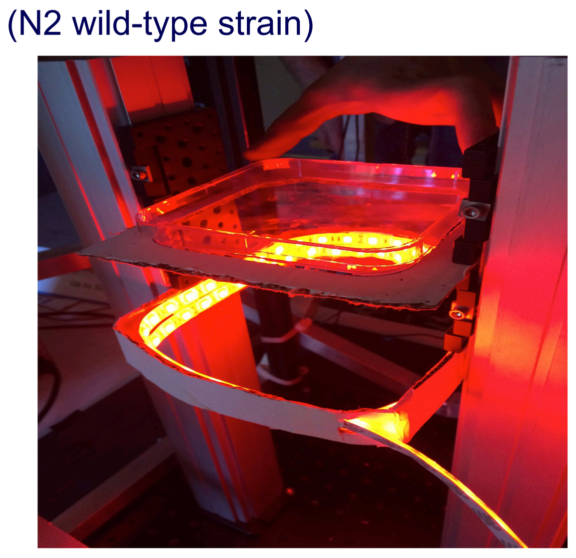


Figure 7 (above). A 10cm plate filled with 2% gelatin and 15-20 N2 WT strain adult *C. elegans.*

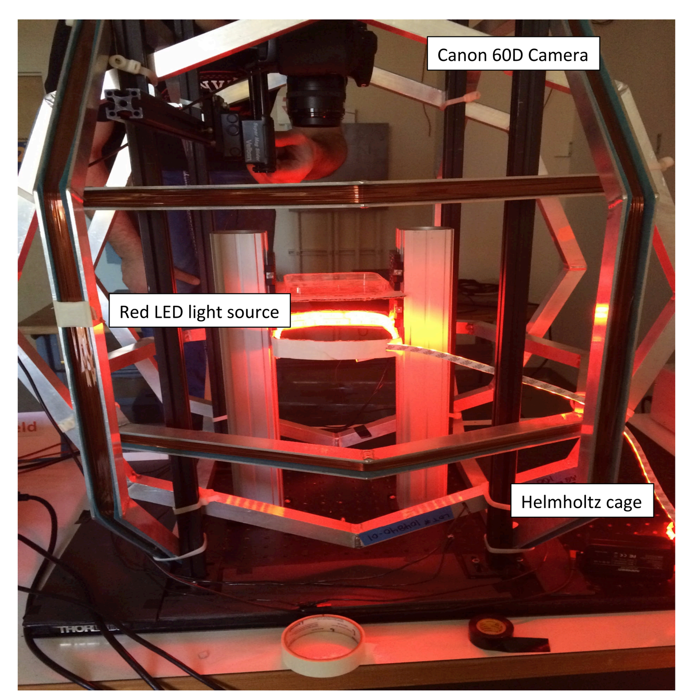


Figure 6:. A 1 m^3 Helmholtz cage, generating an artificial magnetic field in three directions – *x*, *y*, and *z*. Inside this large magnetic platform lies a smaller internal setup, consisting of a 10cm plate resting on a fitted platform attached to two steel pillars. A 60D Canon camera is suspended directly above, and a rectangular cardboard frame lined with red LED light strips illuminates below.

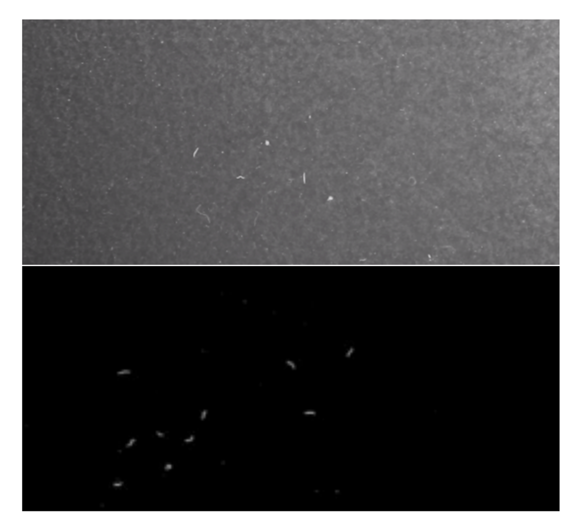


Figure 8. The top image displays a single frame of the worms as captured by the camera during a trial run. The bottom image features a similar image, only enhanced by computer software to improve resolution and visibility.

- Transferred N2 WT strain *C. elegans* onto a 10cm plate filled with 2% agar concentration
  - – N = 20-25 worms per trial
- Ran 30-minute trials with a Canon 60D camera
- Trials were conducted at 0, 1, 3, and 10 Gauss based on similar logarithmic patterns found in nature
  - – 0 Gauss to serve as a control group; 1 Gauss to imitate the Earth's natural magnetic field; 3 Gauss to test above the Earth's magnetic field; and 10 Gauss as an extreme case
- Measured the uniformity of magnetic field with a Gaussmeter
- Camera captured a single frame every three seconds using the built-in TimeLapse feature, collecting approximately 600 individual frames per trial
- Analyzed images with NEMO and Worm Tracker, producing the given graphs

CALIBRATION DATA

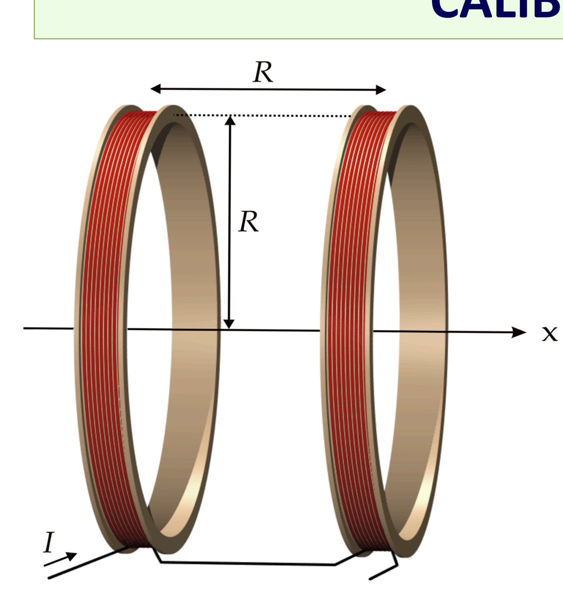


Figure 9 (above): Helmholtz coil pair with two rings separated by a distance of R, which is the radius of the rings. Current moves through the coils and produce a magnetic field in the x direction. Same principle applies to y and z axes.

Principle of Stimulation: The artificial magnetic field is produced by current moving around the *x*, *y*, and *z*-axes. Based on **Ohm's Law** (V=IR), the resistances of the surrounding wires were calculated to be 5.1R, 4.6R, and 4.7R, respectively.

The **uniformity** of the magnetic field was measured via a Gaussmeter to be ±.02 Gauss within the desired magnitude.

Based on **Ampere's Law**, the magnetic field B is proportional to electric current I which serves as its source.

Therefore we used current to indicate the intensity of magnetic field in Table 1.

X A	Y A	Z A
0 Gauss		
0	0	0.063
1 Gauss		
0.431	0	0.063
3 Gauss		
1.263	0	0.063
10 Gauss		
3.967	0	0.063

Table 1: Current being used in each condition to produce the corresponding magnetic field in each axis. The letters X, Y, and Z describe the axes and the letter A describes current being used. Current was measured in Amperes.

RESULTS

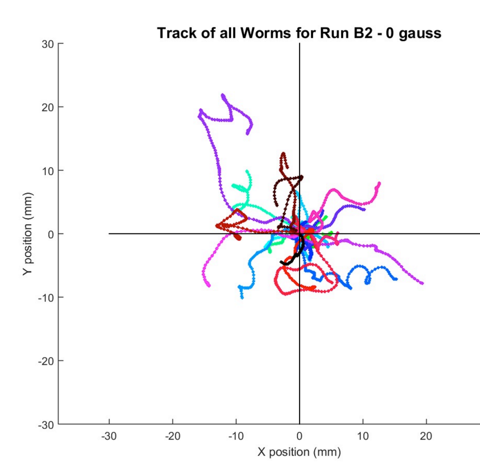


Figure 10. Oriented movement data of *C. elegans* under **0 Gauss** conditions.

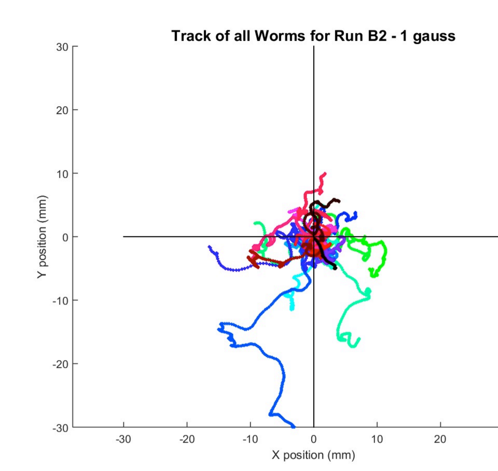


Figure 11. Oriented movement data of *C. elegans* under **1 Gauss** conditions.

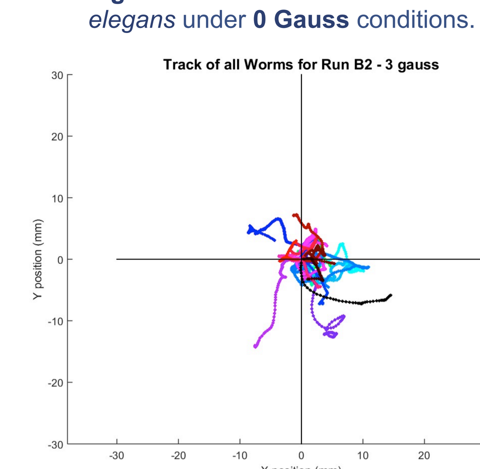


Figure 12. Oriented movement data of *C. elegans* under **3 Gauss** conditions.

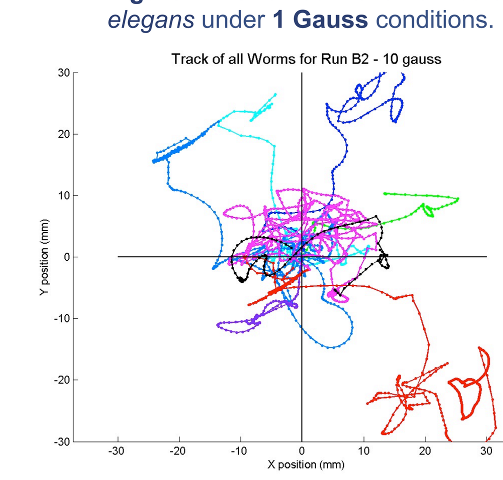


Figure 13. Oriented movement data of *C. elegans* under **10 Gauss** conditions.

- C. elegans' behavior under 0 Gauss (no magnetic field) was random as expected. No particular direction was favored by the worms.
- Under 1 Gauss conditions, which most resemble the Earth's natural magnetic fields, there were two paths favoring the downward direction, but most of the paths were random.
- Under 3 Gauss conditions, no particular direction was favored.
- Under 10 Gauss conditions, the worms' behavior was more active than the other conditions, possibly due to the intensity of magnetic field, but we still do not see any direction specifically favored.

CONCLUSIONS

Our experimental results do not reveal a significant southward trend as proposed by the Vidal-Gadea et al. study (2015); however, neither do they demonstrate our hypothesized diverging trend.

Thus, we cannot clearly define C. elegans' behavior in response to magnetic stimulation. This could be due to the following reasons:

1. Two diverging conical moving patterns are difficult to observe on a two-dimensional agar plate. More accurate visibility might be possible in a three-dimensional environment.
2. If the observed burrowing pattern is correct, then the conditions of our induced environment might not have been tailored accurately enough to mimic the natural habitat of the worms.
3. There might have been discrepancies in the images taken: while images are easy to analyze, they cannot capture worm movement in real-time as accurately as in videos.

Ultimately, while our burrowing migration results were largely inconclusive, they do reveal that the C. elegans specimens display more sensitivity under certain Gauss conditions as opposed to others, suggesting the possibility of further experimentation.

FUTURE EXPERIMENTS

In order to more accurately gauge how the C. elegans worms respond to magnetic stimuli, a new study might place them in a three dimensional environment to better imitate their natural environment in accordance to the Earth's configuration.

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