Damped Sine Wave Fit of *Caenorhabditis elegans* Movement in Electric Field

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INTRODUCTION

Caenorhabditis elegans is a model organism in neuroscience. Its neural circuit consists of 302 neurons, which has been completely mapped. Under electric field, *C. elegans* migrates toward the negative pole with opening angles proportional to the strength of the applied electric field (Fig. 1, Gabel et al. 2007).

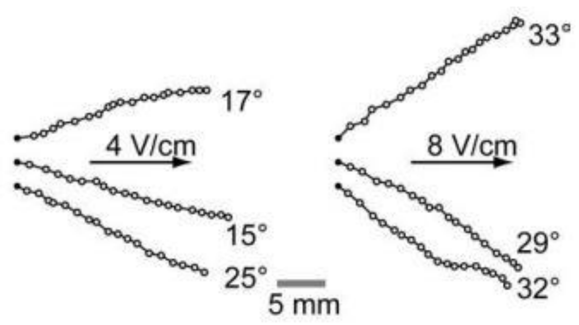


Fig 1. C. elegans *crawl towards the negative pole (to the right) under 2 different electric fields. The angle between each track and the respective electric field direction is indicated. Figure from Gabel et al. (2007)*

However, the "motional attractors" of *C. elegans* undergoing stimulation in an electric field have not been clearly studied. A *C. elegans* in free motion follows a sine wave model (Berri et al. 2009). However, under electric field stimulation, the posterior half of the worms' body was observed to be immobile though the anterior was not. The worms might be partially paralyzed by the electric field

HYPOTHESES AND PREDICTIONS

Hypothesis #1

C. elegans exhibits damped oscillation during electric field stimulation.

Predictions

- A damped sine wave model is a better fit than a sine wave for body movement of *C. elegans* under an electric field.
- The reduced chi squared value for the damped sine wave fitting of a worm's motion under electric field will be significantly closer to 1 than that of a sine wave fitting of a worm's motion.

Hypothesis #2

C. elegans becomes more paralyzed as the magnitude of the applied electric field increases

Predictions

Damping coefficient of the wave function representing *C. elegans* motion increases as the magnitude of the electric field increases

EXPERIMENTAL SET-UP

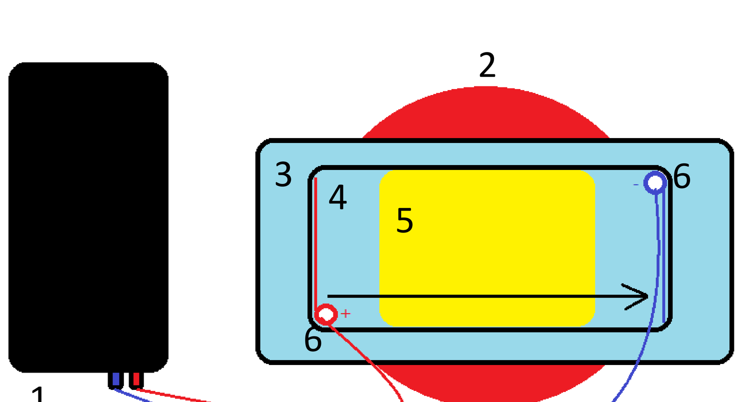
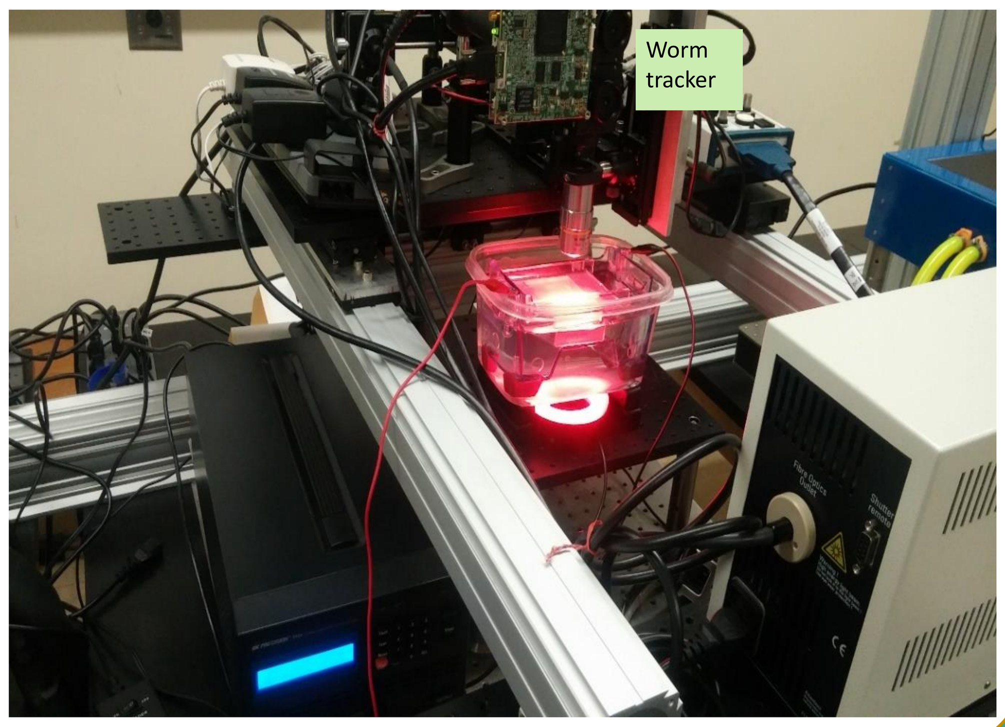


Fig 2. Diagram of electrotaxis experimental setup (refer to Gabel et al. 2007). Black arrow indicates the direction of the electric field
1. Power Source
2. Light source
3. Salt water bath for cooling and conducting current
4. Electrophoresis chamber
5. Agar pad with C. elegans
6. Electrodes

Fig 3. Electrotaxis experimental setup with wormtracker on top

*Field of view: 3mm * 3mm*
*Resolution: 1020px * 1020px*



METHODS

- Each sample of *Caenorhabditis elegans* contained five to ten individuals.
- Each worm was subjected to electric fields between 4 V/cm and 12 V/cm for 1 minute at each electric field value,
- Magnitude of the electric field across the agar was verified using a voltmeter.
- For each sample, an average of three worms could be tracked for free motion and electrotaxis behavior.
- Videos were analyzed with MATLAB
- The wave equation of the worm movement:

$$y = Ae^{-Bx}\sin\left(2\pi\left(\frac{x}{\lambda} - ft + \phi\right)\right)$$

Where B is the damping coefficient.

RESULTS

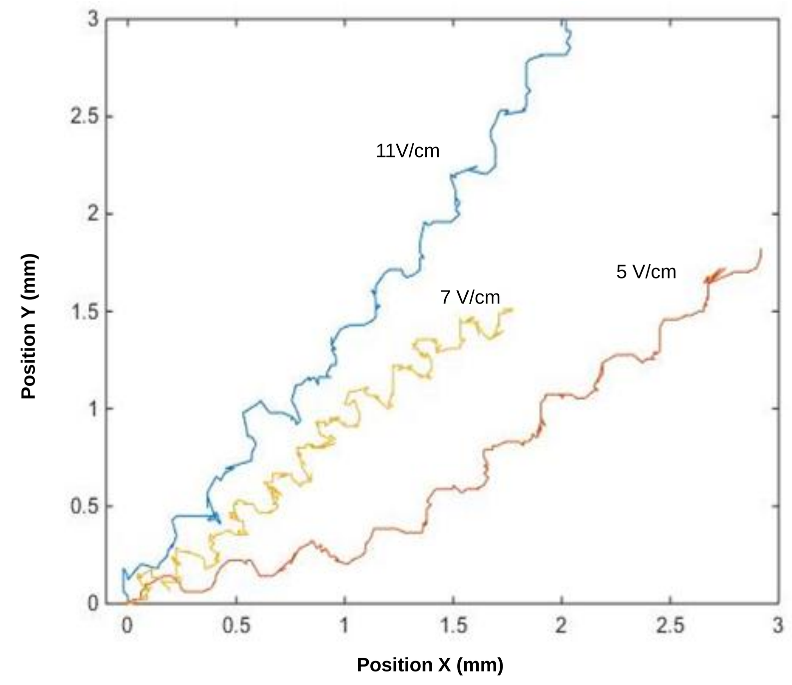


Fig 4. Typical tracks of C. elegans *under different electric fields. The horizontal axis is parallel with the direction of the electric field. Negative pole is in the +x direction. The tracks were reconstructed from the recorded videos using MATLAB.*

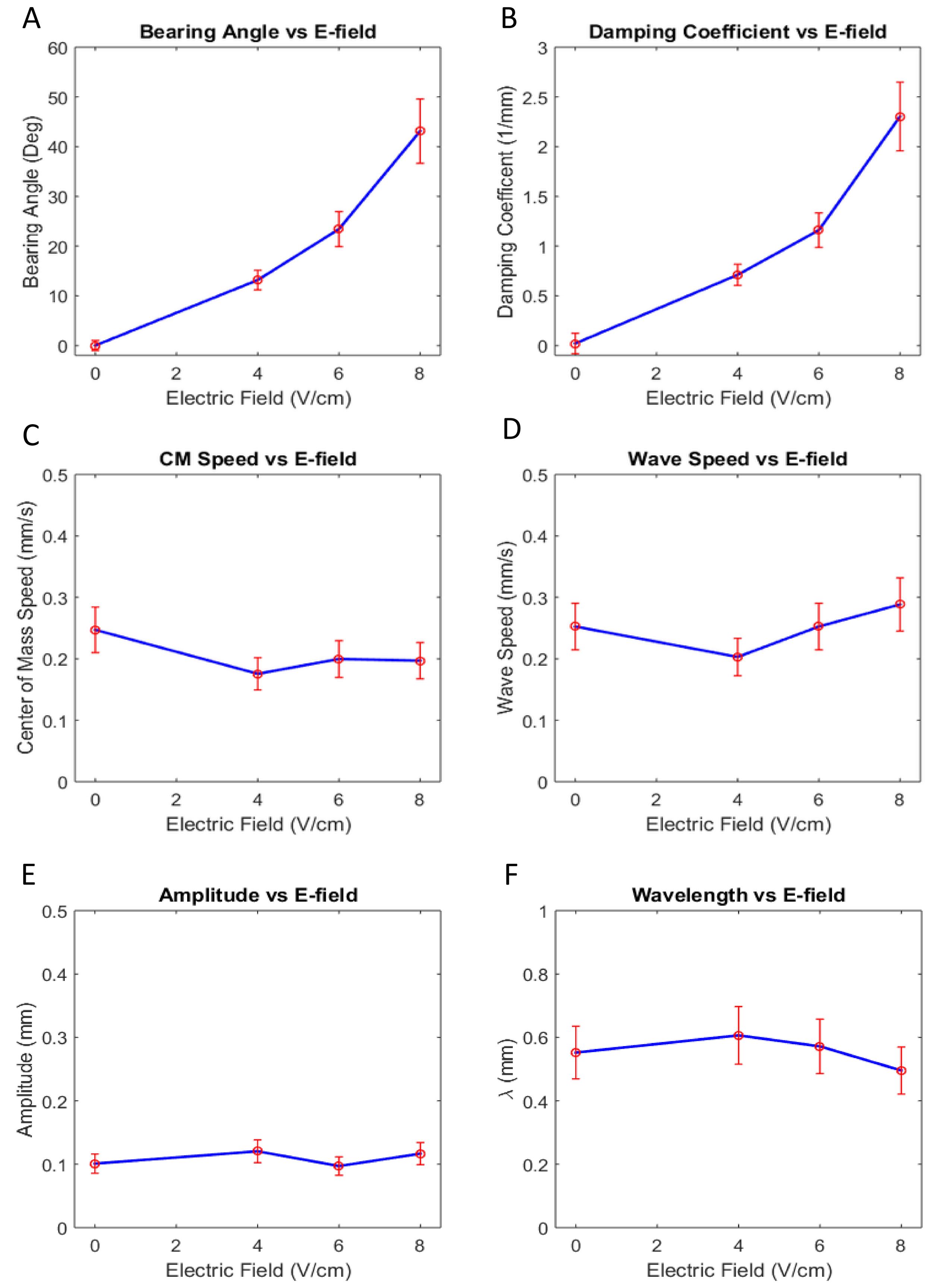


Fig 5. Regression of 4 different variables on the magnitude of the applied electric field (E)
A. Bearing angle vs E
B. Damping coefficient vs E
C. Center of mass speed vs E
D. Wave speed vs E
E. Amplitude vs E
F. Wavelength vs E

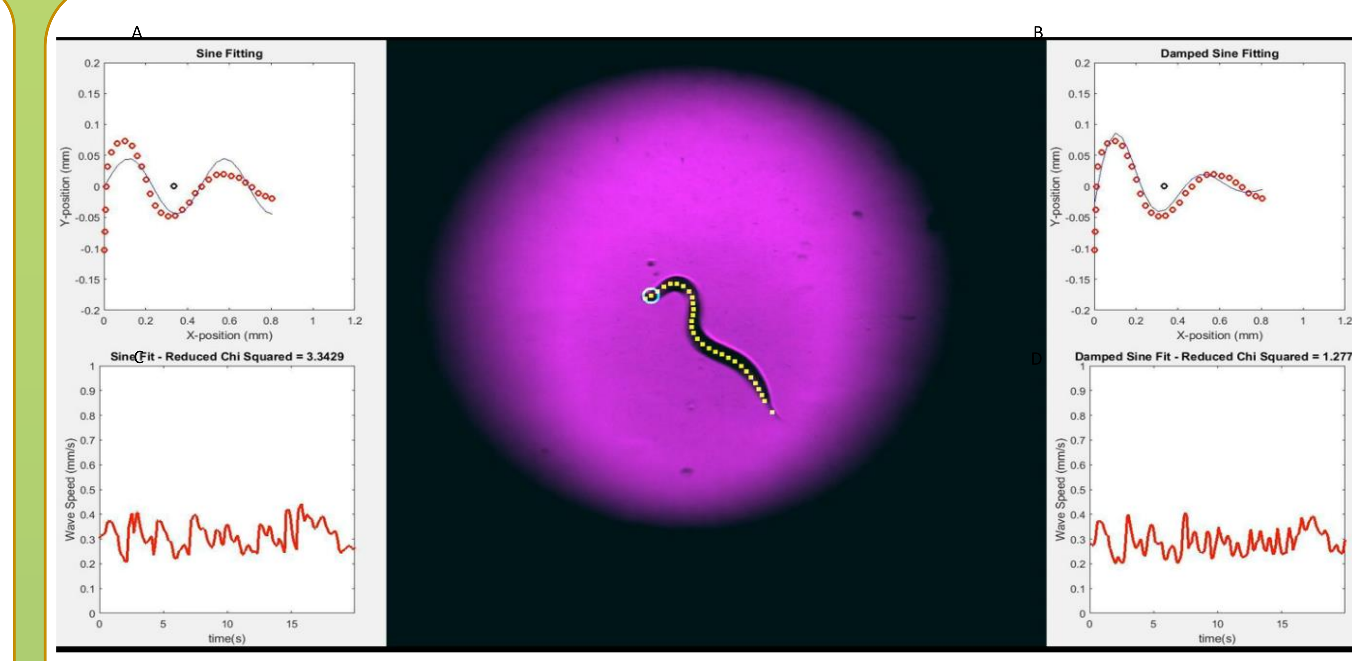


Fig 6. C. elegans *being tracked during electric field stimulation at E = 8 V/cm (central image) with a worm-tracking microscope. Series of yellow dots represents the skeleton fit of the worm.*
(A) Sine wave and (B) Damped sine wave plot of worm movement using skeleton fit at 1 instance with respective chi-squared values.
(B) Wave speed of C. elegans *vs time in sine wave model*
(C) Wave speed of C. elegans *vs time in damped sine wave model*

DISCUSSION & CONCLUSIONS

- As magnitude of the electric field (E) increased, the worms' bearing angle also increased (Fig. 5A). This agreed with the study of Gabel et al. (2007).
- There is no correlation between E and the worm's center of mass speed (Fig. 5C), wave speed (Fig. 5D), wave amplitude (Fig. 5E), wavelength (Fig. 5F)
- The movement of *C. elegans* under electric field fits significantly better in damped sine wave model than in sine wave model, with chi-square value of 1.3 and 3.3 respectively.
- The damping coefficient is positively correlated with the magnitude of the applied electric field (fig 5B).
- The hypotheses are therefore supported by the data.

FUTURE DIRECTIONS

- Scan a larger range of the electric field magnitude (E), from 4 V/cm to 14 V/cm, increment of 2 V/cm.
- Look for an explanation for the positive correlation between worms' moving angle and E, possibly due to drag of damping coefficient
- Observe flashing patterns of the worms' neurons, especially ASJ and ASH, during electric field stimulation using cyan fluorescent protein (CFP) tag

REFERENCES

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