A spiking neuron model of pharmacologically-biased fear conditioning in the amygdala

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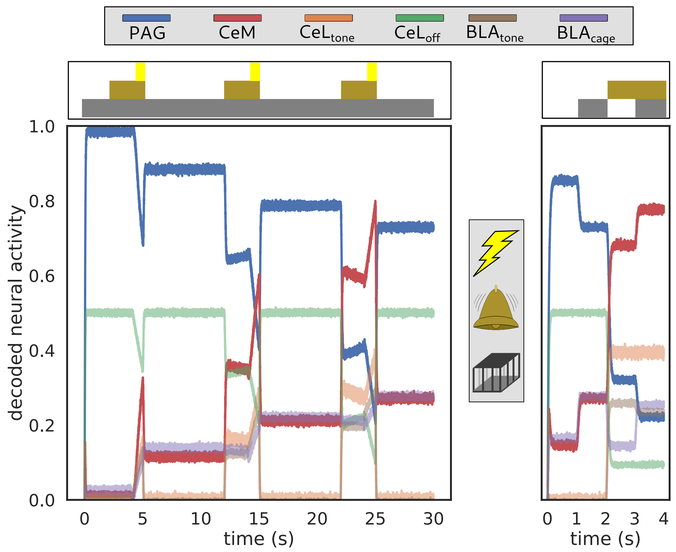
Abstract

Anatomically-detailed spiking neuron model of the amygdala

Learning rules drive fear associations by updating synaptic weights during training

Simulated the impact of pharmacology on conditioning, extinction, and expression

Results consistent with behavioral and neural data



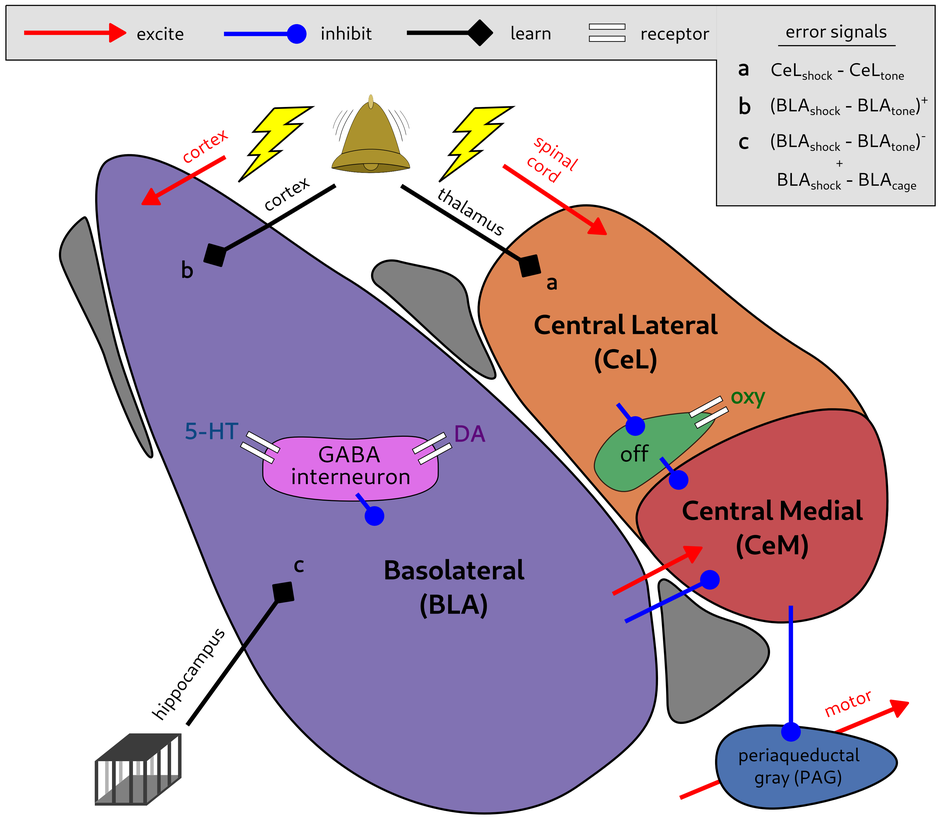
▲ **Figure 1**: Fear conditioning (left) and expression (right)

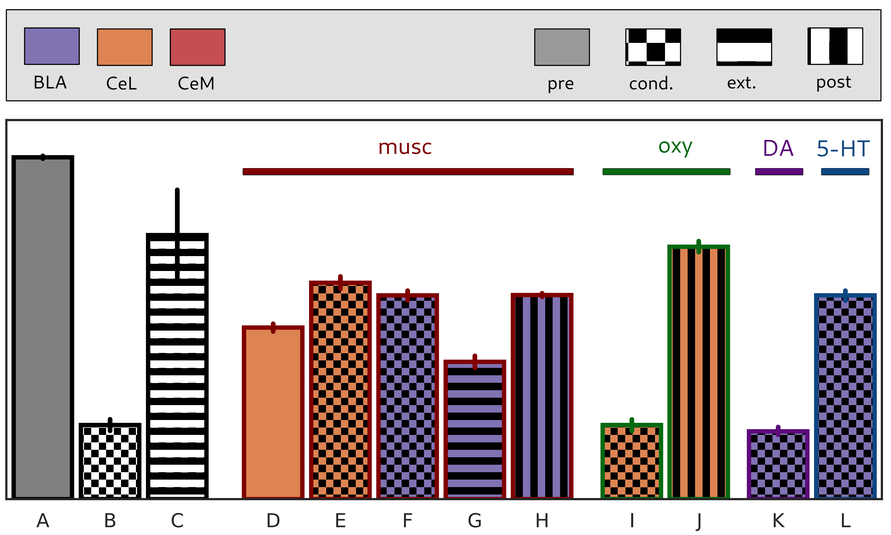
Background

Muscimol (musc): $GABA_A$ agonist that inhibits neural activity in the targeted population [3, 5, 7]
Oxytocin (oxy): Neuropeptide implicated in fear expression. Receptors in CeL_{off}. [4]
Dopamine/Seratonin (DA/5-HT): Implicated in fear learning. Receptors in GABAergic BLA interneurons [6]

Neural Engineering Framework [1]: methods for building biologically-plausible, functional networks using spiking neurons
Perscribed Error Sensitivity [9] : error- and activity-dependent learning rule for updating synaptic weights

$$\Delta \mathbf{d}_i = -k\mathbf{E}a_i$$





▲ **Figure 2**: Simulated freezing under twelve pharmacological manipulations

Model

Anatomical reconstruction of amygdala [2]; 4200 spiking neurons, 16 ensembles, 3 learned connections

Inputs: tone, shock, cage **Outputs**: decoded spikes

Conditioning: (+) error increases response of excitatory tone neurons (CeL, BLA) when tone and shock coincide

Extinction: (-) error increases response of inhibitory cage neurons (BLA) when tone present without shock

Expression: within CeM, tone responses from CeL and BLA compete with cage response from BLA

Pharmacology: (+/-) current applied to neurons

Results

Figure 2 shows fear expression (mean PAG activity during tone, n=10 trials) for twelve simulated experiments.

Control experiments confirm model's fear learning

- **A** no freezing without conditioning (cond.)
- **B** more freezing after cond.
- **C** less freezing after extinction (ext.)

Muscimol's observed effects are captured by the model

- **D** musc to CeL causes unconditioned freezing [5]
- **E** musc to CeL @ cond. impairs learning [5]
- **F** musc to BLA @ cond. impairs learning [3]
- **G** musc to BLA @ ext. impairs learning [7,8]
- **H** musc to BLA @ test impairs expression [3]

Modulator's effects are also recreated by the model

- **I** oxy to CeL @ cond. preserves learning [4]
- **J** oxy to CeL @ test impairs expression [4]
- **K** DA to BLA @ cond. facilitates learning [6]
- **L** 5-HT to BLA @ cond. impairs learning [6]

References

[1] Eliasmith and Anderson. MIT press, 2003.
[2] Duvarci and Pare. Neuron, 2014.
[3] Muller et al. Behavioral neuroscience, 1997
[4] Viviani et al. Science, 2011
[5] Ciocchi et al. Nature, 2010
[6] Ehrlich et al. Neuron, 2009.
[7] Sierra-Mercado, Padilla-Coreano, and Quirk. Neuropsychopharmacology, 2011.
[8] Akirav, Raizel, and Maroun. European Journal of Neuroscience, 2006.
[9] MacNeil and Eliasmith. PloS one, 2011.

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github.com/psipeter/anatomical_amygdala