Target selectivity in the frontal eye field (FEF) is blunted during exploratory choice

R. Becket Ebitz[1], Eddy Albarran[1], Alireza Soltani[3], & Tirin Moore[1,2]

[1] Neurobiology Department and [2] Howard Hughes Medical Institute, Stanford University School of Medicine, [3] Department of Psychological and Brain Sciences, Dartmouth College
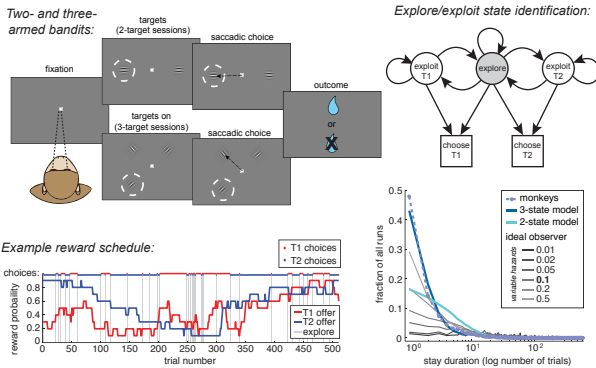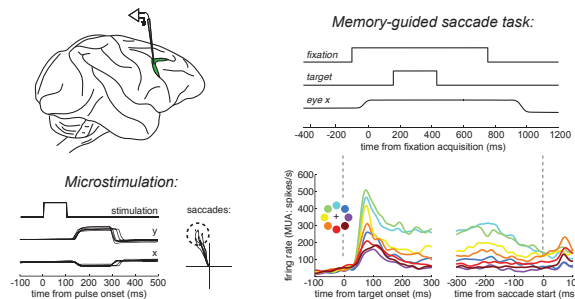
HHMI

1. How do exploratory and exploitative states shape target selectivity in the frontal eye field?

Target selectivity is the enhanced neuronal response to one stimulus at the expense of other, simultaneously presented stimuli. Target selectivity is a hallmark of activity in the frontal eye field (FEF), a prefrontal oculomotor-control region. Previous studies have implicated target selectivity in the FEF in the attentional modulations of extrastriate cortex and in predicting choice likelihood. However, correct performance of most laboratory tasks requires that monkeys make reward-maximizing choices: subjects must exploit known-rewarding options in order to be successful. However, reward information is often noisy in nature, where exploitative choices must be balanced against the exploration of alternatives. Theories of learning and decision-making make conflicting but testable predictions about how exploratory choices should affect attention and saccadic selection. However, little is known about how exploration affects oculomotor and attentional control structures such as the FEF.
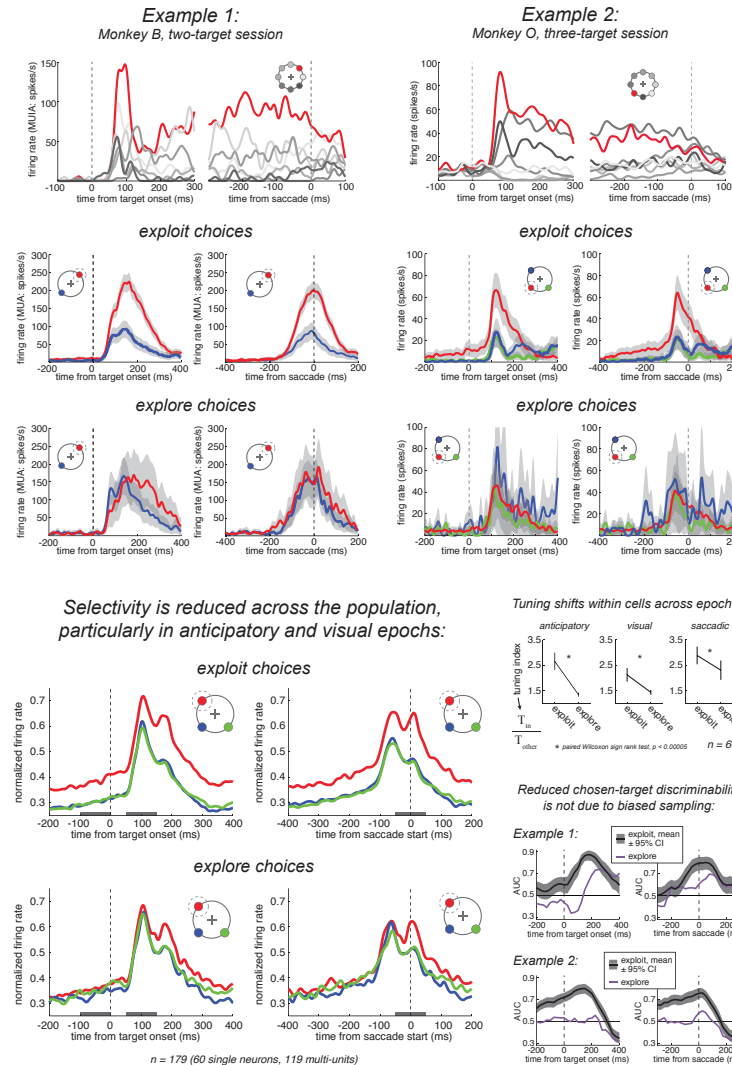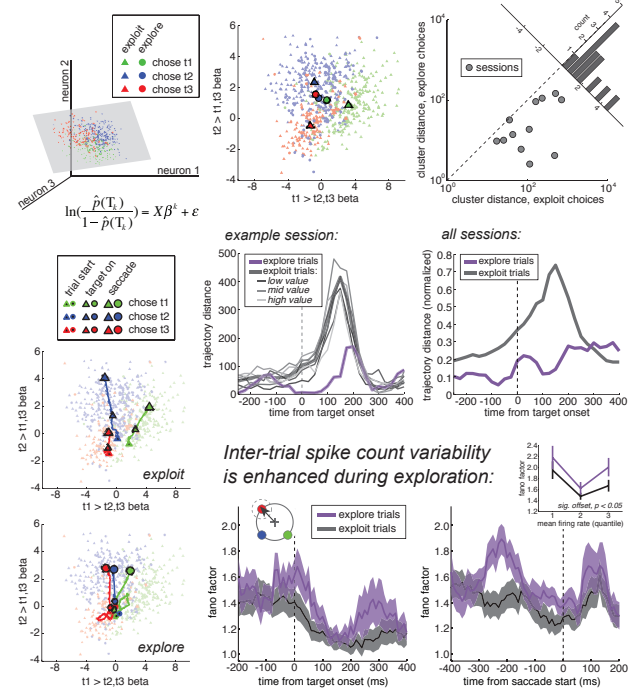
Possible changes in population activity during exploration:

2. Exploratory choice task:

Two- and three-armed bandits:

Explore/exploit state identification:

Example reward schedule:

3. Recording site localization and characterization:

Memory-guided saccade task:

Microstimulation:

4. Target selectivity is reduced during exploration:

Example 1:
Monkey B, two-target session

Example 2:
Monkey O, three-target session

exploit choices

explore choices

Selectivity is reduced across the population, particularly in anticipatory and visual epochs:

exploit choices

explore choices

n = 179 (60 single neurons, 119 multi-units)

Tuning shifts within cells across epochs:

anticipatory   visual   saccadic

* paired Wilcoxon sign rank test, $p < 0.00005$ n = 60

Reduced chosen-target discriminability is not due to biased sampling:

Example 1:

Example 2:

5. Choice-predictive population activity is disorganized during exploration:

$$\ln\left(\frac{\hat{p}(T_k)}{1-\hat{p}(T_k)}\right) = X\beta^k + \varepsilon$$

example session:

all sessions:

Inter-trial spike count variability is enhanced during exploration:

sig. offset, $p < 0.05$

6. Several differences in FEF activity between states:

During **exploit choices**:
1. FEF had robust target selectivity in anticipatory, visual, and saccadic epochs.
2. FEF population activity was organized in distinct, choice-predictive clusters.
3. FEF had clear trajectories in choice space.
4. inter-trial neuronal variability was low.

During **explore choices**:
1. target selectivity was blunted, particularly in the anticipatory and visual epochs.
2. inter-cluster distance between choices was reduced within every session.
3. choice trajectories became disorganized.
4. inter-trial neuronal variability was enhanced.

Target selectivity in FEF is not a deterministic consequence of choice, rather it may depend on the exploitatory states so essential in the performance of most laboratory tasks. Computationally, noisy decision rules are an efficient way to induce exploration and these observations suggest that exploration is also associated with increased noise in choice-predictive neural signals.