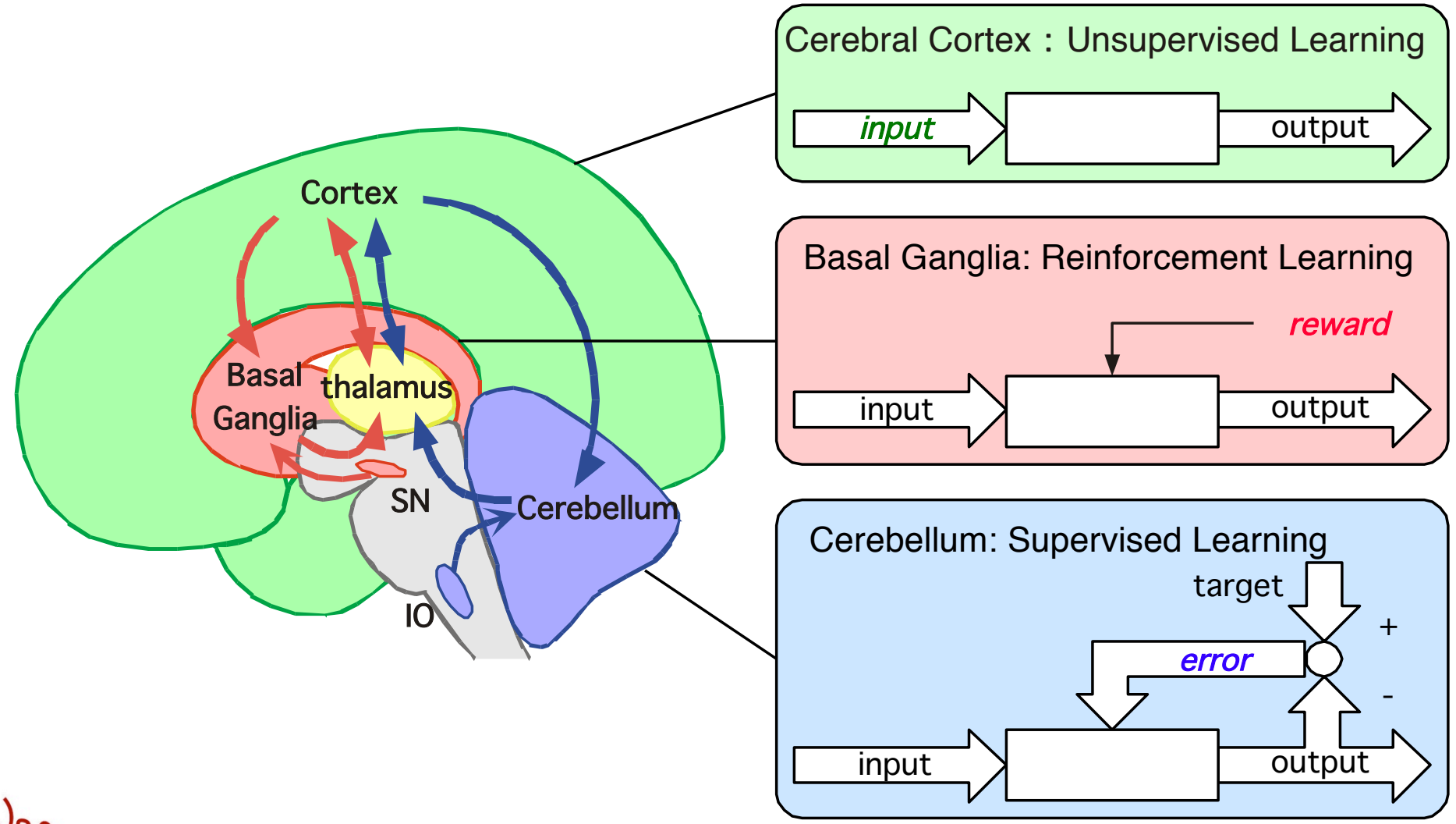
Mental Simulation

Brain's process using an action-dependent state transition model
$s'=f(s,a)$ or $P(s'|s,a)$

- Estimate the present from past state/action
  - perception under noise/delay/occlusion
- Predicting the future
  - model-based decision, action planning
- Imagining in a virtual world
  - thinking, language, science,…

Specialization by Learning Algorithms

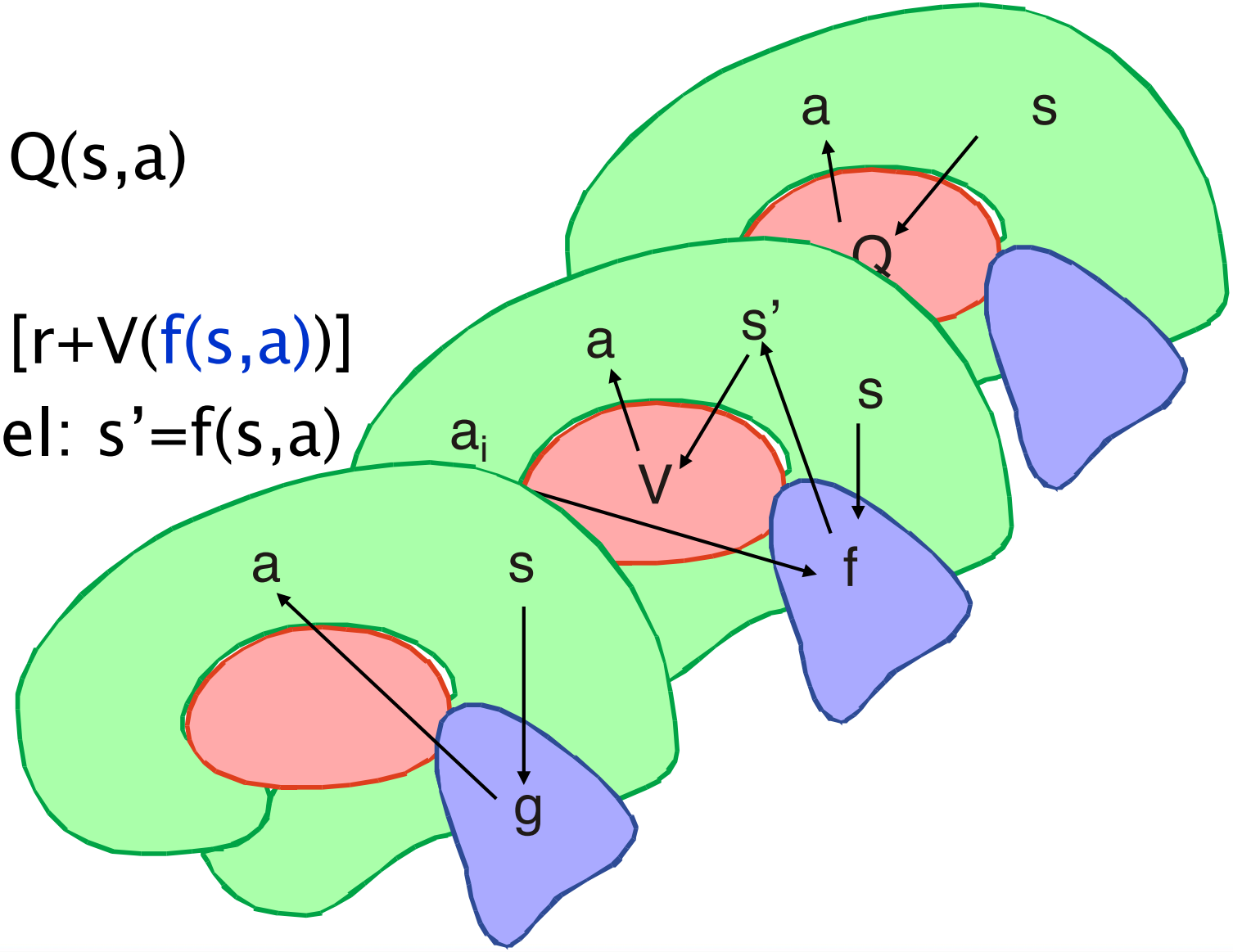
(Doya, 1999)



Multiple Ways of Action Selection

- Model-free
  - $a = \text{argmax}_a\ Q(s,a)$
- Model-based
  - $a = \text{argmax}_a\ [r+V(f(s,a))]$

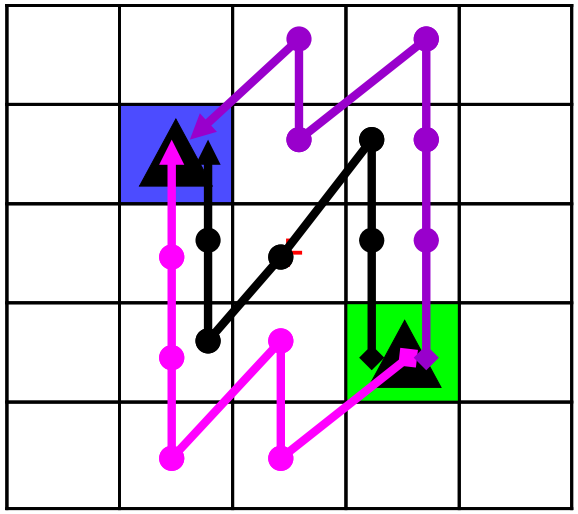
  forward model: $s'=f(s,a)$
- Memory-based
  - $a = g(s)$

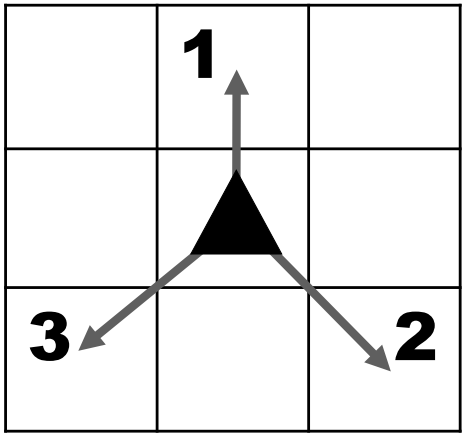


‘Grid Sailing’ Task

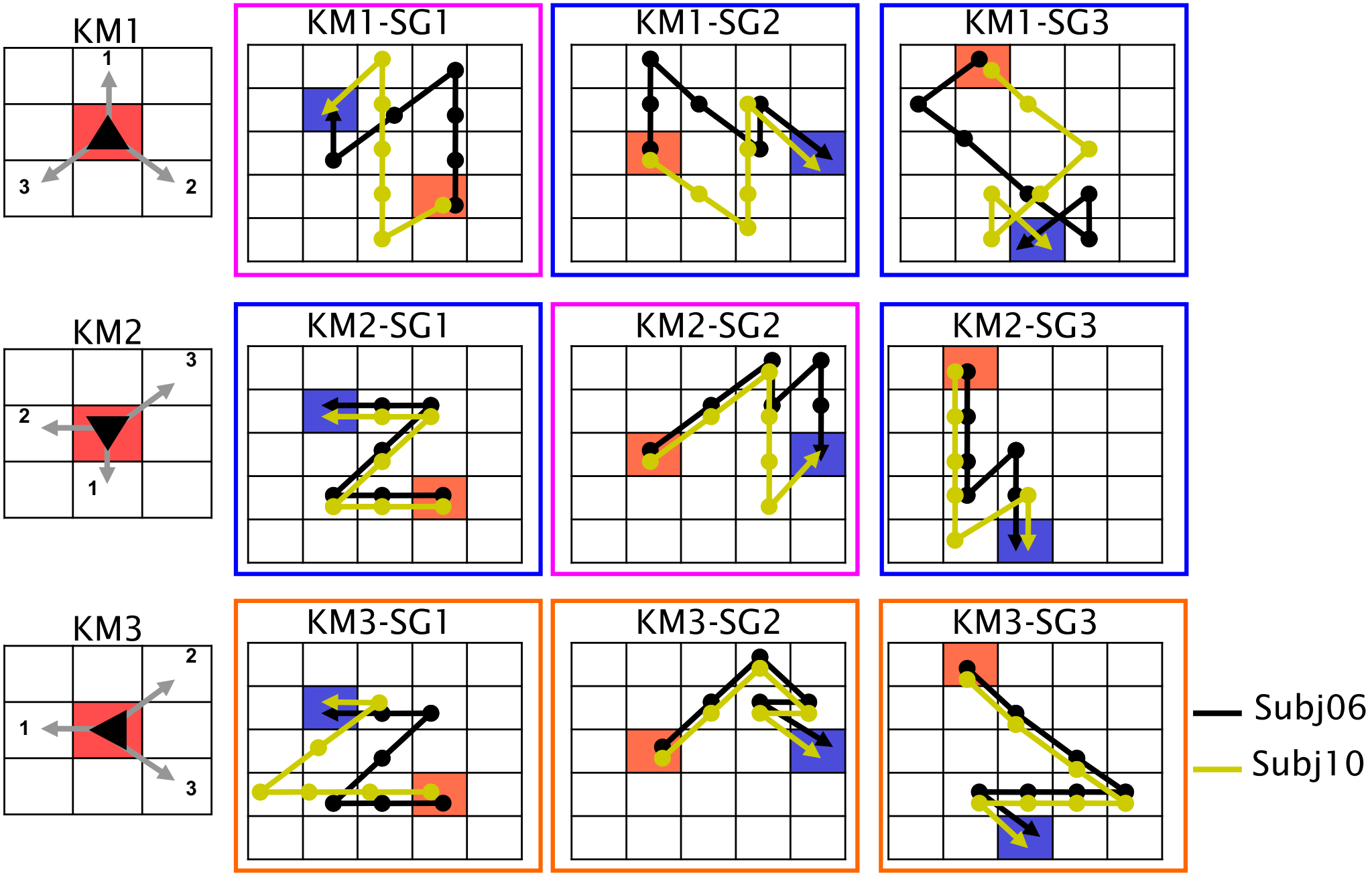
(Fermin et al., 2016, Scientific Reports)

- Move a cursor to the goal
  - 100 points for shortest path
  - -5 points per excess steps
- Keymap
  - only 3 directions
  - non-trivial path planning
- Immediate or delayed start
  - 4 to 6 sec for planning
  - timeout in 6 sec



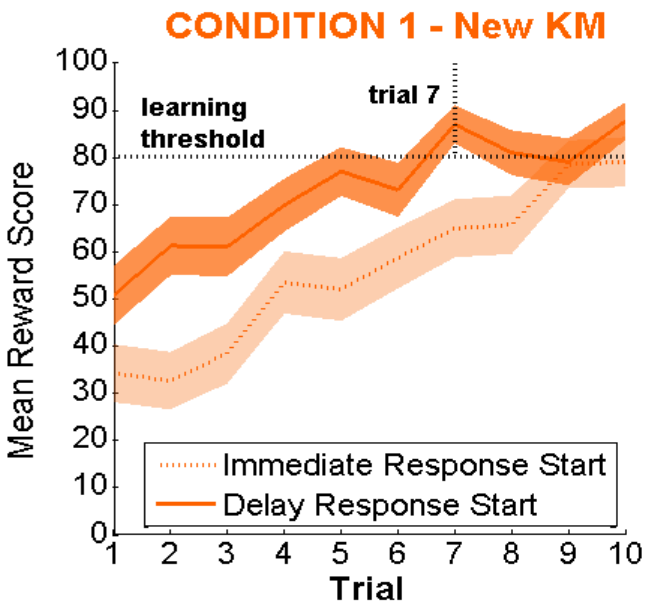


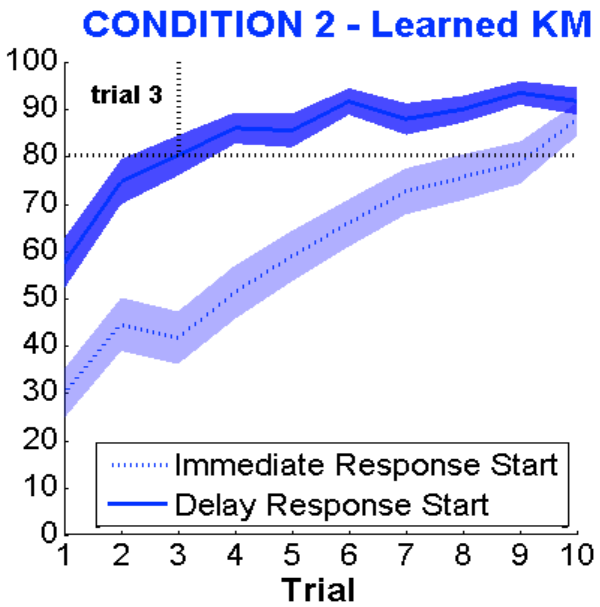
Examples of Learned Sequences

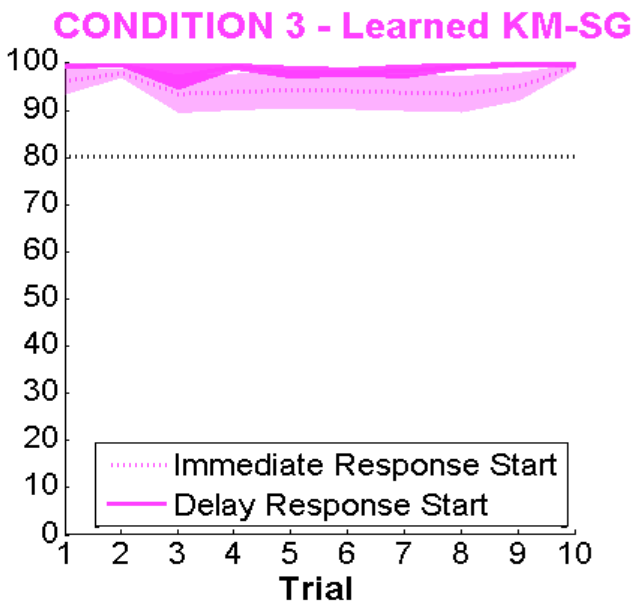


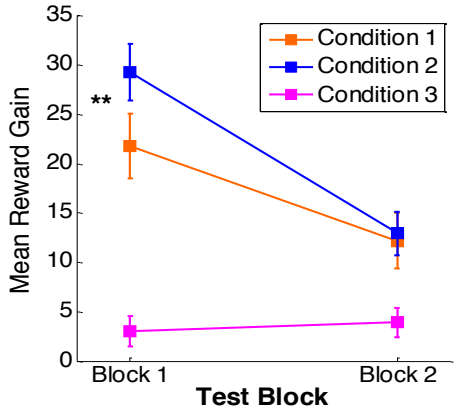
Effect of Pre-start Delay Time

New Learned key-map Learned

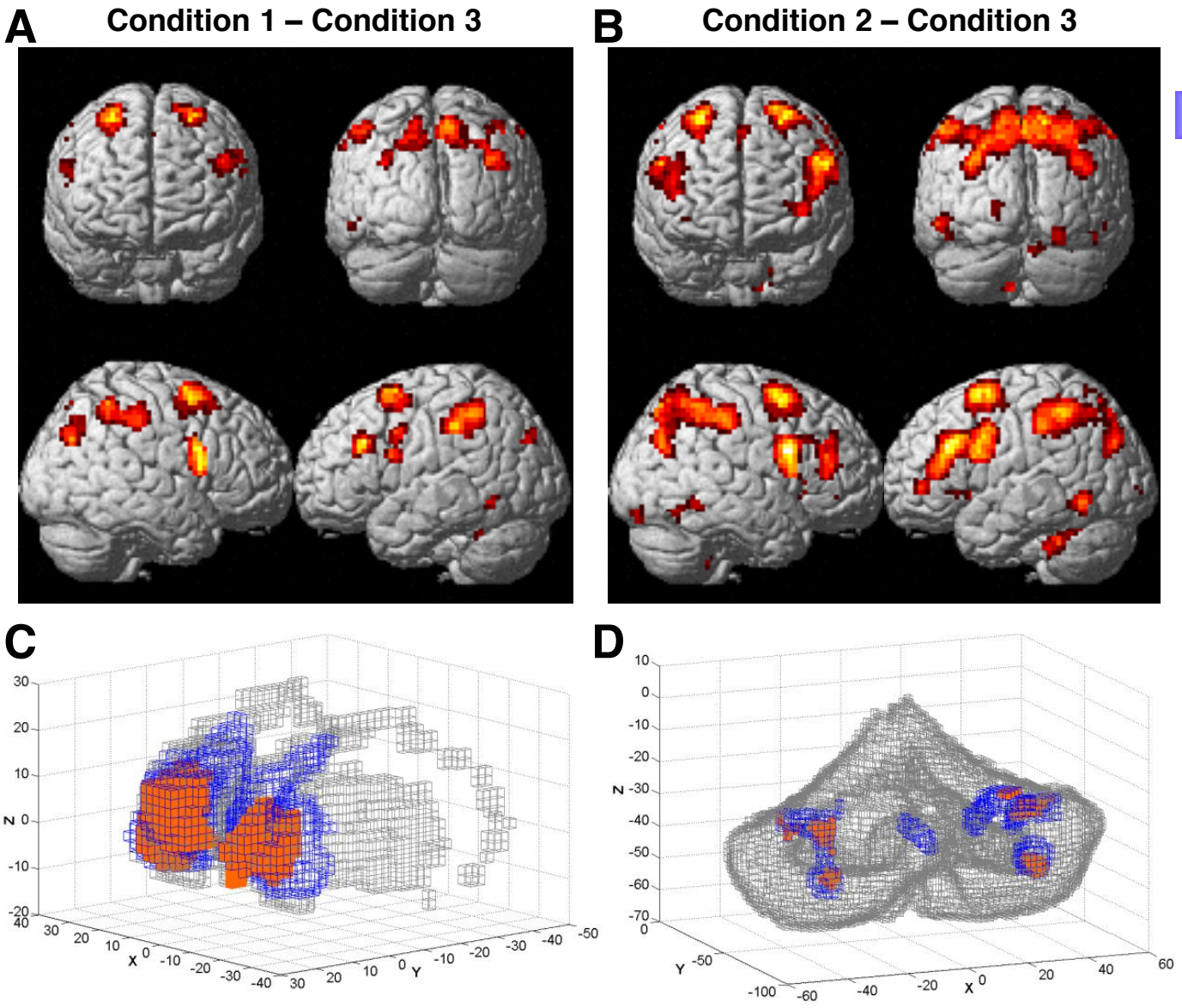








Delay Period Activity



- Condition 2
  - DLPFC
  - PMC
  - parietal
  - anterior striatum
  - lateral cerebellum

Grid Sailing Task – Summary

- Behaviors
  - benefit from delayed start more in condition 2, using pre-learned keymap
  - model-based action planning

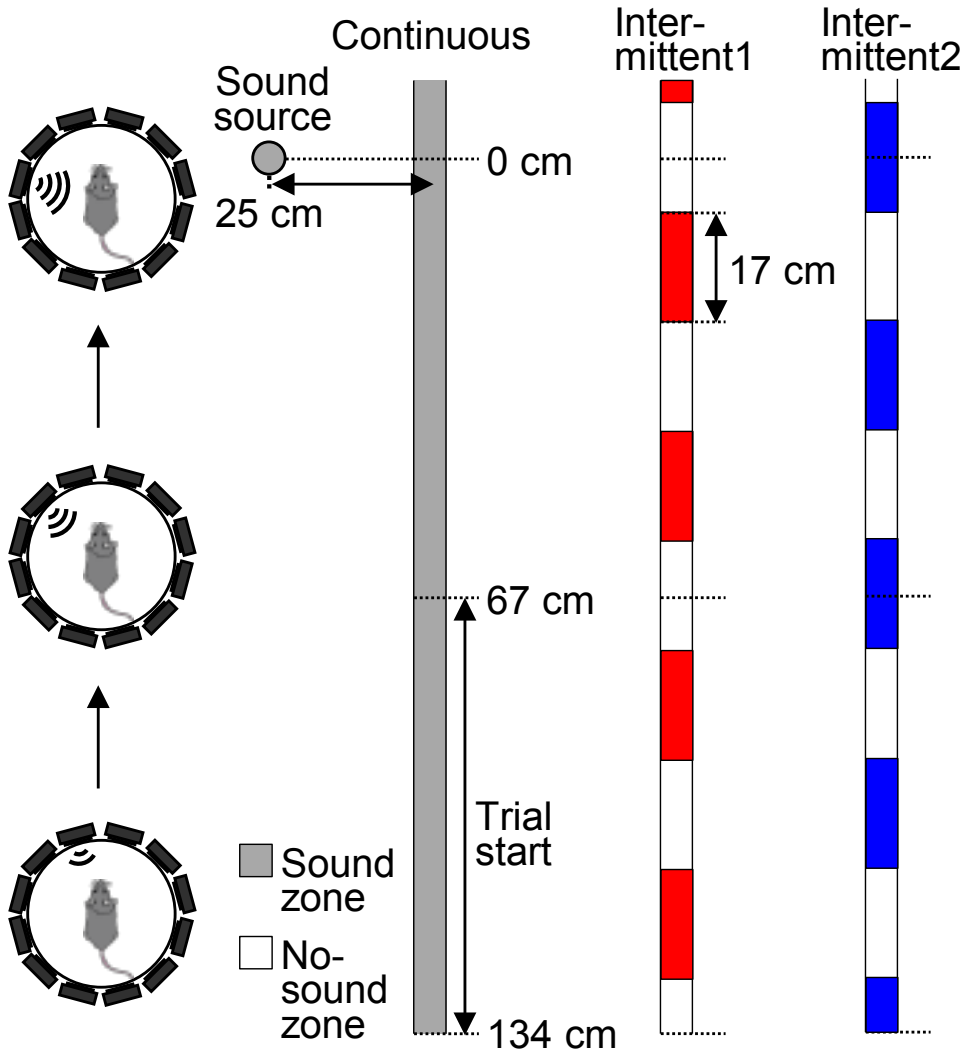
- fMRI: delay period activity in condition 2
  - DLPFC, PMC, parietal: working memory, imagery
  - lateral cerebellum: forward model?
  - striatum: evaluation of predicted state?

nature neuroscience

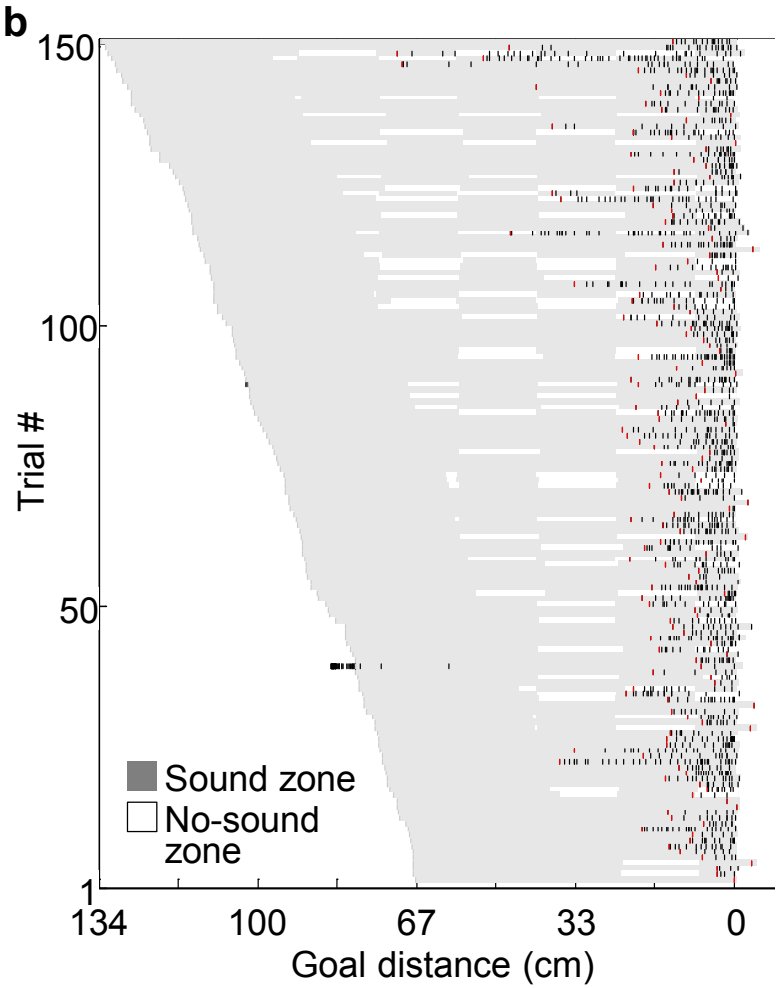
Neural substrate of dynamic Bayesian inference in the cerebral cortex

Akihiro Funamizu[1,2], Bernd Kuhn[2] & Kenji Doya[1]

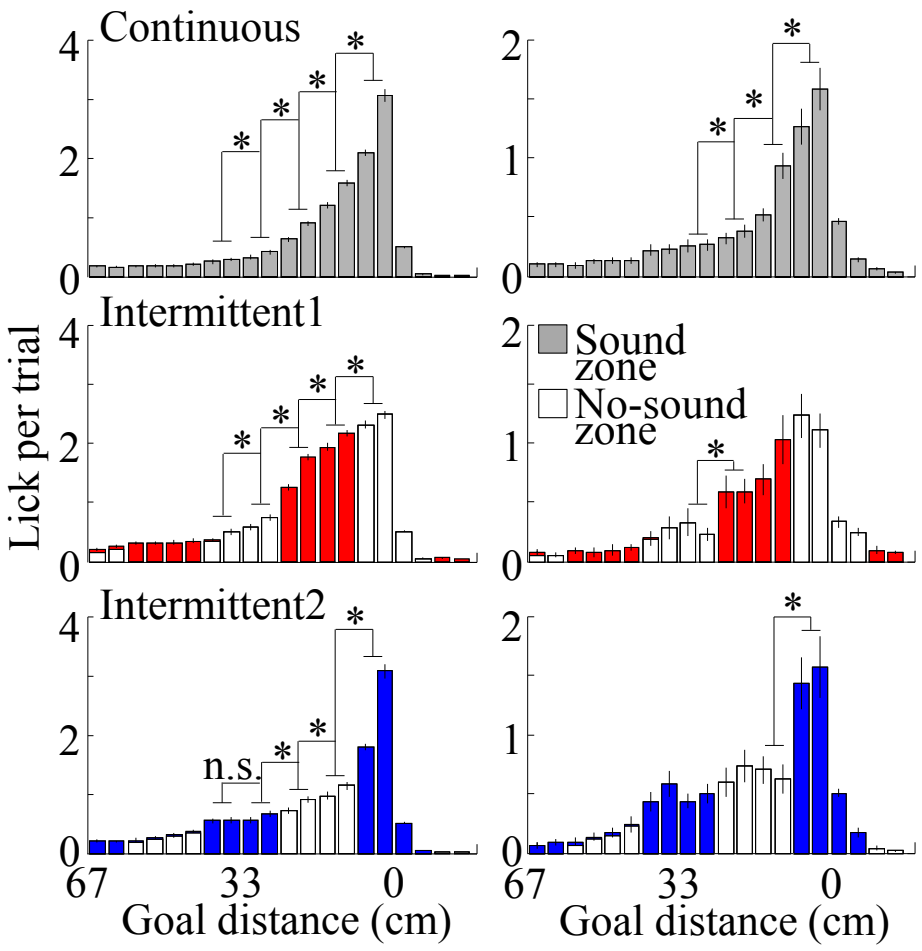
- Auditory virtual environment



Anticipatory Licking



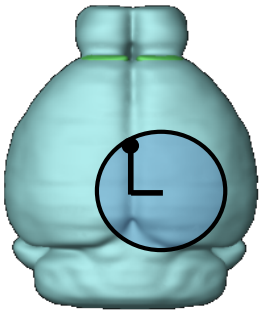
Muscimol
(1ng/1nL, 70 nL)

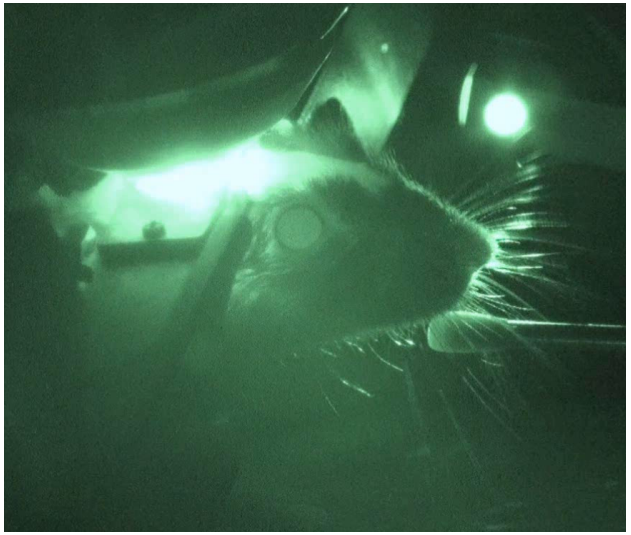


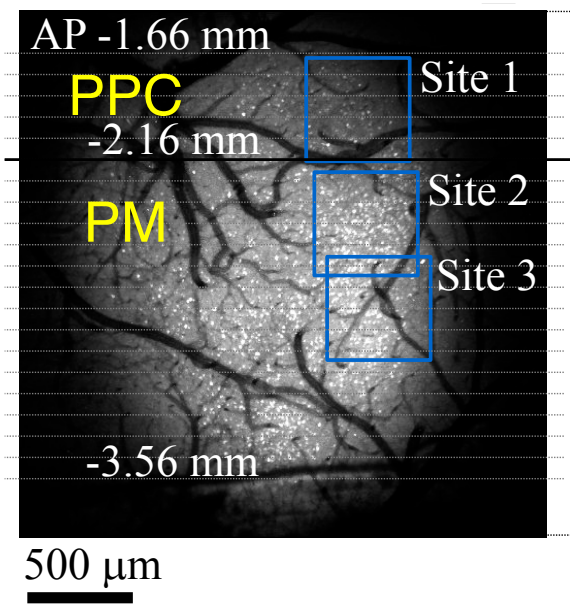
- Mice estimated goal distance in no-sound zone
  - impaired by muscimol injection in PPC

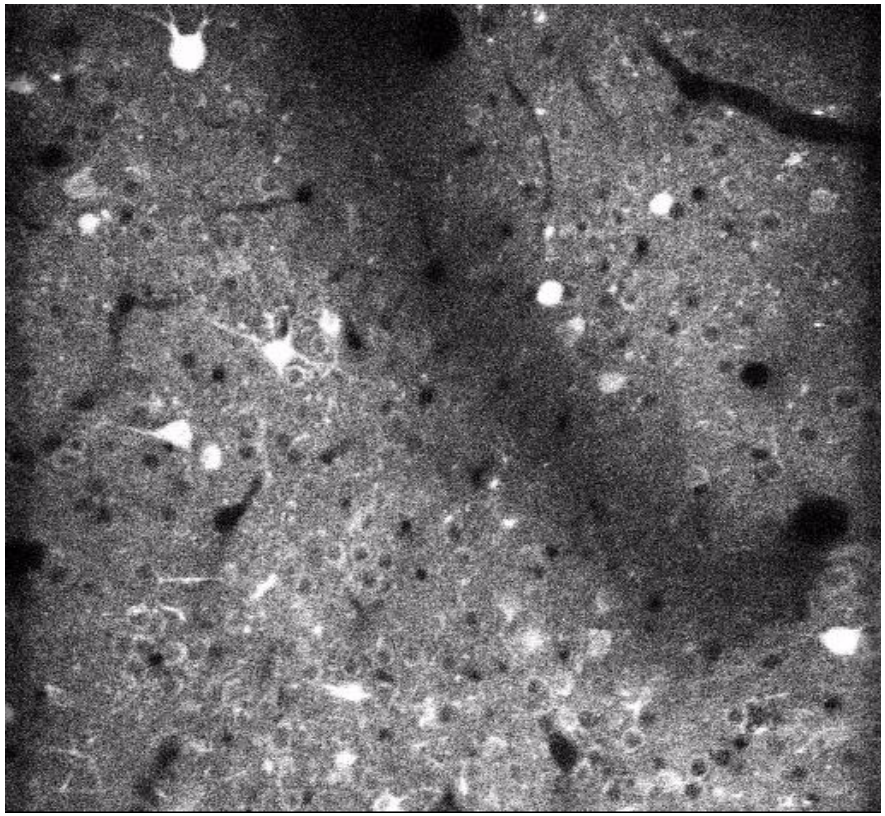
Two Photon Imaging

- GCamp6 expressed in cortical pyramidal neurons
  - posterior parietal cortex (PPC)
  - posterior medial area (PM)

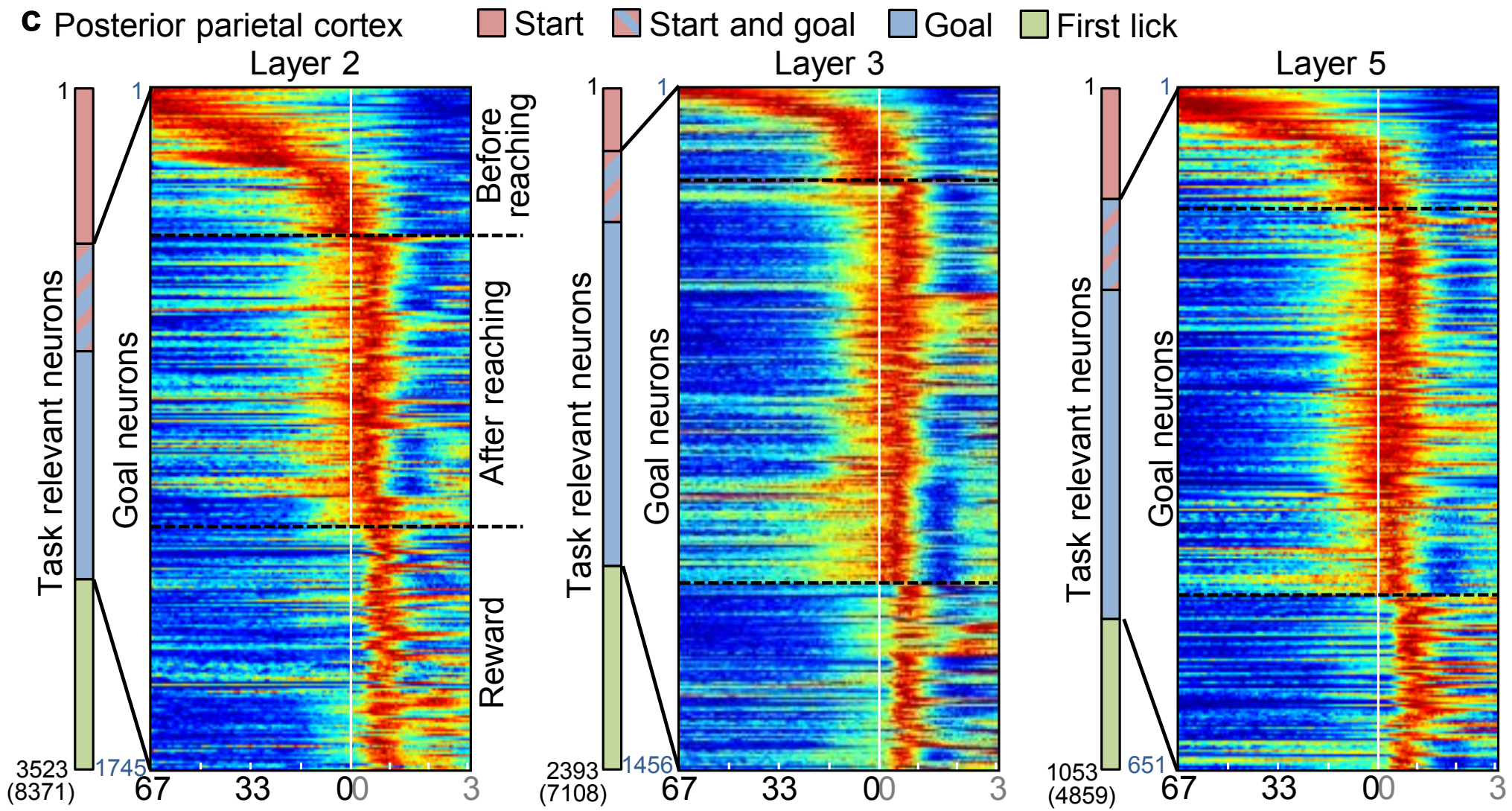






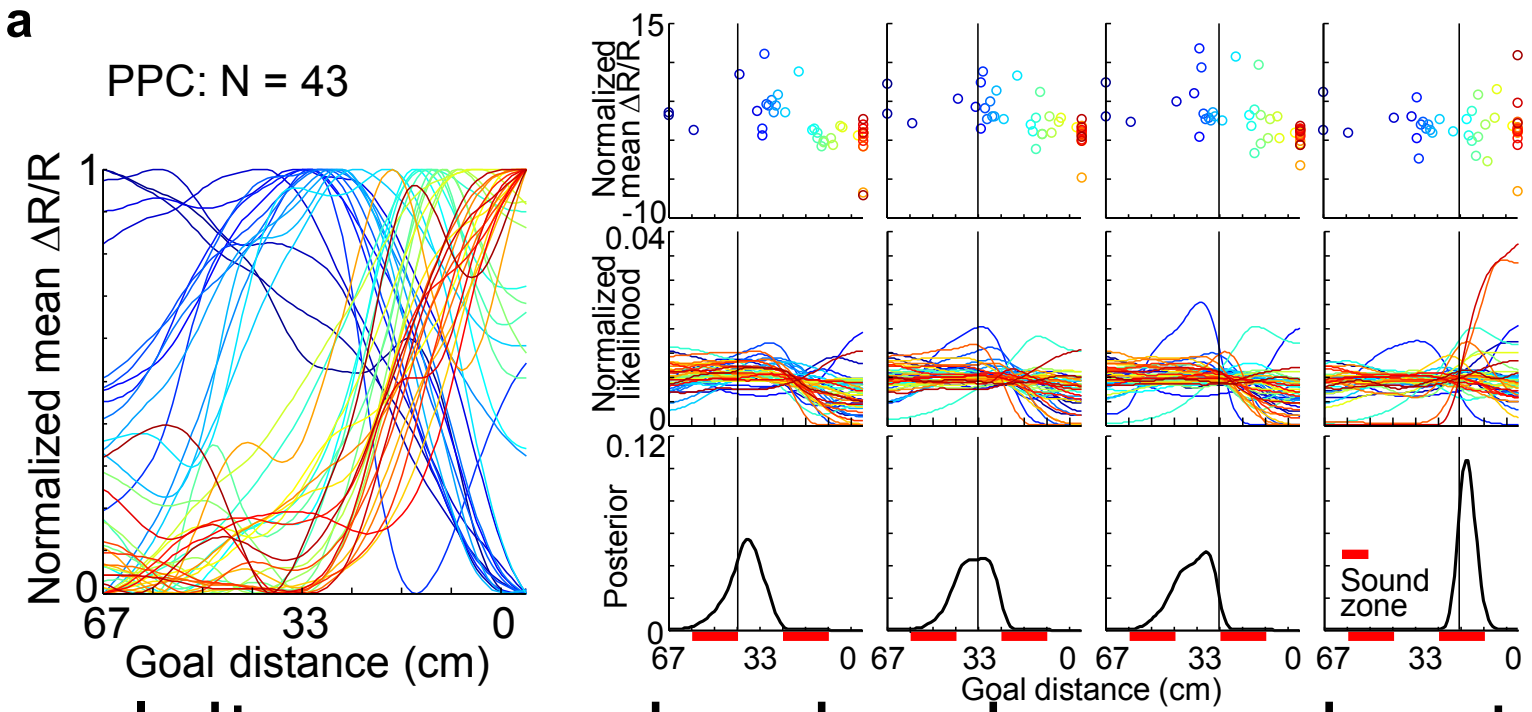


Overall Activities



Decoding the Goal Distance

- Neuron *i* activity f_i at distance x
  - response model $p(f_i|x)$
- Bayesian decoder: $p(x|f_1,\ldots,f_N) \propto \Pi_i p(f_i|x)p(x)$

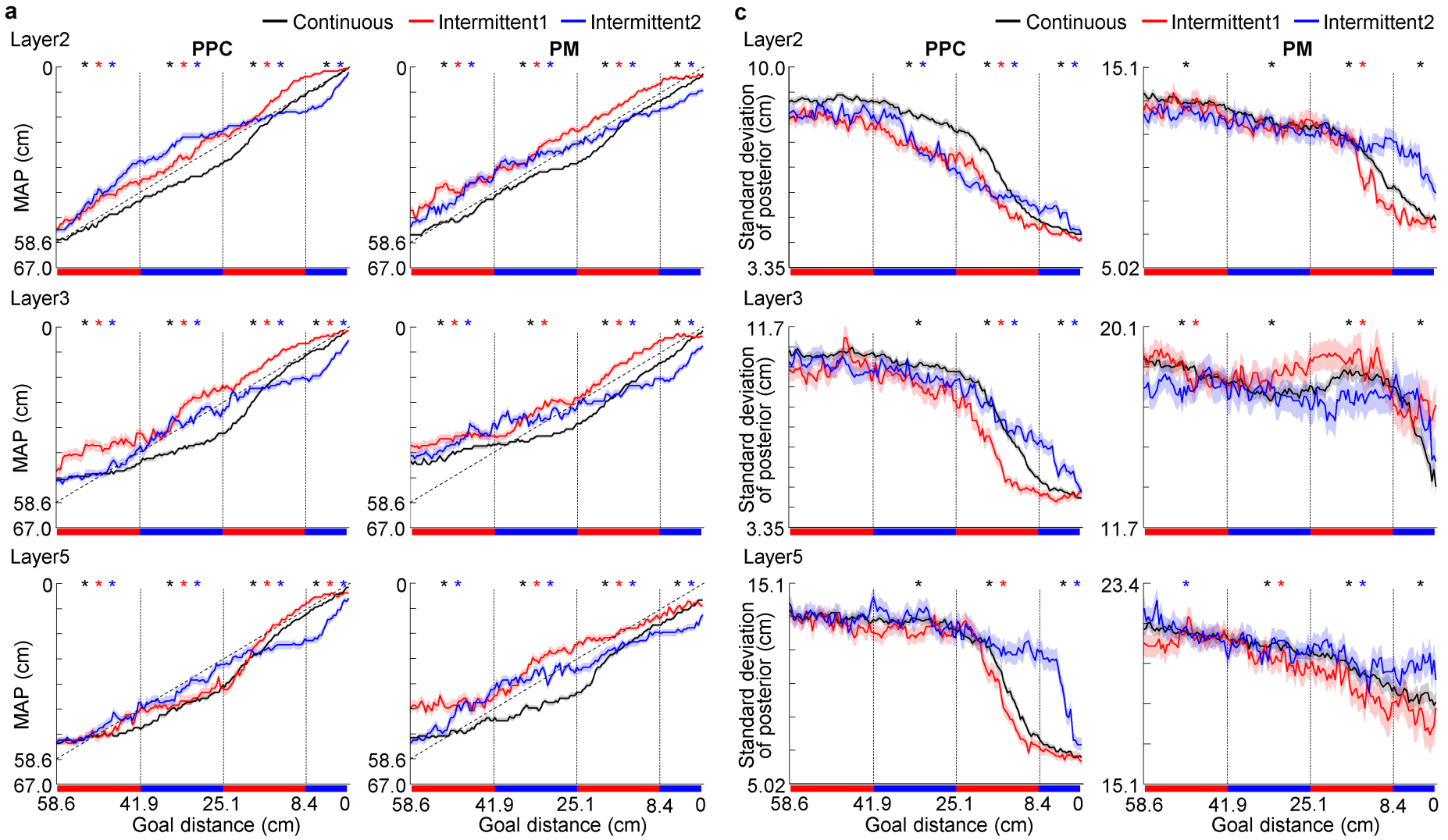


- goal distance updated under sound omission

Decoded Distance and Uncertainty

MAP Estimate

Width of Posterior



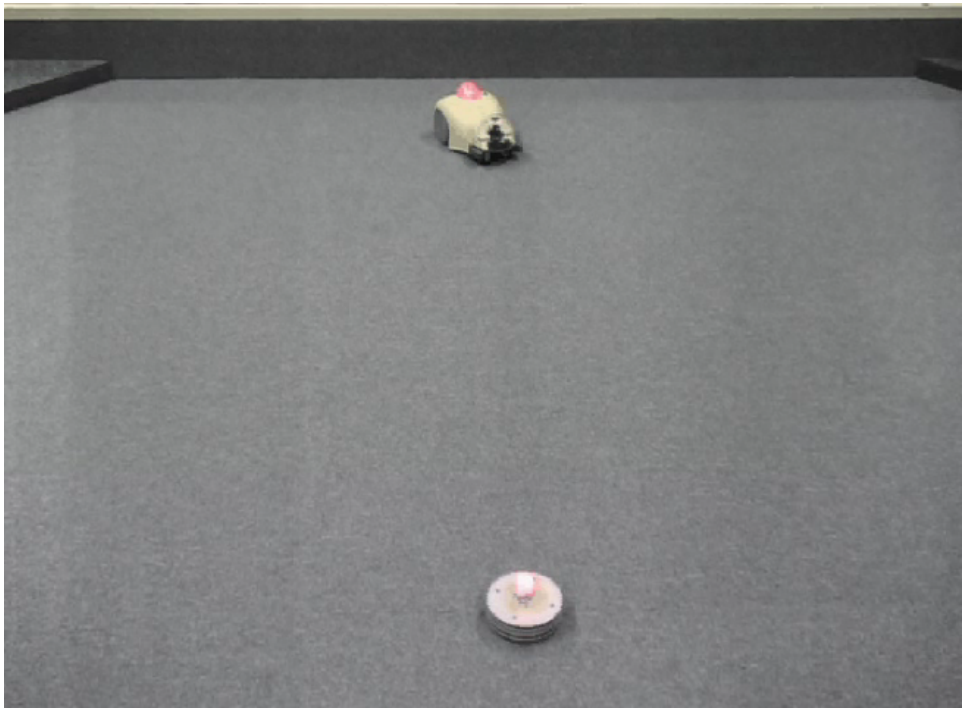
- advance in no-sound zone
- shrink with sound input

Two-Photon Imaging: Summary

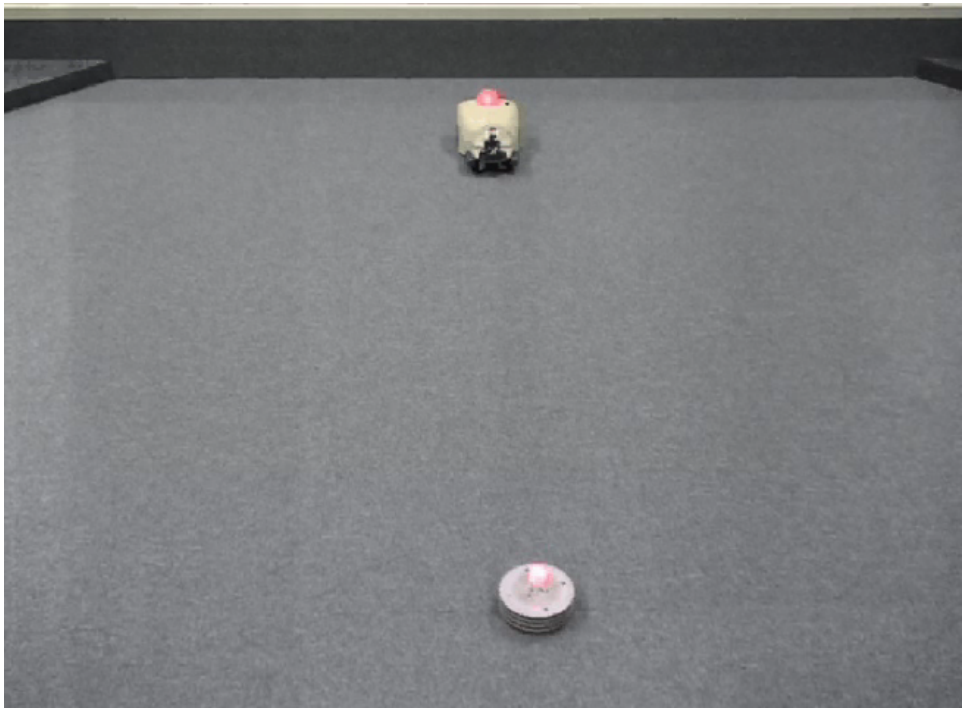
- Auditory virtual navigation task for mice
  - estimate goal distance during no-sound phase from its own action using an internal model
- Two-photon imaging from PPC and PM
  - goal distance can be decoded from population activity even during no-sound phase
  - variance reduced during sound phase
  - more reliable in PPC than in PM
- Future
  - network mechanisms for action-dependent prediction and sensory-based refining

Temporal Discount Factor γ

- Large γ
  - reach for far reward



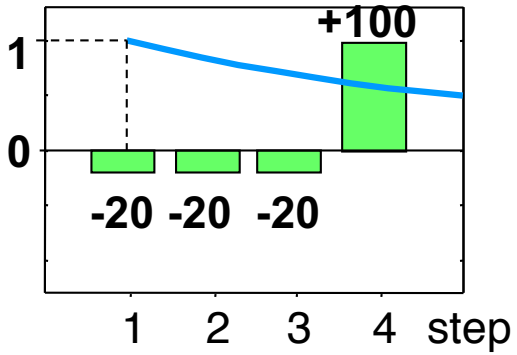
- Small γ
  - only to near reward



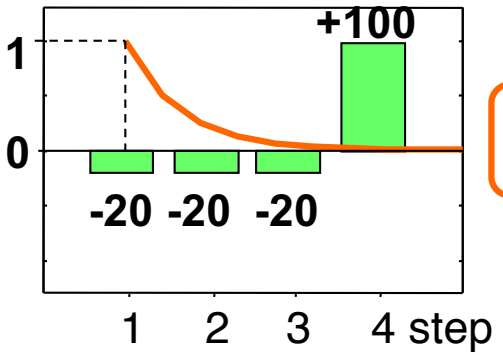
Temporal Discount Factor γ

- $V(t) = E[\, r(t) + \gamma r(t+1) + \gamma^2 r(t+2) + \gamma^3 r(t+3) + \ldots]$
  - controls the 'character' of an agent

γ large



γ small



Depression?

no pain, no gain!

V =18.7

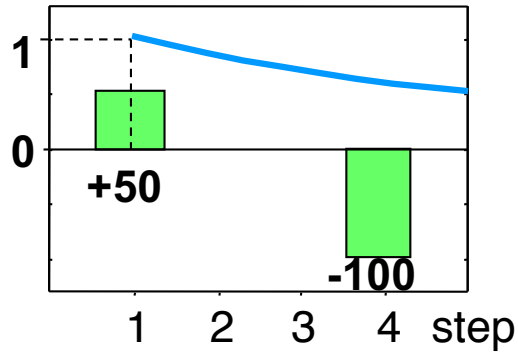
better stay idle

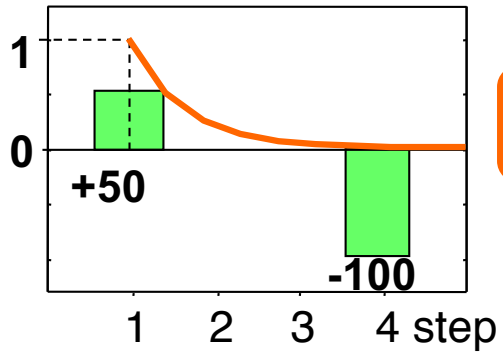
V =-25.1

Impulsivity?

stay away from danger

V = -22.9





can't resist temptation

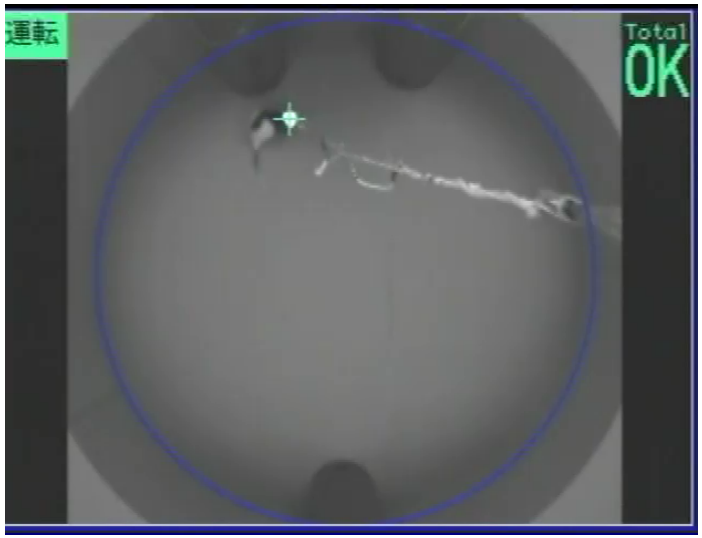
V = 47.3

Serotonin?

Dorsal Raphe Neuron Recording

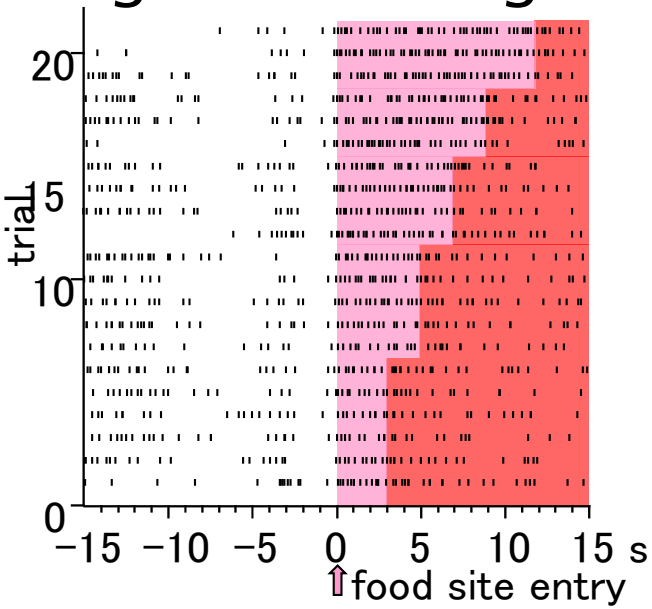
(Katsuhiko Miyazaki et al. 2011 JNS)

Food Water

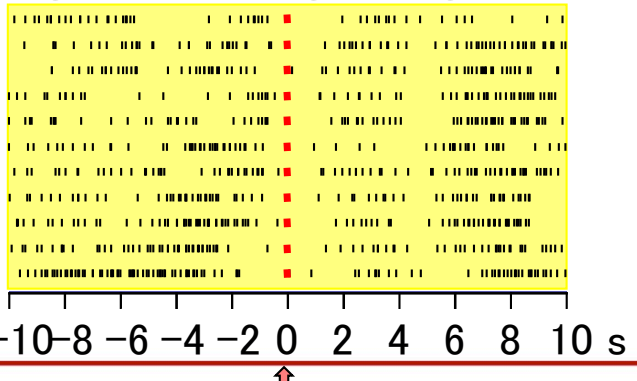


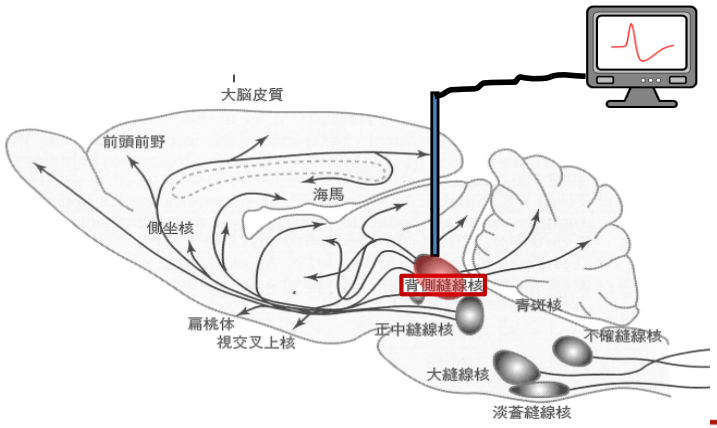
Tone

- Keep firing while waiting

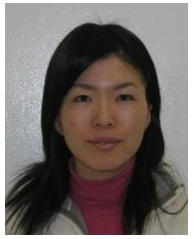


- Stop firing before giving up



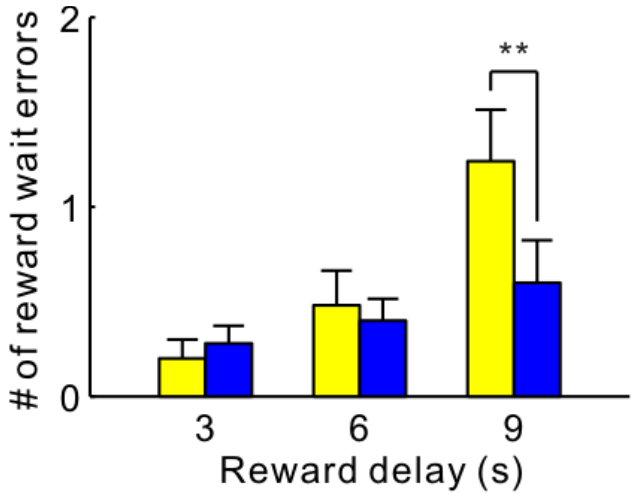


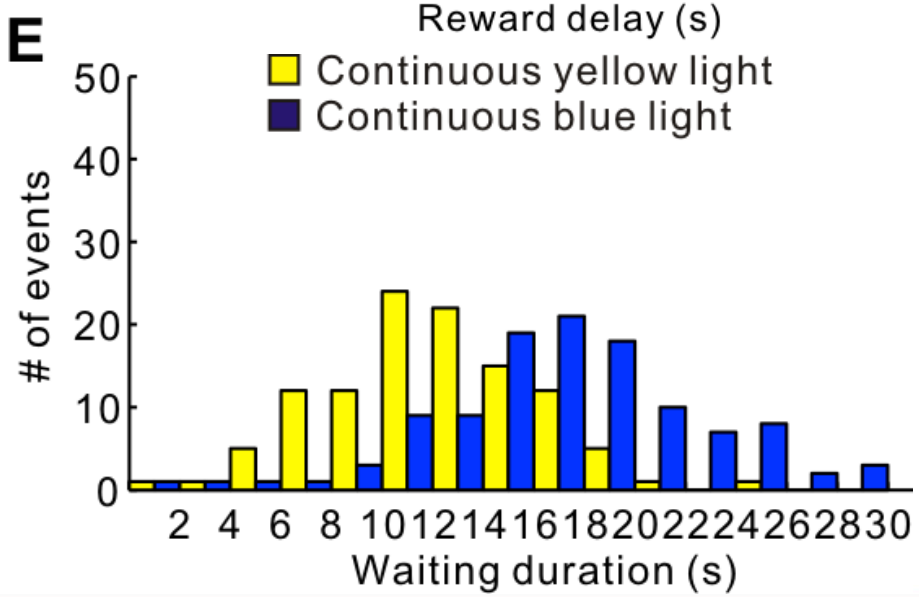
Optogenetic Stimulation of Dorsal Raphe Serotonin Neurons




(Miyazaki et al., 2014, Current Biology)

- Reward Delay Task (3, 6, 9, ∞ sec)



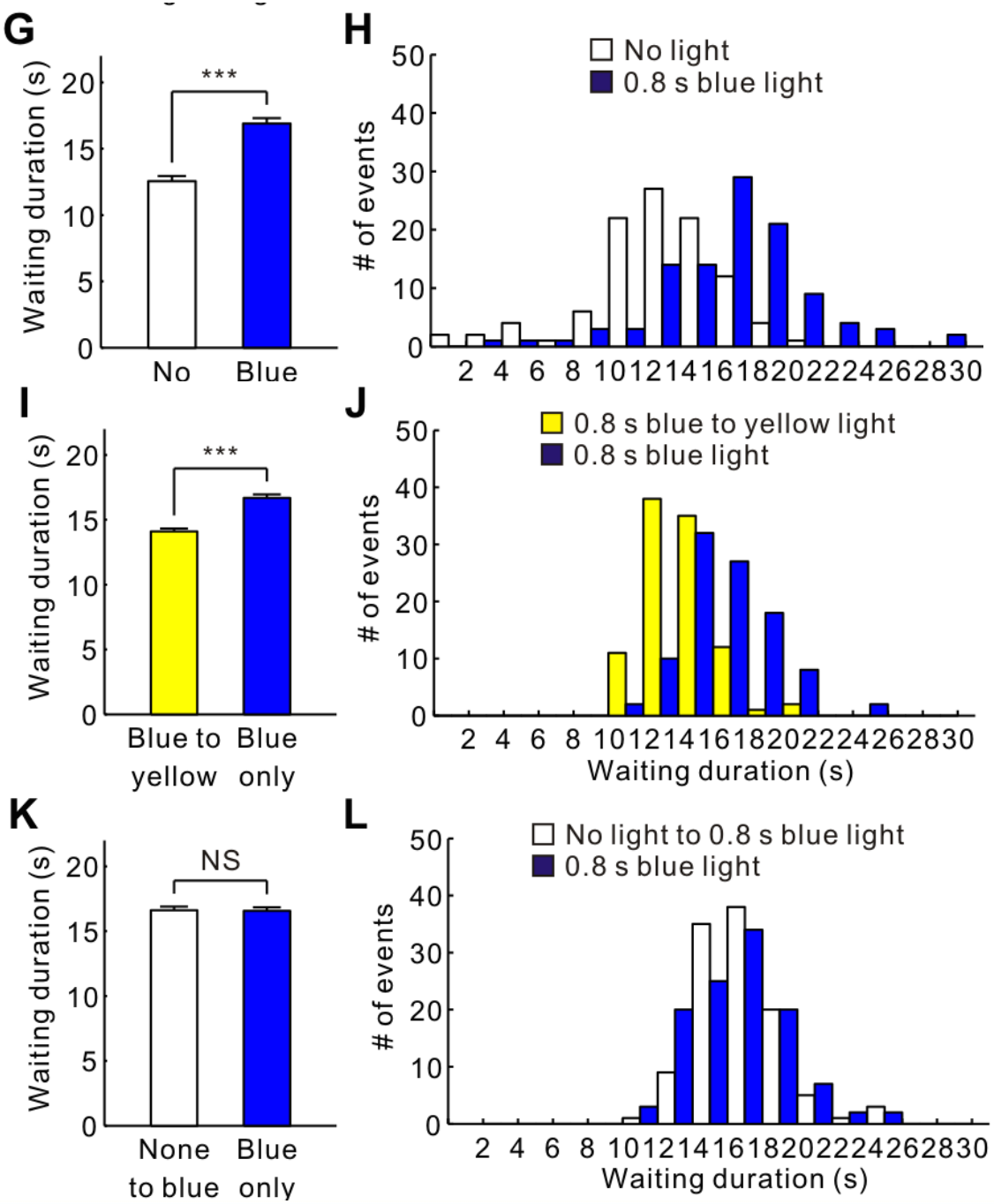


- 3 sec: success
- omission: 12.1 s
- omission: 20.8 s

Timing Matters!

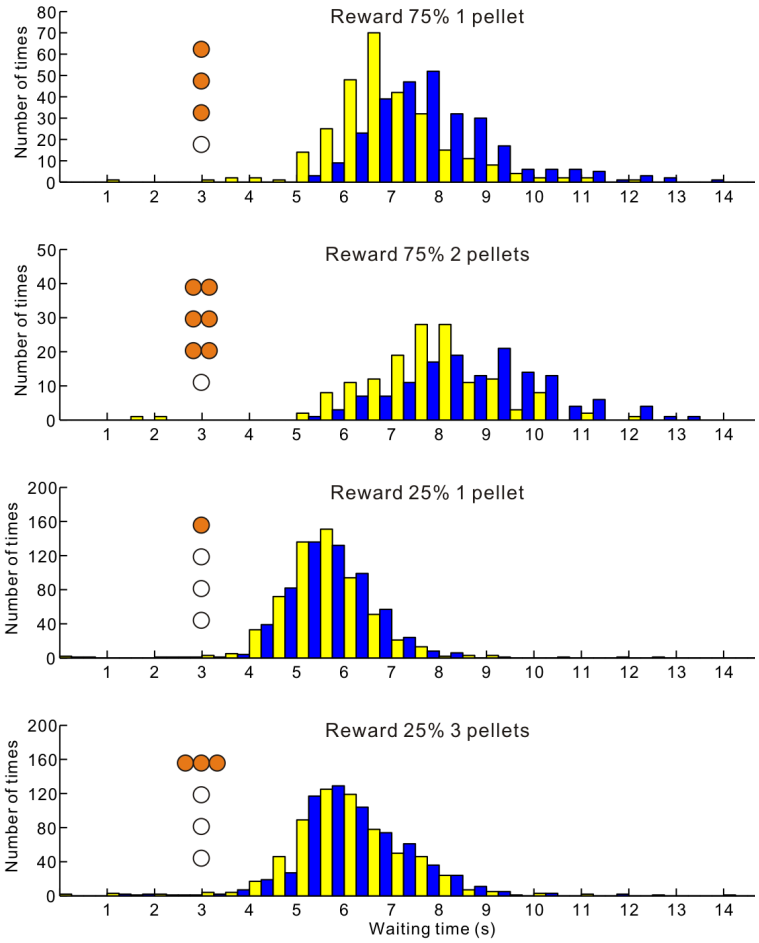
- no stim. vs full stim.
- first 10 sec vs full stim.
- after 10 sec vs full stim

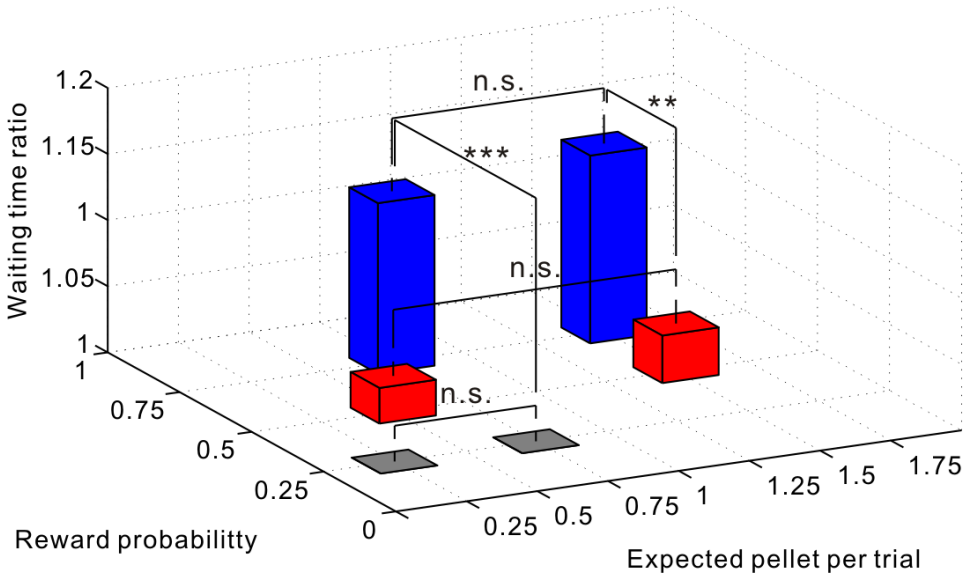
At the time of deciding "give up or hang on"



Dependence of Reward Probability

- Reward probability, not value





Summary

- Serotonin recording
  - microdialysis: high 5-HT release in waiting
  - neural recording: 5-HT firing till giving up
- Serotonin manipulation
  - pharmacology: impatient by 5-HT blockade
  - optogenetics: more patient by 5-HT stimulation

Not directly aversive/inhibitory

More dynamic than discounting parameter

Bias subjective prior vs sensory evidence?

Outline

Reinforcement Learning

- Can robots create their own reward function?

  (Elfwing et al., 2011 Adaptive Behavior, 2014 PLoS CB)

- Value function and basal ganglia

  (Ito & Doya, 2015 JNS)

Mental Simulation

- Model-based action planning

  (Fermin et al., 2016 Sci. Rep.)

- Dynamic Bayesian inference

  (Funamizu et al., 2016 Nat. Neurosci)

- Patience, confidence and serotonin

  (Miyazaki et al., 2014 Curr. Biol.)

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- Striatum recording
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  - **Katsuhiko Miyazaki**
- Optogenetics
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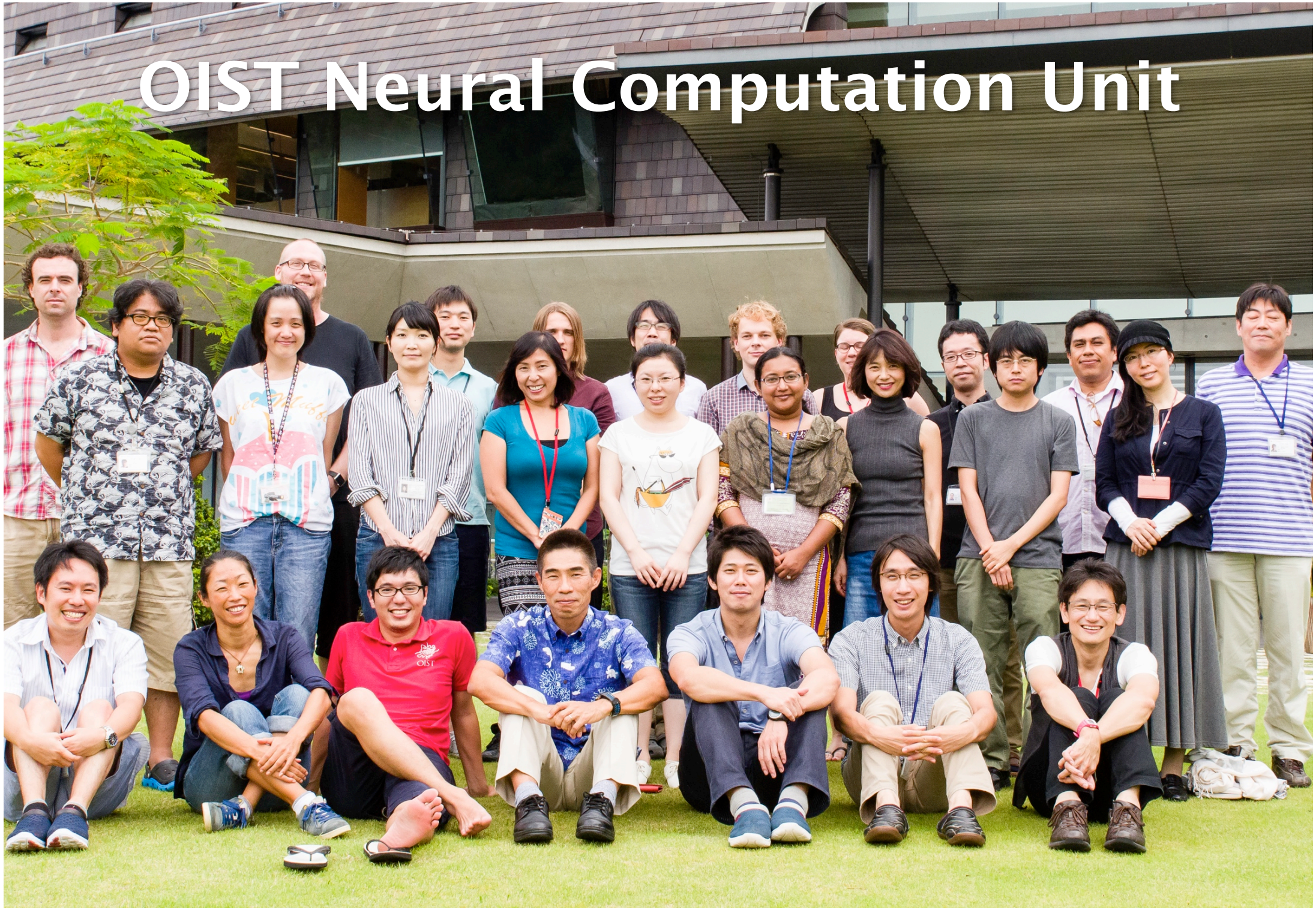
  - Naoto Yoshida (Tohoku U)
  - **Paavo Parmas**

Scientific Research on Innovative Areas
Strategic Research Program for Brain Sciences
Brain/MINDS Project
High Performance Computing Infrastructure
Post-K Supercomputing Program

OIST Neural Computation Unit



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募集中
期間：2017年8月2日（水）～8月4日（金）

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2017-03-22 Summer School

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