Insect Physiology

Navigation by Odours

David Merritt

Major questions:

- How do insects use scents to move through the environment?
- How do insects use scents to reach a target?
- How important is scent for navigation vs scent to assess food quality?

Attributes of odours as orientation signals

+

Transmission across a long range
Transmission across physical barriers
Can be used in darkness
Able to discriminate based on volatile composition

−

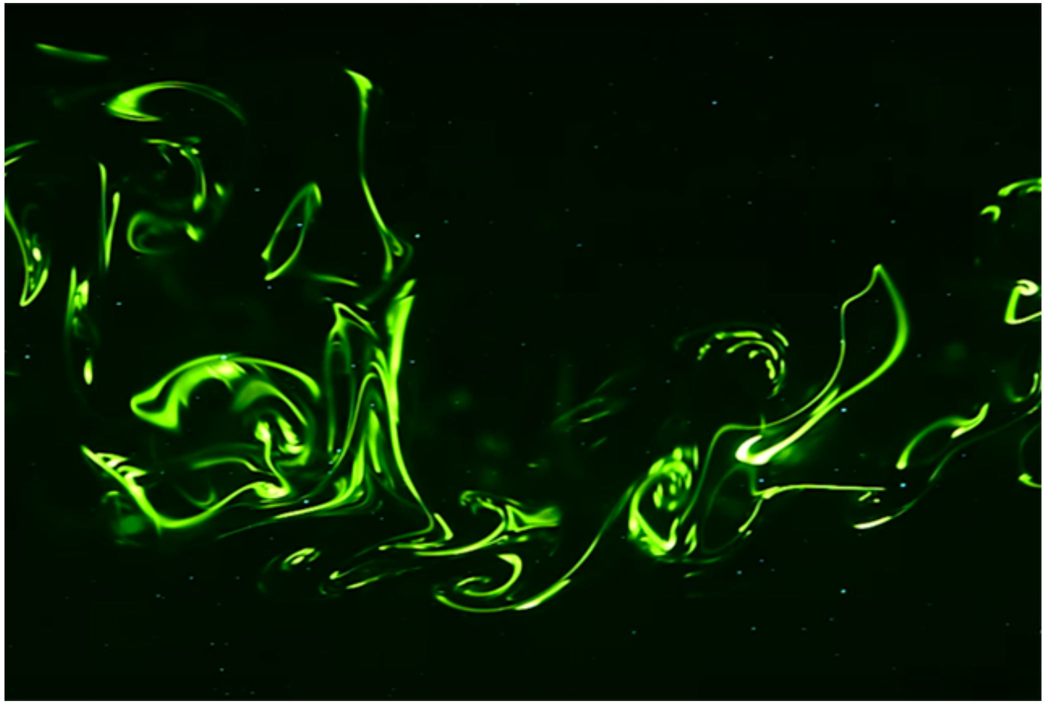
Slow to move
Diluted by distance
Temporary
Localisation of source can be difficult

Compare these attributes with other sensory modalities such as sound, vision, gustation

Odour gradients

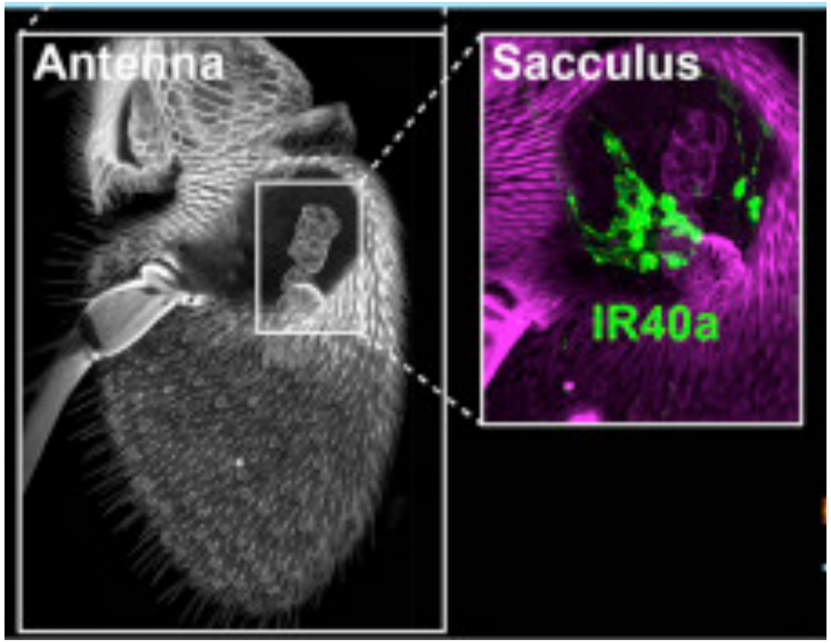
- Molecular diffusion eventually leads to even concentration, no gradient
- But odorants are distributed according to diffusion *and* fluid dynamics
- Odour plumes are due to the movement of the medium (air or water) according to fluid dynamics

- Fluid dynamics, turbulence, rotations of air masses, 3D whirlpools or eddies
- Filaments of concentrated volatiles –> intermittent detection



Orientation in Odour Plumes

- Boundary layer is a layer of reduced movement adjacent to a substrate
- Antennae have a boundary layer, depending on size and surface microstructure
- Sense organs in pits exploit the boundary layer
- Sacrifice rapid detection for slow detection but not subject to short term inaccuracies



Humidity receptor sensilla in the sacculus
IR40a is an ionotropic receptor detecting humidity

Orientation in Odour Plumes

Chemical Information

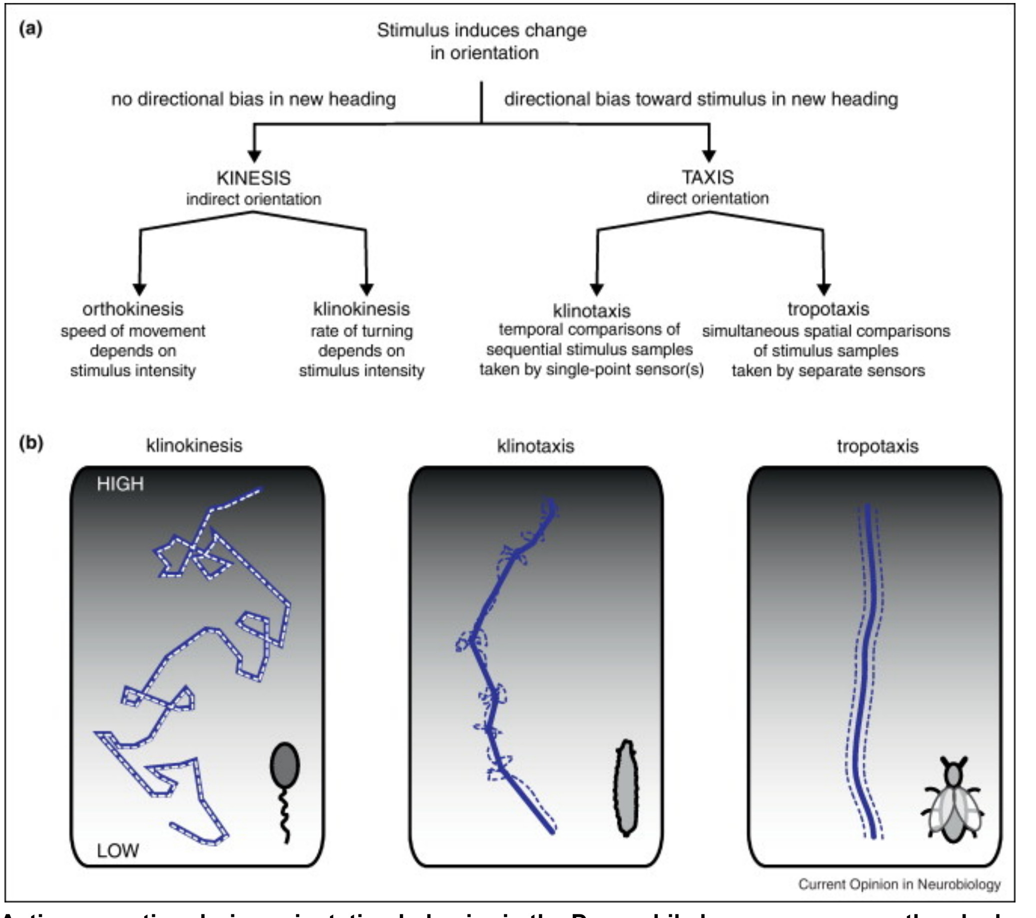
- Presence/absence: switch to vision when a signal is detected
- Concentration gradient: how to know what direction to go?
- Intermittency

Fluid flow information

- Direction of flow detected visually. Detect fixed points in landscape. Flying animals need to be able to distinguish air-flow created by movement of odour plume from their own movement within the medium
- Direction of flow detected by other sensory systems such as mechanoreceptors, antennal deflection

Navigating Odour Plumes

1. Commonly, animals move upwind or upstream on detecting odourant
2. Sometimes regularly turn across the plume
3. **Taxes** refer to the ability to direct motion relative to the source of stimulation, e.g., up or down a chemical gradient. **Directed reactions**. Chemotaxis
4. Klinotaxis: orientation by alternating lateral deviations (zig-zag)
5. Tropotaxis: orientation by turning to the more or less stimulated side
6. **Kineses** are generally reserved for situations in which some measure of locomotory output increases or decreases, but the resulting motion is random with respect to the stimulus source. **Undirected reactions**.

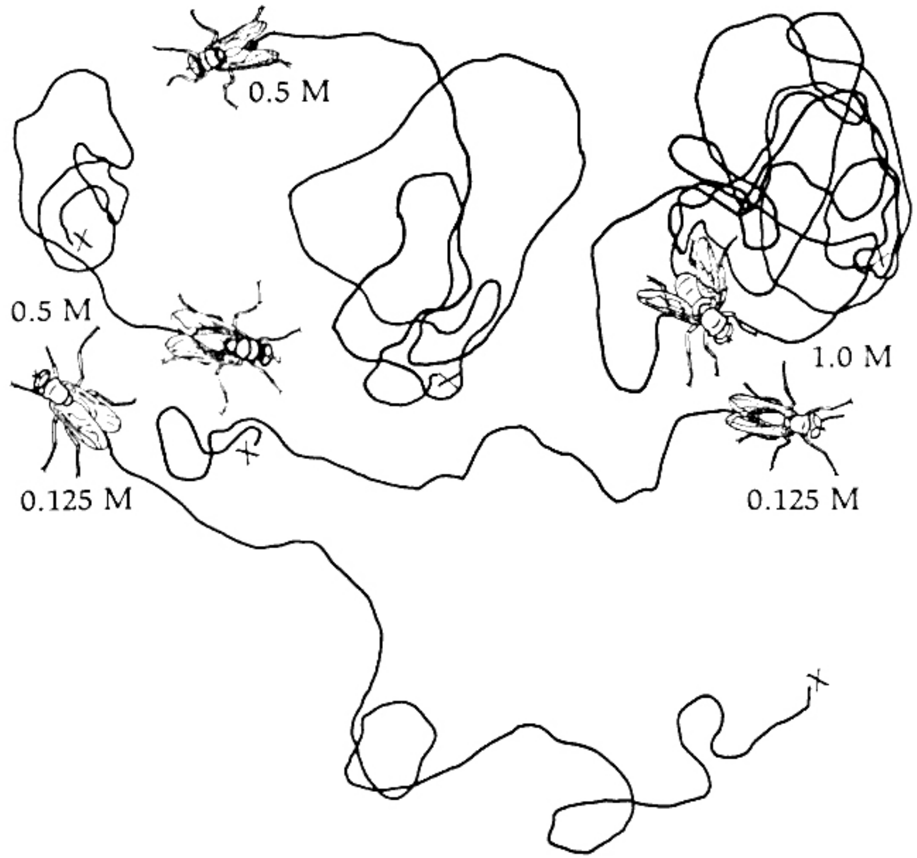


Active sensation during orientation behavior in the Drosophila larva: more sense than luck

http://dx.doi.org/10.1016/j.conb.2011.11.008

Navigating Odour Plumes

Kineses are generally reserved for situations in which some measure of locomotory output increases or decreases, but the resulting motion is random with respect to the stimulus source. **They are undirected reactions**.



On encountering a drop of sugar-water a hungry fly starts a series of turns whose tightness and duration depends on sugar concentration. Leads to an apparent “search” pattern through klinokinesis

Know it is not a “real” search pattern because it persists if the insect is moved to a different location

Navigating Odour Plumes

Rheotaxis (face flow direction)

or

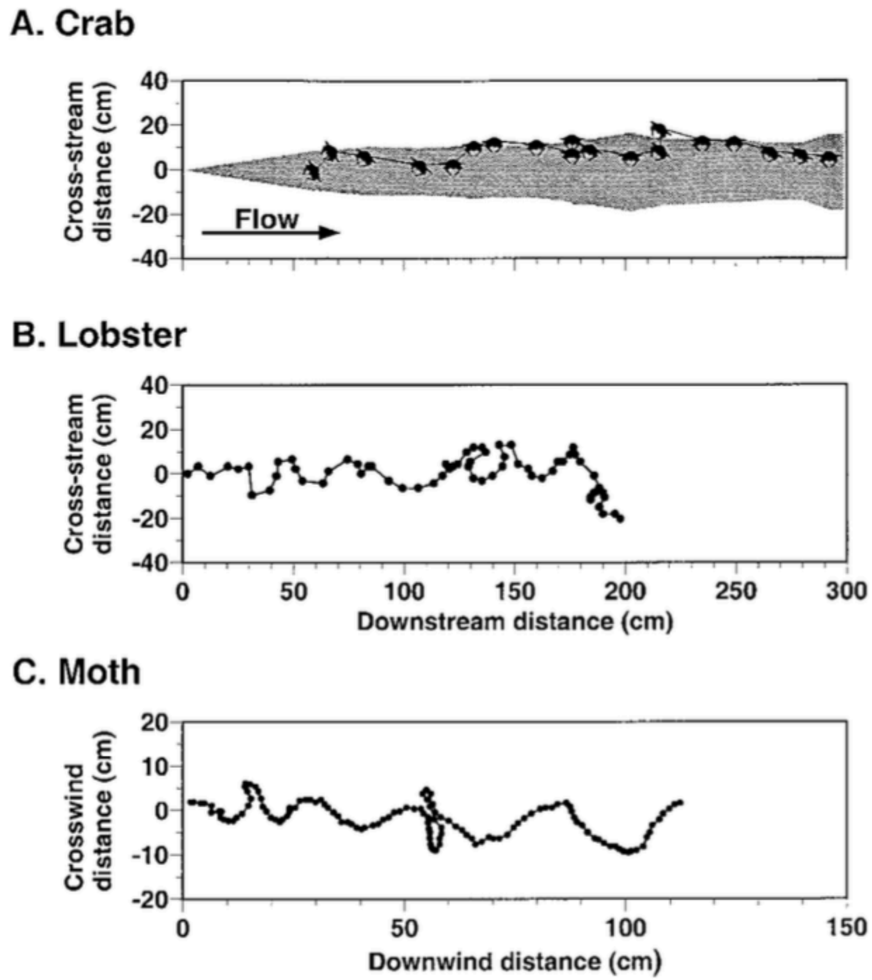
Chemotaxis (lateral gradient)

Chemotropotaxis (simultaneous, spatial comparisons of chemical signals)

Chemoklinotaxis

Optomotor anemotaxis

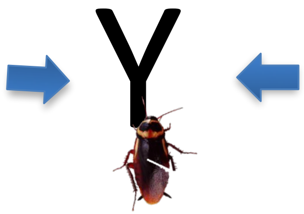
Counterturning (=zig-zag)

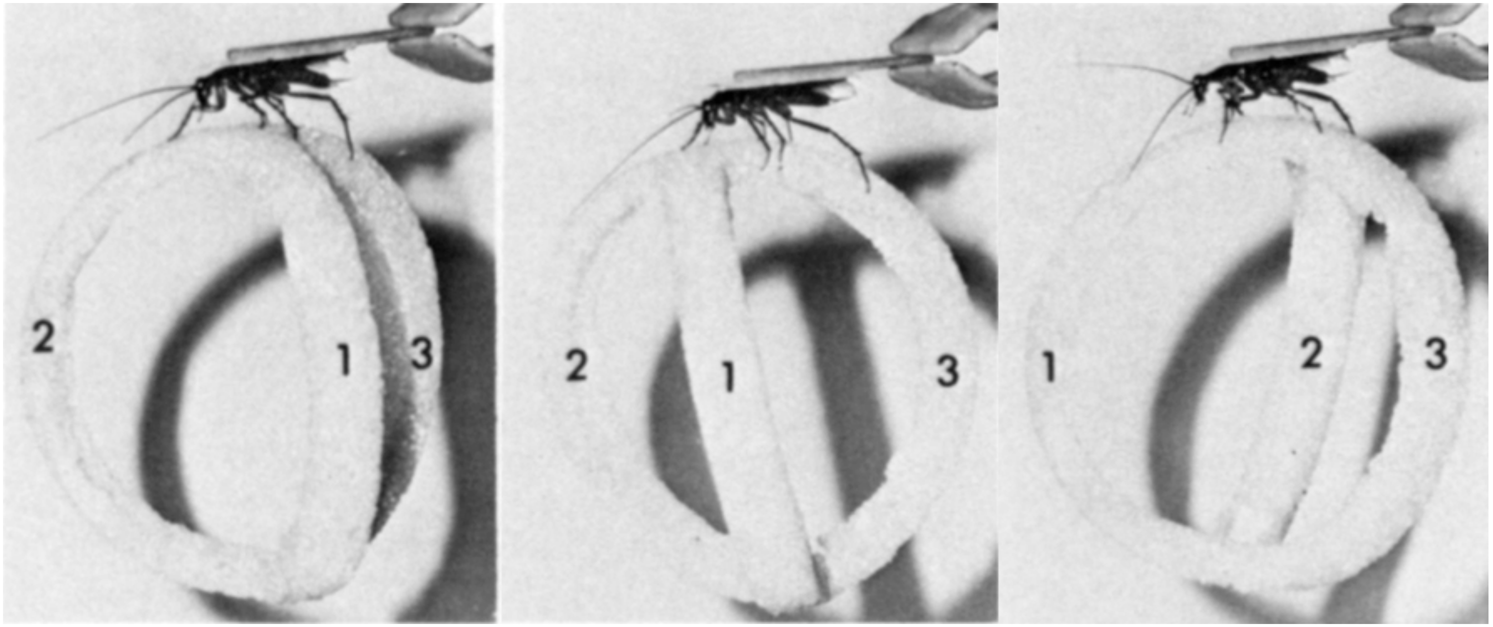


Vickers NJ (2000) Mechanisms of animal navigation in odor plumes. The Biological Bulletin 198:203-212

Methods for tracking paths

Cockroach chemo-anemotaxis





Rust & Bell (1976)

Male cockroach has choices on a “Y-ring globe”: when pheromone in air current, turns toward the side receiving the air current. chemoanemotaxis

Are these experimental results reliable? Consider design of lighting, acclimatisation, experimental repeats

Methods for tracking paths

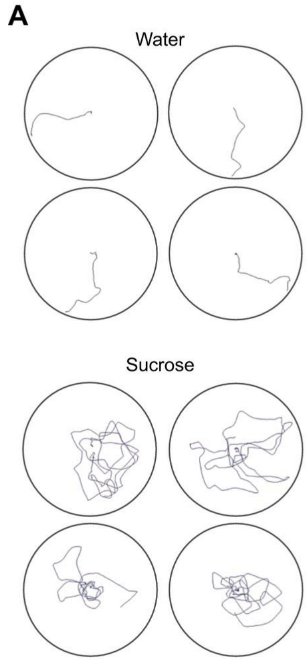
Fictrac developed at QBI allows camera to record path of insect by rotating a styrofoam ball.

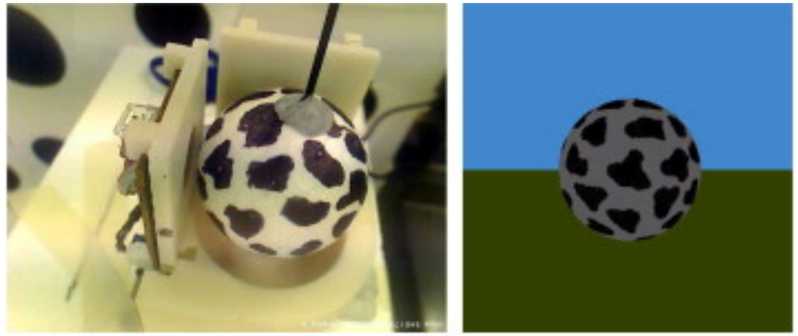
Insect is fixed.

Open loop (no visual feedback) v closed loop (visual feedback)

So far used for visual orientation experiments, not odour orientation.

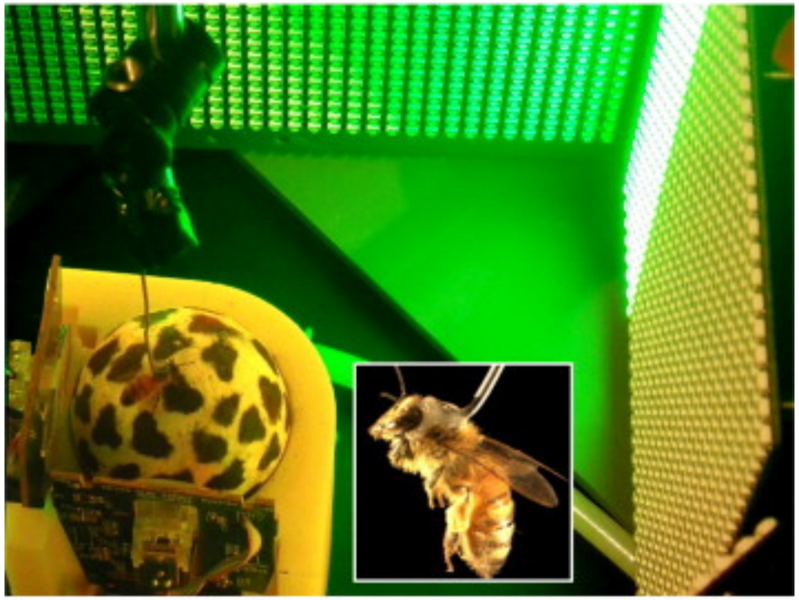
Fee-moving insects tracked using video analysis





(a) Raw input frame during calibration.

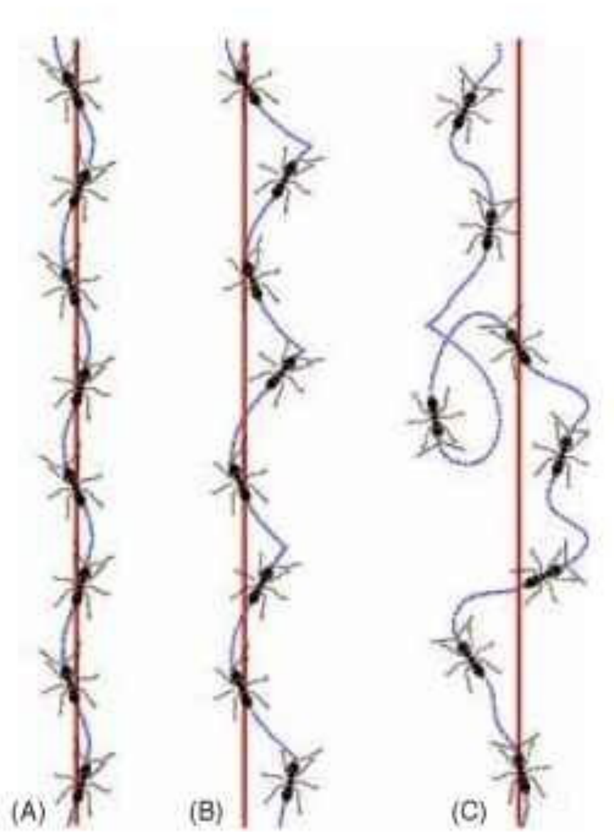
(b) Rendered frame.



(c) Tethered walking preparation for the honeybee.

Moore RJ, Taylor GJ, Paulk AC, Pearson T, van Swinderen B, Srinivasan MV (2014) FicTrac: a visual method for tracking spherical motion and generating fictive animal paths. J Neurosci Methods 225:106-119

Odour-guided navigation in Ants



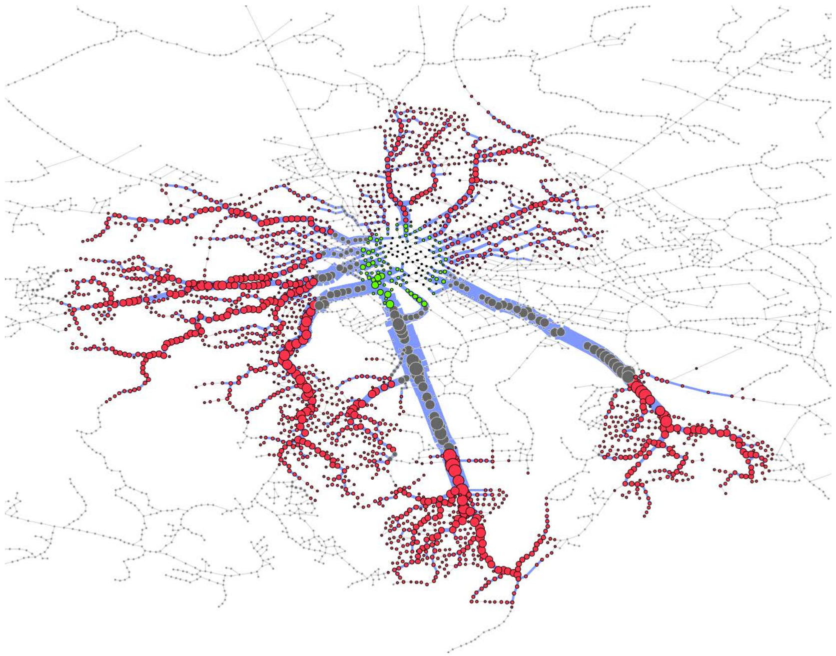
A. Normal path

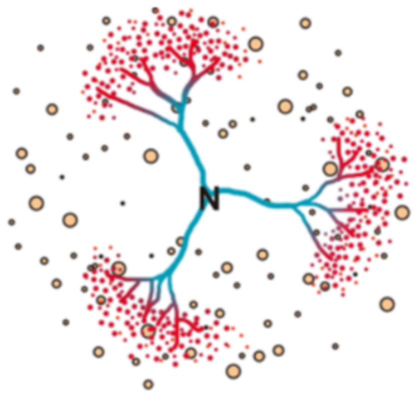
B. Left antenna removed: veer to the intact side

C. Antennae crossed then glued

Tropochemotaxis: simultaneous sampling, two sensory inputs

Odour-guided navigation in Ants





Pheromone trails are short-lived, refreshed by use

Y

Foraging trails tend to be tree-like (dendritic)

Possibly polarised due to angle of branching:

(1) direction is toward food source; ants have choices based on similar angles

(2) nest direction, one acute angle and one obtuse angle

Odour-guided navigation in cockroach

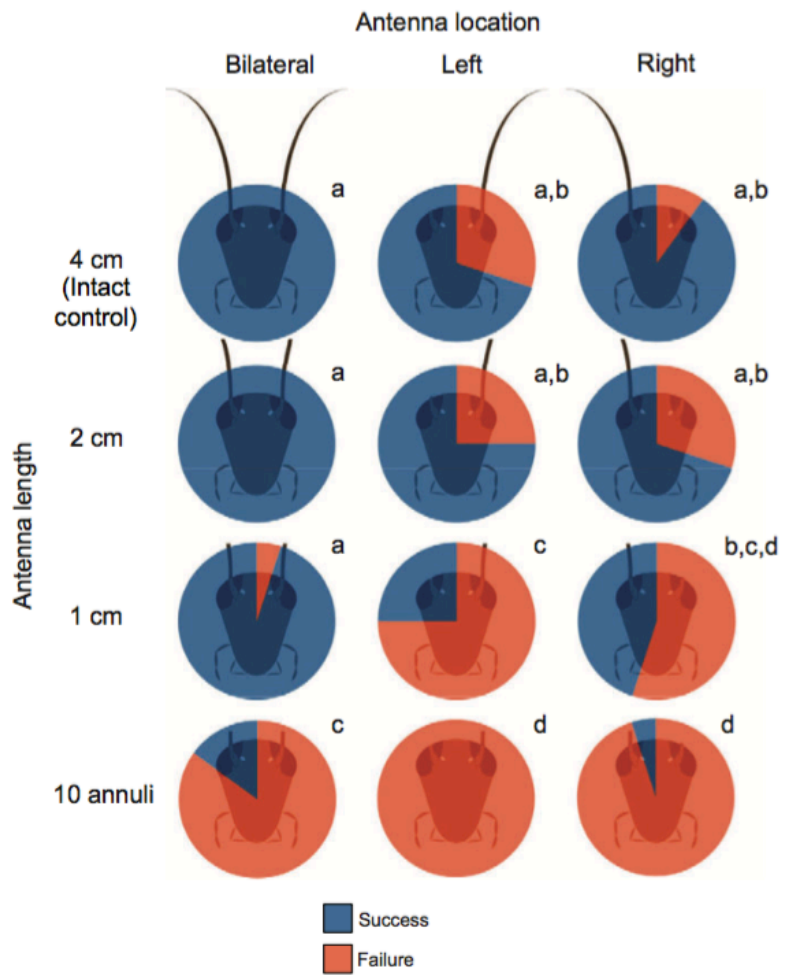
Antenna length, not bilateral symmetry, is most important in cockroach odour tracking

Animals with one antenna can track odour: no L or R bias

Animals with longer antennae perform better

Animals with same total length of antenna are similar in performance

Same letters means not statistically different

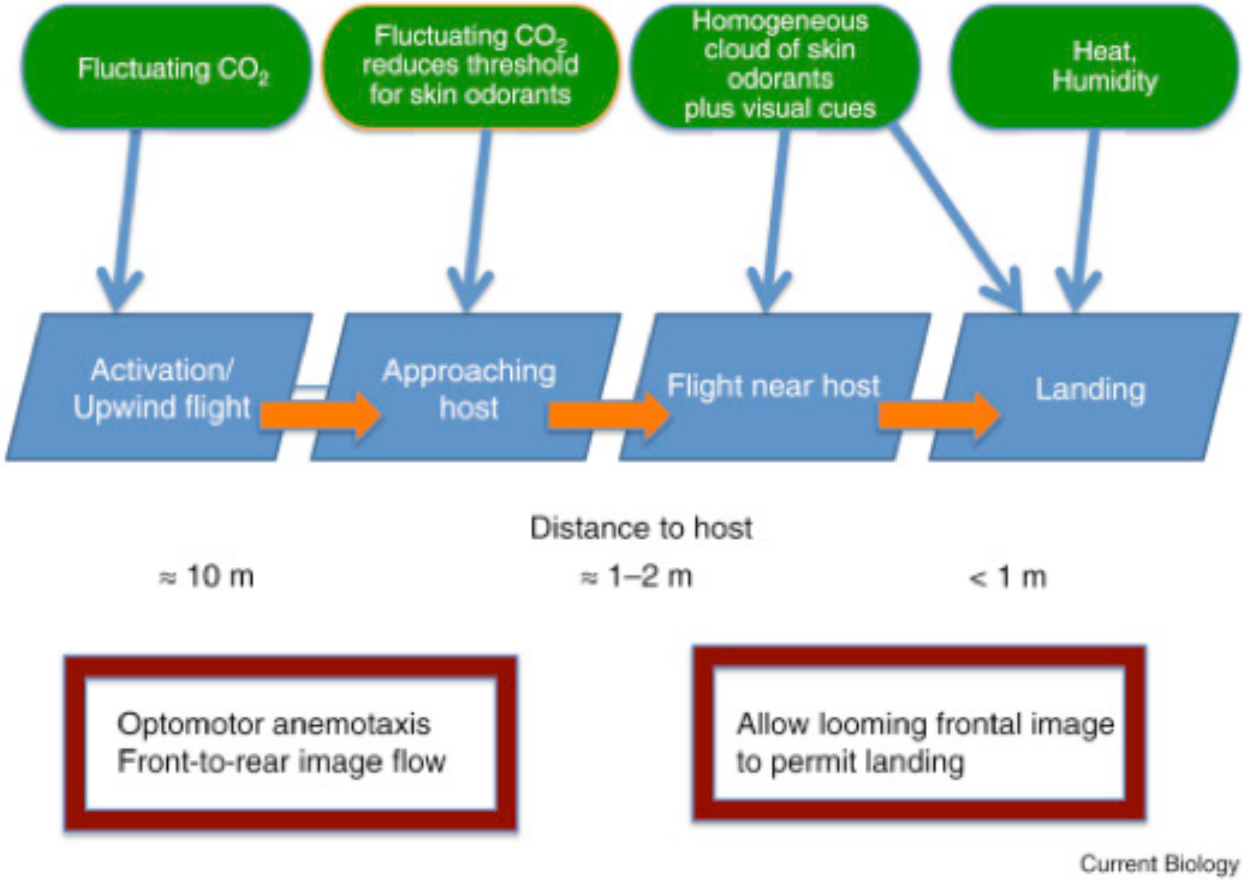


Odour-guided navigation in Moth

Odour encountered: optomotor anemotaxis: move upwind as calculated from visual flow

No odour encountered: counterturn (cast) until odour detected -> surge

Odour-guided navigation in Mosquitoes



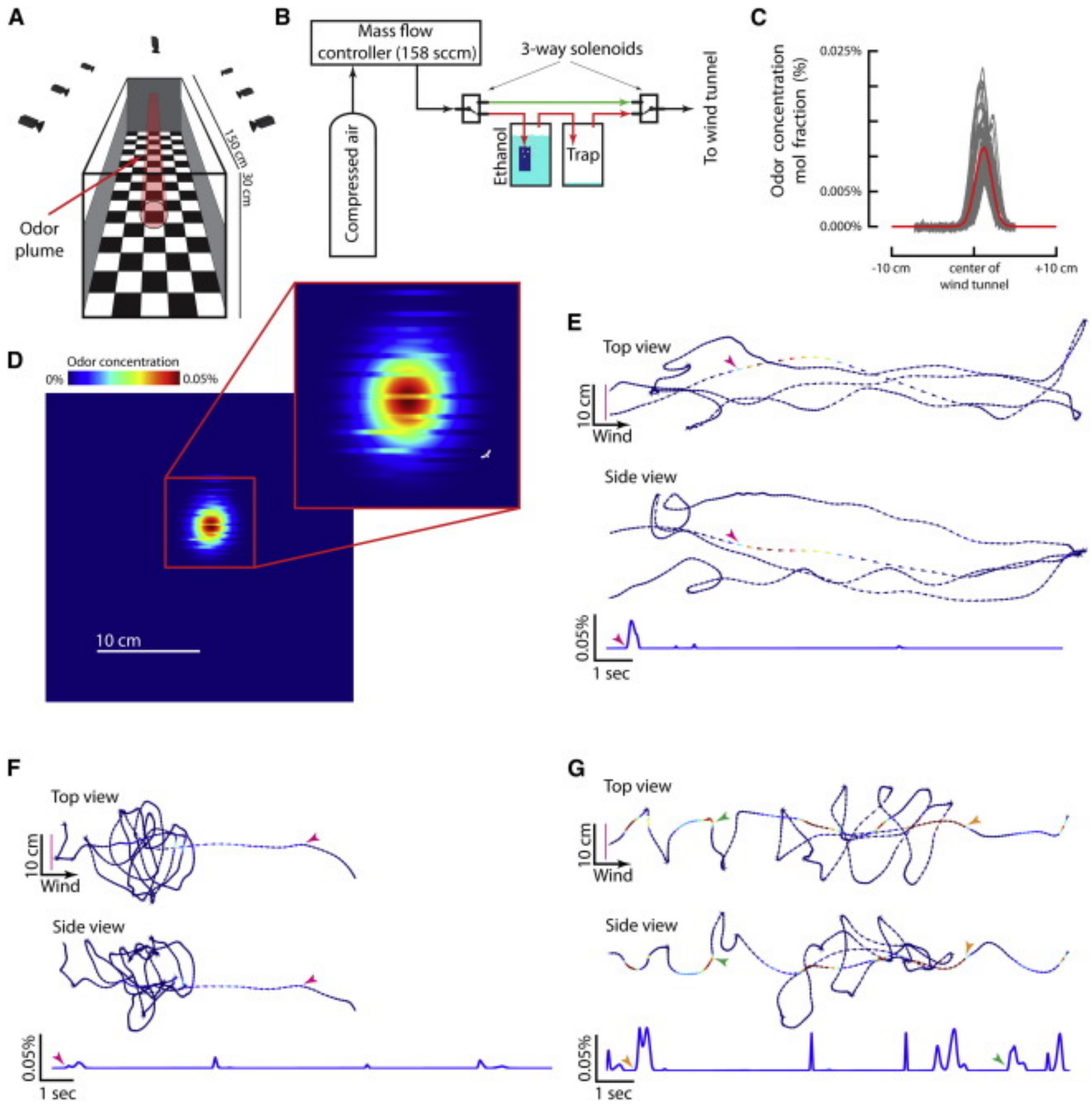
Odour-guided Navigation in Drosophila

(1) 190 ms after ***encountering*** a plume, flies **increase their flight speed and turn upwind**, **using visual cues to determine wind direction**. Due to this substantial response delay, flies pass through the plume shortly after entering it.

(2) 450 ms after ***losing*** the plume, flies initiate a series of vertical and horizontal casts, **using visual cues to maintain a crosswind heading.**

(3) After sensing an attractive odor, flies exhibit an **enhanced attraction to small visual features**, which increases their probability of finding the plume's source.

(4) Computer modelling showed these delays are close to optimal for following plume



(E) Example from pseudoplume of clean air.

(F) Example from pulsed ethanol plume.

(G) Example from continuous ethanol plume.

van Breugel, F. and Dickinson, M. H. Plume-Tracking Behavior of Flying Drosophila Emerges from a Set of Distinct Sensory-Motor Reflexes. *Curr. Biol.* **24**, 274–286.

http://what-when-how.com/insects/orientation-insects/

Michael Dickinson TED talk c 15 min https://youtu.be/e_44G-kE8lE

van Breugel, F. and Dickinson, M. H. Plume-Tracking Behavior of Flying Drosophila Emerges from a Set of Distinct Sensory-Motor Reflexes. *Curr. Biol.* **24**, 274–286.

Lockey JK, Willis MA (2015) One antenna, two antennae, big antennae, small: total antennae length, not bilateral symmetry, predicts odor-tracking performance in the American cockroach *Periplaneta americana*. J Exp Biol 218:2156-2165

Luca Turin https://youtu.be/yzOcvINn8Iw