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Changes in the velocity of an approaching object are tracked by a locust motion-sensitive visual interneuron

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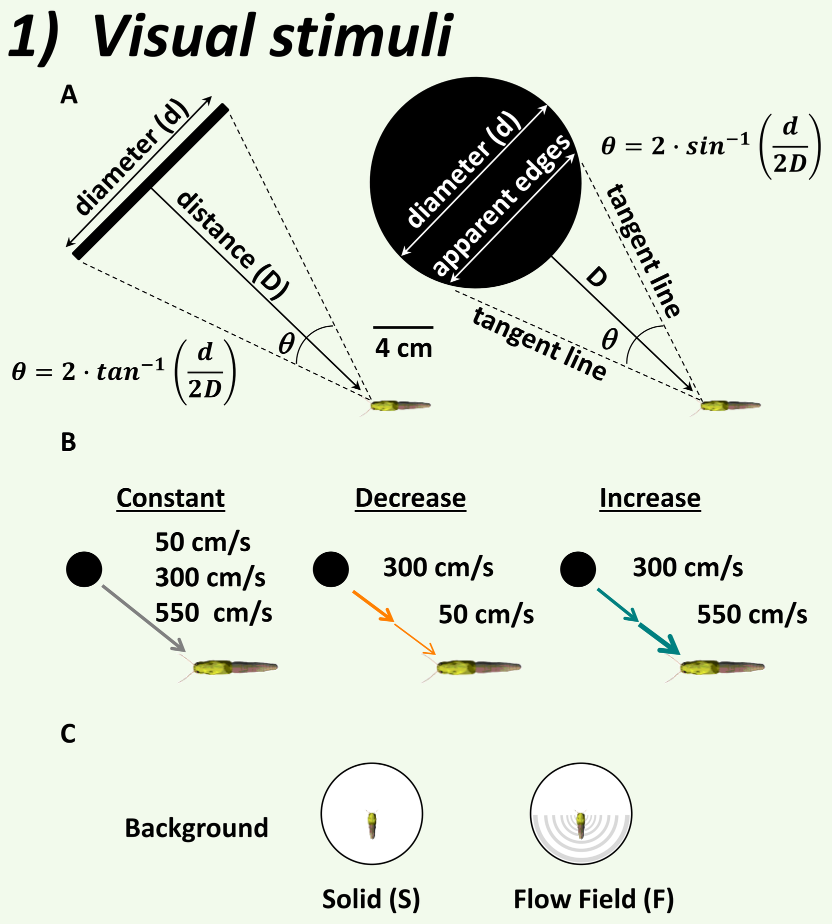
Introduction

Animals in their natural environment are continually challenged with variable, 3-D visual cues that may represent a threat, such as approaches of a predator. A locust motion-sensitive visual neural pathway, the Lobula Giant Movement Detector (LGMD) and its postsynaptic partner, the Descending Contralateral Movement Detector (DCMD), respond robustly to objects approaching on a collision course[1] and the time of peak DCMD firing during an approach is related the ratio of the half size of the object (l) to the absolute approach velocity $|v|$[2]. Many previous studies challenged this pathway with approaches of 2-D shapes approaching at constant velocity. To test for effects of simulated 3-D shapes on the relationship between peak time and $l/|v|$, we recorded from DCMD while presenting a simulated looming disc or sphere at constant velocities. To test for effects of object velocity changes, we presented a looming sphere that increased or decreased in speed during approach. These experiments further explore the ability of this well described pathway to encode complex object motion.

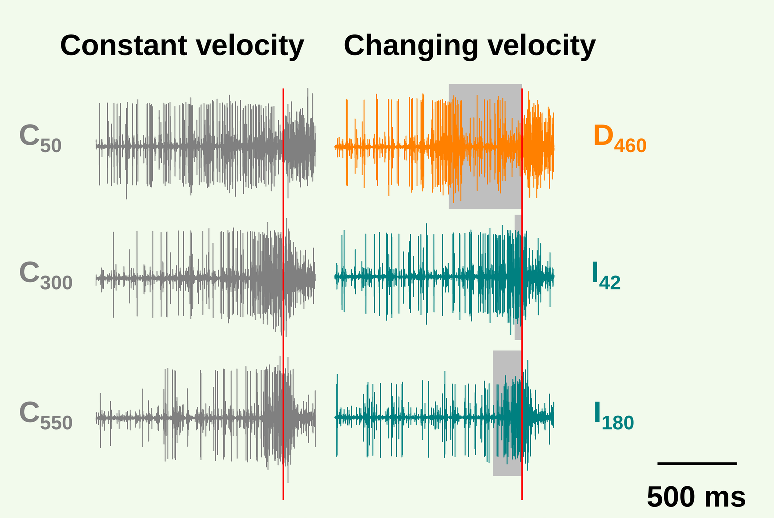
Materials and Methods

1) Visual stimuli



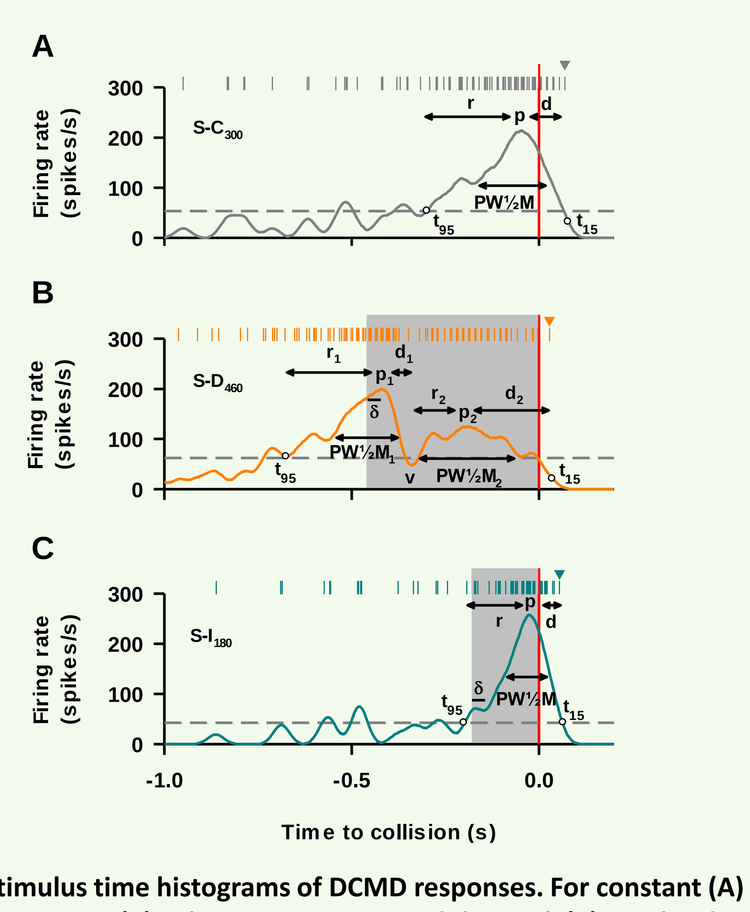
We presented a disc or sphere (A) approaching at constant or changing velocities (B) against a solid or flow field background (C).

2) Sample DCMD recordings



DCMD responded with spiking that increased leading up to time of collision (TOC), and varied based on stimulus type. Grey shading - time during final velocity after change. $C_{50, 300, 550}$ – constant velocity at 50, 300 or 550 cm/s, D_{460} – velocity decrease 460 ms before TOC, $I_{42, 180}$ – velocity increase 42 or 180 ms before TOC.

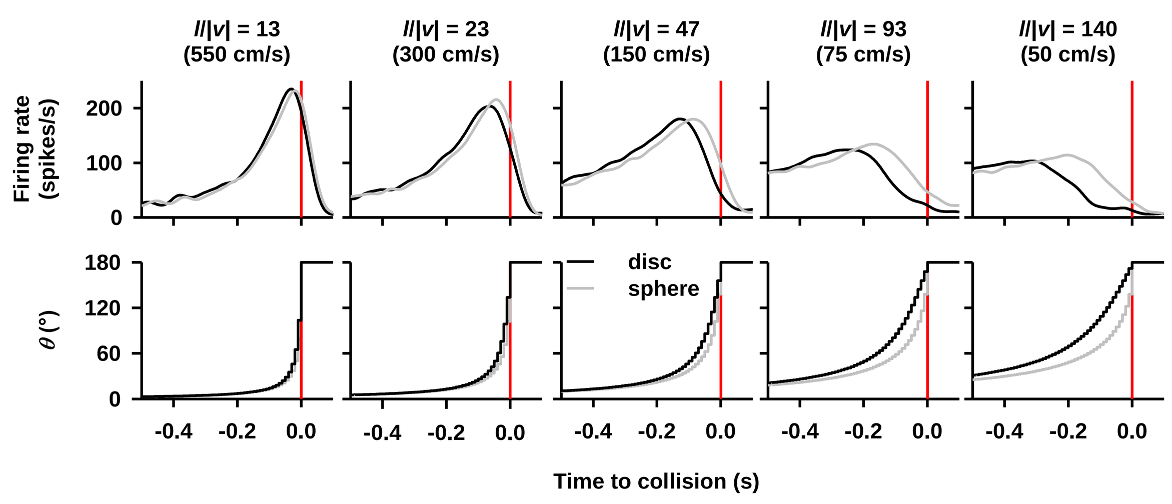
3) DCMD firing parameters

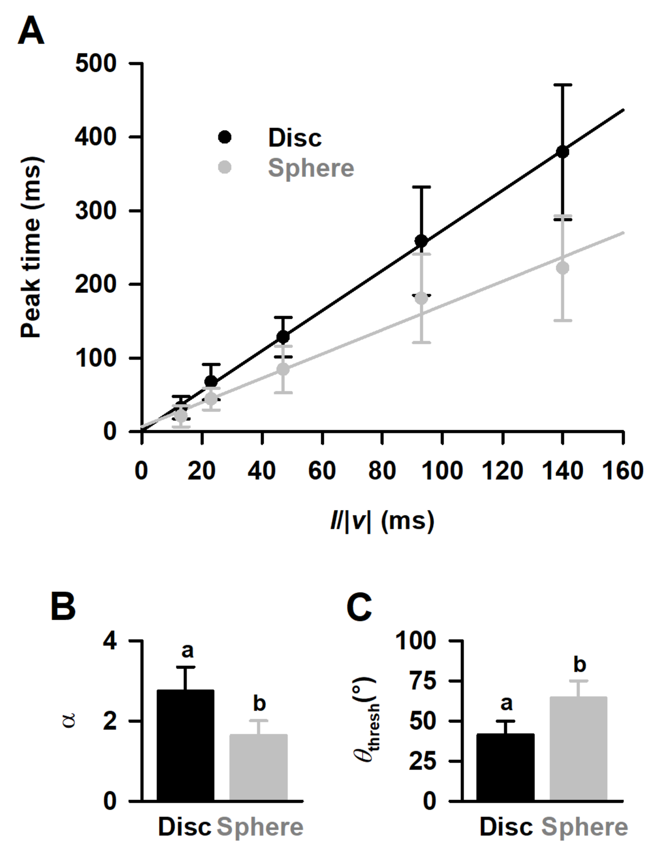


Peristimulus time histograms of DCMD responses. For constant (A) and increasing (C) velocities we measured the peak (p) amplitude and time, the peak width at half maximum (PW½M), the number of DCMD spikes, and the rise (r) and decay (d) phases. For a decreasing velocity (B), we measured the same parameters, as associated with each of the two distinct firing rate peaks.

Results

4) Object shape affects relationship between peak firing time and $l/|v|$





TOP:

For a given value of $l/|v|$, a sphere evokes later DCMD peak firing compared to a disc. Top row of plots show the mean PSTH in response to approaches at five values of $l/|v|$ (and corresponding velocity in cm/s). N = 42 approaches pooled from 3 velocity replicates for each of 14 locusts. Bottom row of plots show the change in subtense angle (θ) for each value of $l/|v|$. Data from an approach of a disc or sphere are shown as black or grey lines, respectively. The red vertical lines indicate time of collision.

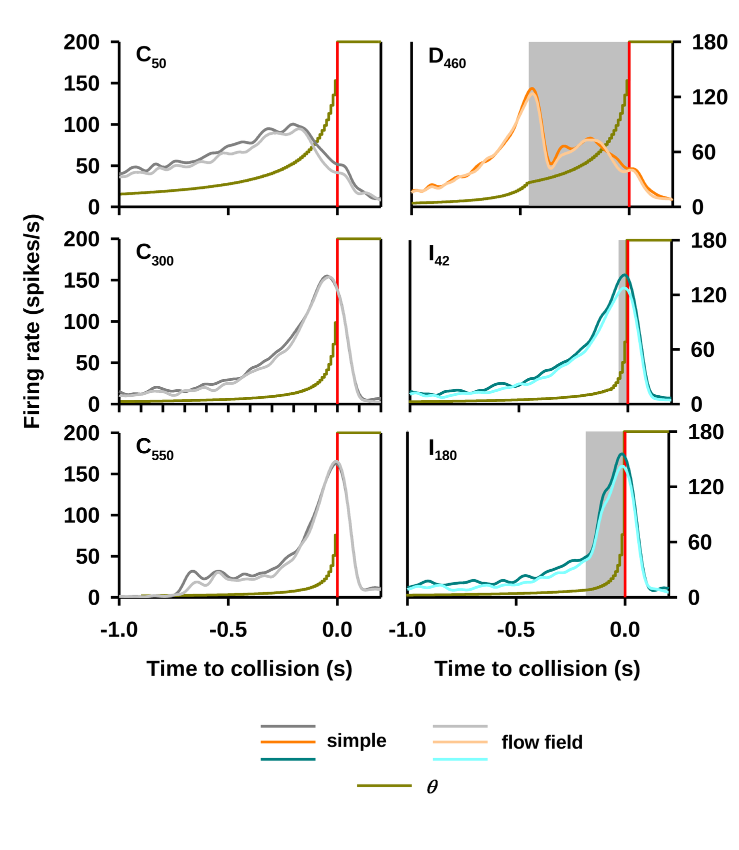
LEFT:

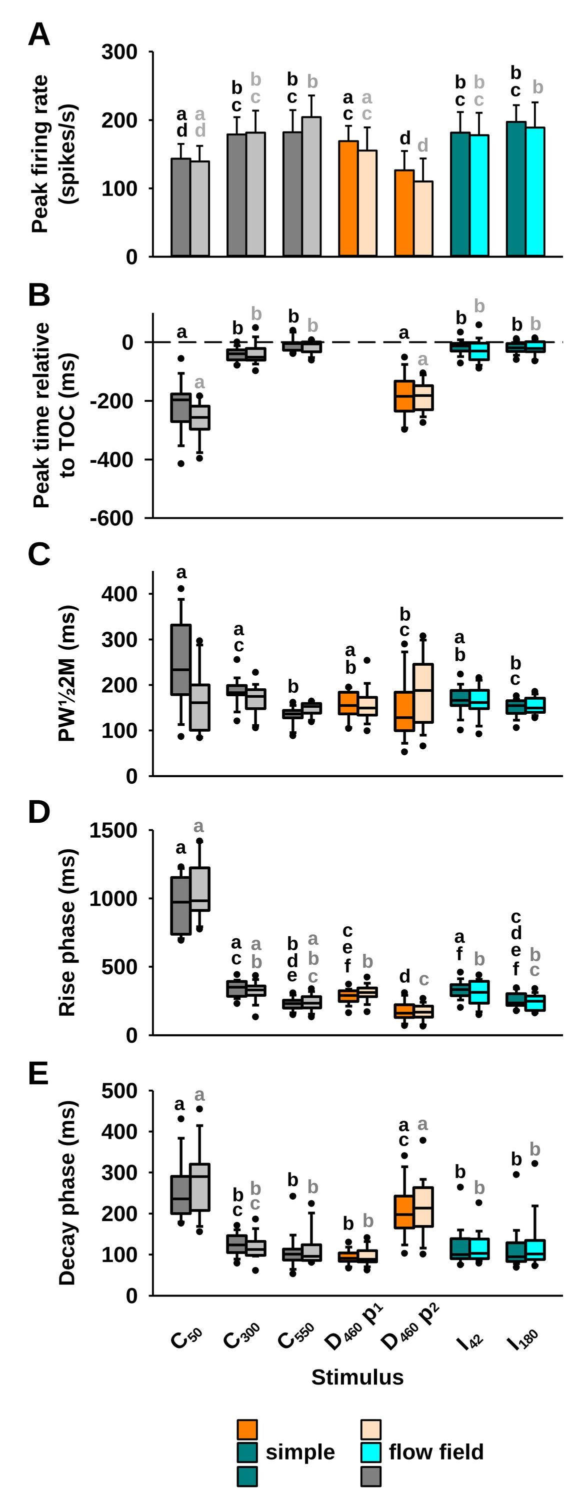
Object shape effects the relationship between $l/|v|$ and peak firing times. A) Circles and error bars (disc - black, sphere - grey) represent the mean $\pm$ SD (N = 14 locusts). Peak-time for each locust was calculated from the mean of the three replicates of each stimulus. Regression lines were calculated using the peak time from each approach (N = 35 - 42) for each value of $l/|v|$. B) Mean regression lines from each locust show that the slope (α) was significantly lower in response approaches of a sphere (student's t-test). C) The threshold angle for peak firing was calculated as:

$$\theta_{thresh} = 2 \cdot tan^{-1}\left(\frac{1}{\alpha}\right)^{(2)}$$

and the mean was significantly higher for a sphere. Different letters above each bar represent a significant difference. Error bares represent $\pm$ SD.

5) DCMD responses to constant velocity approaches and velocity changes





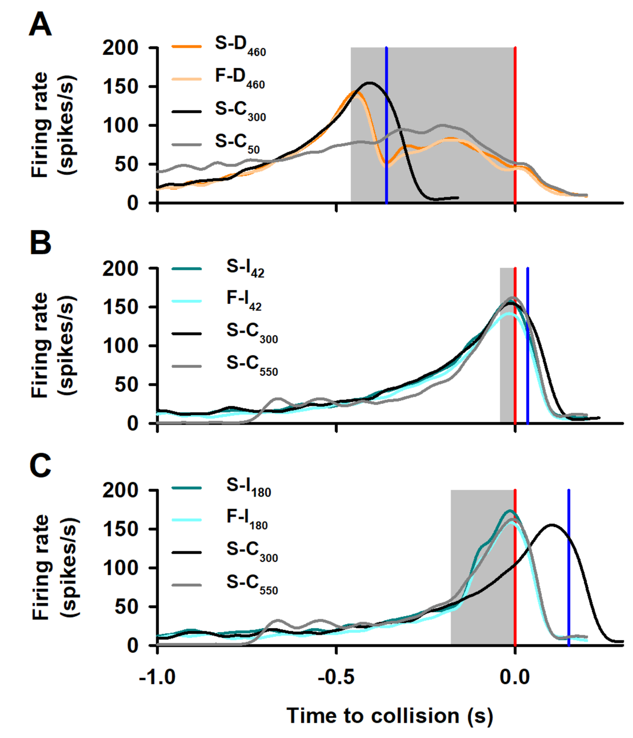
LEFT:

Mean DCMD responses to approaches at constant or changing velocities against a simple or flow field background. PSTHs used a 1 ms bin width and were smoothed with a 50 ms gaussian filter. For each panel, the lines depicting the PSTH (grey, orange, or cyan) refer to approaches against a solid background (darker shade) or a flow field background (lighter shade). Gold lines indicate the time-aligned subtense angle (θ). Red vertical lines indicate TOC and the grey shaded areas indicate the time window when the sphere travelled at the slower or faster approach velocities.

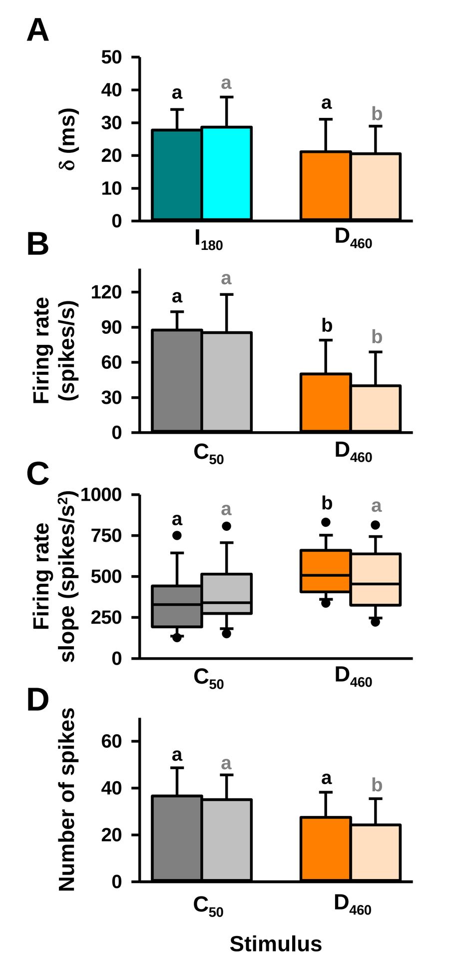
RIGHT:

Summary of DCMD firing parameters. A) Peak firing rate, B) Time of peak firing, C) PW½M, D) Rise phase, E) Decay phase. Parametric data (A) tested with a One-Way ANOVA follow by a Holm-Sidak multiple comparison between stimulus conditions (presented as means plus positive S.D). Non-parametric data (B-E) tested with a Kruskal-Wallis One-Way ANOVA on Ranks followed by a Dunn's multiple comparison between stimulus conditions (presented as box plots with median line, 25th and 75th percentile as box boundaries, 10th and 90th percentiles as error bars, and outliers as small filled circles). There were no significant differences in any parameter between matched stimuli against a simple or flow field back ground. Different letters above bars or boxes represent significant differences within each background type.

6) Velocity changes modulate responses to looming



Overlays of DCMD responses to a velocity decrease (orange) or increase (cyan) with time-adjusted responses to associated constant velocities. Black = 300 cm/s, grey = 50 cm/s (A) or 550 cm/s (B, C). Red line is TOC, blue line is shifted TOC for C_{300}.



Response delay and comparison of time matched firing rate properties in response to constant and decreasing velocities. A) Response delay (δ, see 3B,C) for the valley in I_{180} (cyan) and the first peak in D_{460} (orange). B) Firing rate at the time of the valley in response to a decreasing velocity (orange) and at the corresponding time (calculated for each locust) in response to C_{50} (grey). C) Slope of line from the time of the valley to the time of the second peak for D_{460} and over the same time for C_{50}. D) Number of spikes from the valley to TOC for D_{460} and over the same time for C_{50}. Dark and light shades for each colour represent data from simple and flow field background conditions, respectively.

Summary/Conclusions

- Object shape affects the relationship between object expansion and peak DCMD firing times, subsequently affecting the threshold angle for evoking the peak.
- An instantaneous velocity decrease evokes a temporary decrease in the DCMD firing rate.
- An instantaneous velocity increase advances DCMD peak firing.
- Effects of velocity changes are likely mediated through delayed effects on inhibitory circuits.

References and Acknowldegements

[1]Rind, F. C. and Simmons, P. J. (1992). Orhtopteran DCMD neuron: a reevaluation of responses to moving objects. I. selective responses to approaching objects. *J. Neurophysiol.* 68, 1654–1666.

[2]Gabbiani, F., Krapp, H. G. and Laurent, G. (1999). Computation of object approach by a wide-field motion-sensitive neuron. *J. Neurosci.* 19, 1141.

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