Avoidance, Extinction and Dopamine-guided learning in Drosophila Melanogaster

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Introduction

Experiments have shown that olfactory reinforcement learning in the fruit fly requires only presynaptic and dopaminergic activity and postsynaptic spikes are dispensible (Hige et al 2015). Furthermore, plasticity at the site of neurons implicated in olfactory reinforcement learning appears to be LTD (depression) only.

We propose learning rules that can reproduce aversive learning and extinction, appetitive learning and extinction and re-learning experiments.

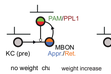
We introduce a simple transformation of firing rates into a model Performance Index.

LTD occurs if there is presynaptic activity (KC) and dopamine activity above baseline level

LTP occurs if there if presynaptic activity (KC) and dopamine activity significantly below baseline level

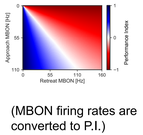
Name	Literature name	Role
Compartment 1		
$MBON\text{-}A1$	$MVP2_MBON\text{-}1ped$	Approach
$PPL1$	$PPL1\text{-}1ped$	Shock reinforcement
Compartment 2		
$MBON\text{-}A2$	$V2_MBON\text{-}o2ae$	Approach
$PPL2$	$PPL1\text{-}c3$	Shock reinforcement
Compartment 3		
$MBON\text{-}R1$	$M6_MBON\text{-}\gamma5\beta'2a$	Retreat
$PAM1$	$PAM-\gamma5$	Reward reinforcement
Compartment 4		
$MBON\text{-}R2$	$M4_MBON\text{-}\beta'2mp$	Retreat
$PAM2$	$PAM\text{-}\alpha4$	Reward reinforcement

(compartments modelled)



$$\Delta w \propto -\eta \times pre \times \mathcal{H}(DA - \theta_{dopa})$$

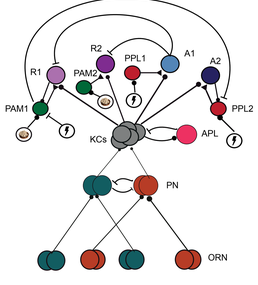
(learning rule depends on dopa and pre)

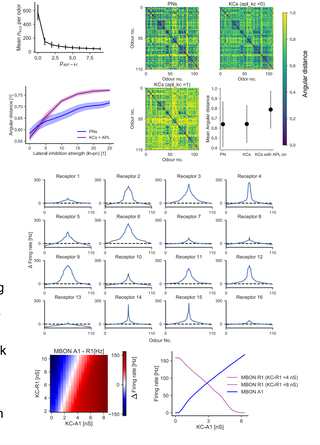


(MBON firing rates are converted to P.I.)

Sparse decorrelated odour representation

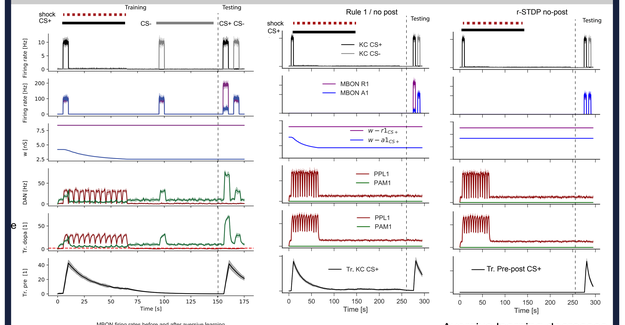
- Four layer circuit; the Hallem and Carlson 2006 ORN firing rates to 110 different odours as input
KC-APL feedback inhibition facilitates sparse decorrelated odour representation
- KC-APL feedback inhibition facilitates sparse odour decorrelated representation
- MBONs tuned to obtain equal firing rates for approach (A1,A2) and retreat (R1, R2) MBONs.
- A1 inhibits R1, if A1 decreases R1 will increase in its firing rate which we will obtain using LTD based learning rules.

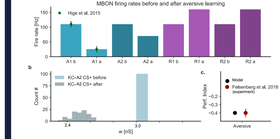


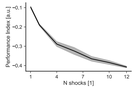


- Olfactory Circuit decorrelates overlapping representations and creates a sparse, normalized representation in the firing rates of KCs in the mushroom body
- Both lateral inhibition in PNs and feedback inhibition in the mushroom body increases angular separation between odours. APL mediated feedback inhbibition ensures sparse population activity in response to an odour.

Aversive learning





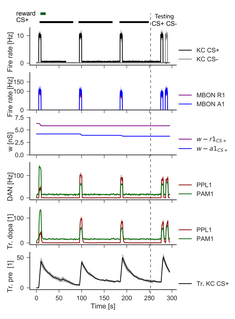


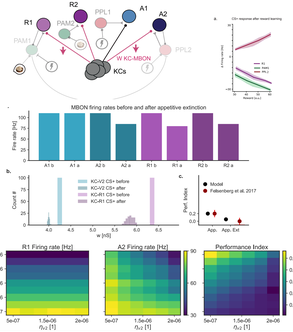
experiment

Aversive learning decreases the firing rate of MBON A1 and A2 and increases the activity of MBON R1 and R2 through disinhiibition. Post-synaptic spikes are dispensible for aversive learning.

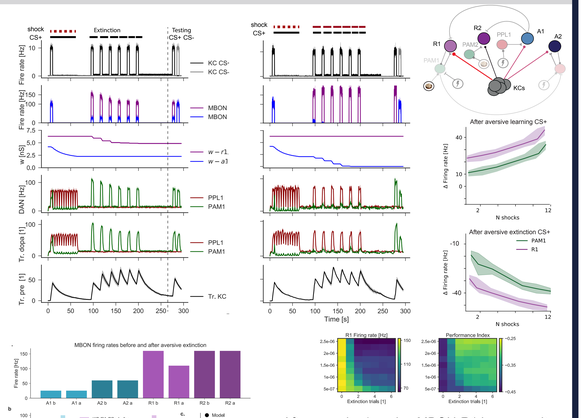
Appetitive extinction

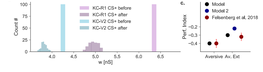
Appetitive learning reduces the firing rates of MBON R1 and R2 and PAM1 DAN to the trained odour and increases the activity of PPL2. If an odour is presented without the expected reward KC-A2 MBON connections will undergo LTD. Appetitive extinction forms parallel opposing memory in MBON-R1, MBON-R2 and MBON-A2 compartments.





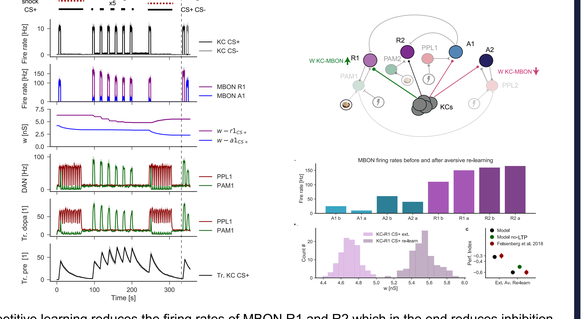
Aversive extinction





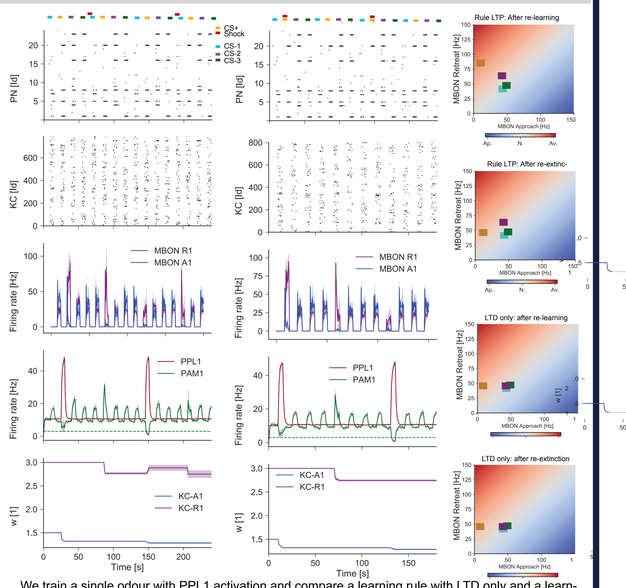
After aversive learning MBON-R1 increases its activity to the trained odour which excites PAM1. Absence of shock used during training leads to plasticity in the KC-R1 compartment.

Aversive re-learning



Appetitive learning reduces the firing rates of MBON R1 and R2 which in the end reduces inhibition onto shock coding PPL2 DAN. If an odour is presented without the expected reward KC-A2 MBON will undergo LTD. - Performance Index depends on A2 and R1 and R2 MBONs. Thus, after extinction R1, R2 and A2 MBONs are reduces and we can obtain full extinction, similar to experimental results.a

Re-learning with LTP enables re-extinction



We train a single odour with PPL1 activation and compare a learning rule with LTD only and a learning rule that potentiates KC-MBON synapses at low PAM1 activity levels. LTP learning rule can learn, extinguish, re-learn and re-extinguish. LTD only rule can not re-extinguish.

Summary

Our model explains a series of experimental results by proposing that LTD together with circuit mechanism can explain learning and extinction, while potentiation is required for re-learning and re-extinction. To test our model we predict that if an odour is exposed while PAM1 DANs are silenced an aversive memory will form. Imaging R1 MBON before and after re-learing can validate our model for plasticity.

Circuit architecture feature	Required for
MBON - DA feedback	Appetitive extinction, Aversive extinction
DA - DA inhibition	Appetitive extinction
MBON - MBON inhibition	Bi-Directional learning, aversive extinction
KC-MBON potentiation	Re-learning

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