MEMORY, LEARNING, AND INSECT BEHAVIOUR

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Angelique Paulk

Objectives

- How does learning and memory operate at the behavioral level?
- How can you train an insect?
- What are the different types of memory?

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Learning, memory, and everything else insects do!

- Learning and memory enables insects to adapt to their environment, their situations, and to become one of the most successful groups on the planet.
- To study learning and memory, researchers have focused on two main model species:

1. The vinegar fly *Drosophila melanogaster*
2. The honeybee *Apis mellifera*

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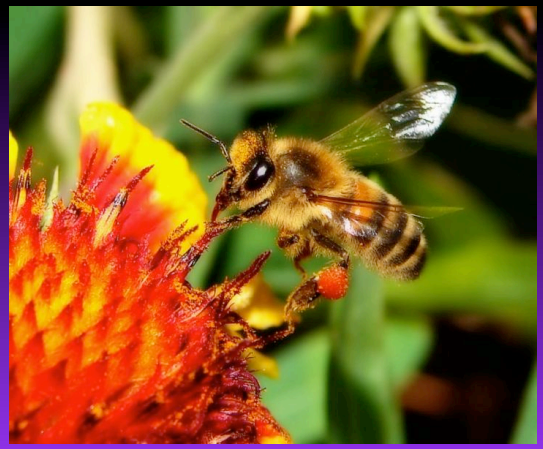

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The vinegar fly *Drosophila melanogaster*: a model for understanding the role of genetics in learning and memory

- *Drosophila melanogaster* has been essential for understanding the function of synapses, of neurons, and various aspects of the nervous system

- The genetic 'toolkit' available for studying the genetic mechanisms underlying behaviour has allowed researchers to dissect neural circuits while looking at animal behaviour

- The learning and memory assay: the Tully paradigm to train large groups of flies to associate an odour with electrical foot shock

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http://en.wikipedia.org/wiki/Drosophila

Learning and memory: How to train a fly

- The study of learning and memory have been addressed in *Drosophila* using the olfactory shock treatment
- Using this population approach, numerous learning and memory mutants have been found.

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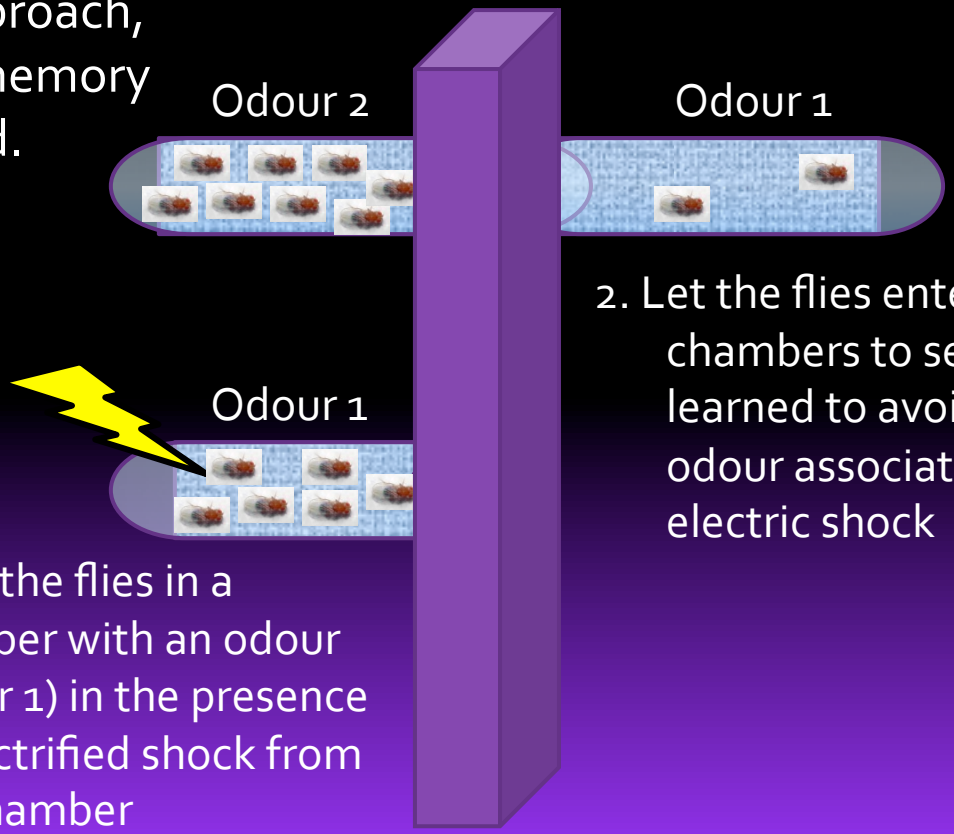

1. Place the flies in a chamber with an odour (odour 1) in the presence of electrified shock from the chamber

2. Let the flies enter two chambers to see if they learned to avoid the odour associated with electric shock

http://en.wikipedia.org/wiki/Drosophila

Learning and memory: How to train a fly

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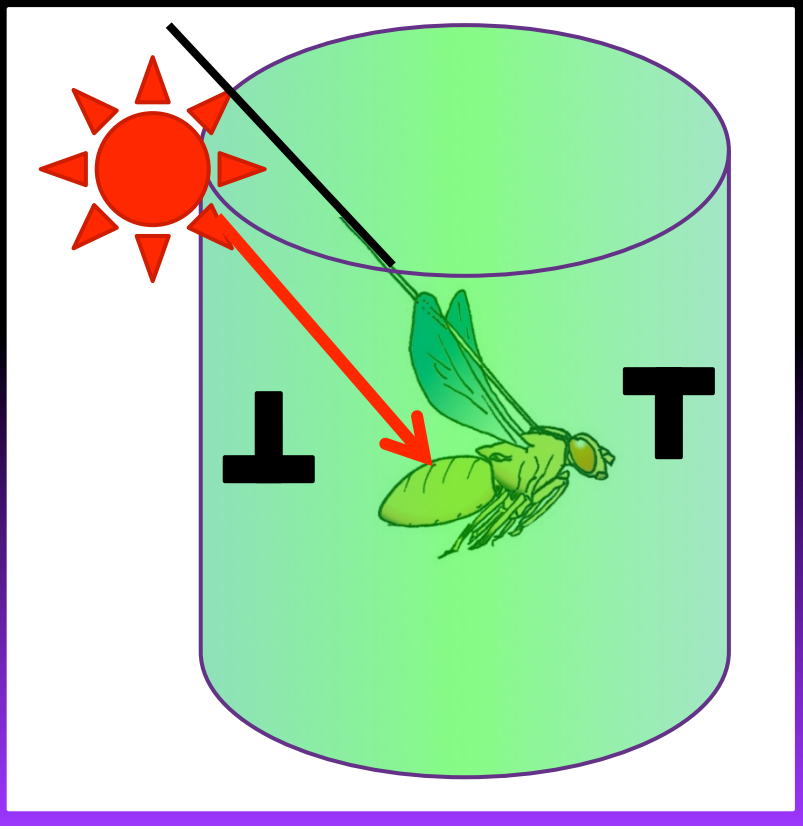
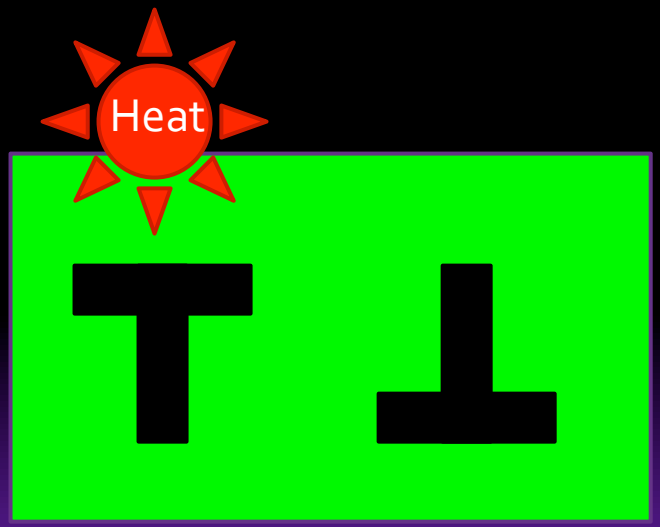
- Another setup involves tethering the fly to a post and using a torquemeter to detect when the fly tries to turn left or right, called the tethered flight arena setup
- Check out movies of this online: http://www.physci.ucla.edu/research/frye/movies.htm
- The fly can be trained to avoid 'looking' at one object when the object is associated with heat





Avoidance No avoidance

Liu G, Seiler H, Wen A, Zars T, Ito K, Wolf R, Heisenberg M, Liu L (2006) Distinct memory traces for two visual features in the *Drosophila* brain. Nature. 439:551-556.

The honeybee *Apis mellifera:* a model for understanding learning and memory

- Honeybees have long been used and domesticated by humans for pollination.
- They forage from a central site, have to navigate a terrain, and learn optimal foraging approaches.
- They can be trained to learn colours, patterns, motion cues, etc.

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The honeybee *Apis mellifera:* a model for understanding learning and memory

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Karl von Frisch, the researcher who discovered the honeybee waggle dance, also found honeybees can detect colour by training them to coloured objects.

von Frisch K (1914) Der Farbensinn und Formensinn der Biene. Jb Abt Allg Zool Physiol 37: 1-238.
von Frisch K (1965) The Dance Language and Orientation of Bees. Cambridge: Belknap Witthöft W (1967) Absolute Anzahl und Verteilung der Zellen im Hirn der Honigbiene. Z Morph Tiere 61:160-184.

The honeybee *Apis mellifera:* a model for understanding learning and memory

- Honeybees can be trained to learn colours, patterns, motion cues, etc.
- Numerous researchers have found that honeybees can perform complex behavioural tasks:

Dyer AG, Chittka L (2004). Fine colour discrimination requires differential conditioning in bumblebees. Naturwissenschaften 91: 224-227.

Dyer AG, Rosa MGP, Reser DH (2008) Honeybees can recognise images of complex natural scenes for use as potential landmarks. J Exp Biol 211: 1180-1186.

Giger A, Srinivasan MV (1996) Pattern recognition in honeybees: chromatic properties of orientation analysis. J Comp Physiol A 178:763-769.

Giger AD, Srinivasan MV (1995). Pattern recognition in honeybees: eidetic imagery and orientation discrimination. J Comp Physiol A 176: 791-795.

Giurfa M (2007) Behavioral and neural analysis of associative learning in the honeybee: a taste from the magic well. J Comp Physiol A 193:801-24.

Giurfa M, Eichmann B, Menzel R (1996) Symmetry perception in an insect. Nature 382: 458-461.

Giurfa M, Zhang SW, Jennett A, Menzel R, Srinivasan MV (2001) The concepts of sameness and difference in an insect. Nature 410:930-933.

Lehrer M, Srinivasan MV, Zhang SW, Horridge GA (1988) Motion cues provide the bee's visual world with a third dimension. Nature 332:356-357.

Srinivasan MV (1993) Pattern recognition in the honeybee: recent progress. J Insect Physiol 40:183-194.

Srinivasan MV, Lehrer M (1988) Spatial acuity of honeybee vision and its spectral properties. J Comp Physiol A 162: 159-172.

Srinivasan MV, Zhang SW (1998) Probing perception in a miniature brain: Pattern recognition and maze navigation in honeybees. Zoology 101:246-259.

Srinivasan MV, Zhang S, Altwein M, Tautz J (2000). Honeybee navigation: nature and calibration of the 'odometer'. Science 287: 851-853.

Srinivasan MV, Zhang SW, Bidwell NJ (1997). Visually mediated odometry in honeybees. J Exp Biol 200: 2513-2522.

Zhang SW, Bartsch K, Srinivasan MV (1996). Maze learning by honeybees. Neurobiol Learn Mem 66: 267-282.

Zhang SW, Lehrer M, Srinivasan MV (1999) Honeybee memory: navigation by associative grouping and recall of visual stimuli. Neurobiol Learn Mem 72: 180-201.

Learning and memory: How to train a bee

- The honeybees can be trained to go to a specific area or visual cue by associating it with a sugar reward.
- In honeybees (and bumblebees) can be trained to extend their proboscis with the application of sugar to the antenna, which is called the proboscis extension reflex (PER).
- In this case, the sugar reward can be associated with an olfactory or visual cue.

Before training, the odour reward does not elicit a response

Touching sugar to the antenna triggers proboscis extension

By adding the odour stimulus before the sugar reward, the bee can associate the odour with the sugar.

Presenting the reward alone triggers proboscis extension

Learning and memory: Different types of memory

- Learning and memory can involve three main phases:
  1. Acquisition: the formation of the memory, such as associating a stimulus with a sugar reward or an aversive shock (training)
  2. Consolidation: neural changes occur to allow for the stabilization of the memory, which happens for the period after training
  3. Retrieval: the process of remembering the association or the memory, which is tested after training

Before training, the odour reward does not elicit a response

Touching sugar to the antenna triggers proboscis extension

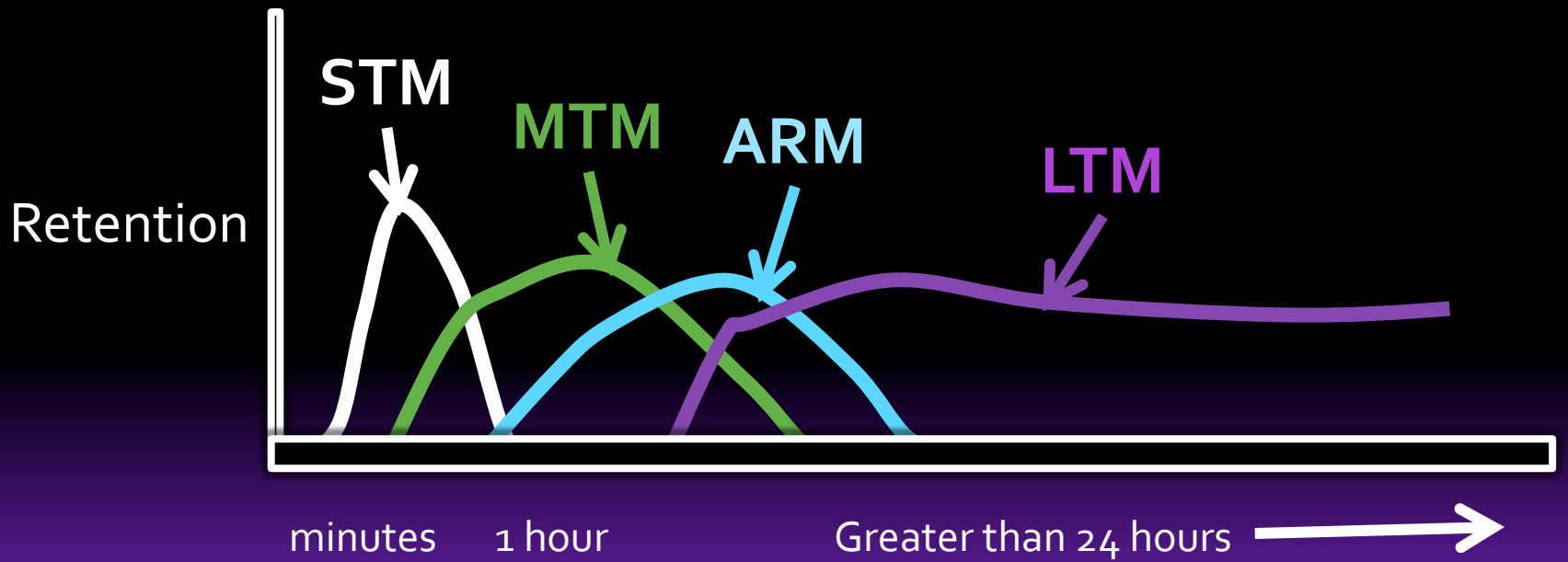
By adding the odour stimulus before the sugar reward, the bee can associate the odour with the sugar.

Presenting the reward alone triggers proboscis extension

Heisenberg M (1998) What do the mushroom bodies do for the insect brain? Learn Mem 5:1-10.
Heisenberg M (2003) Mushroom body memoir: from maps to models. Nat Rev Neurosci 4:266-75.

Learning and memory: Different types of memory

- Memory can be divided into short-term (STM), middle-term (MTM), and long-term (LTM) memory.
- The different types of memory have different time courses:

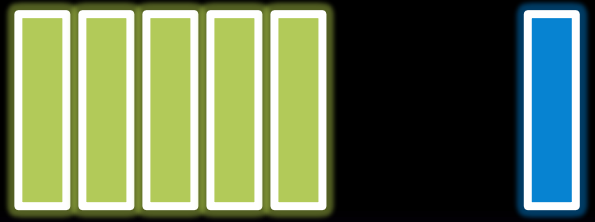


- In *Drosophila*, a fourth type of middle-term memory was discovered which is anaesthesia-resistant memory (ARM). While other mid-term memory can be blocked with placing the flies on ice a certain period of time after training, ARM survives the procedure.

Learning and memory: types of training

- Insects, and, really, any animal, can be trained to learn in several ways.
- These different training regimes can trigger different short and long term memory pathways.

Massed training

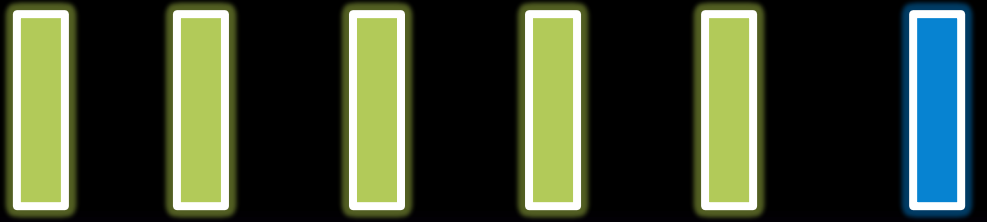


Training sessions one after another, with no time in between training sessions

test

Massed training tends to trigger short term, mid term and even anaesthesia resistant memory

Spaced training



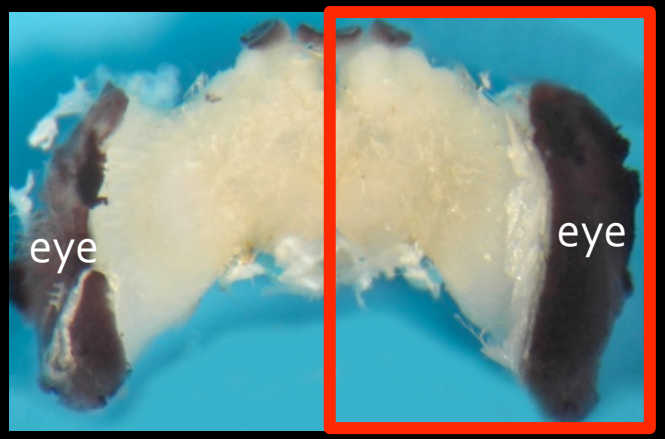
Spaced training, with some time in between training sessions

test

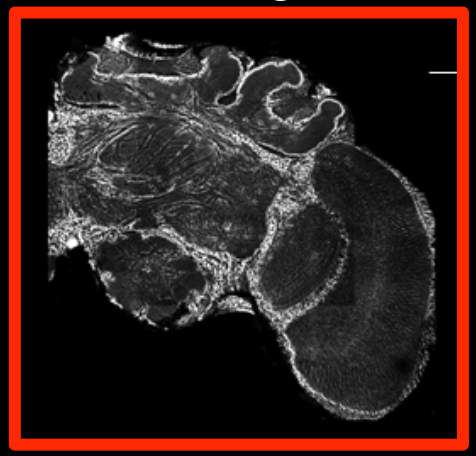
Spaced training triggers all types of memory, and is more likely to induce long term memory

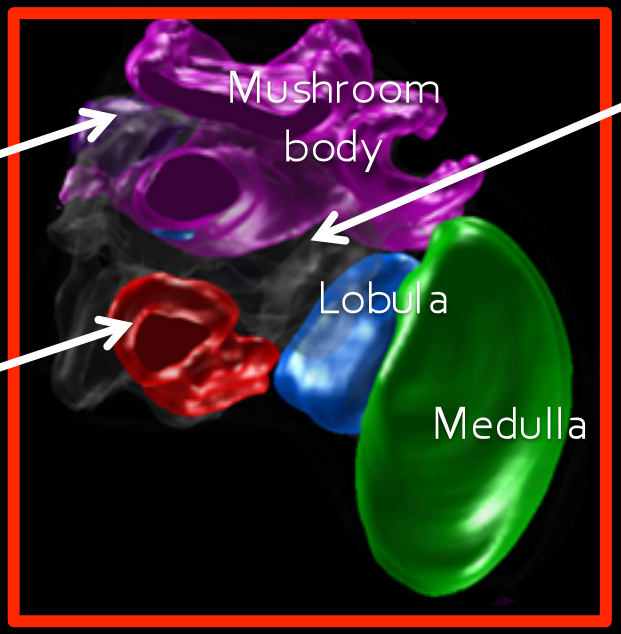
Learning and memory: how does it work in the brain?

Bumblebee brain



Section through the brain





Three dimensional reconstruction of brain structures

The next question:
How can insects learn and what brain areas are involved?