Neural mechanisms of cognition

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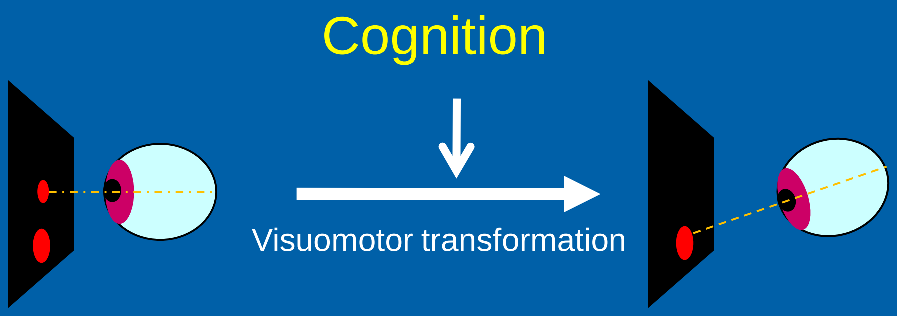
What is cognition?

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses".

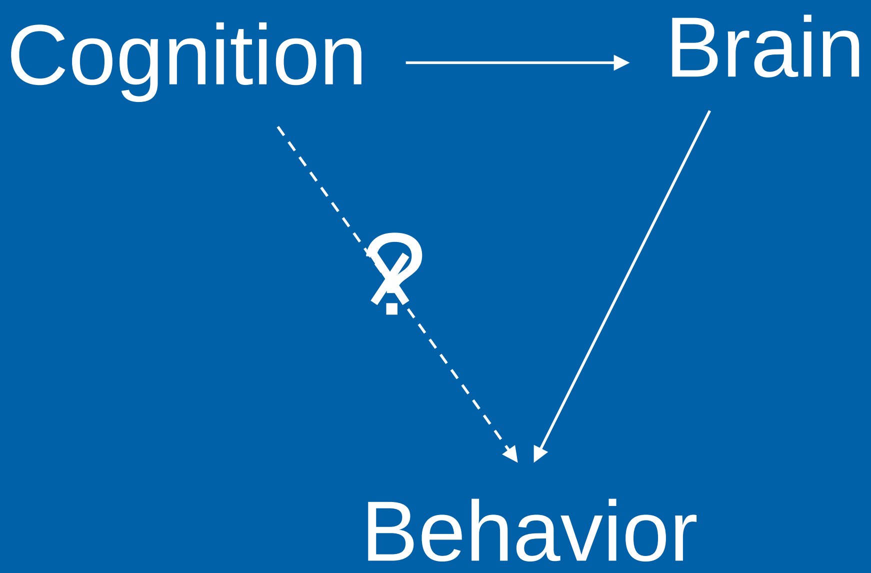
It encompasses many aspects of intellectual functions and processes such as perception and attention, the formation of knowledge, memory and working memory, judgment and evaluation, reasoning and "computation", problem solving and decision making, comprehension and production of language.

Cognitive processes use existing knowledge and generate new knowledge.

What is the function of cognition?



How to study cognition?



Outline

- Visual perception: visual stability and category in primates
- Attention: bottom-up and top-down attention
- Memory: long-term and short-term memory
- Decision making
- Prediction

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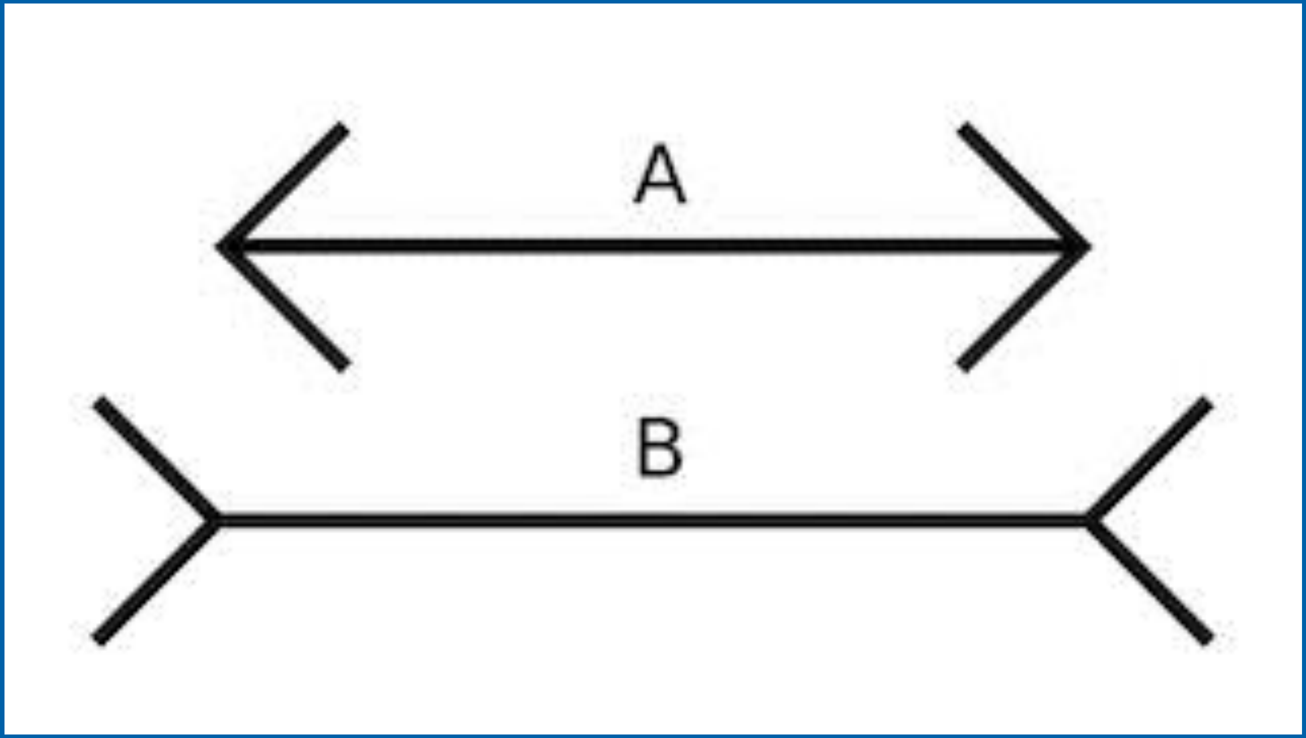
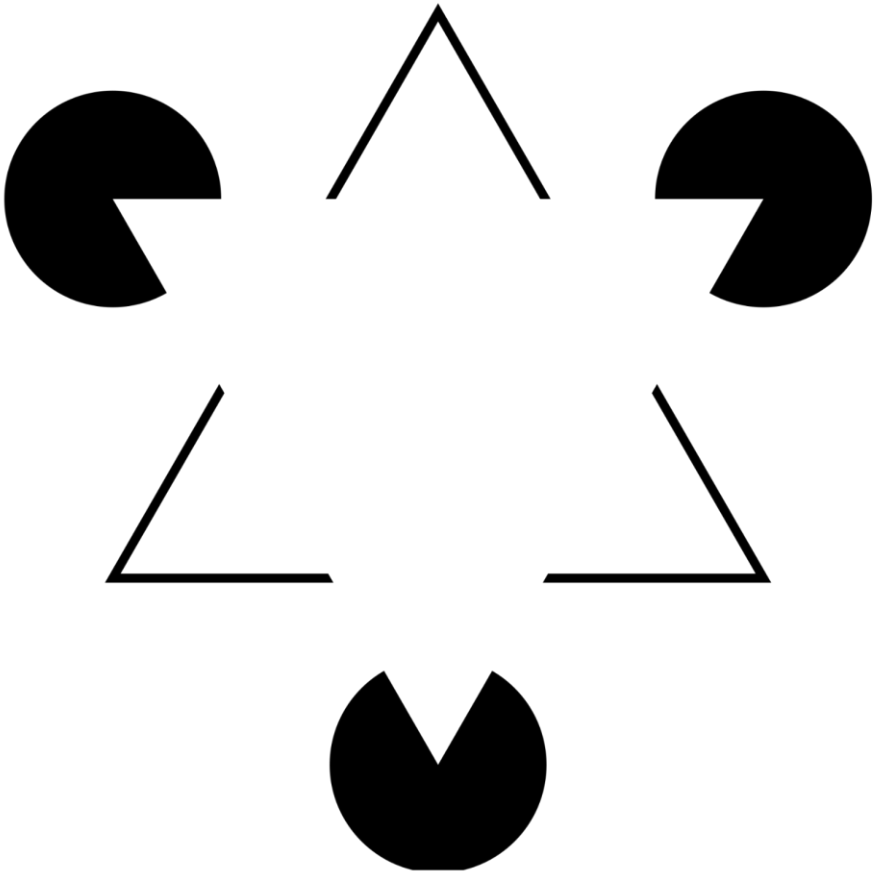
Dissociation between sensation and perception



Dissociation between sensation and perception



Dissociation between sensation and perception

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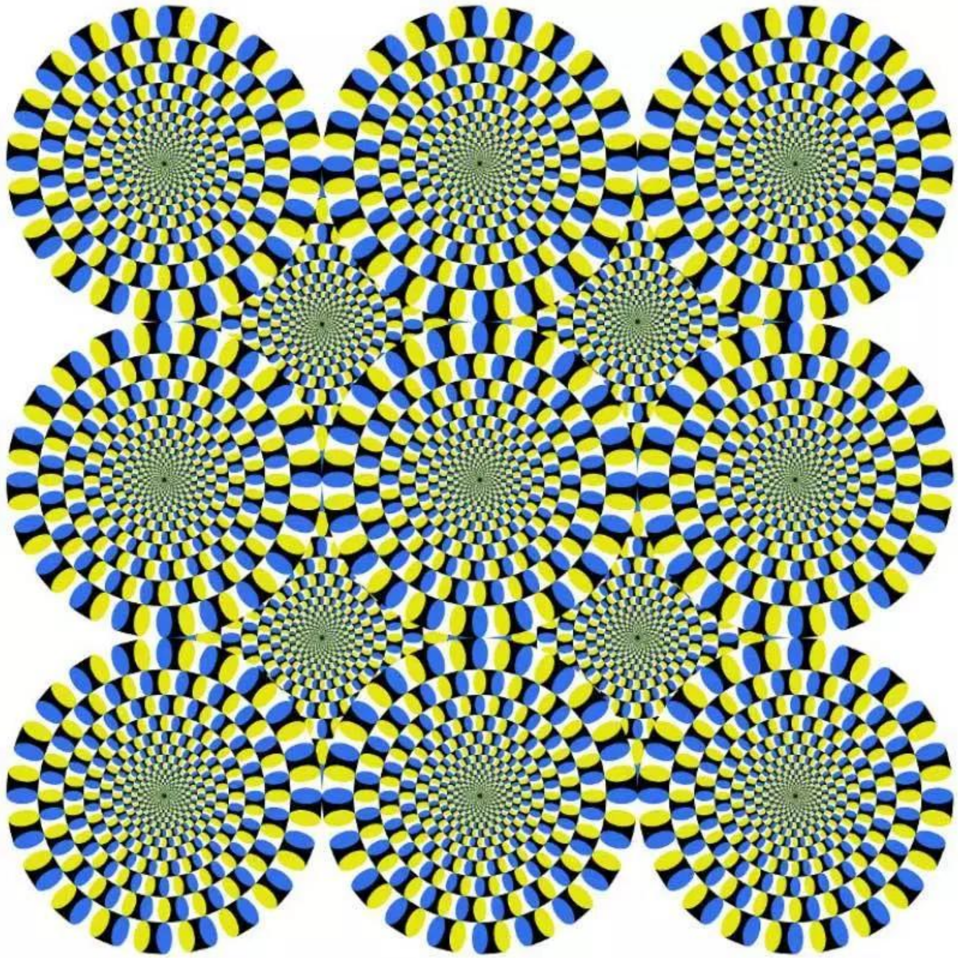


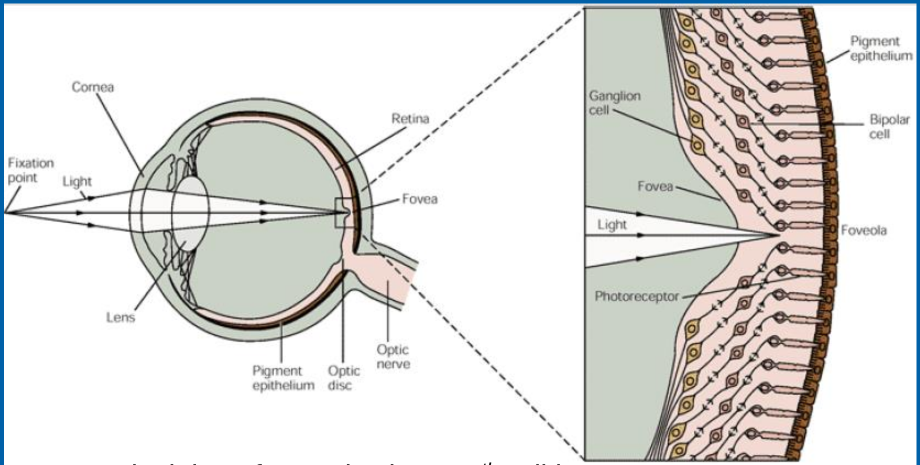
Problem caused by eye movements to visual perception

- Many animals explore surrounding environment by using visual system. For instance, vision takes about 80% of sensories in primates.
- There are 6 types of eye movements in primates: saccade, smooth pursuit, vestibular-oculomotor reflex, converged and diverged, fixation.

Saccadic eye movement in human

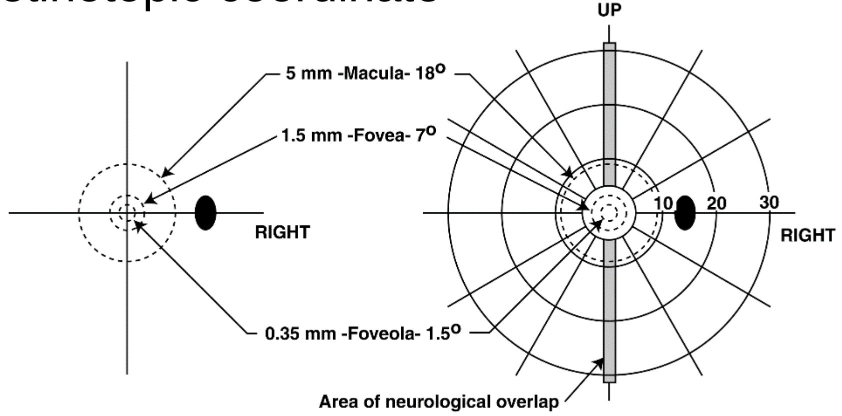
Saccadic eye movement in monkey

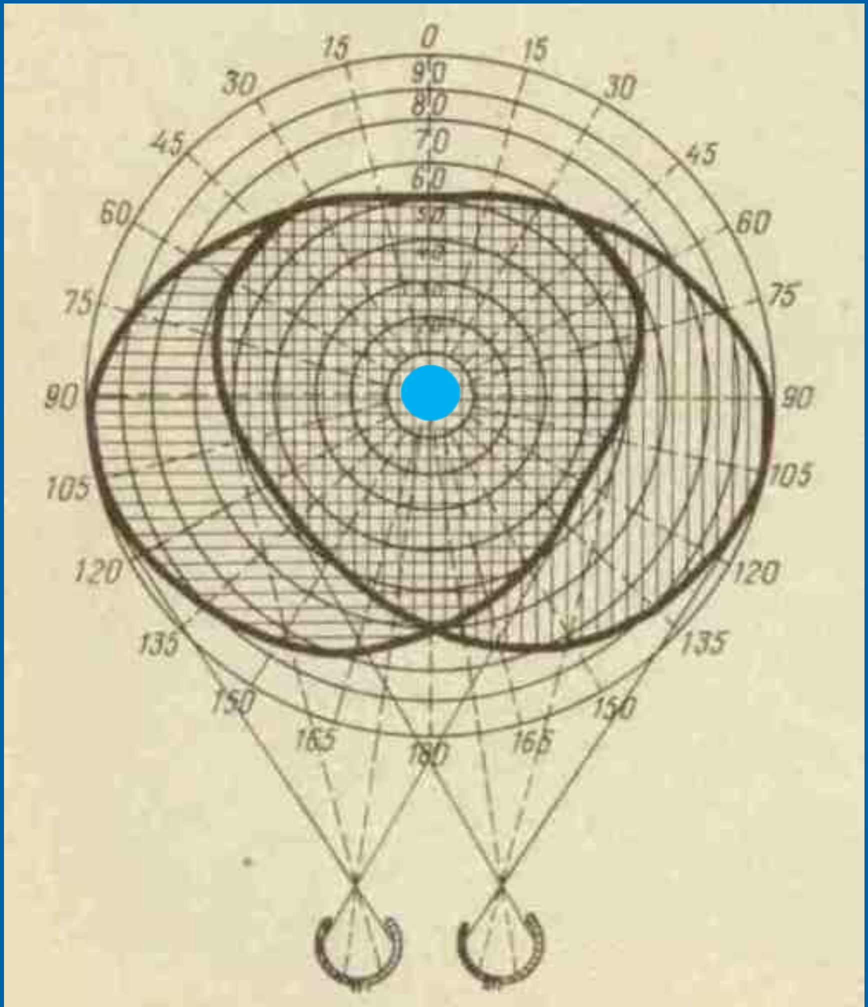
Structure of human's eye and binocular visual field



Principles of neural science 5th edition

Retinotopic coordinate





Saccade and vision

Saccade and vision

Saccade and vision

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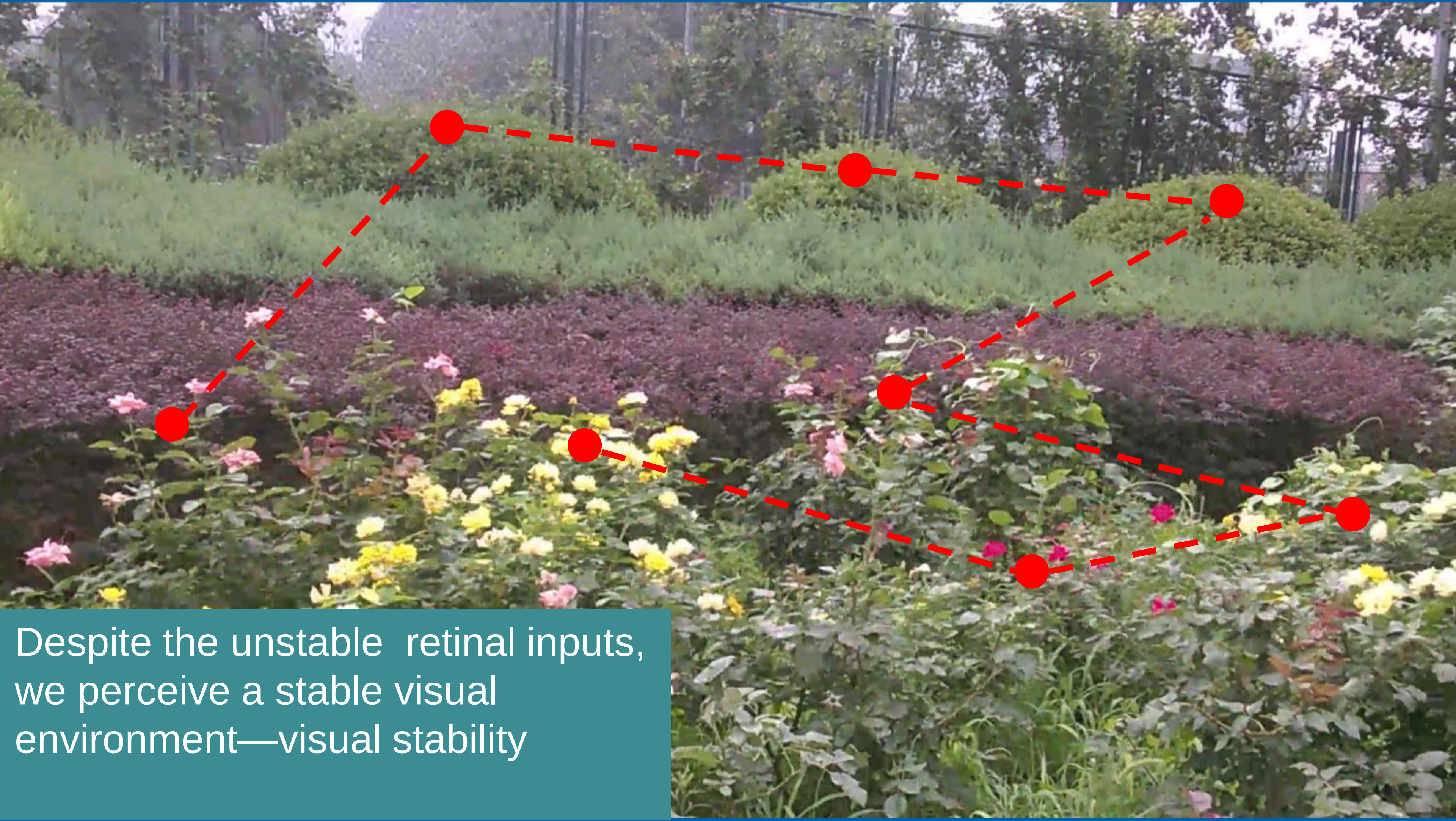
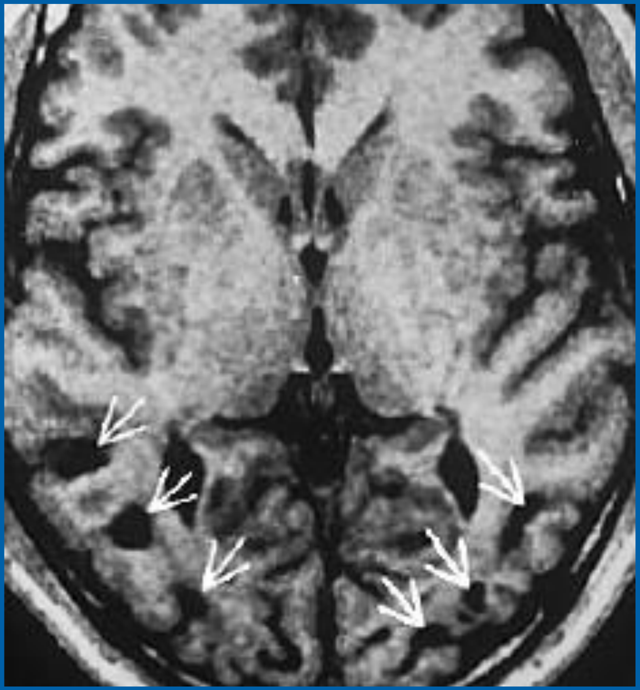
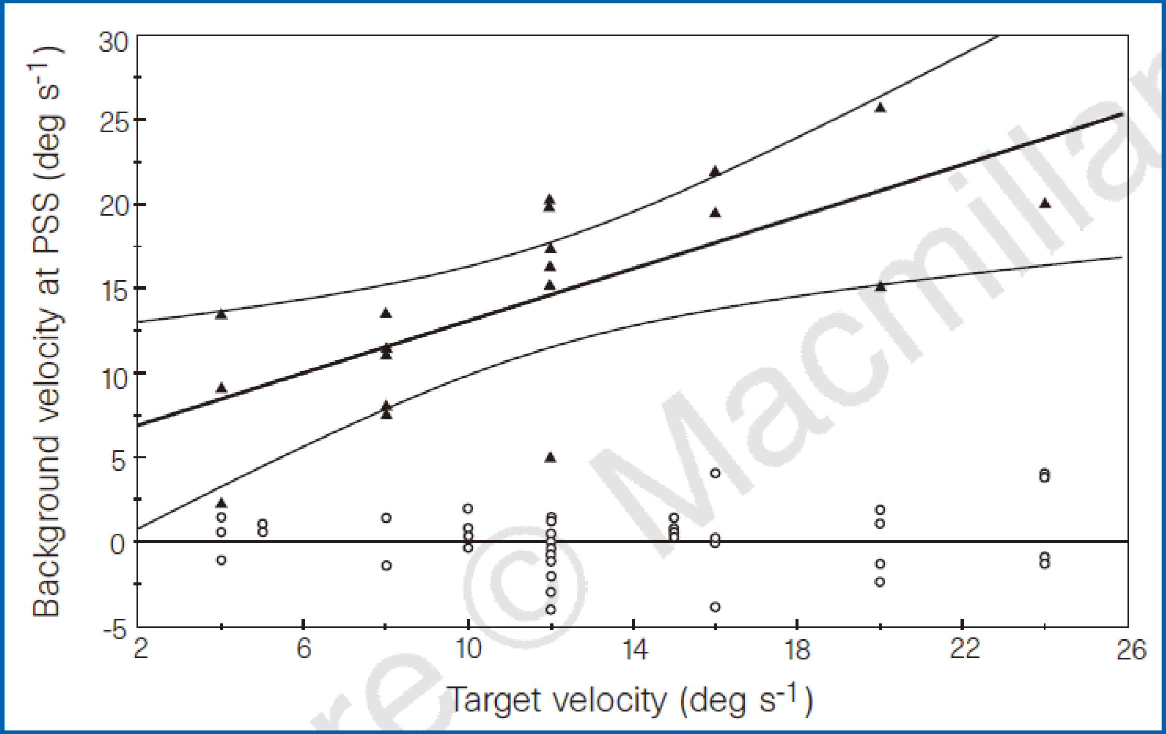


Despite the unstable retinal inputs, we perceive a stable visual environment—visual stability

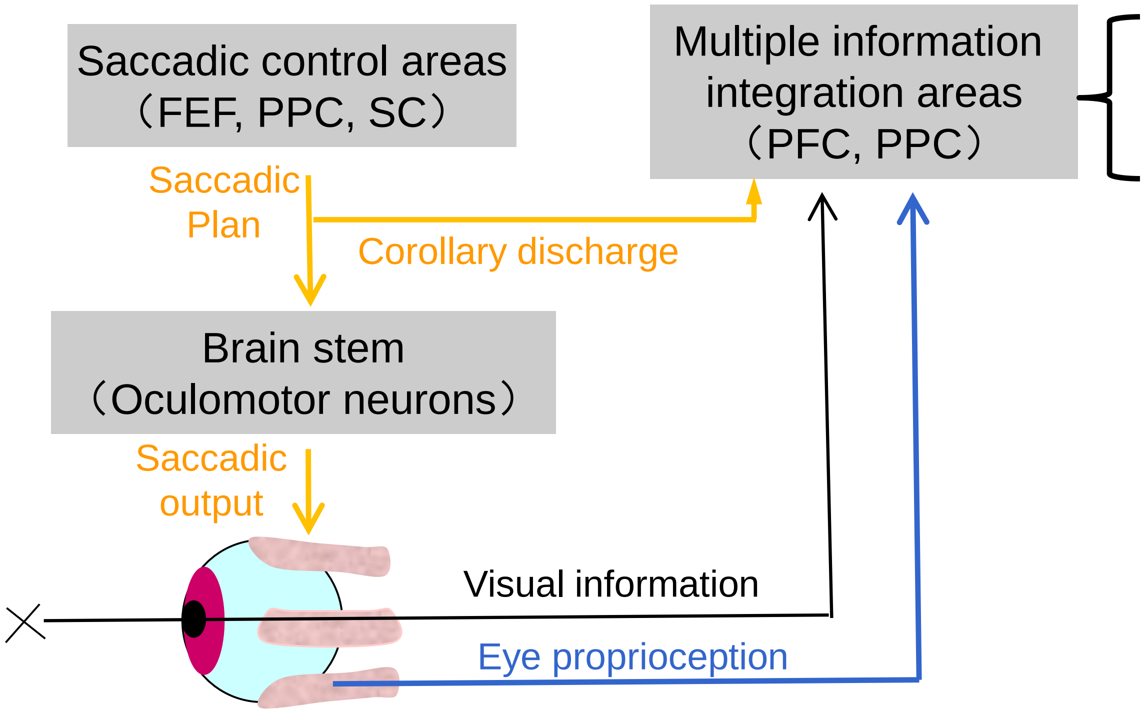
Lesion of occipitoparietal cortex impairs visual stability





Haarmeier et al. Nature 1992

Remaining visual stability needs to integrate retinal and extraretinal information (e.g., eye position, head position, etc.)

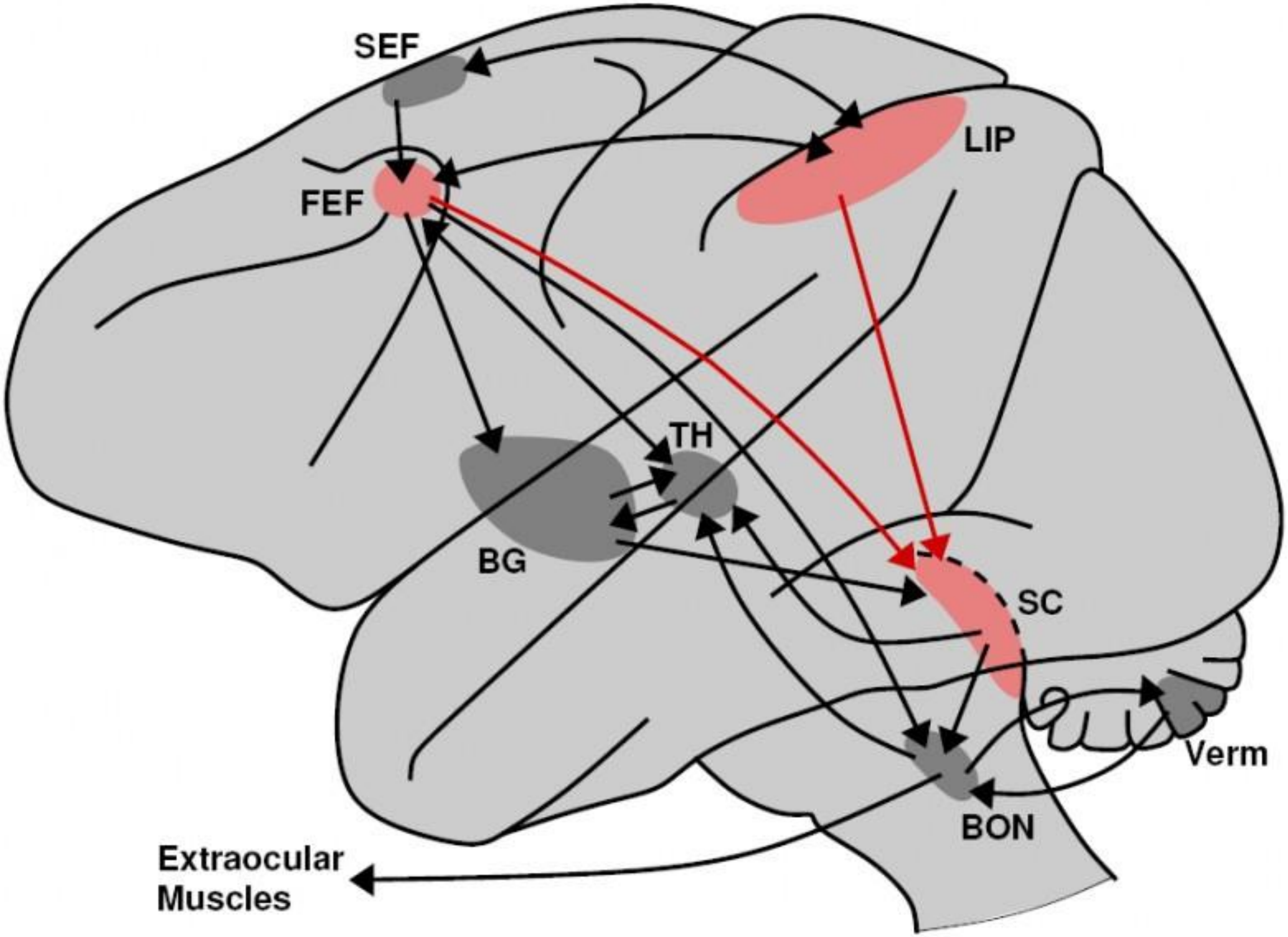


1.Retinotopic coordinate hypothesis: transsaccadic retinal and extraretinal information are integrated in retinotopic coordinate frame.

2. Spatiotopic coordinate hypothesis: the integration of multiple information creates a spatiotopic coordinate frame.

Visual stability

Neural circuits involved in saccadic control



How to monitor eye movements and brain activity?

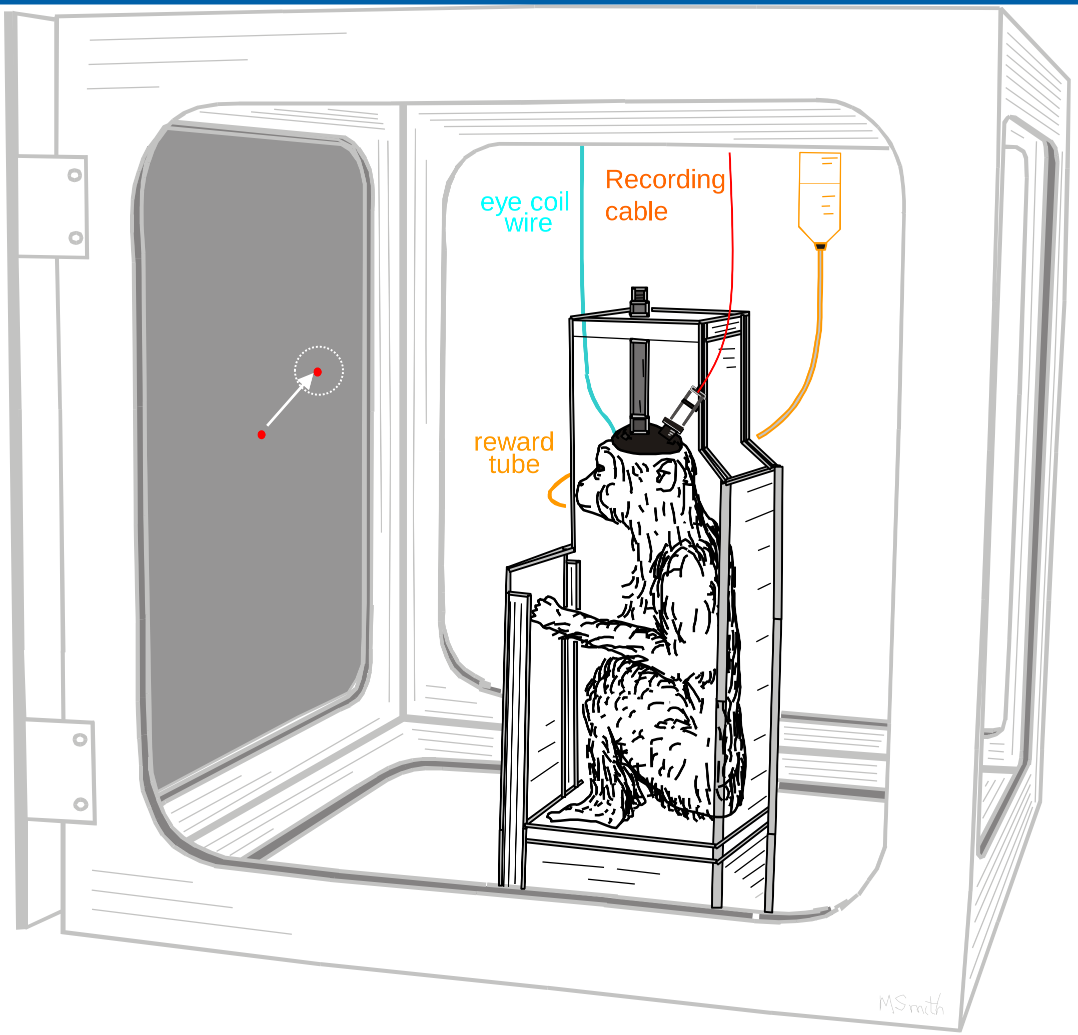
Measure eye movements:

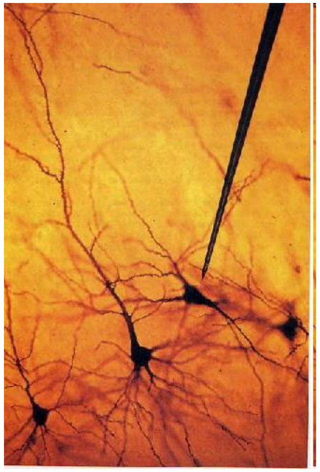
- Electromagnetic field technique/Eye coil technique: non-human study
- Image technique: human study

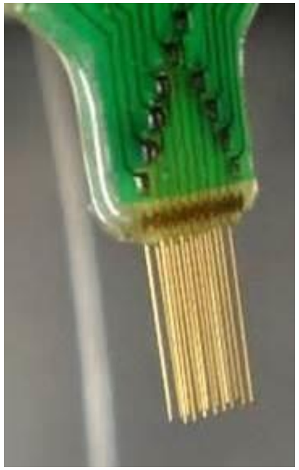
Measure Brain activity

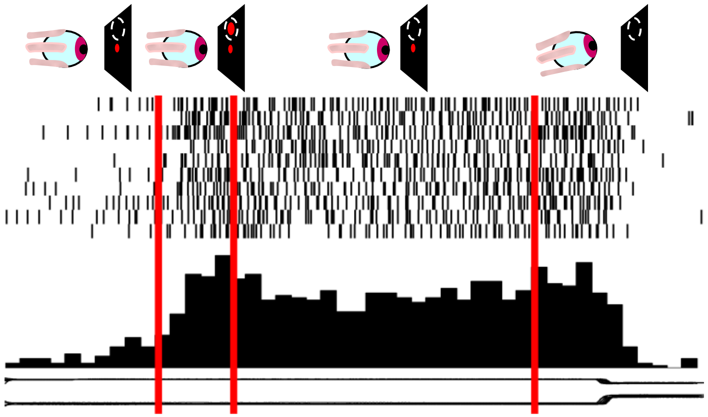
- Electrophysiology: recording of neuronal activity (single cell, multiple cells, LFP, EEG, ect.)
- Brain imaging: fMRI, PET, etc.

Extracellular recording of single neuron's activity in behaving monkeys to explore the neural basis for remaining visual stability

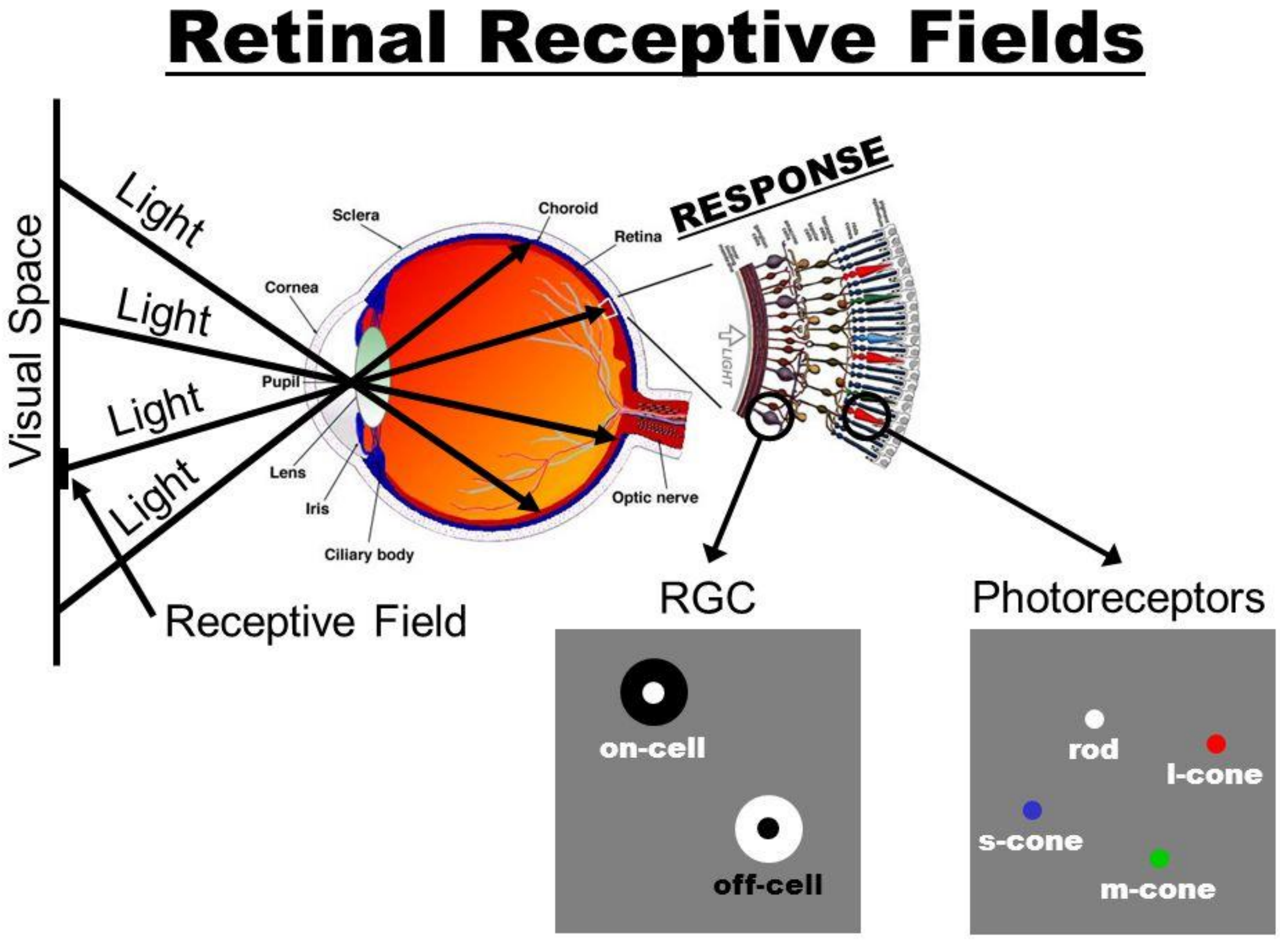




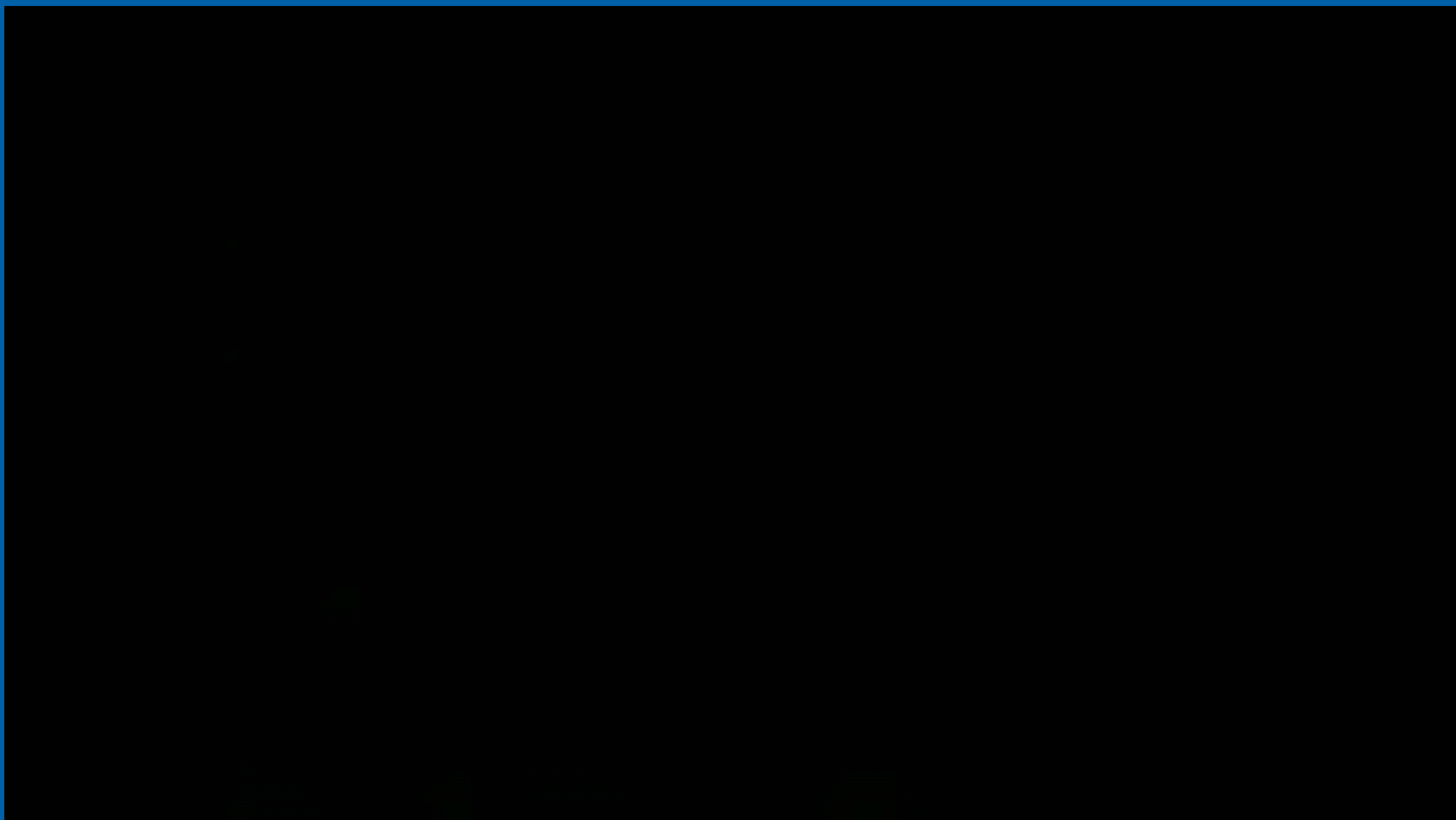




The first step of coding the visual spatial information: retinotopic receptive field

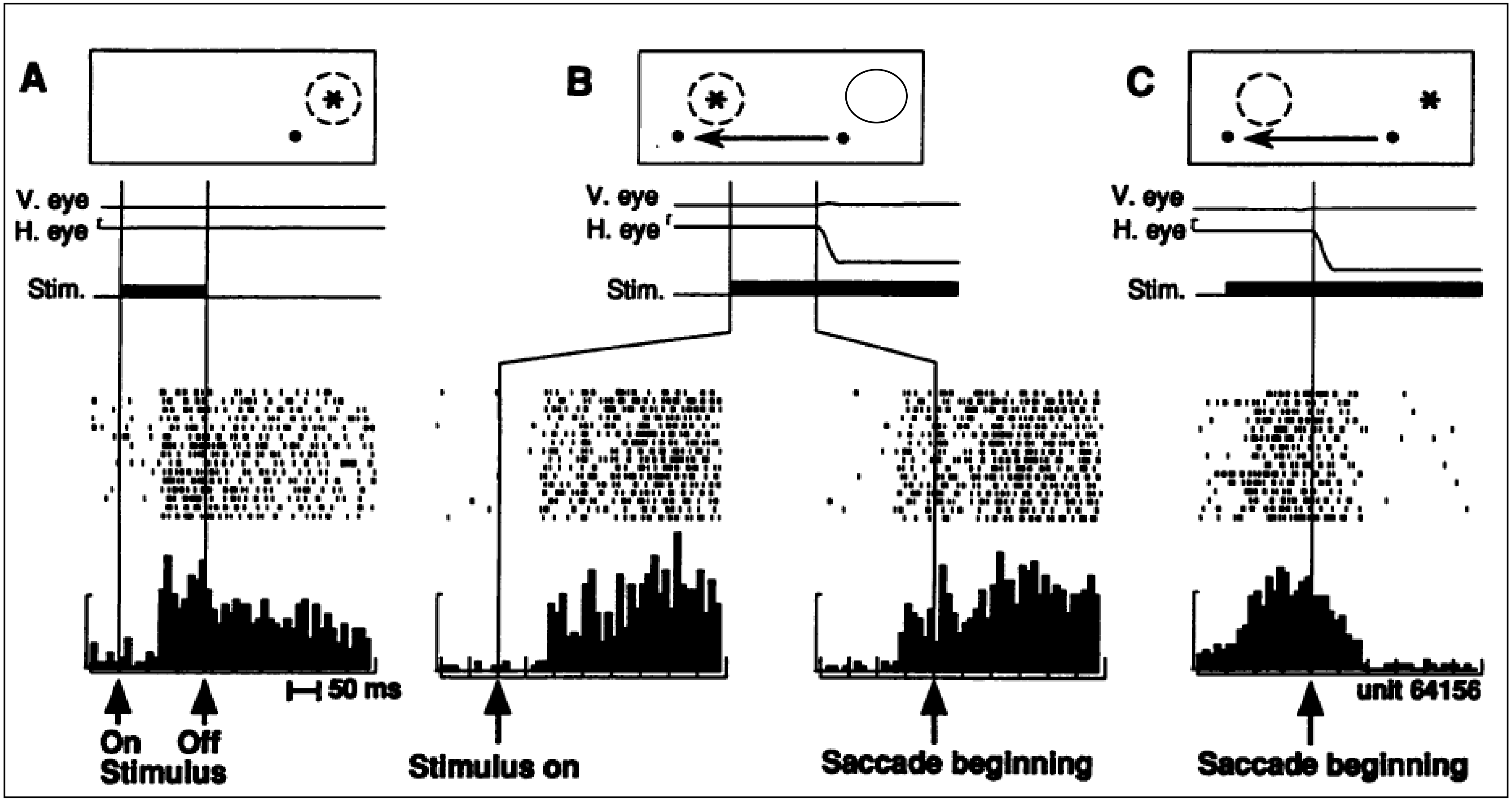


Retinotopic receptive field



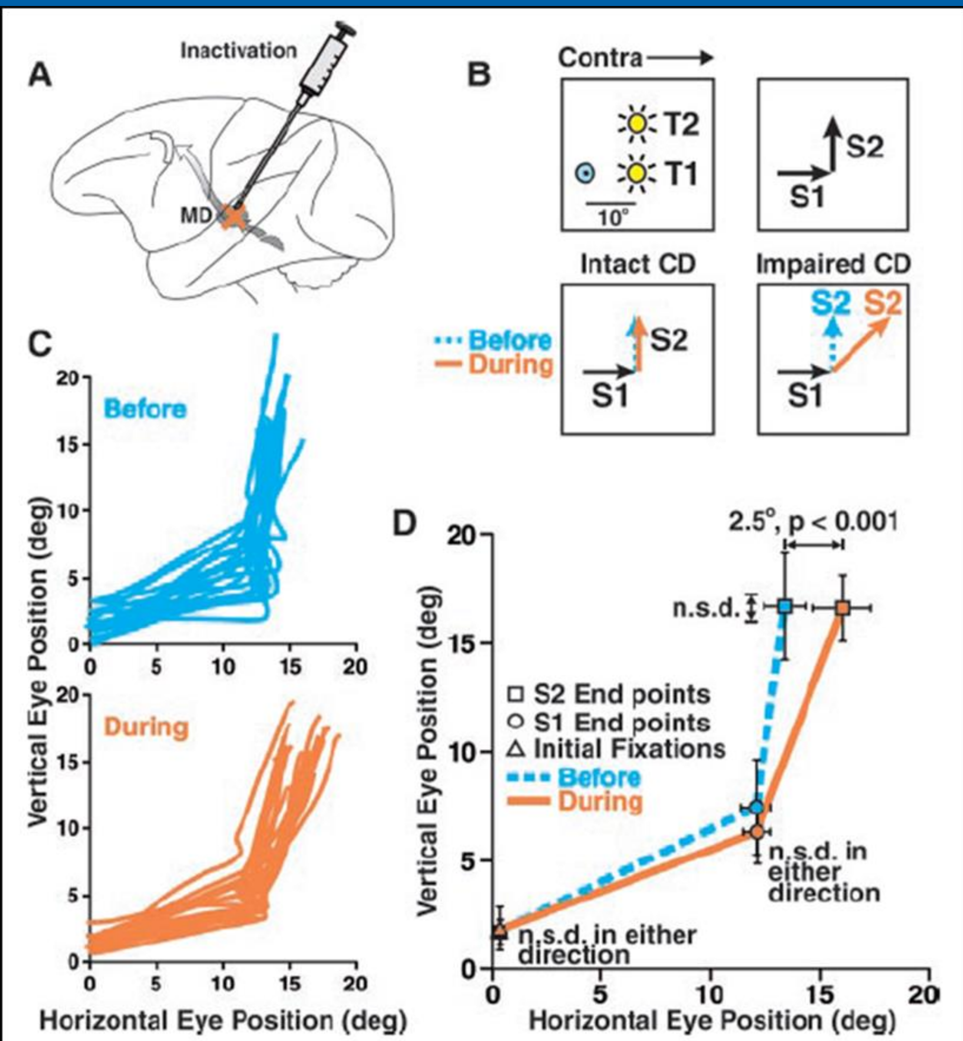
One mechanism for remaining visual stability: trans-saccadic comparison (preview theory)

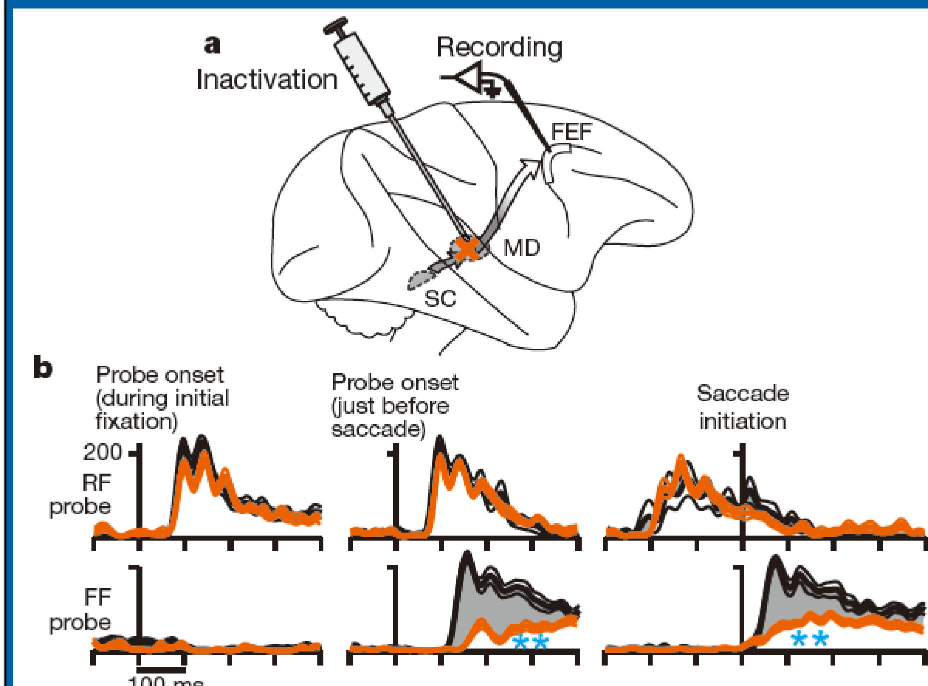
Evidence supporting preview theory: remapping of receptive field



Duhamul et al. Science 1992

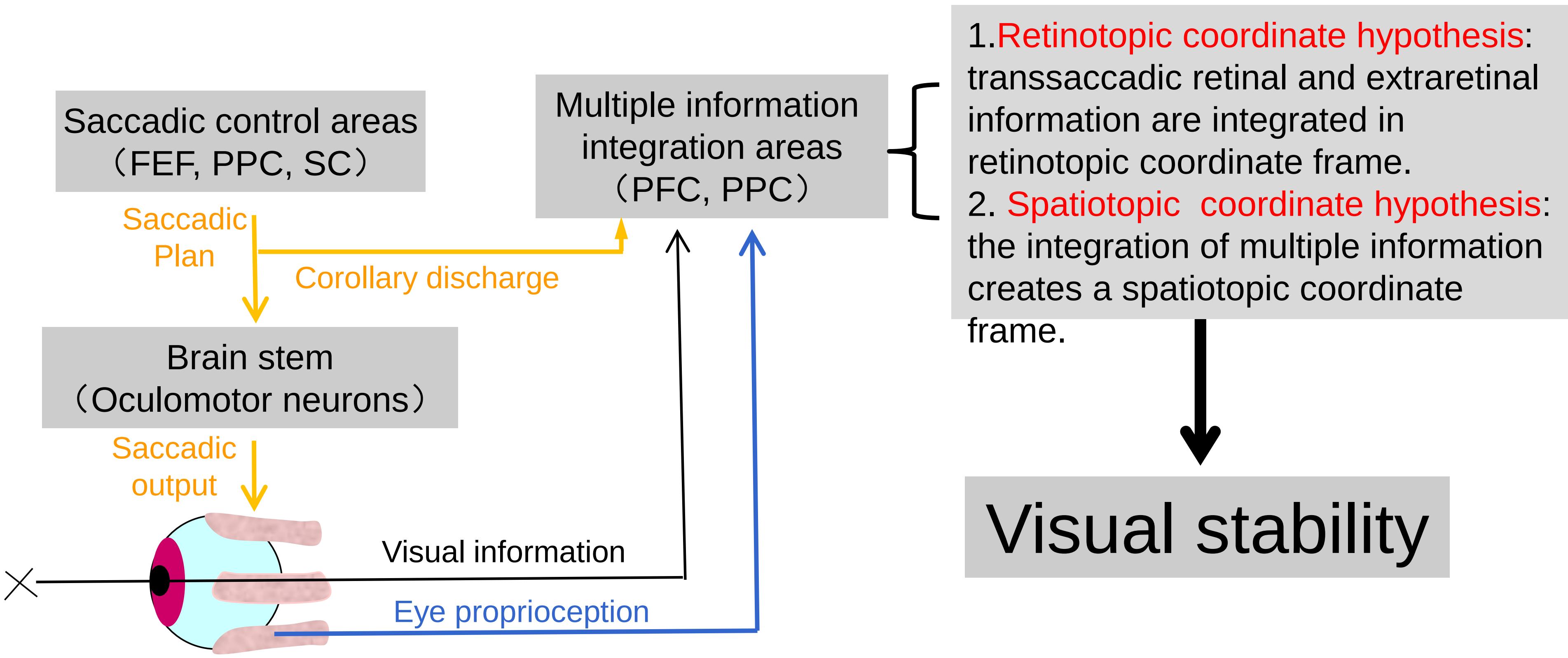
What caused the change of neuron's receptive field?





Sommer and Wurtz, 2002, 2006

Summary



Saccadic control areas
（FEF, PPC, SC）
Saccadic
Plan
Corollary discharge
Brain stem
（Oculomotor neurons）
Saccadic
output
Visual information
Eye proprioception
Multiple information
integration areas
（PFC, PPC）
1.Retinotopic coordinate hypothesis: transsaccadic retinal and extraretinal information are integrated in retinotopic coordinate frame.
2. Spatiotopic coordinate hypothesis: the integration of multiple information creates a spatiotopic coordinate frame.
Visual stability

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Visual category

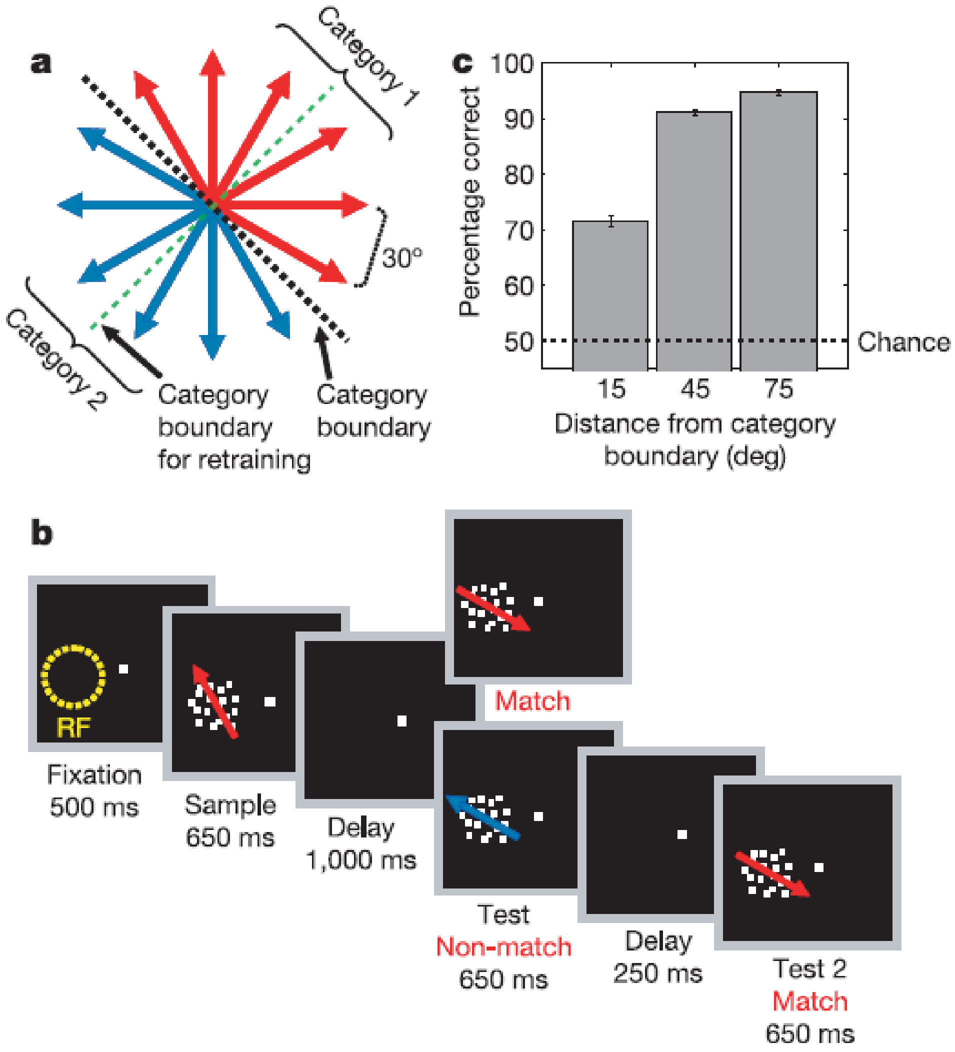


Figure 1 | Behavioural task. a, Monkeys grouped 12 motion directions into two categories (the red and blue arrows) separated by a 'category boundary' (black dotted line). The green dotted line is the boundary used for retraining with the new categories. **b**, Delayed match-to-category (DMC) task. A sample stimulus was followed by a delay and test. If the sample and test were in the same category, monkeys were required to release a lever before the test disappeared. If the test was a non-match, there was a second delay followed by a match (which required a lever release). **c**, Monkeys' average DMC task performance across all recording sessions was greater than chance (50%) for sample stimuli that were close to (15°) and farther from (45° or 75°) the boundary. Error bars are s.e.m.

Visual category

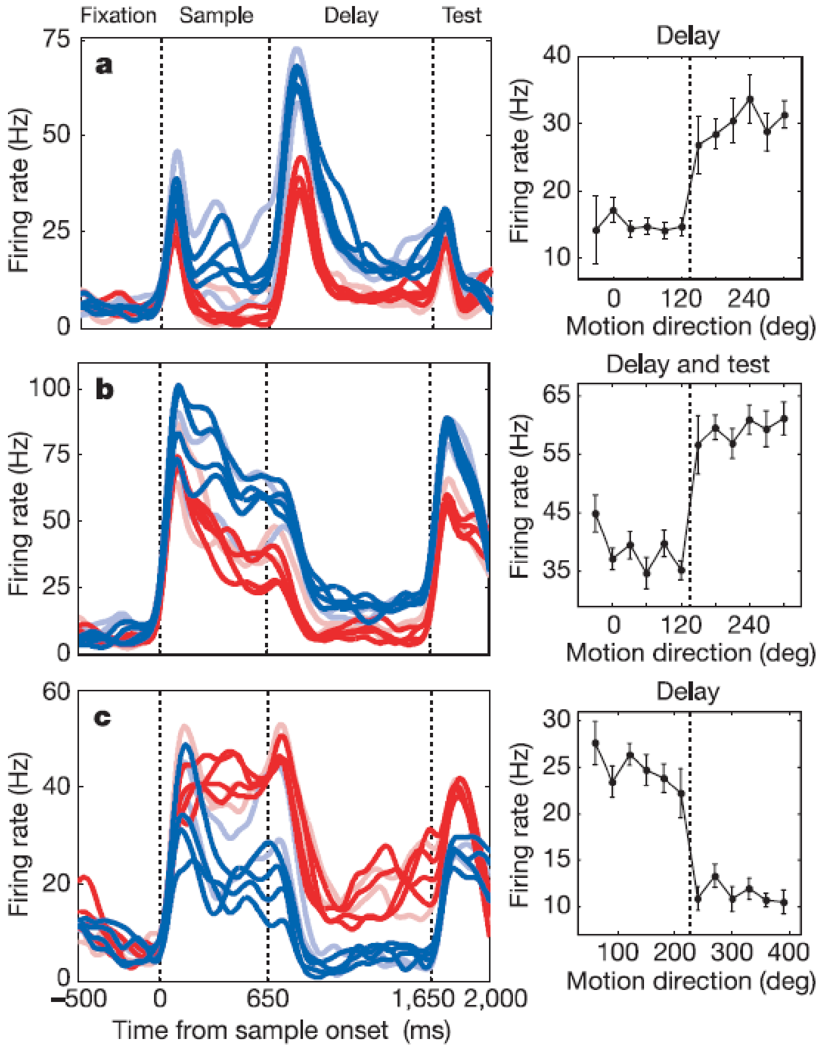


Figure 2 | Examples of three category-selective LIP neurons. Average activity to the 12 sample directions for three LIP neurons is shown. The red and blue traces correspond to directions in the two categories (red, category 1; blue, category 2), and pale traces indicate the directions closest to (15°) the boundary. The three vertical dotted lines indicate (from left to right) the timing of sample onset, the sample offset and the test-stimulus onset. The neurons in **a** and **b** were recorded with the original category boundary. The neuron in **c** was recorded after the monkey had been retrained on the new categories. The plots at the right of each peri-stimulus time histogram (PSTH) show activity (means ± s.e.m.) for the 12 directions during the delay (**a**), delay and test (**b**) and delay (**c**).

Visual category

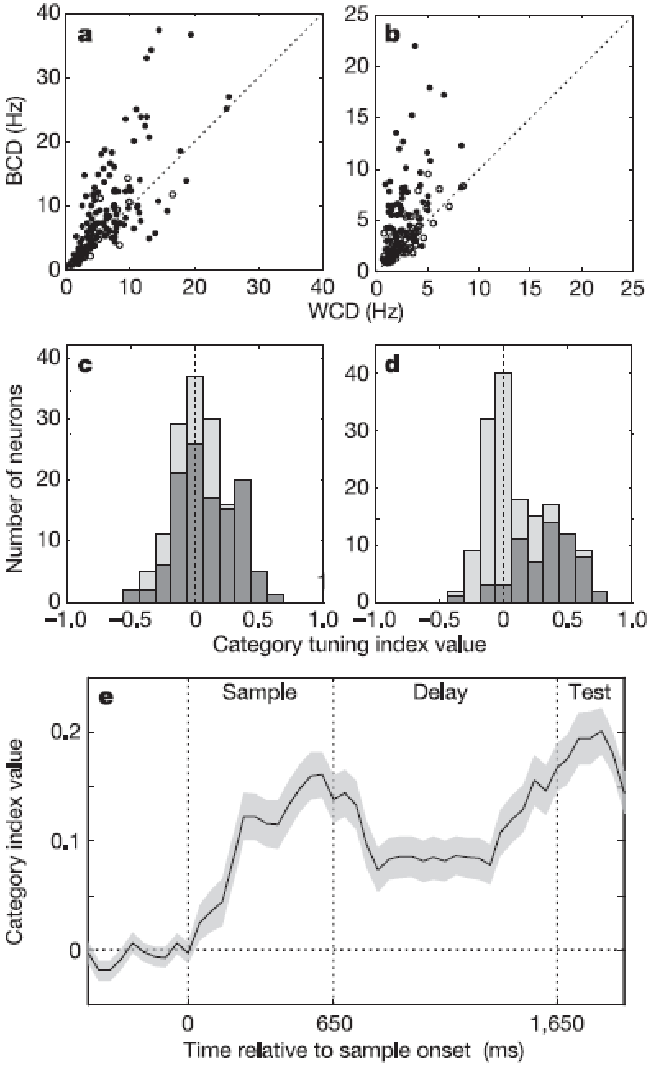


Figure 3 | Category effects across the LIP population. a, b, For each neuron, BCD and WCD values are shown for the sample (**a**) and delay (**b**). The filled and open circles indicate direction-selective and non-direction-selective neurons, respectively. **c, d,** A category index was computed from the BCD and WCD values. Positive index values indicate greater selectivity between categories and/or more similar activity within categories. The light grey bars show index values across all neurons ($n = 156$). The dark grey bars show index values for direction-selective neurons during sample (**c**) and delay (**d**). **e,** The time course of average category indices across 122 direction-selective neurons (during sample and/or delay).

BCD: between-category difference
WCD: within-category difference

Visual category

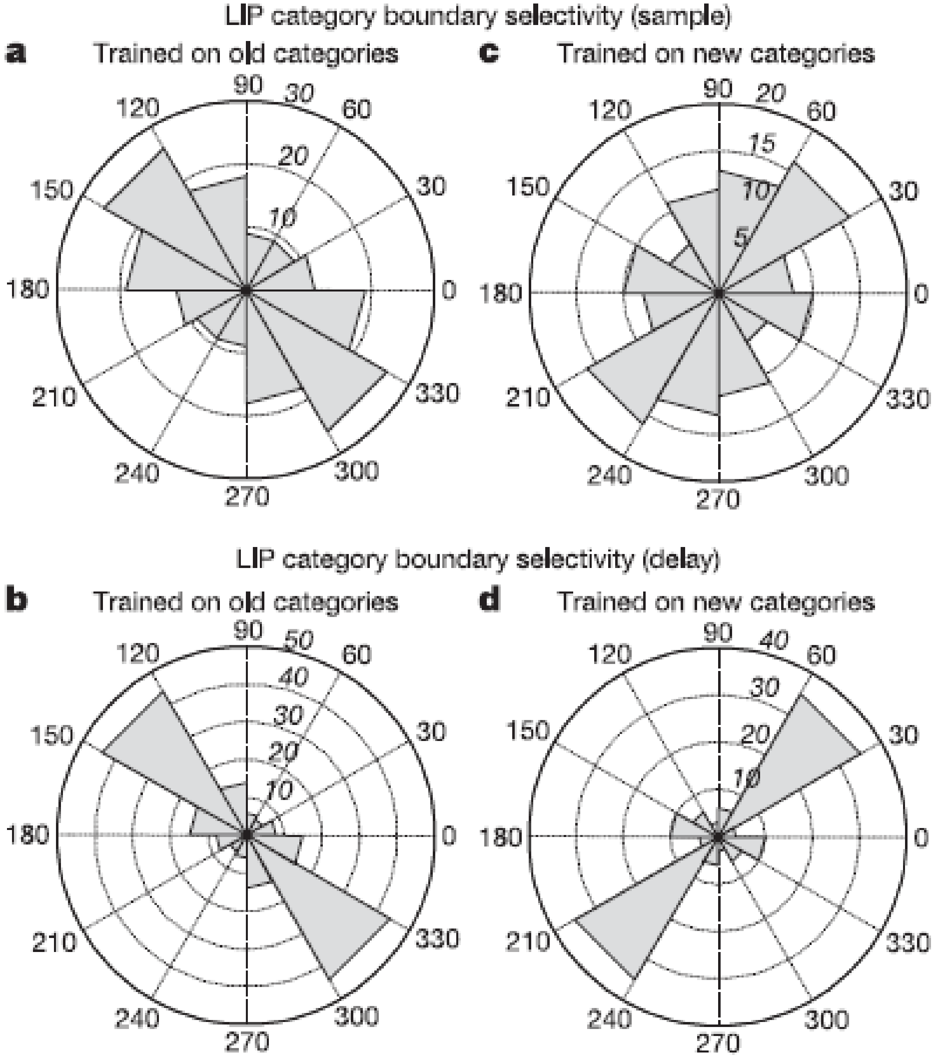
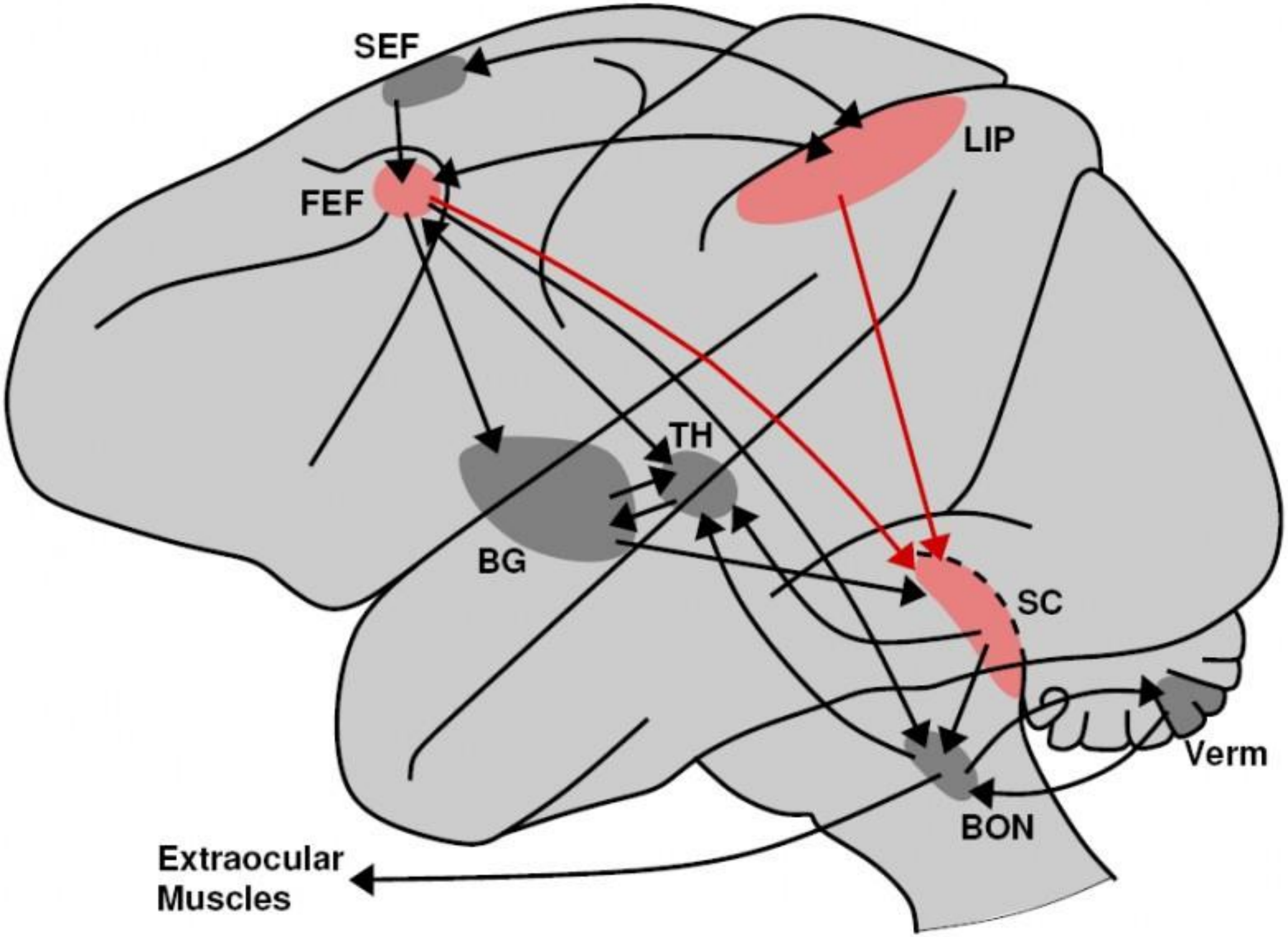


Figure 4 | LIP category selectivity followed retraining. After the recording of 92 neurons with the original category boundary, monkeys were retrained to categorize the same stimuli with a boundary perpendicular to the original one; we then recorded an additional 64 neurons. For each neuron we determined which of six possible boundaries (that is, the 'new' and 'old' boundaries, plus the four boundaries that we did not use) gave the largest difference in average activity among directions on either side of the boundary. **a**, **b**, Polar distribution of the best boundary for the sample (**a**) and delay (**b**) activity of all neurons with monkeys trained on the original boundary. The number of neurons that preferred each boundary (measured on the concentric scale with numbers in italics) corresponds to the radius of either of the two opposite 'bowtie' segments (but the two should not be added). **c**, **d**, Distribution of the best boundary for the activity of all neurons after retraining on the new categories.

Summary



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Limitation of visual perception

Limitation of visual perception

Limitation of visual perception

Limitation of visual perception

Attention - William James

William James (January 11, 1842 – August 26, 1910) was an American philosopher and psychologist who was also trained as a physician

Attention - William James

- Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought...It implies withdrawal from some things in order to deal effectively with others.

James made us aware of the power of attention to

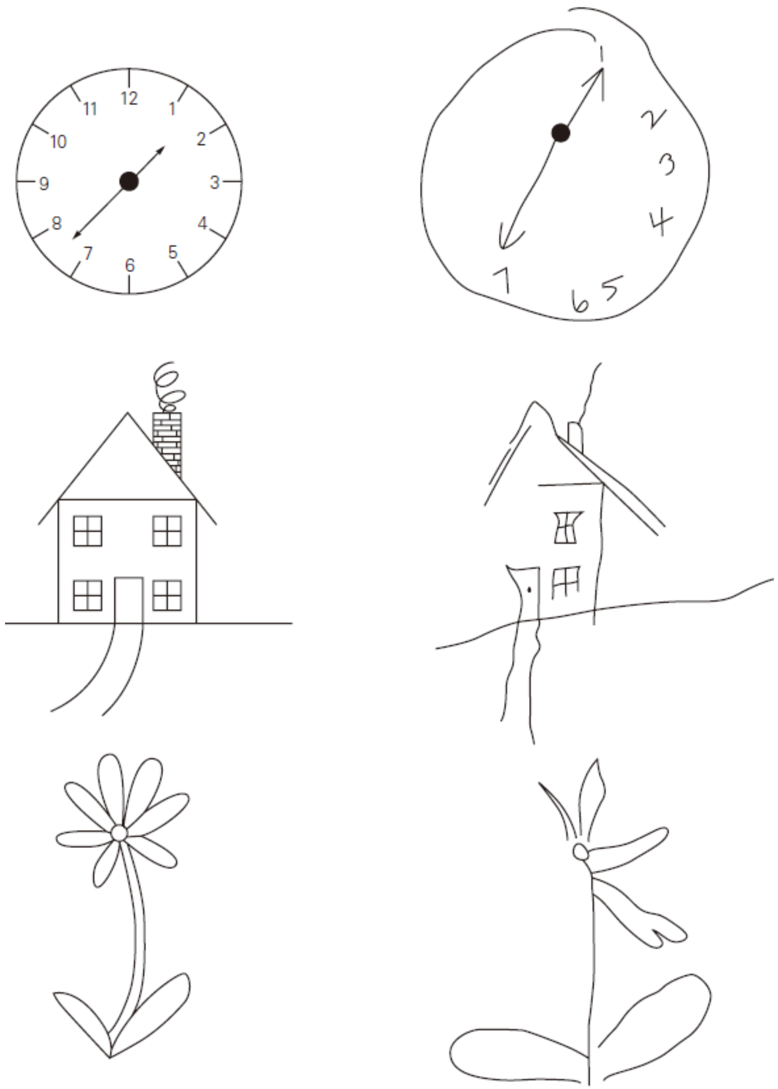
- Shorten reaction time
- Enhance perception

More James: Two varieties of attention

- Non-voluntary (bottom-up, exogenous)
- Voluntary (top-down, endogenous)

The effects of attention deficit in behavior

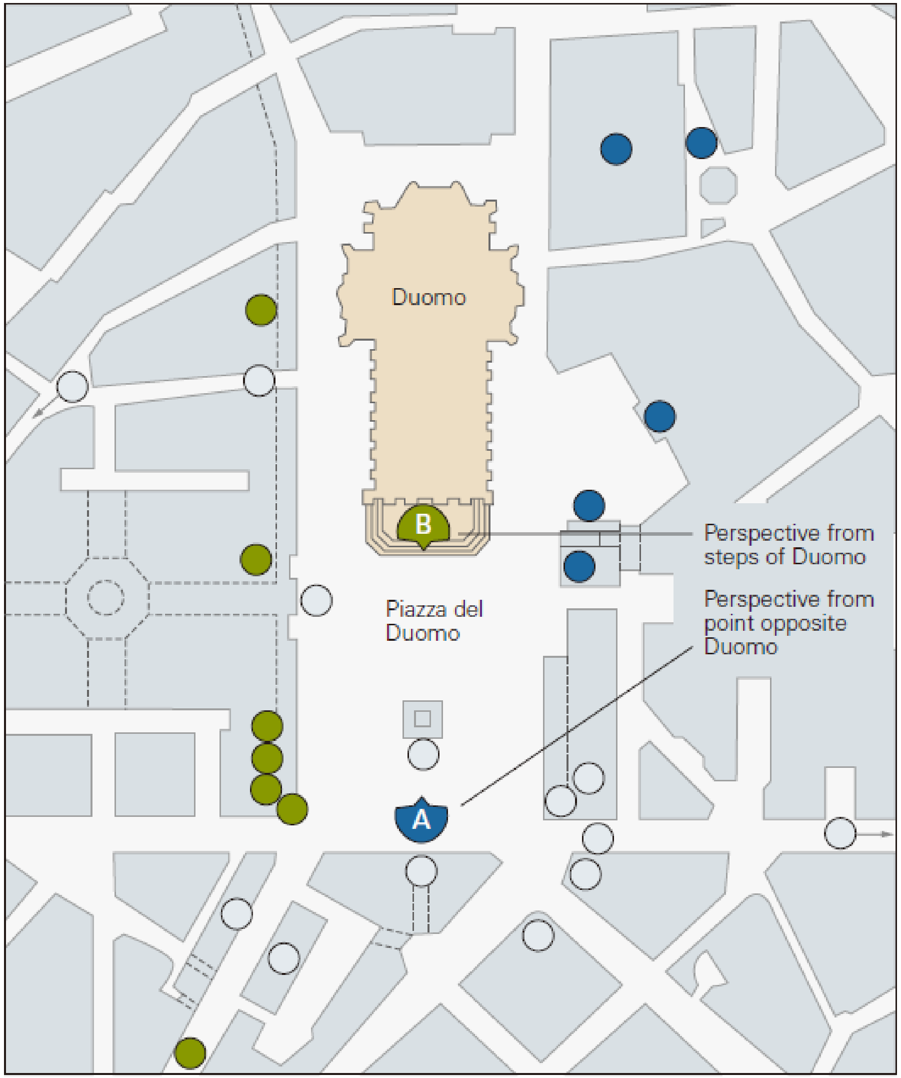
Perceptual deficits in patients with frontoparietal injury



Principle of neural science 5th

Memory deficits in patients with frontoparietal injury

Figure 17–14 Milanese patients with lesions of the right posterior parietal cortex are able to recall only landmarks on their right in the Piazza del Duomo in Milan. Patients were asked to recall landmarks from memory from two points in the square. The **blue circles** in the map represent landmark buildings recalled from perspective A opposite the Duomo; the **green circles** represent landmark buildings recalled from perspective B on the steps of the Duomo. (Adapted, with permission, from Bisiach and Luzzatti 1978.)



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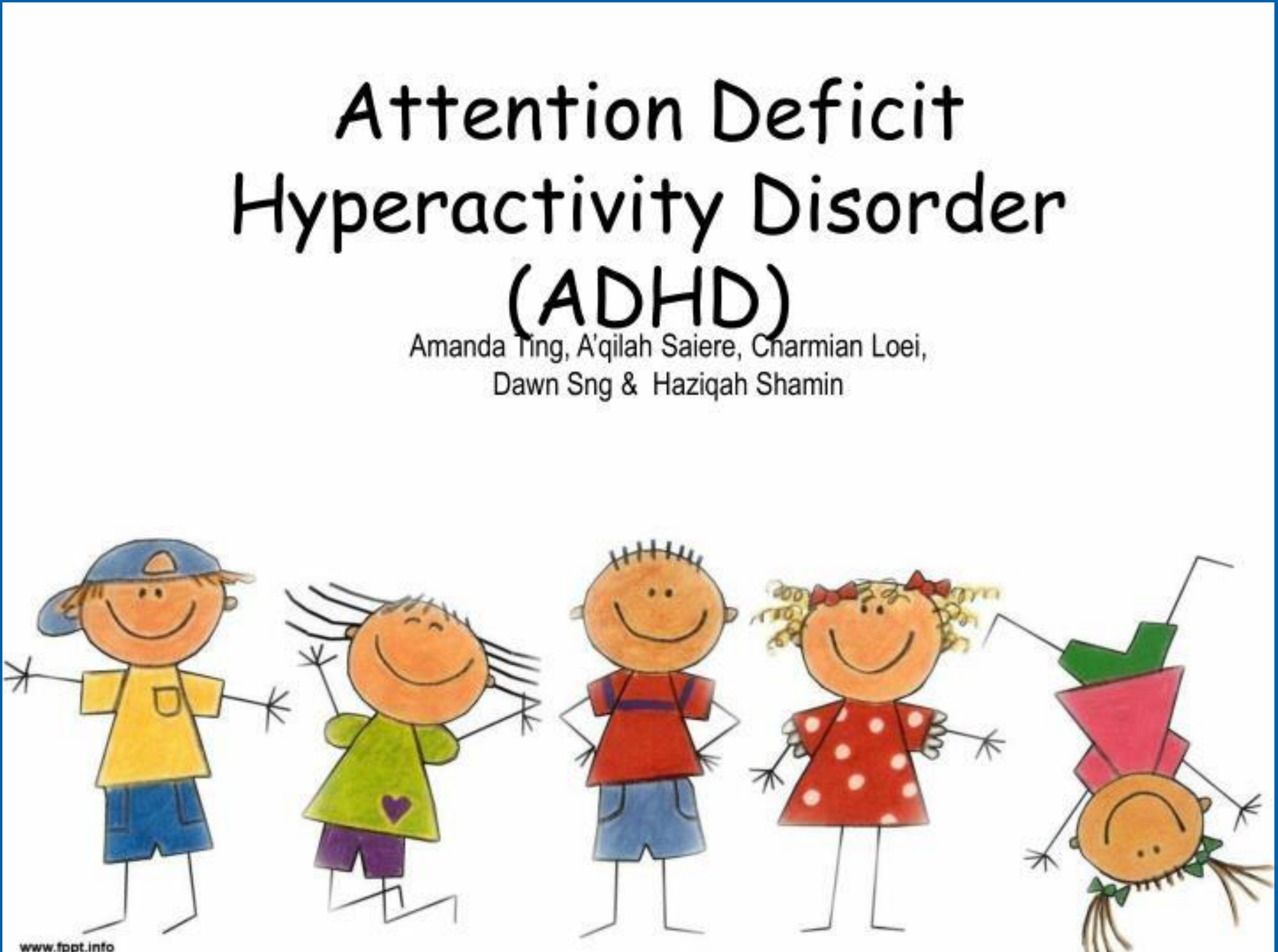
Attention deficit in Children



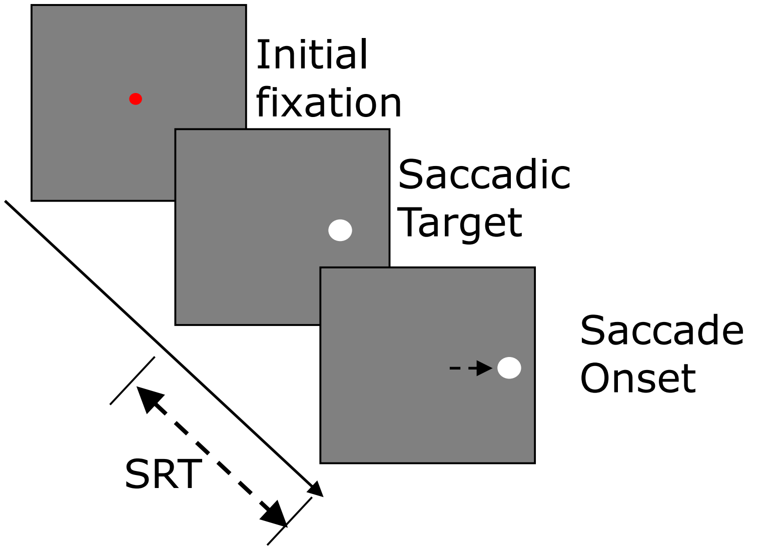
Attention deficit in Children

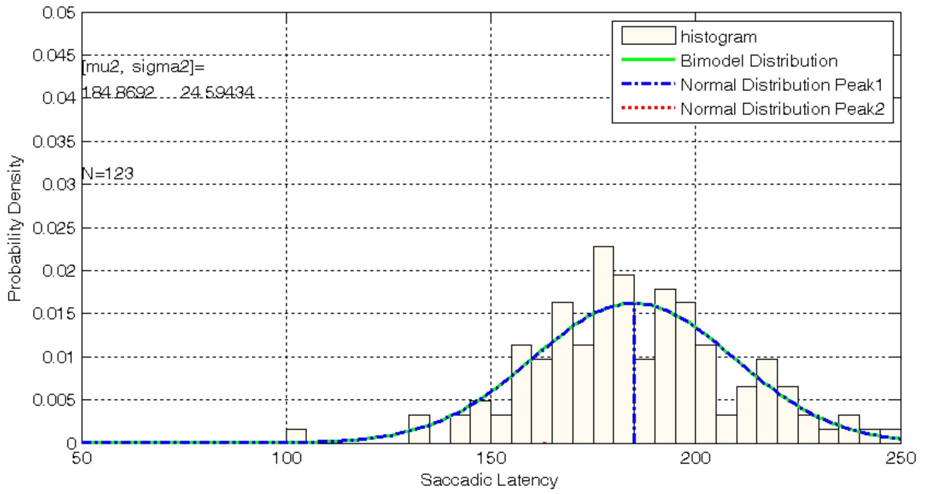
Attention-deficit/hyperactivity disorder (ADHD) is a brain disorder marked by an ongoing pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development.

- Inattention means a person wanders off task, lacks persistence, has difficulty sustaining focus, and is disorganized; and these problems are not due to defiance or lack of comprehension.
- Hyperactivity means a person seems to move about constantly, including in situations in which it is not appropriate; or excessively fidgets, taps, or talks. In adults, it may be extreme restlessness or wearing others out with constant activity.
- Impulsivity means a person makes hasty actions that occur in the moment without first thinking about them and that may have high potential for harm; or a desire for immediate rewards or inability to delay gratification. An impulsive person may be socially intrusive and excessively interrupt others or make important decisions without considering the long-term consequences.

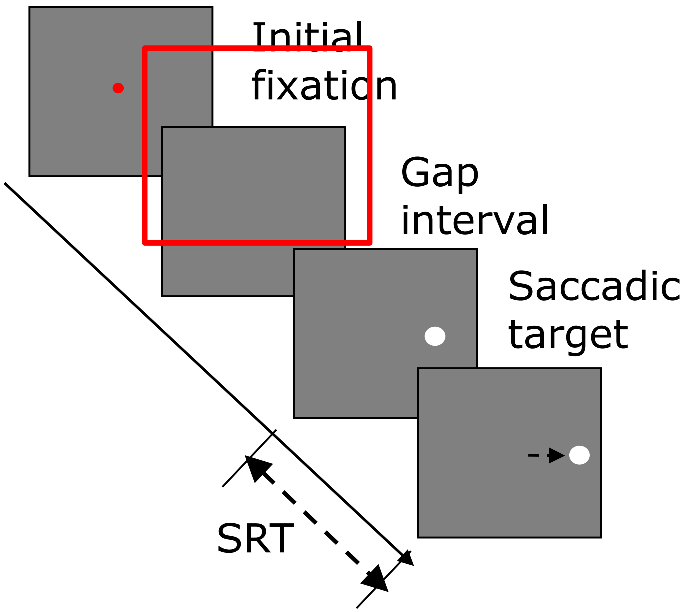
Study the neural mechanisms of attention by employing saccade

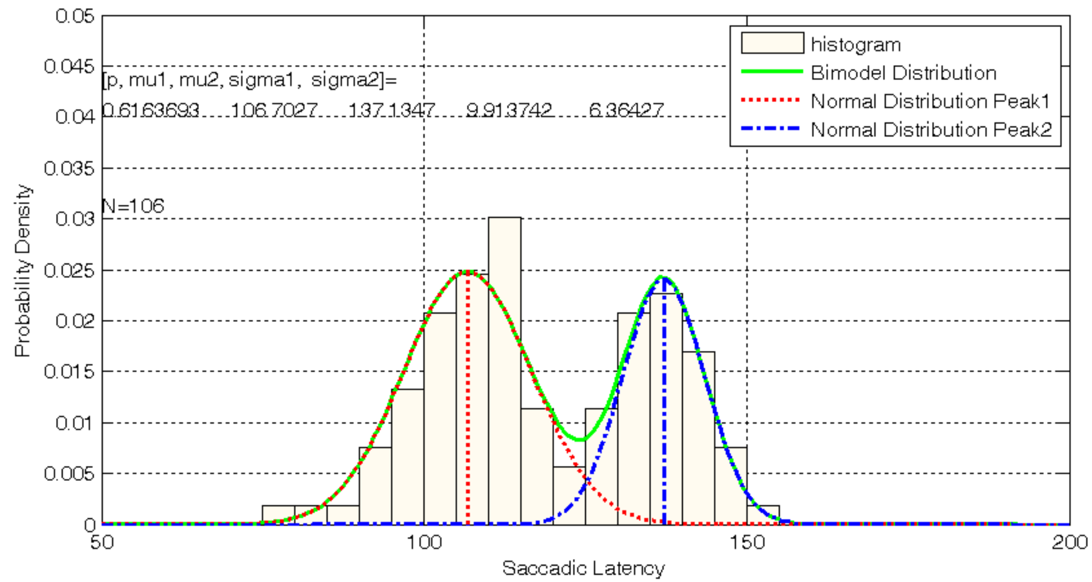
Saccadic reaction time (SRT) reflects the time of sensorimotor transformation





The bimodal distribution of SRT in gap task



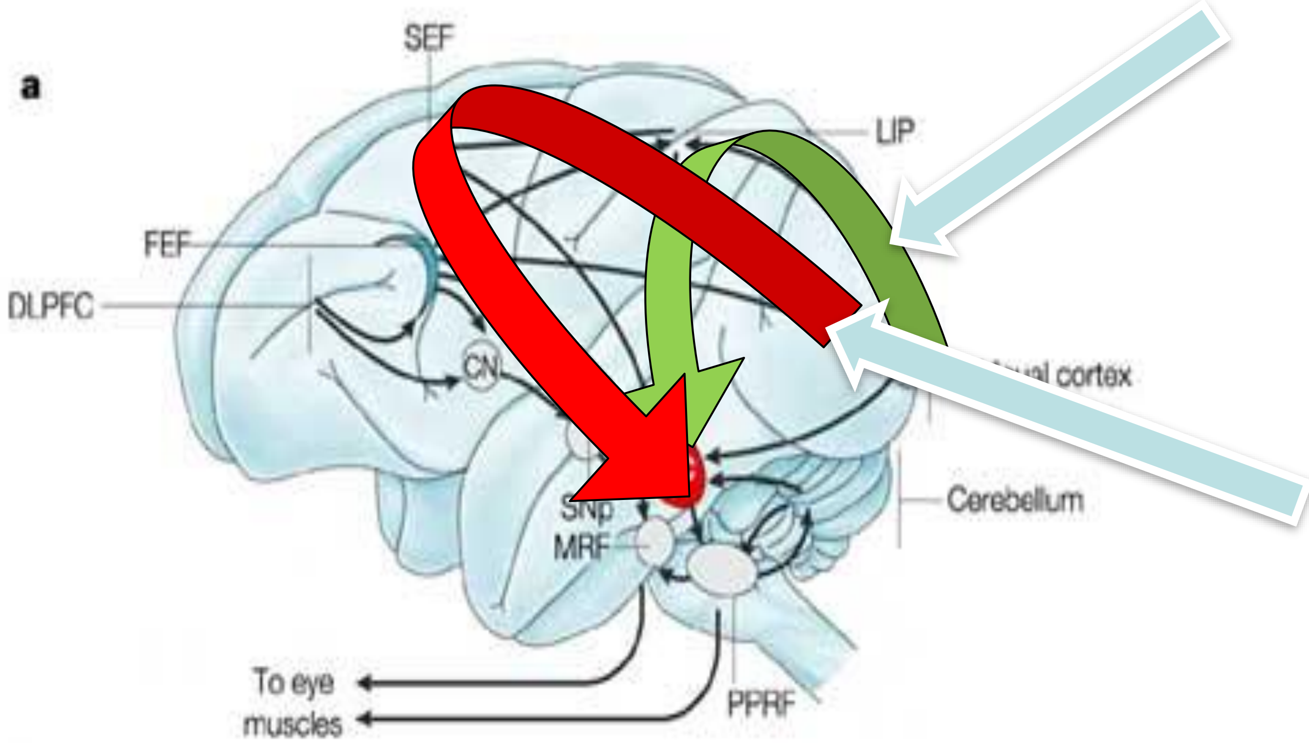


Bimodal Distribution is elicited under this condition.

The first peak: **Express Saccade**

The second peak: **Regular Saccade**

Two saccadic circuits in brain cause the bimodal distribution of SRT

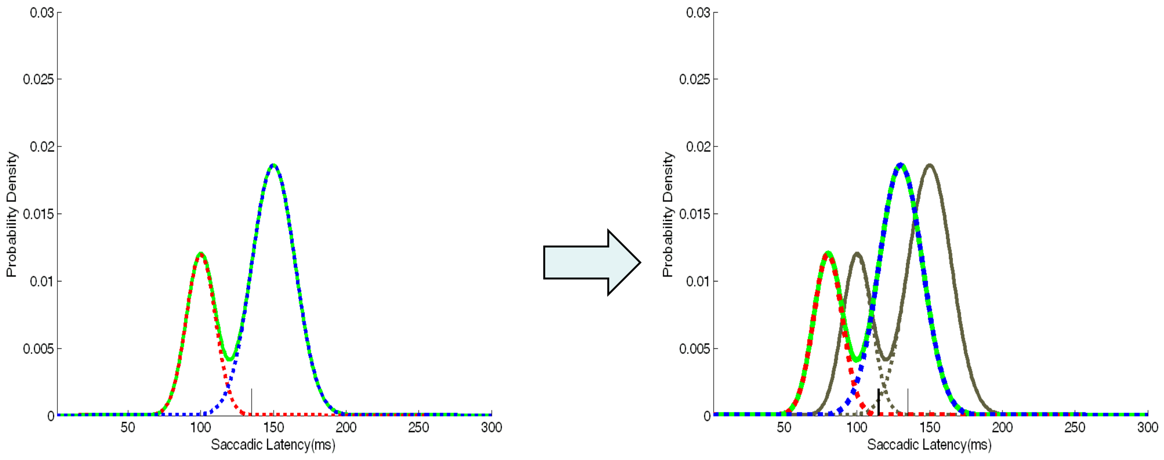


Short pathway : from V1 to LIP to SC

Longer pathway : from V1 to LIP to FEF to SC

Bimodal distribution of SRT is a useful behavioral model to assess how attention modulates visuomotor transformation

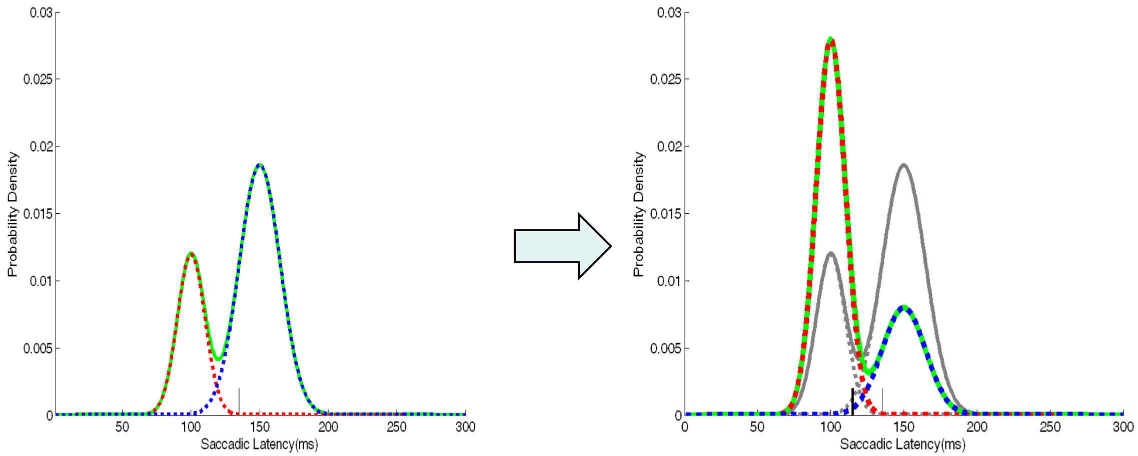
- **Facilitate** the visual signal processing



Two peaks should shift to left

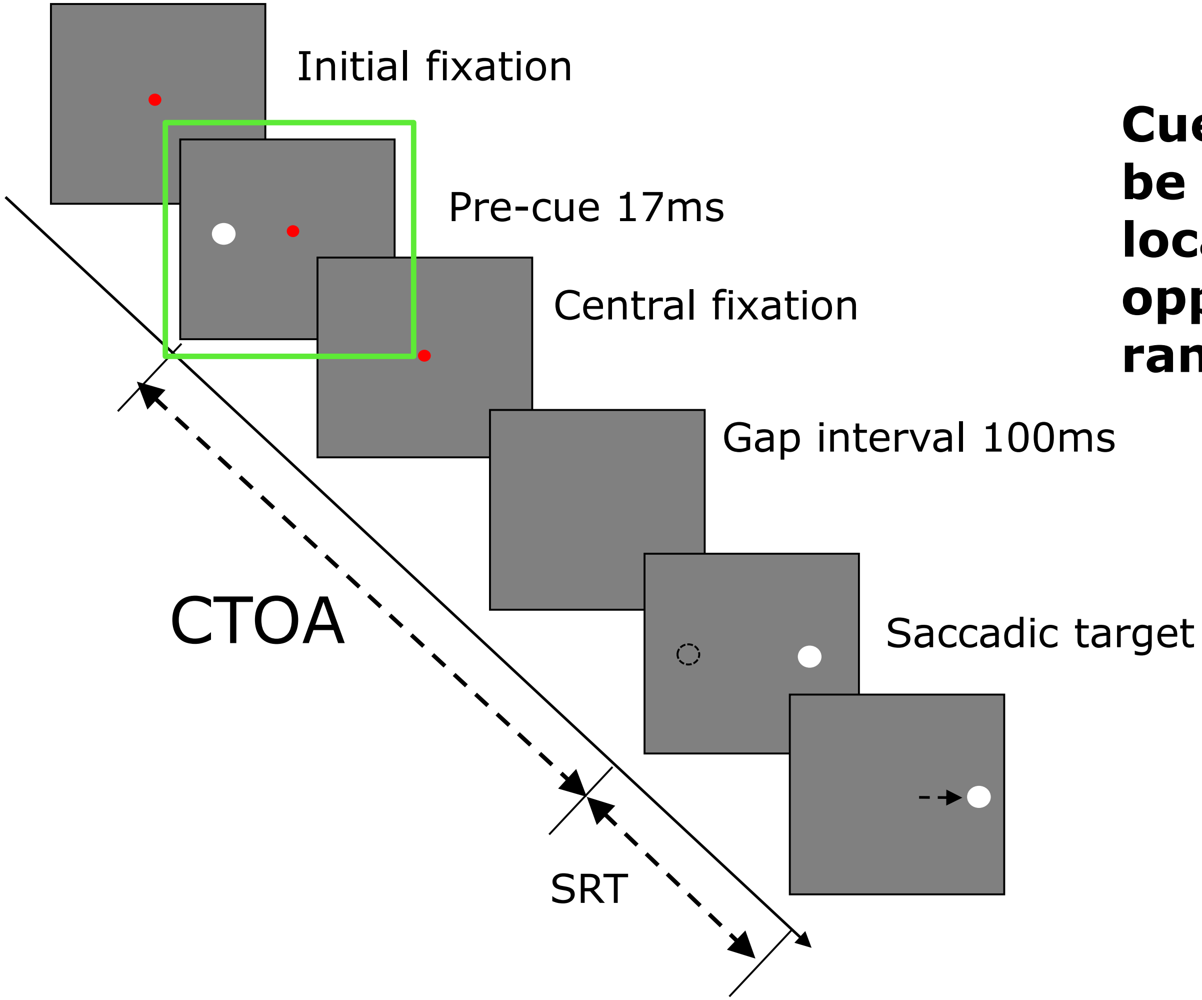
Bimodal distribution of SRT is a useful behavioral model to assess how attention modulates visuomotor transformation

- **Route** the visual-motor transduction pathway



Two peaks should change the distribution proportion

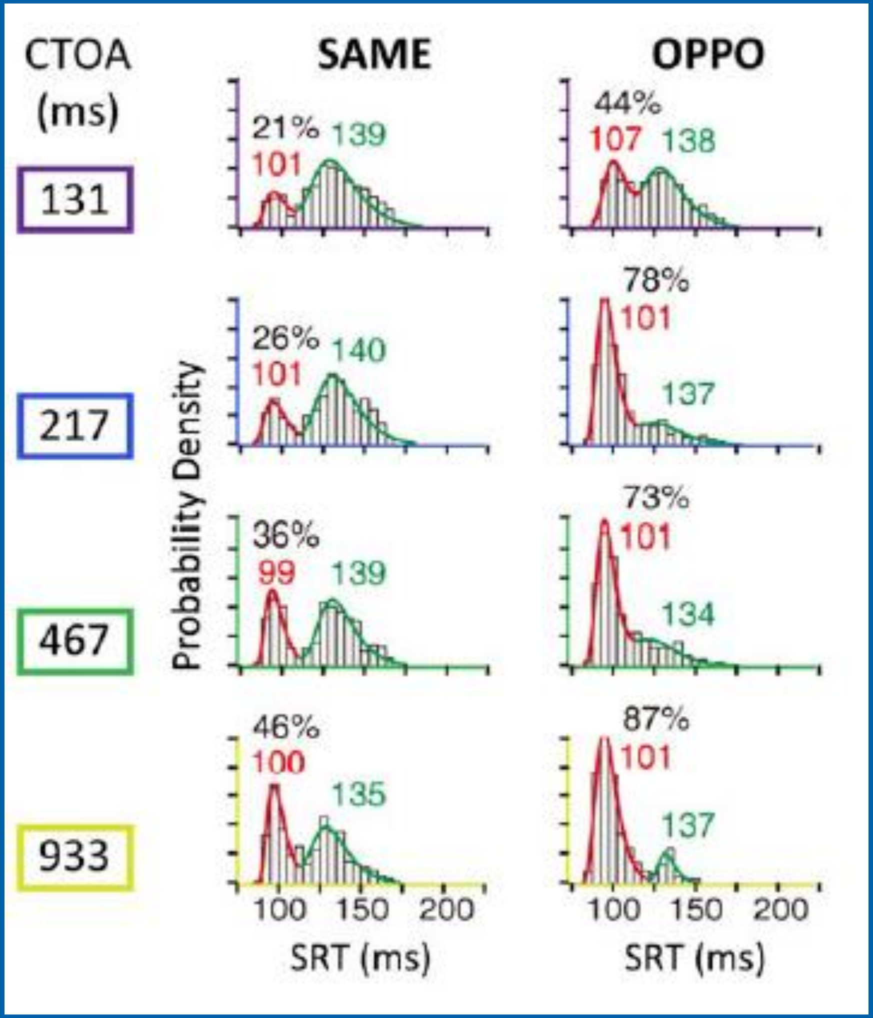
Cue and gap saccade paradigm



Cue and target may be in the same location or in the opposite location randomly

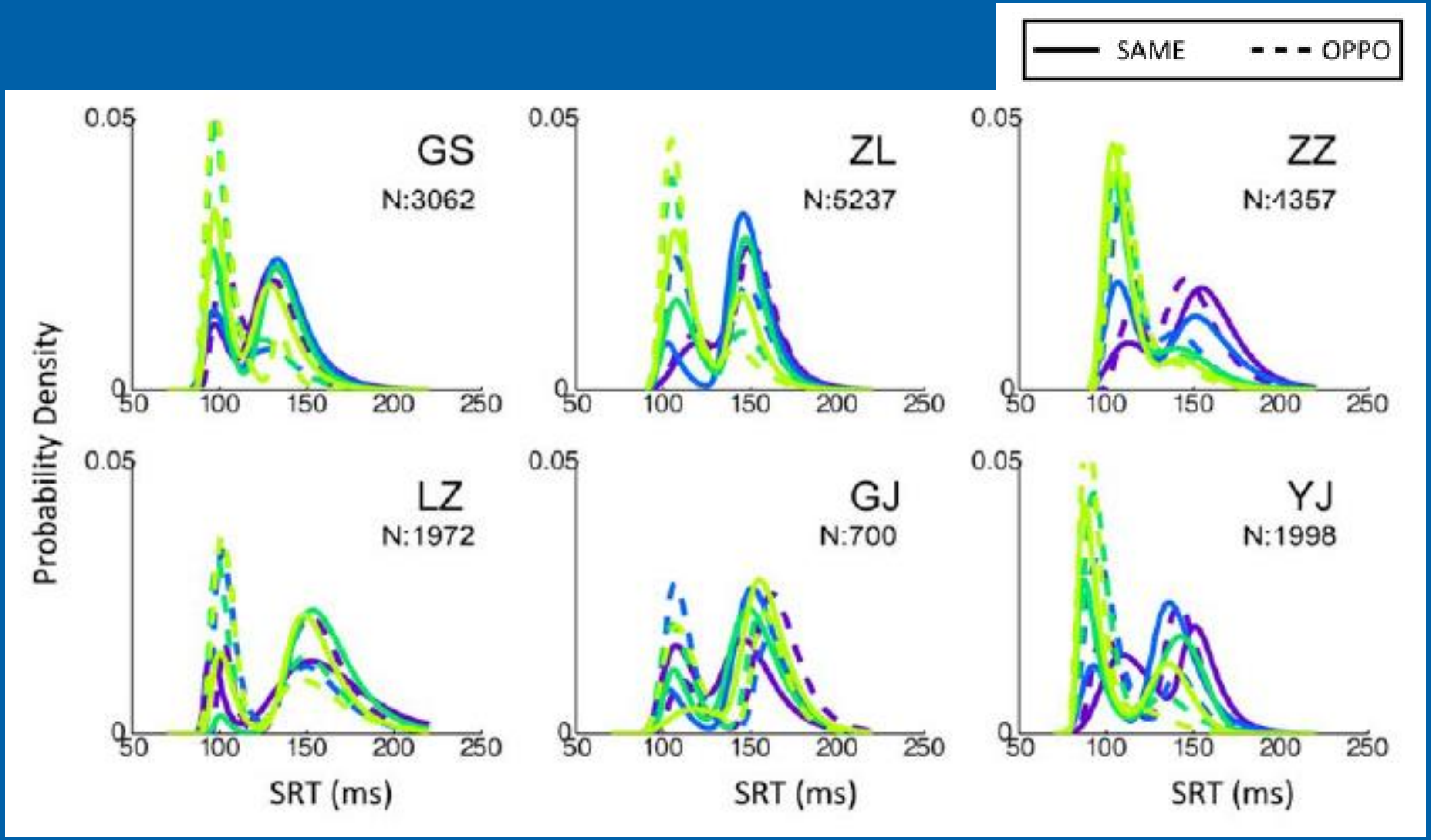
CTOA: cue target onset asynchrony

The ratio of bimodal distribution in different CTOA and different cue-target spatial condition



Guang et al., 2012, *Journal of Neurophysiology*

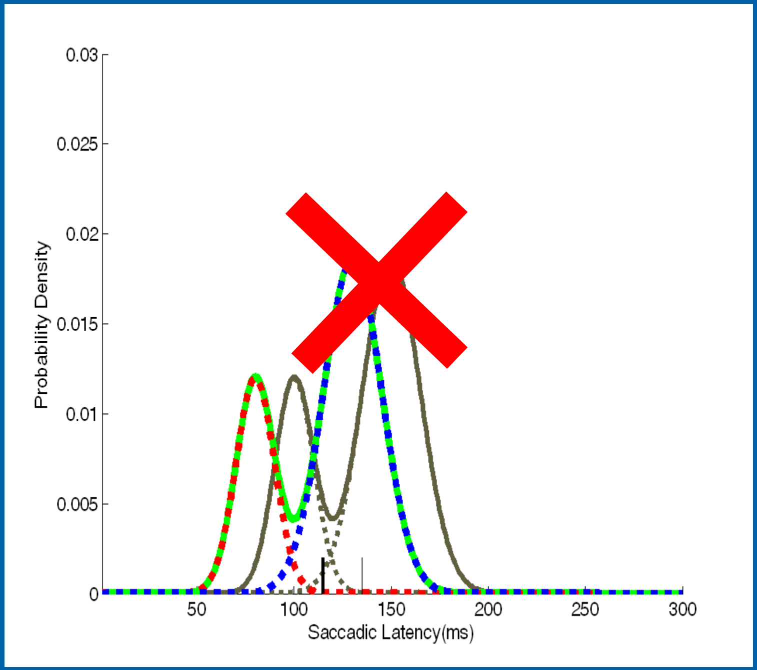
The ratio of bimodal distribution in different CTOA and different cue-target spatial condition

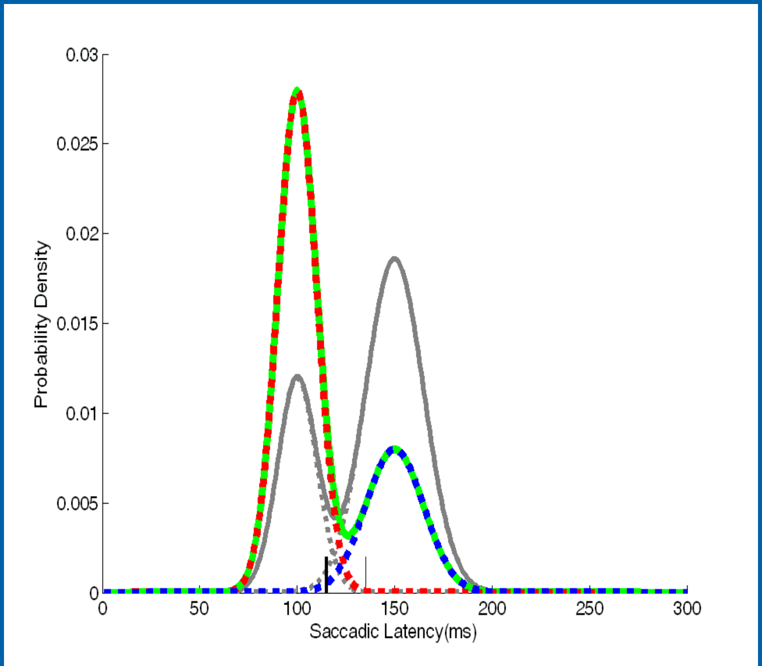


Guang et al., 2012, *Journal of Neurophysiology*

Summary

Attention modulates saccadic reaction time most likely through the routing mechanism, rather than just facilitating the process of visuomotor transformation.





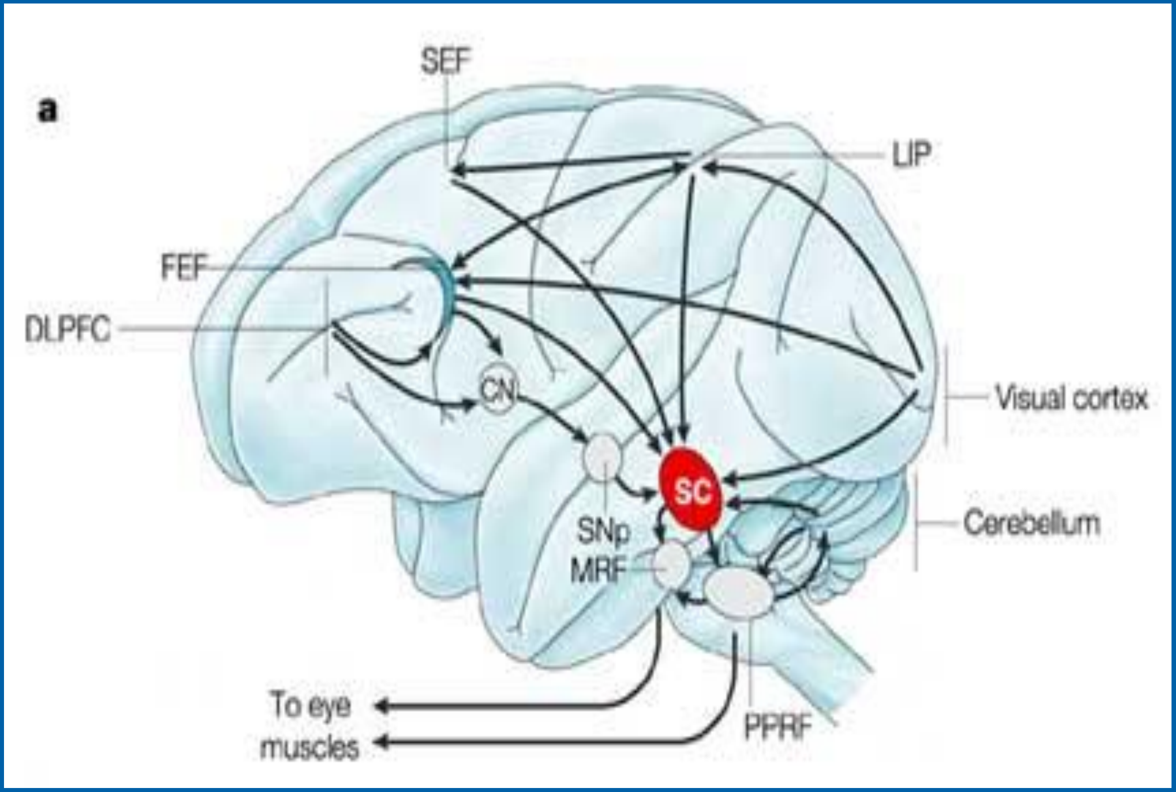
Guang et al., 2012, *Journal of Neurophysiology*

Shaobo Guan

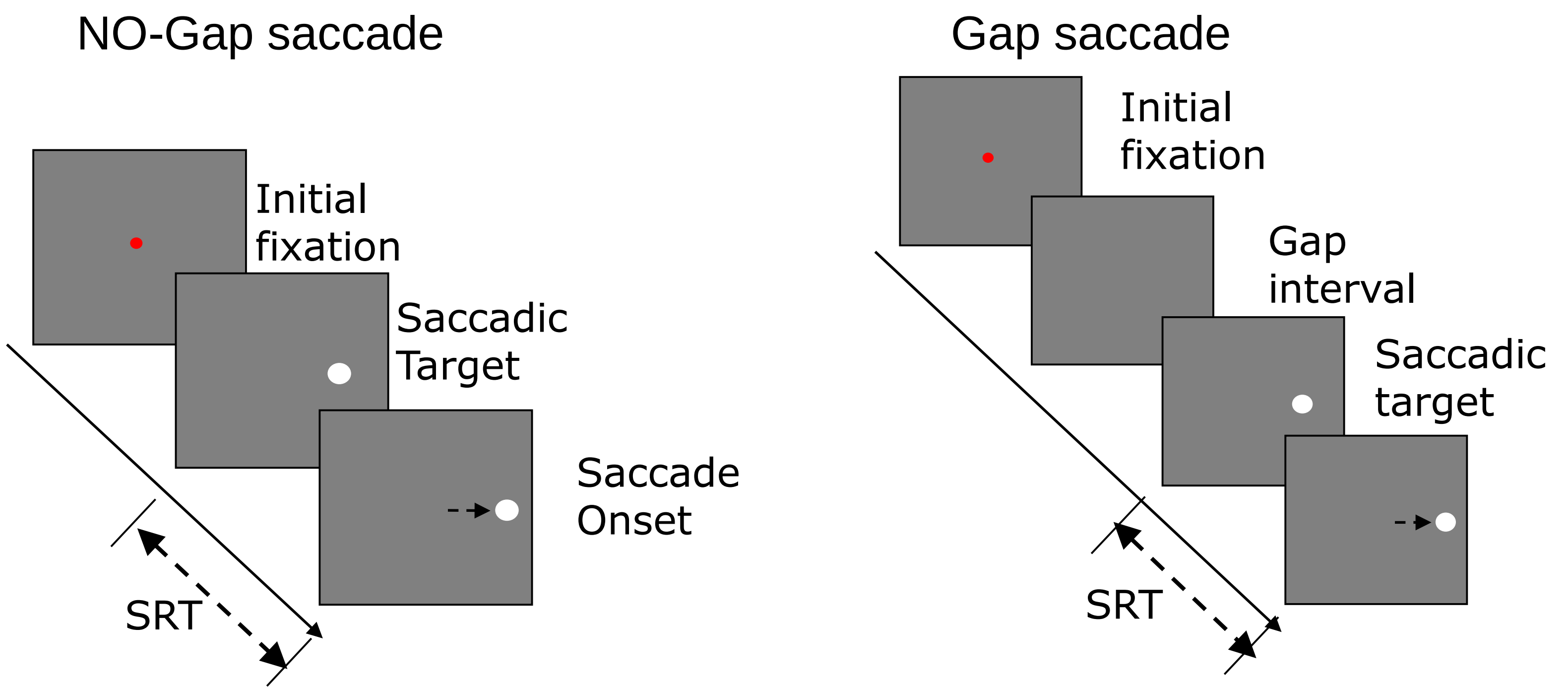
Yu Liu

Questions remind:

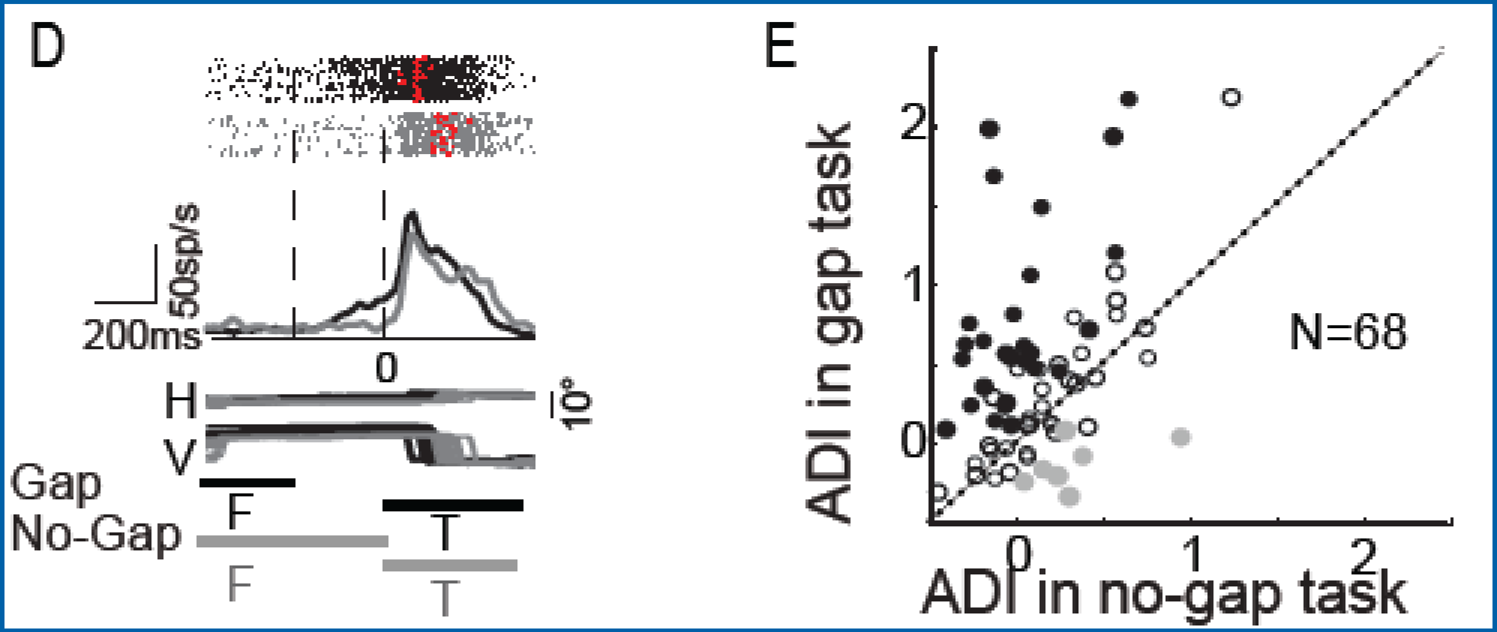
Where does attention routing occur?



Behavioral tasks

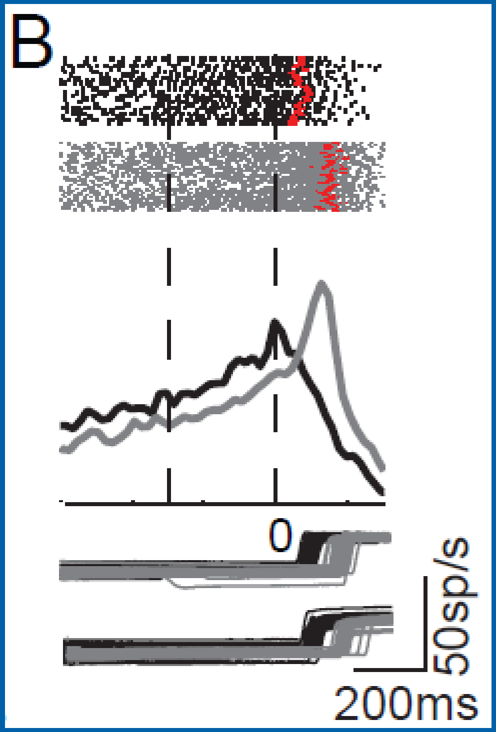


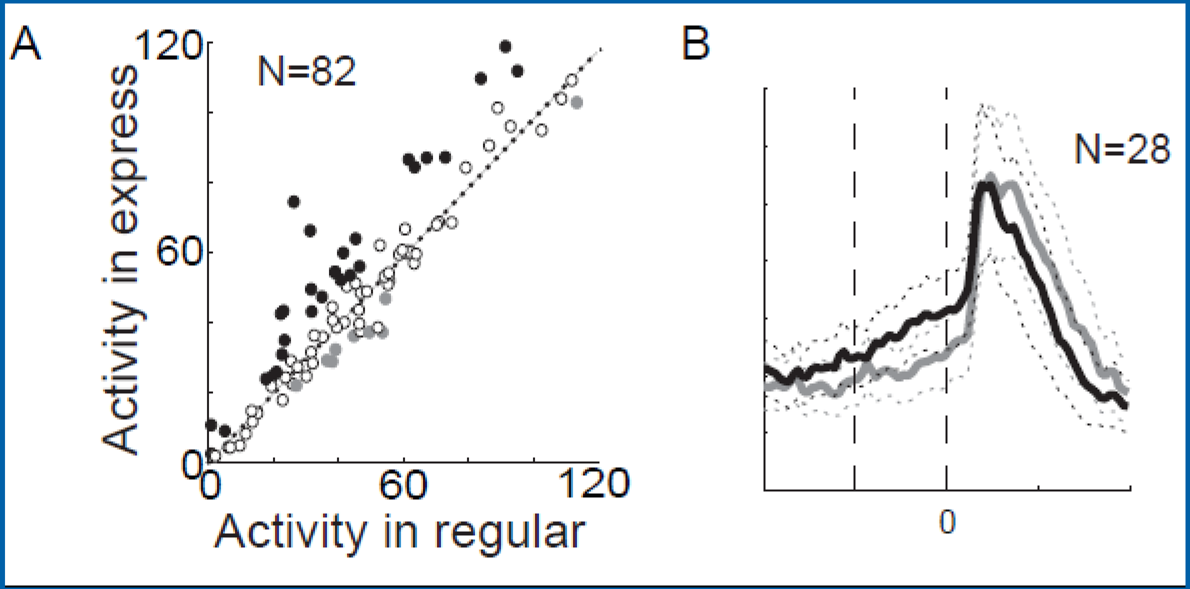
Most LIP neurons increase activity during gap saccades



Chen et al., Journal of Neuroscience, 2012

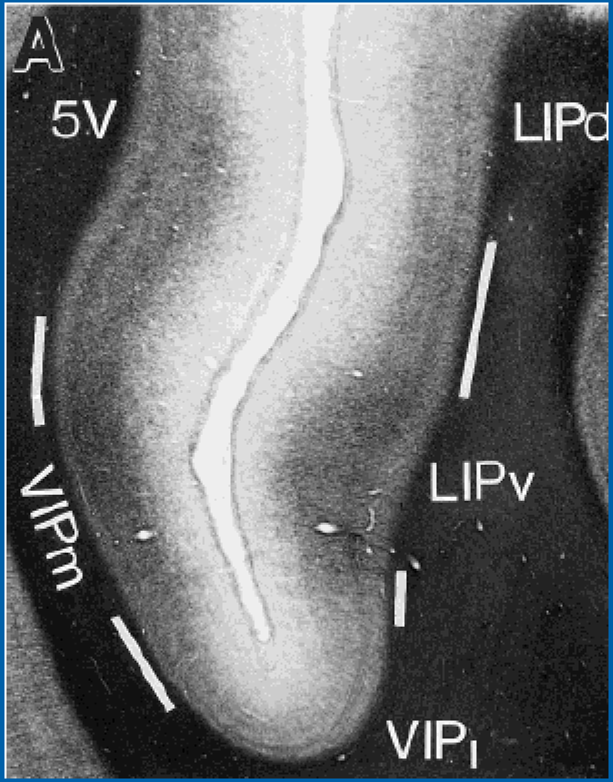
A group of LIP neurons exhibit stronger activity in express saccades than that in regular saccade





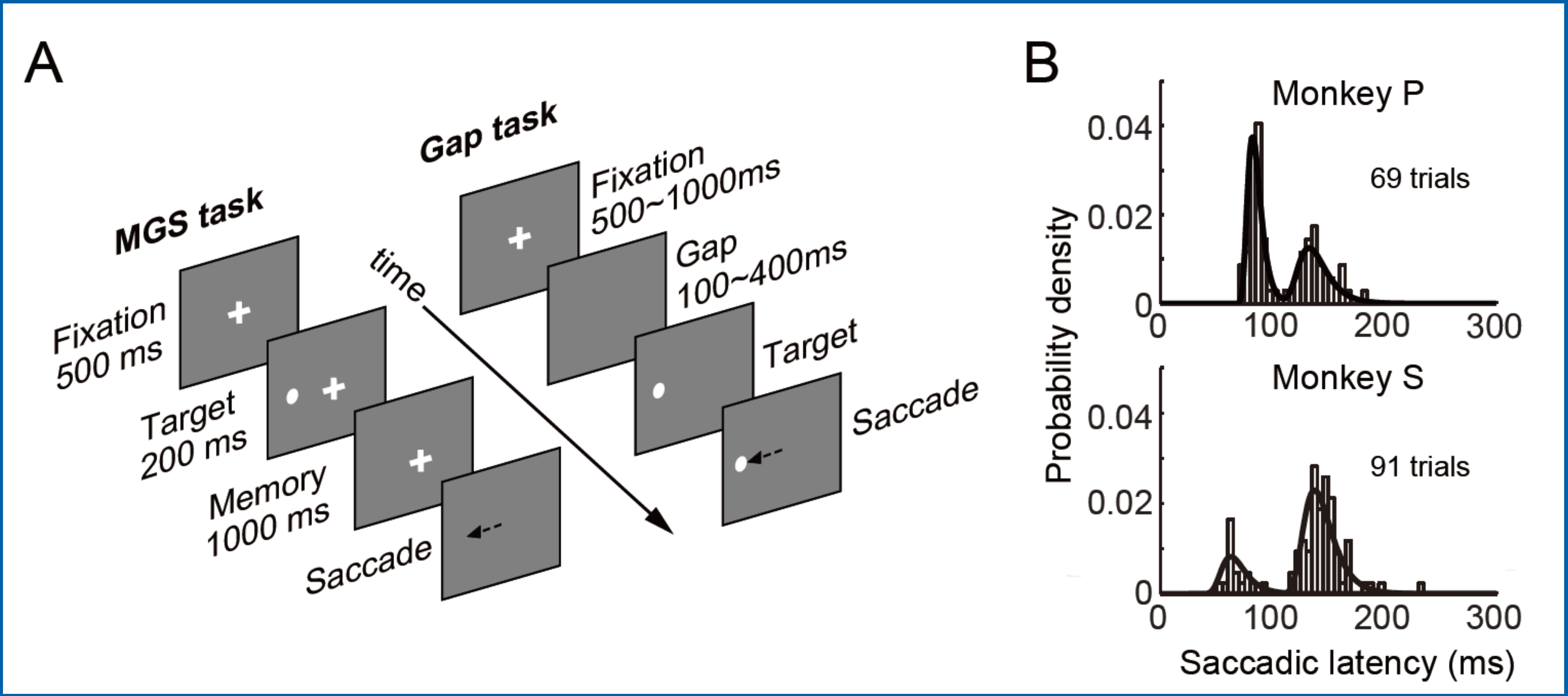
Chen et al., Journal of Neuroscience, 2012

The anatomical features of LIP reveal two distinct subdivisions

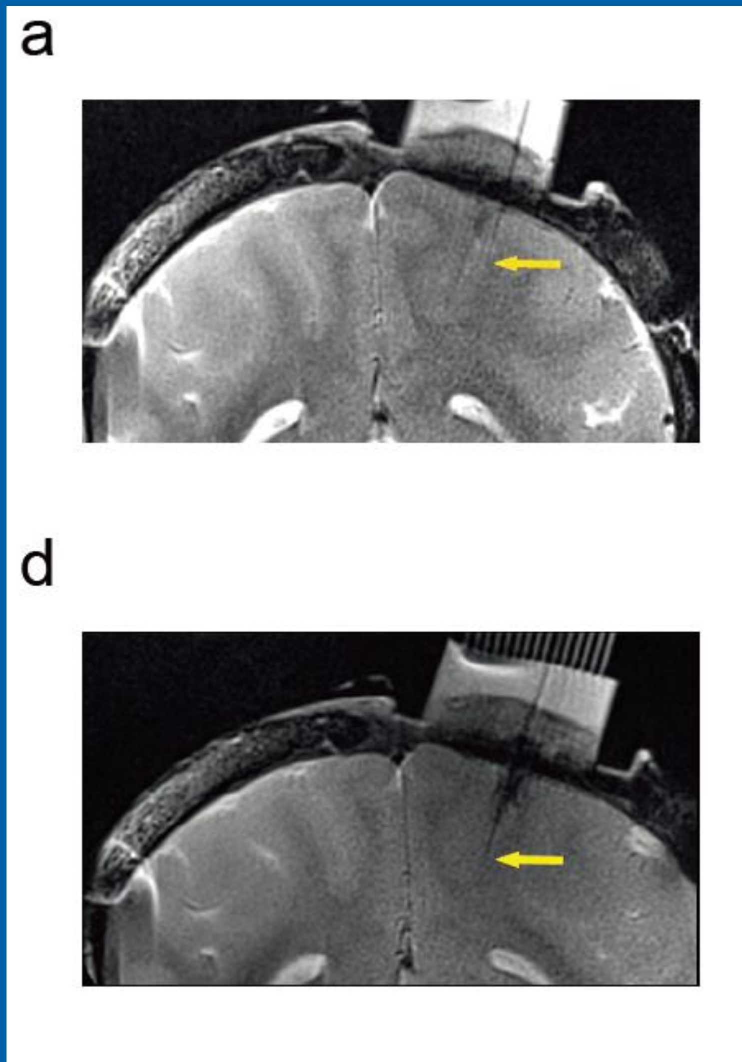


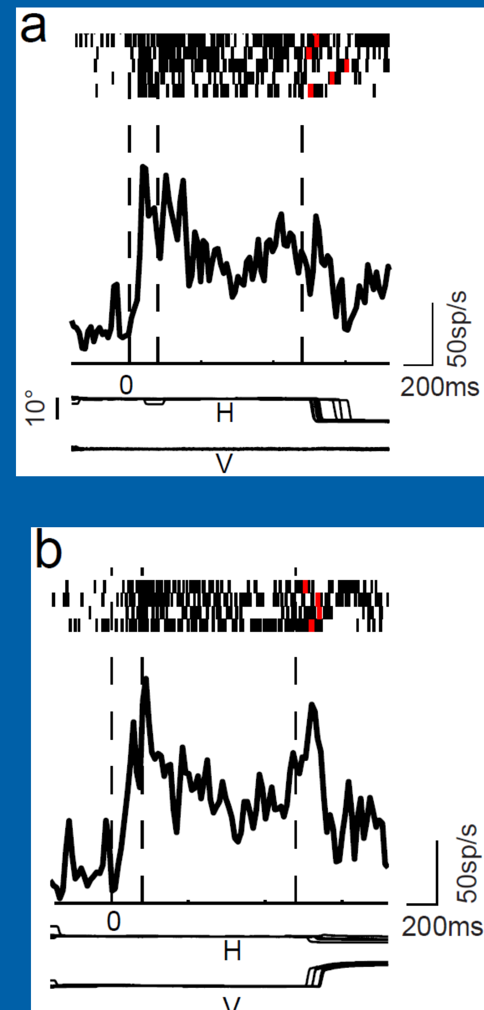
- LIPd is lightly myelinated and primarily connects with the visual cortical areas V4 and TE
- LIPv is densely myelinated and receives visual input from V3 and parietal-occipital area (PO)
- LIPv has much stronger connection with the core of frontal eye field (c8, Brodmann) and the deeper layers of superior colliculus

Memory-guided and gap saccade tasks



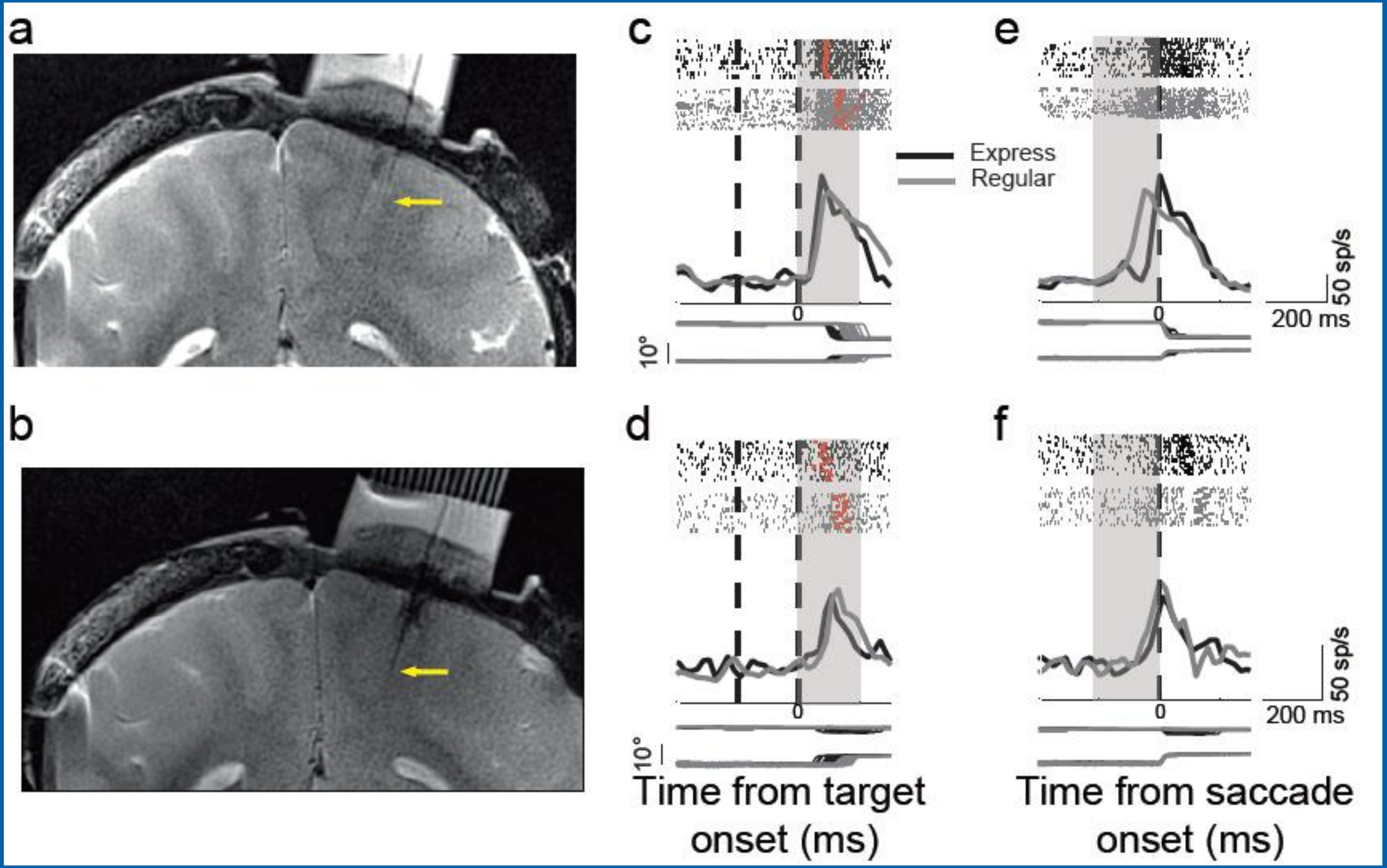
Persistent activity during memory guided saccades in LIPd and LIPv





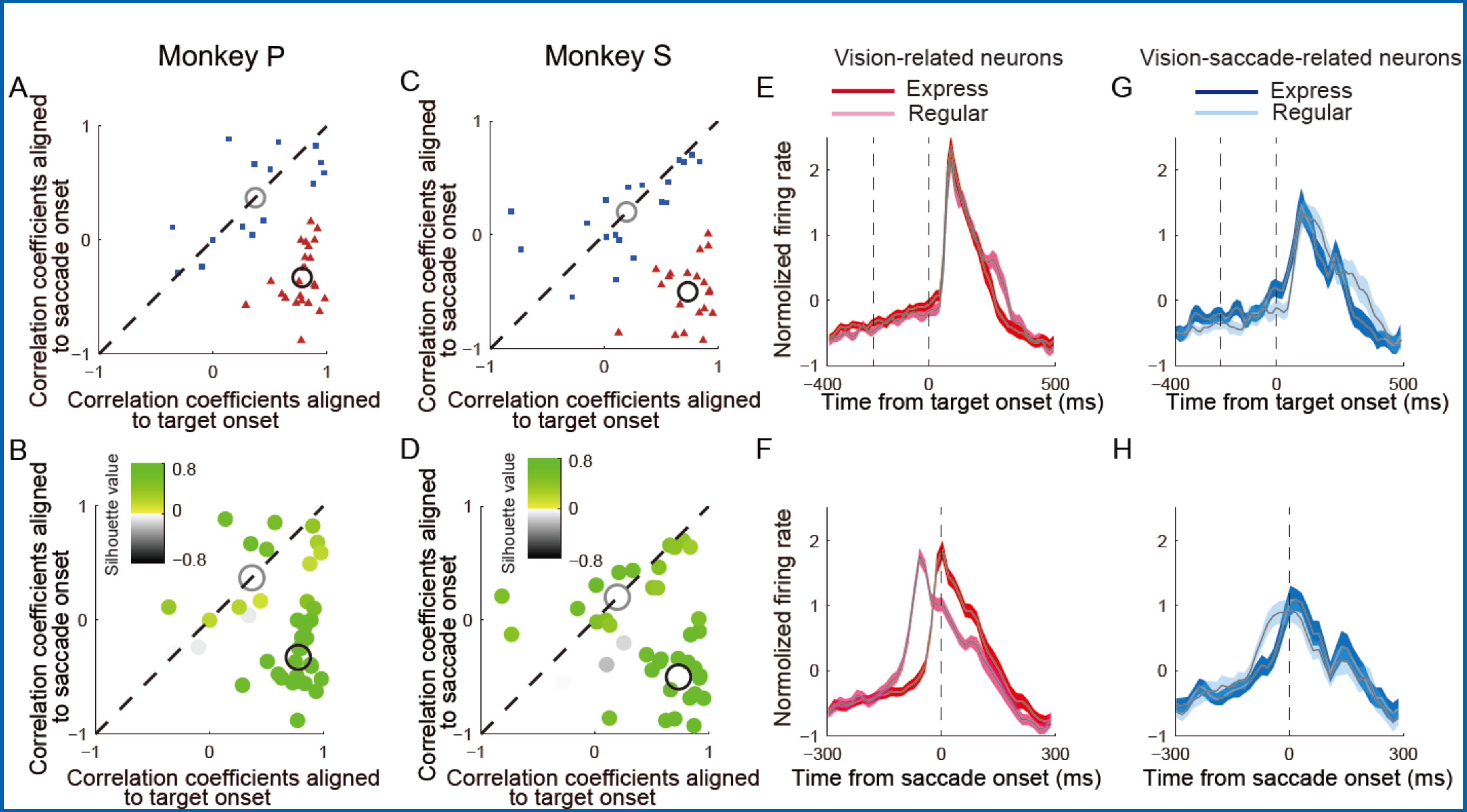
Chen et al., PNAS, 2016

Examples of neural activity recorded from LIPd and LIPv



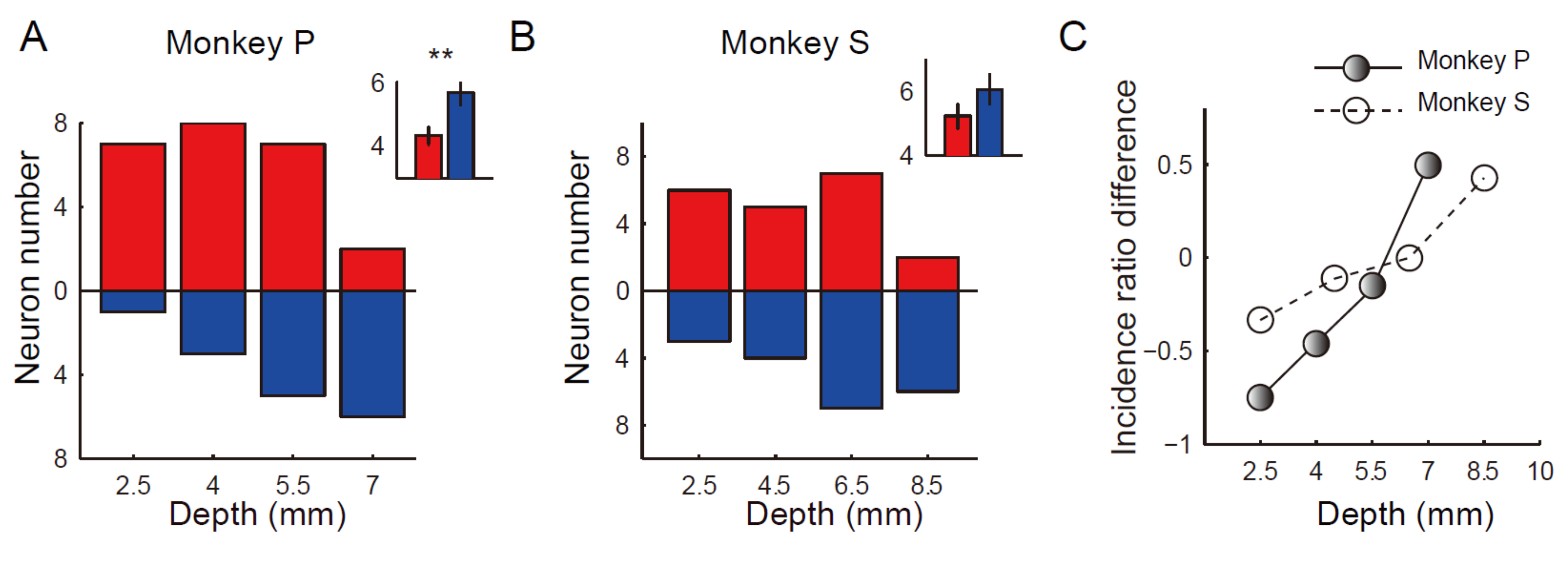
Chen et al., PNAS, 2016

Data of correlation coefficient analysis show two distinct clusters



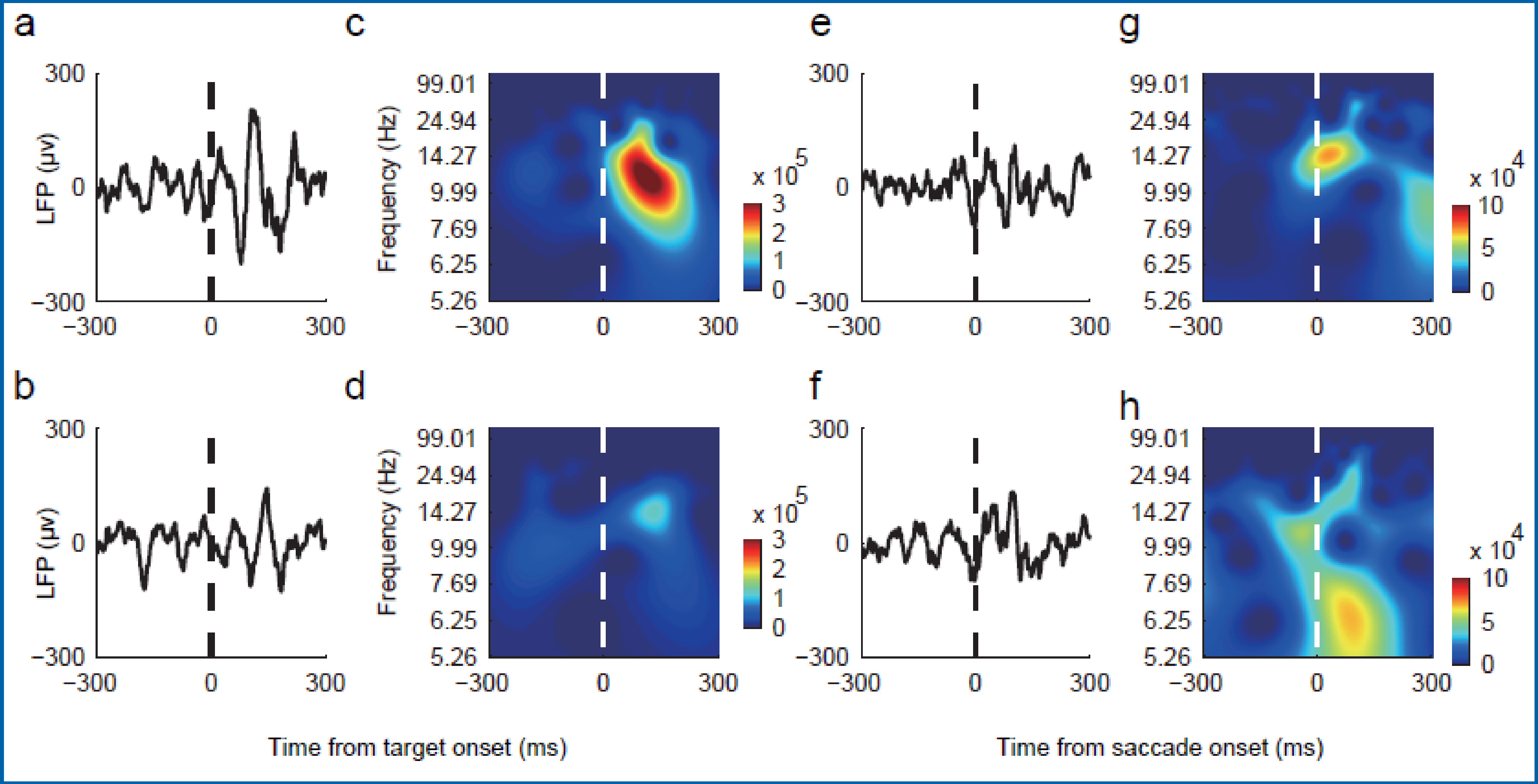
Chen et al., PNAS, 2016

The locations of vision-related and vision-saccade-related neurons were distributed asymmetrically in LIPd and LIPv



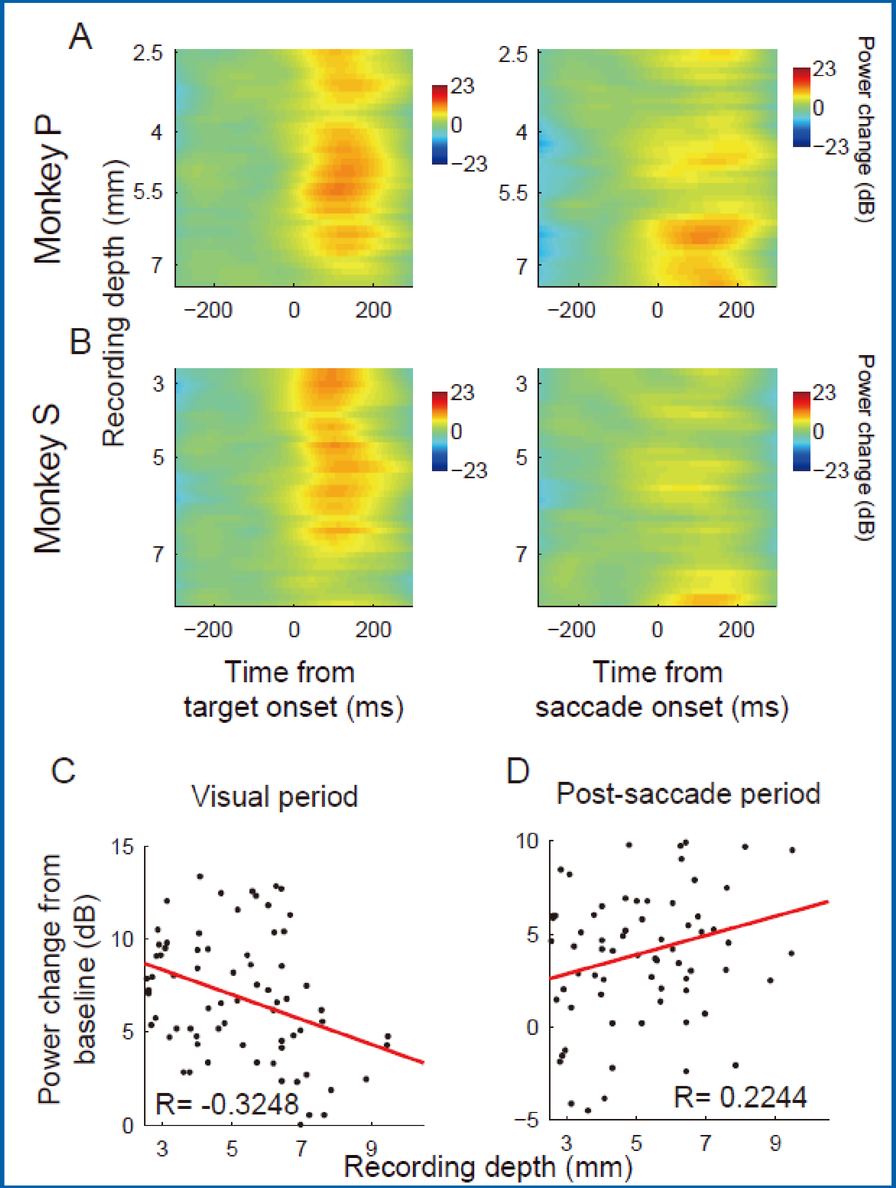
Chen et al., PNAS, 2016

Local field potential data show vision-related potential in LIPd and saccade-related potential in LIPv



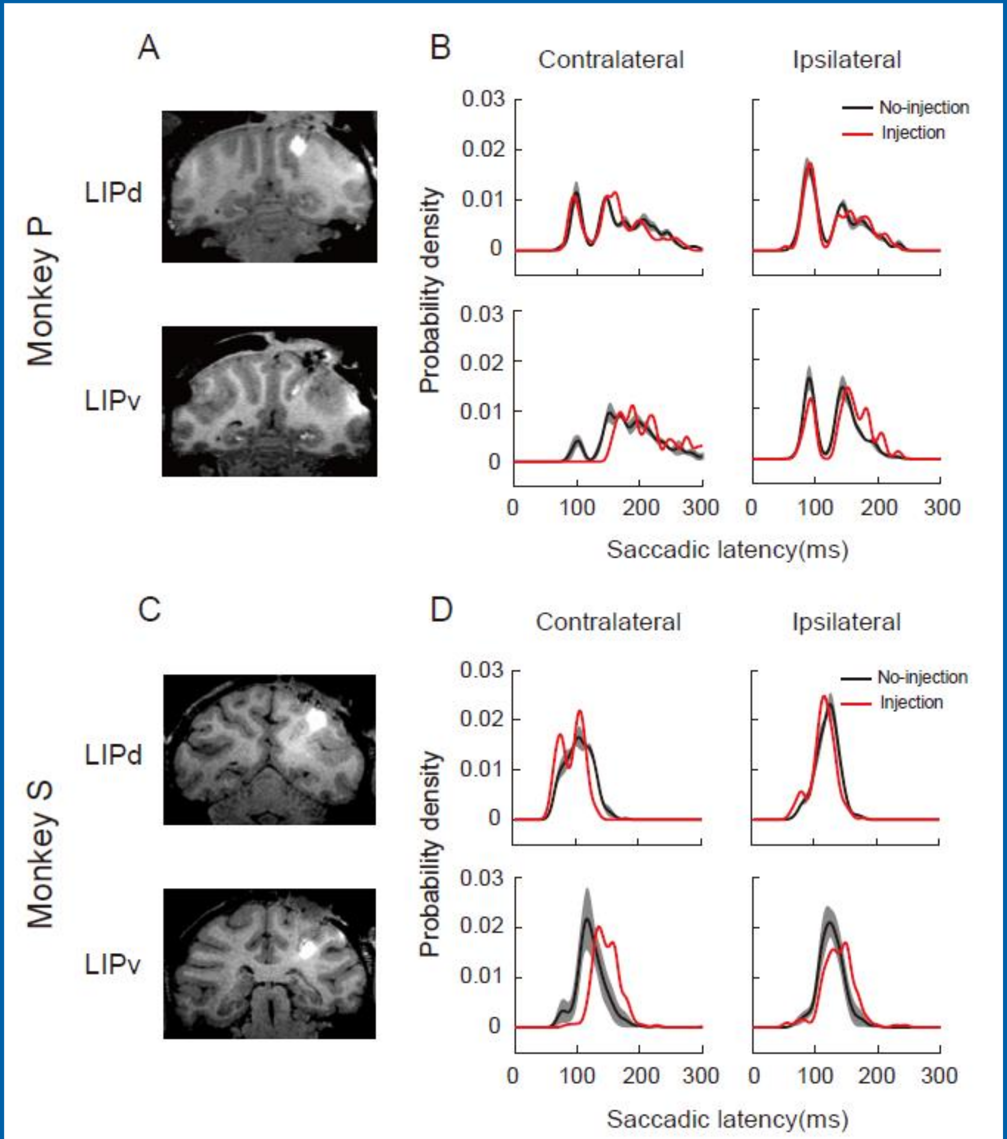
Chen et al., PNAS, 2016

The local field potential (LFP) changed from visual evoked to saccadic evoked following the increase of recording depth



Chen et al., PNAS, 2016

Inactivation of LIPv decreases the proportion of contralateral express saccades and prolongs the SRT of regular saccades



Chen et al., PNAS, 2016

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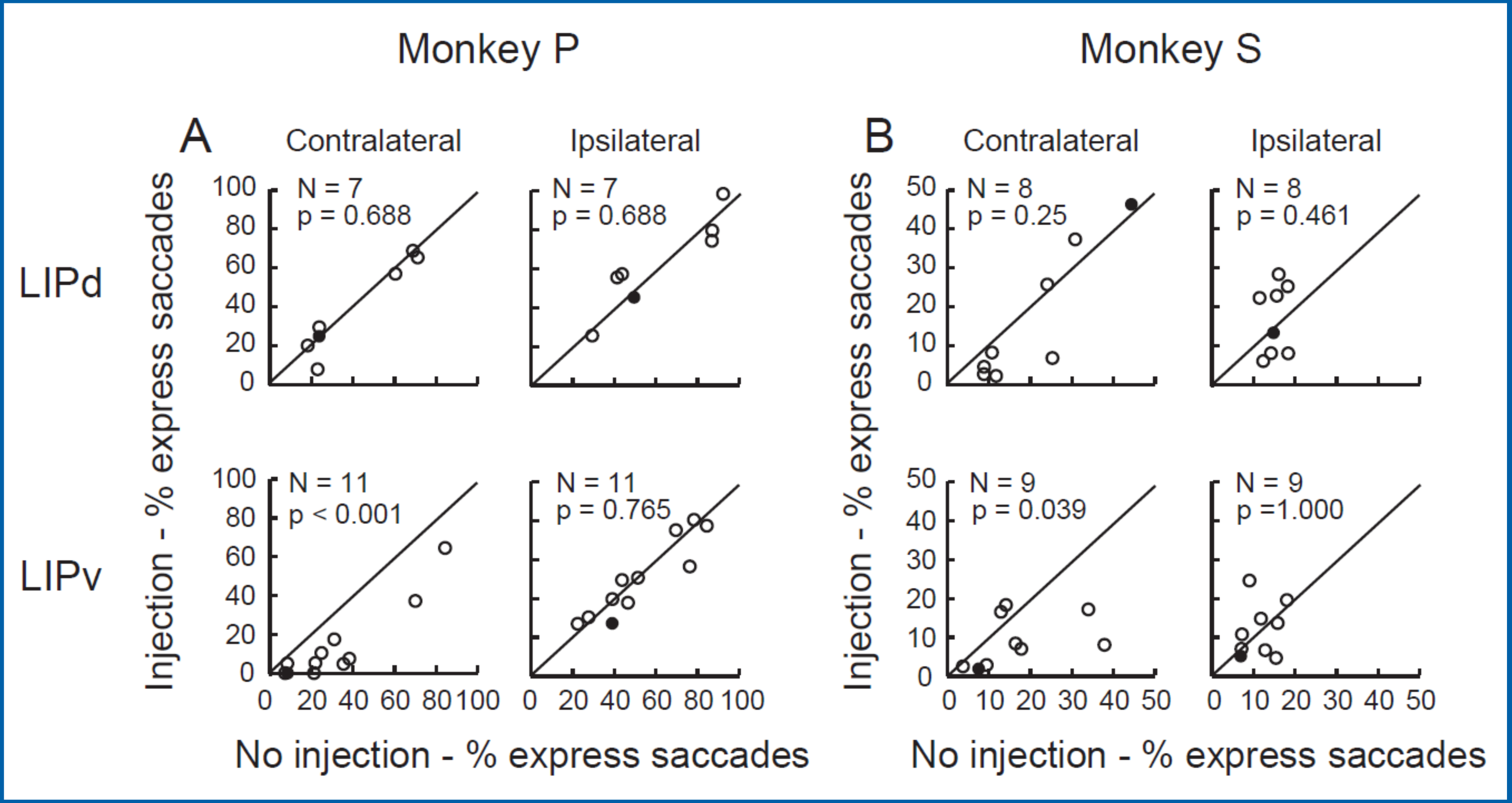
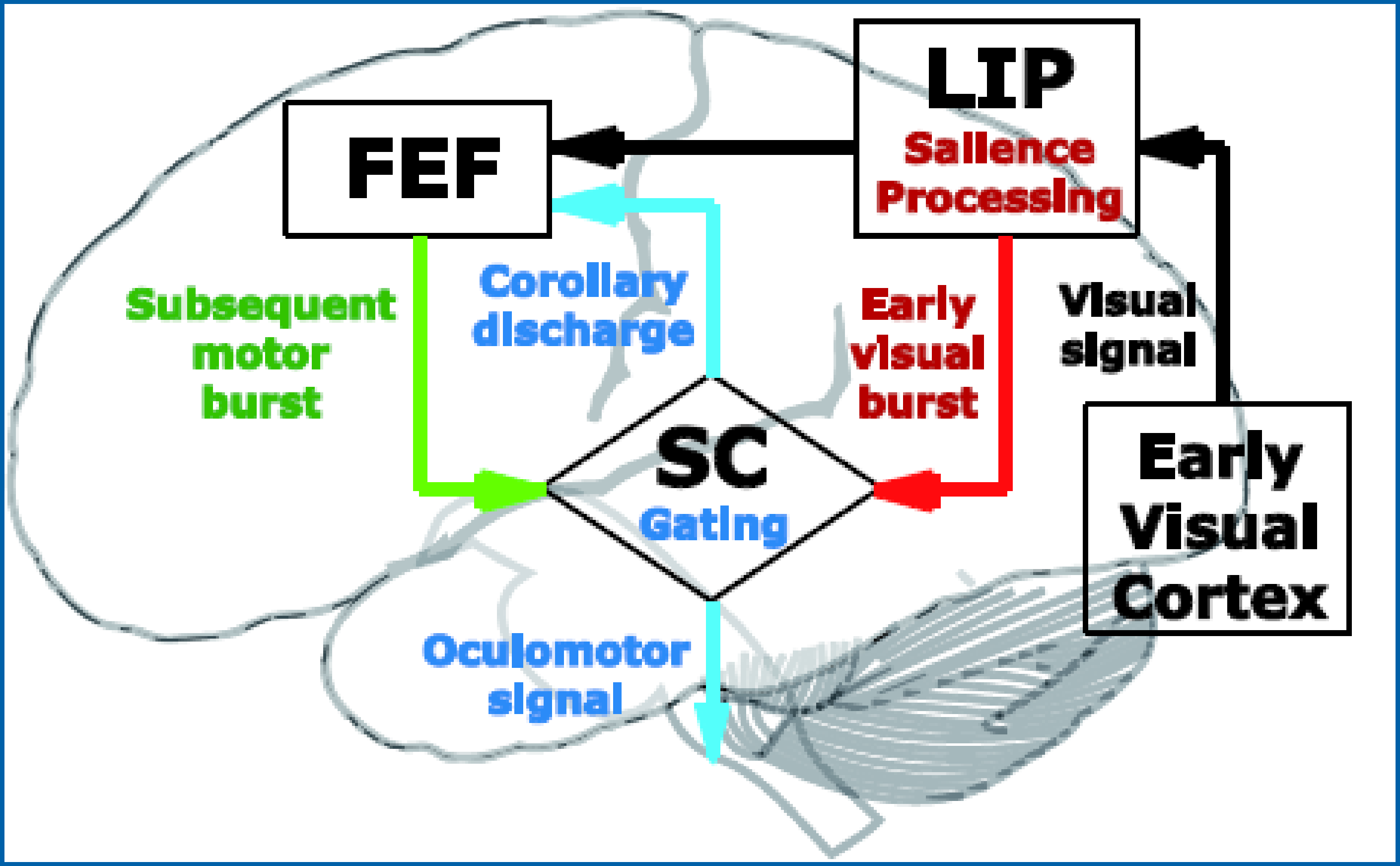


Chen et al., PNAS, 2016

Summary

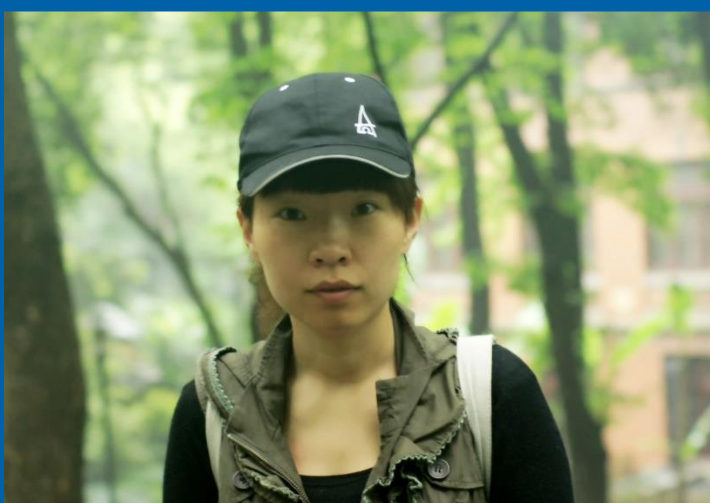
- The MRI images and the 3-D construction of recording sites indicate that the vision-driven neurons are mainly distributed in the shallow part of LIP (LIPd) whereas the saccade-driven neurons are mainly distributed in the deeper part of LIP (LIPv).
- The local field potential (LFP) data show that, the vision-related potential is vigorous in the shallow LIP but gradually attenuated following the increase of recording depth; conversely, the saccade-related potential only emerges in the deep part of LIP.
- Local injection of muscimol (GABA agonist) in LIPv dramatically prolongs the saccadic reaction time and reduces the proportion of express saccade in the contralateral side. Such effect does not see after injection of muscimol in LIPd.
- Putting together, our results indicate that LIPd is primarily involved in processing vision-related information whereas LIPv processes visual and saccade-related information. The functional distinctions between the two subdivisions of LIP might explain the controversial findings among previous studies.


LIP
Salience Processing
FEF
Subsequent motor burst
Corollary discharge
Early visual burst
Visual signal
SC
Gating
Early Visual Cortex
Oculomotor signal

Yu Liu

Bing Li

Jing Guang

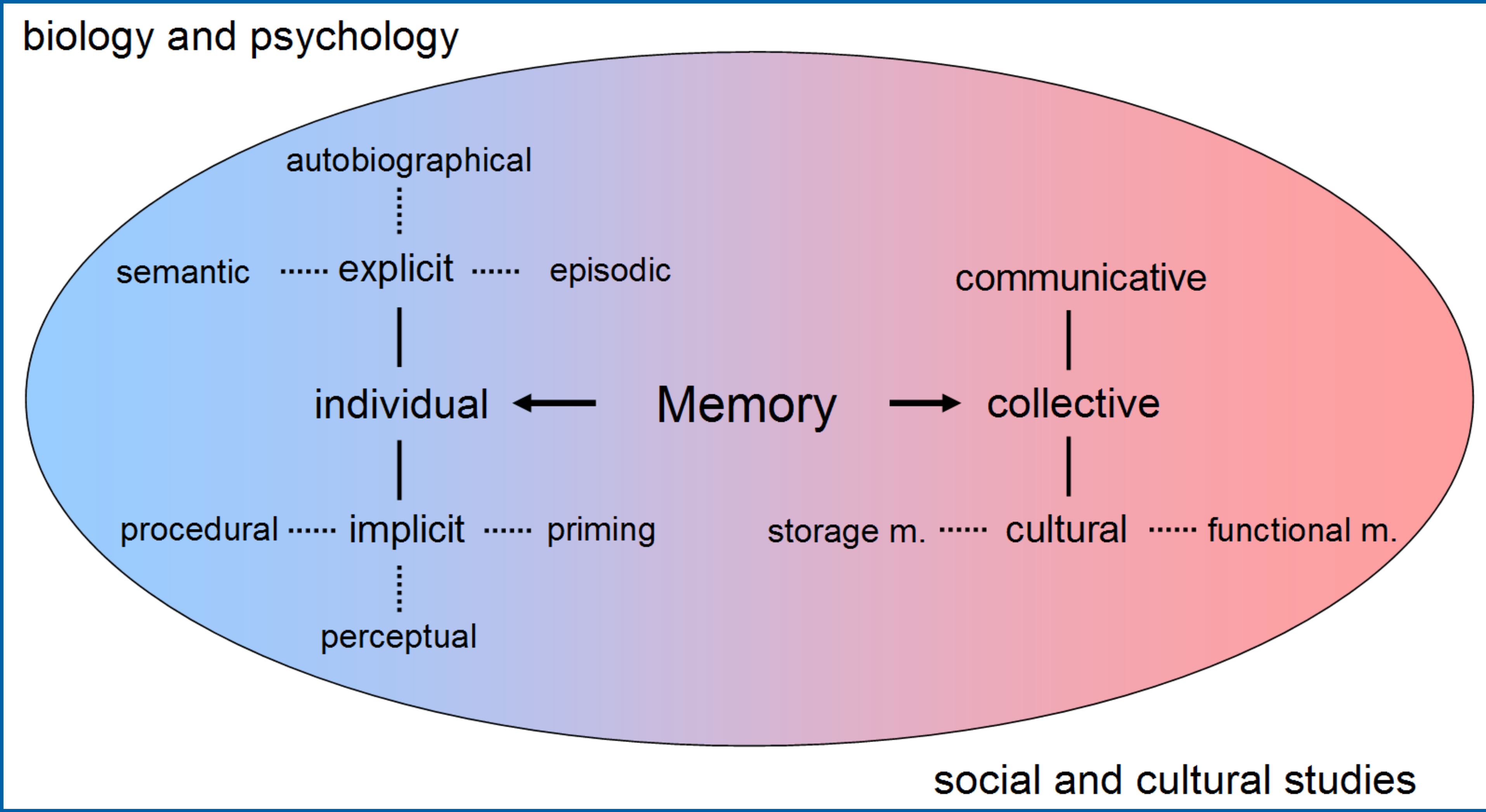


Mo Chen

Outline

- Visual perception: visual stability and category in primates
- Attention: bottom-up and top-down attention
- Memory: long-term and short-term memory
- Decision making
- Prediction

The classification of memory



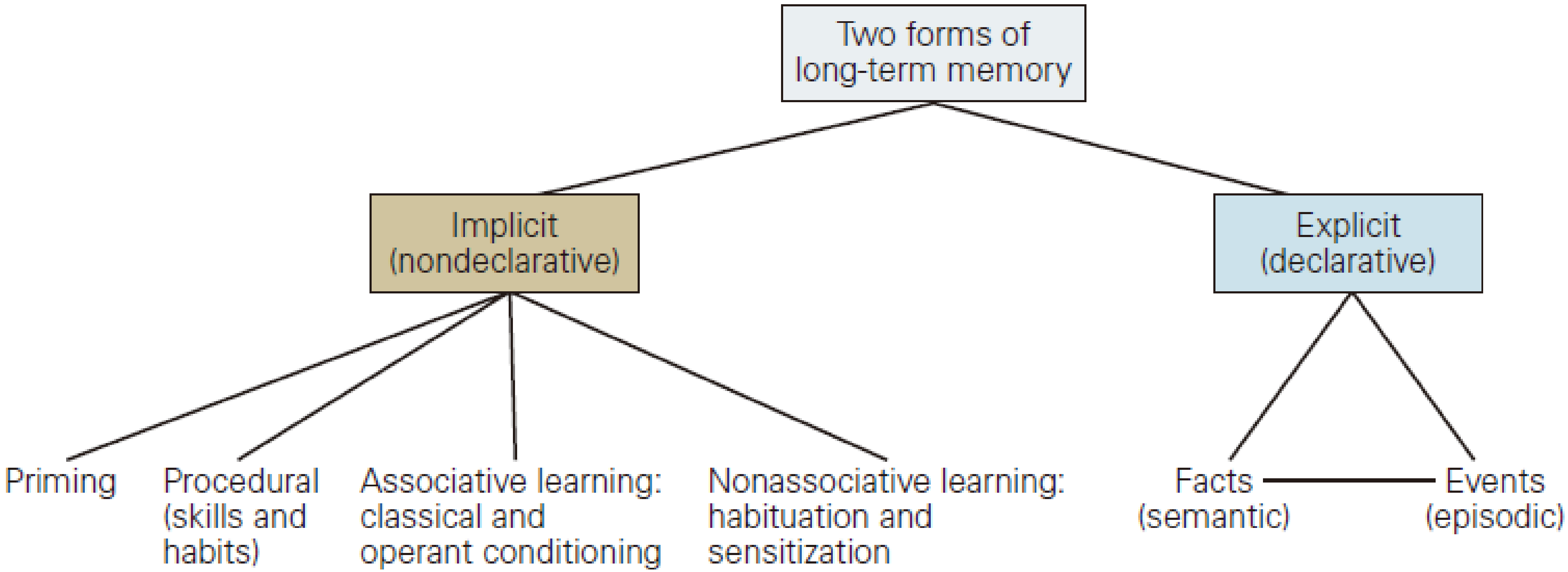
The importance of memory in our life

- Memory is the faculty of the brain by which information is **encoded, stored, and retrieved** when needed.

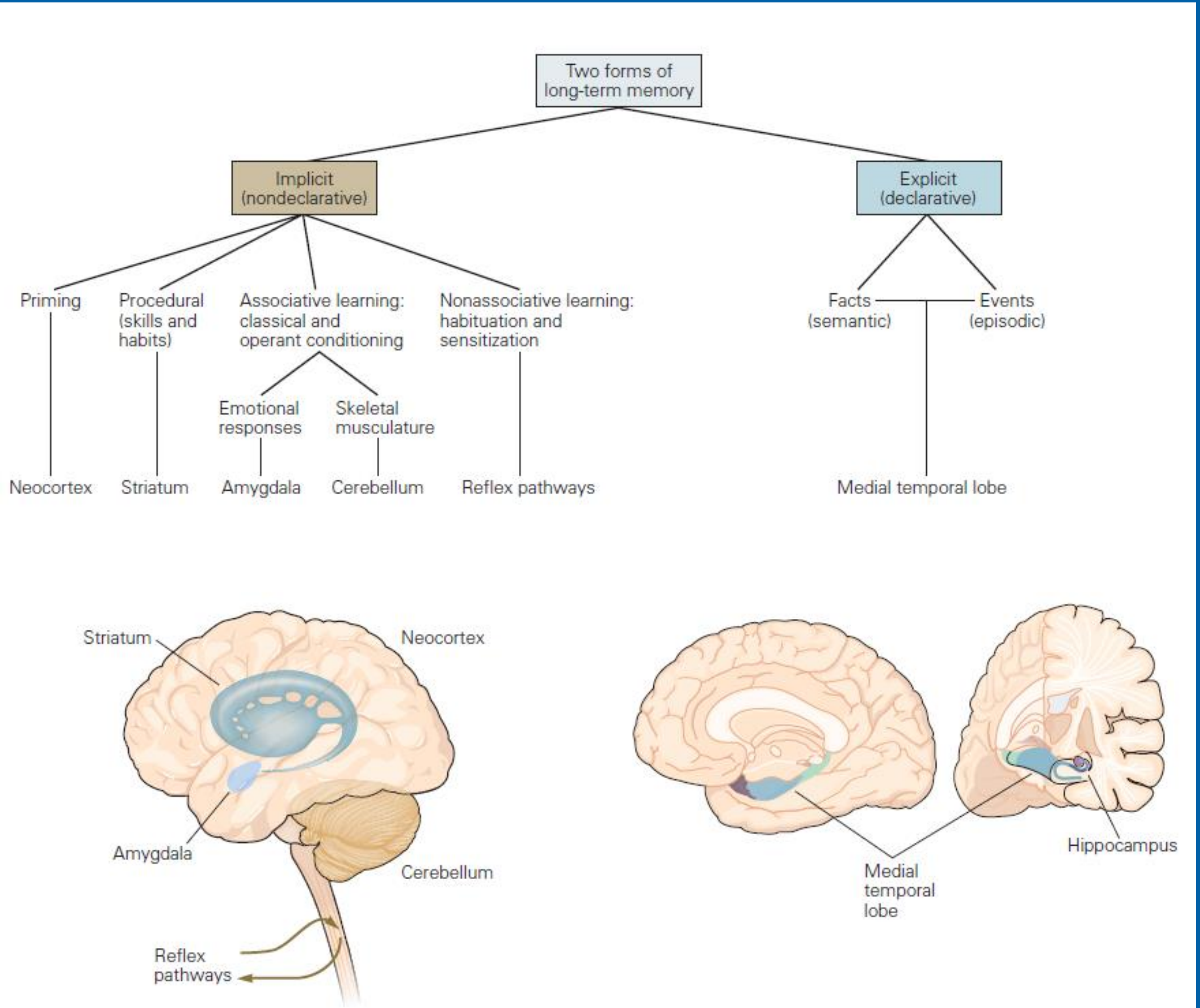
- Memory is vital to experiences, it is the retention of information over time for the purpose of influencing future action. If we could not remember past events, we could not learn or develop language, relationships, or personal identity (Eysenck, 2012).

- According to Miller, whose paper in 1956 popularized the theory of the "magic number seven", **short-term memory** is limited to a certain number of chunks of information, while **long-term memory** has a limitless store.

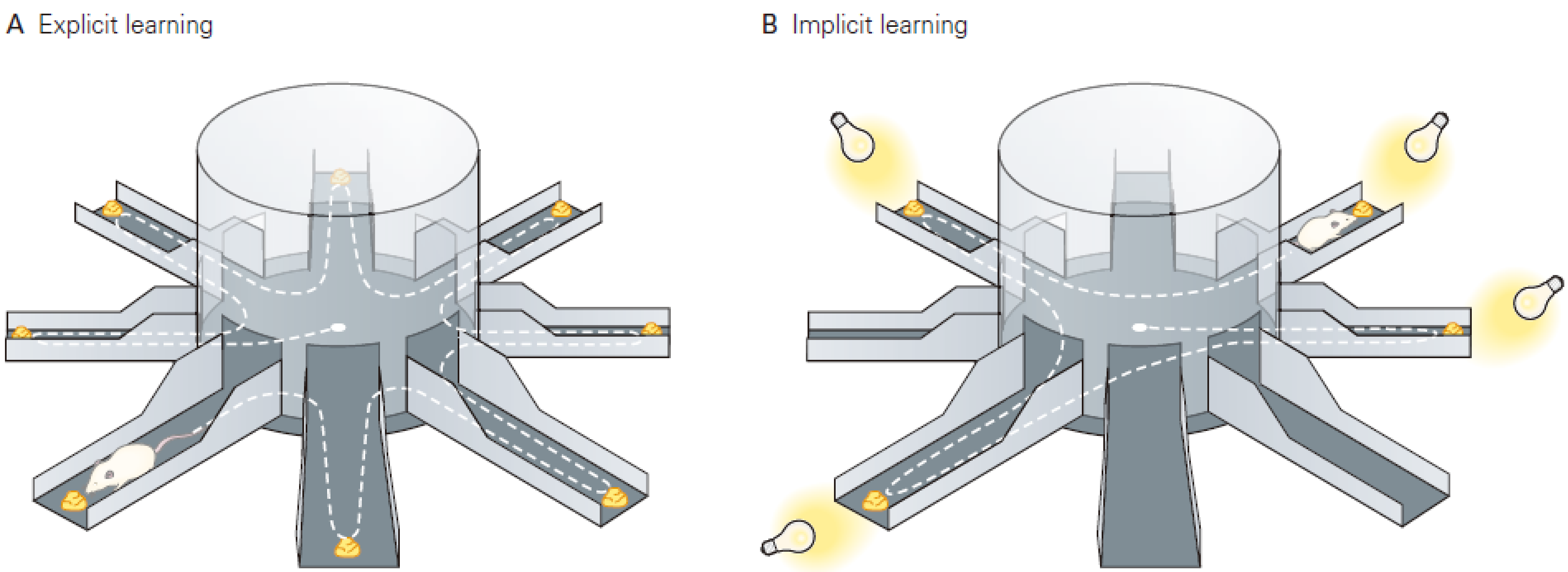
Long term memory is either explicit (conscious) or implicit (subconscious)



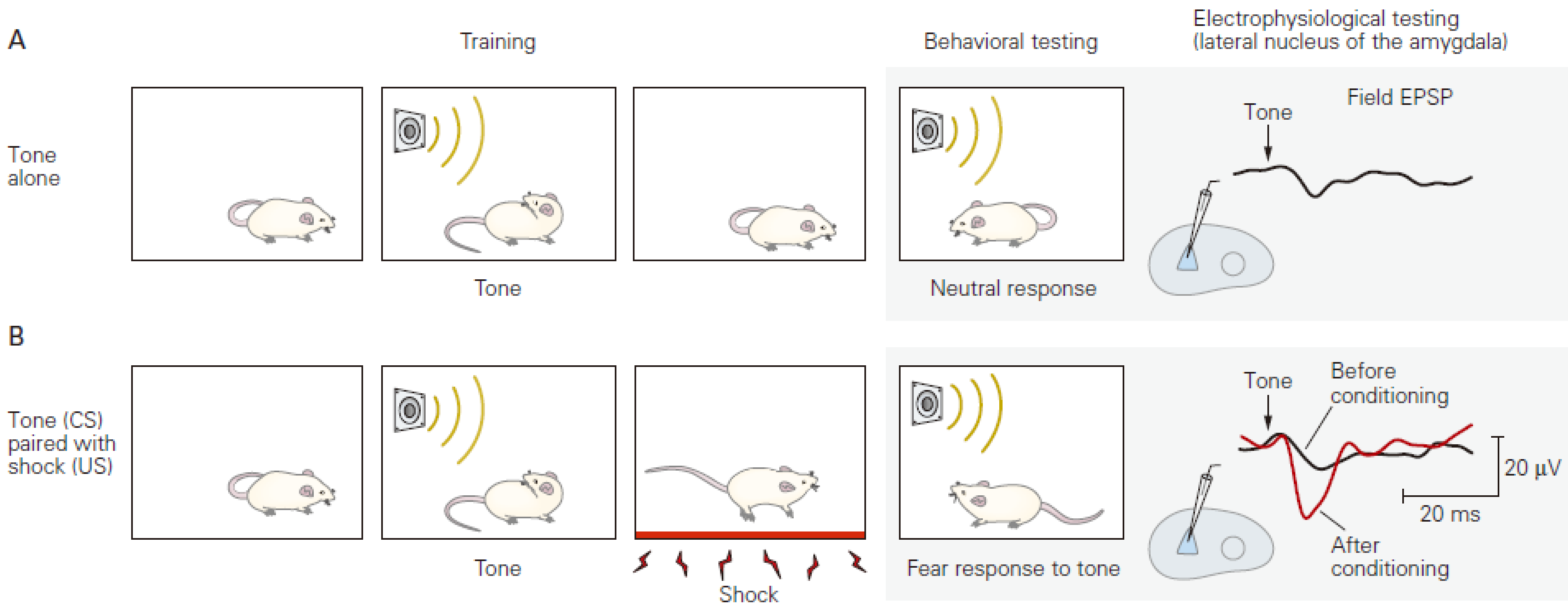
Two forms of long-term memory involve different brain systems



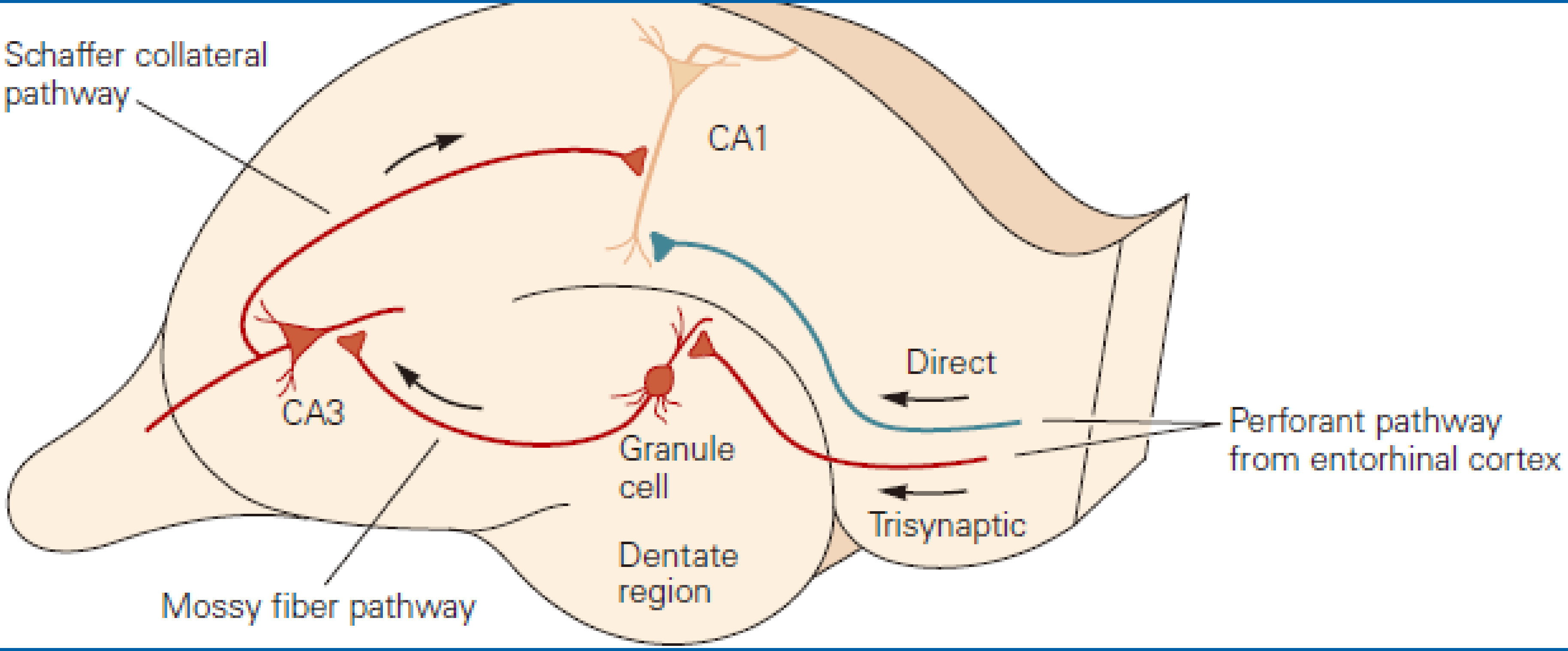
An eight-arm maze is used to demonstrate the difference between explicit and implicit learning



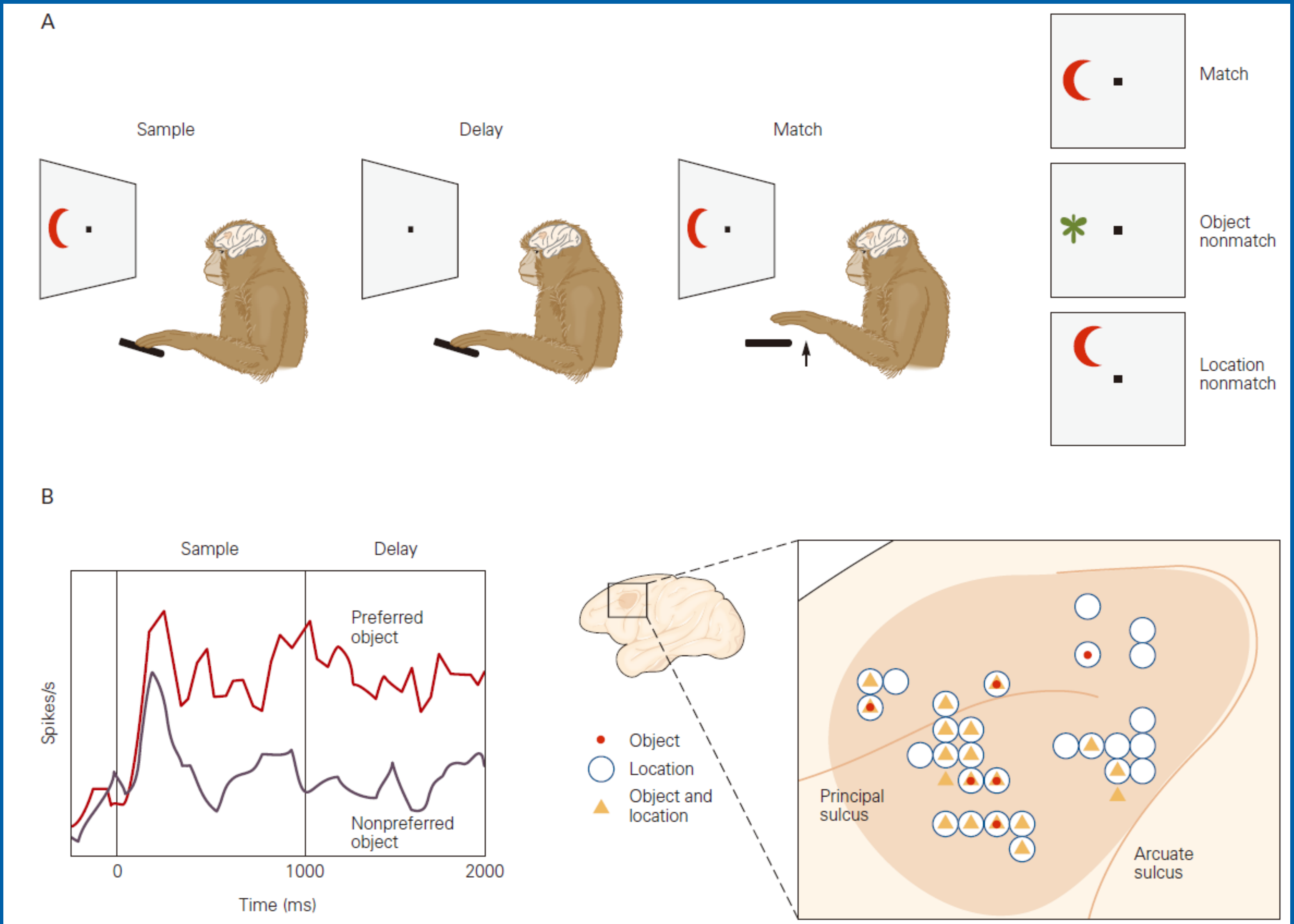
Learned fear produces parallel and correlated behavioral and electrophysiological changes



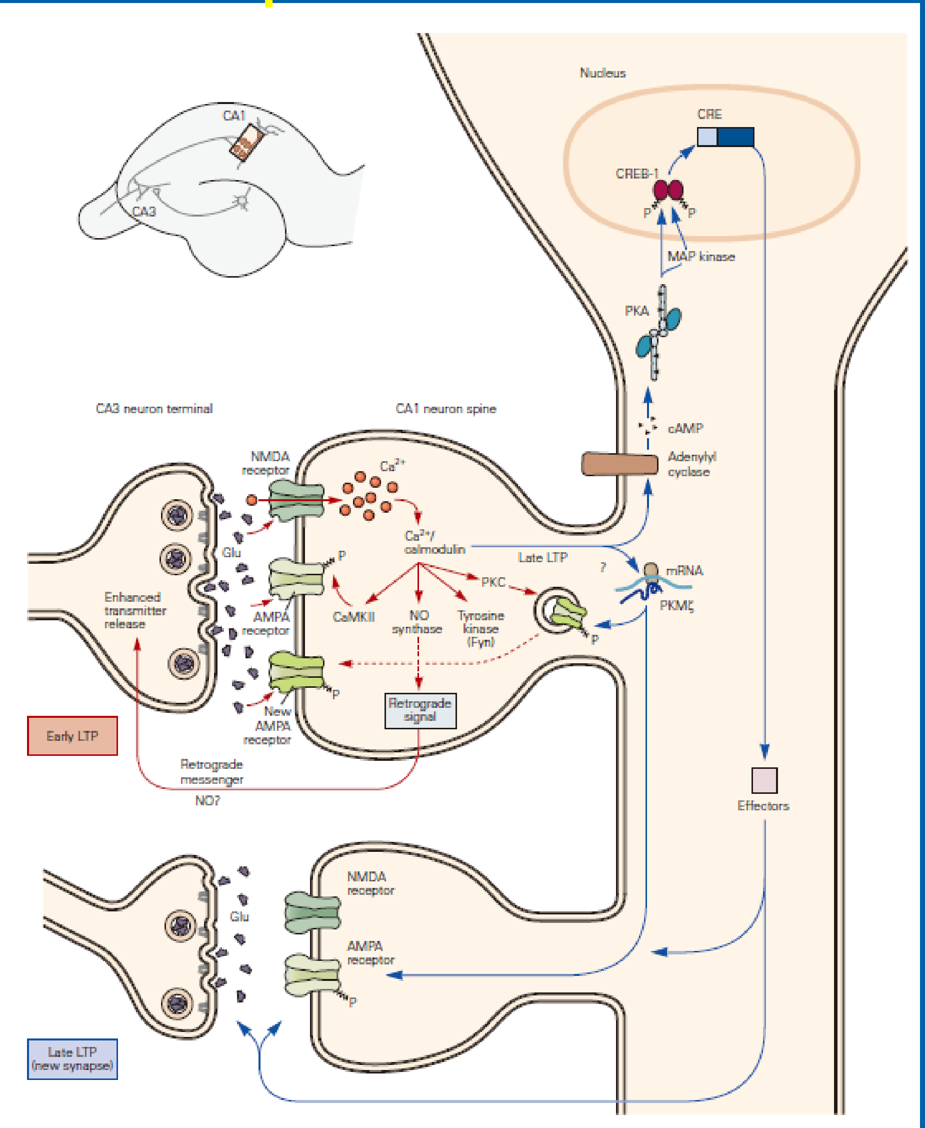
The hippocampal synaptic circuit is important for declarative memory



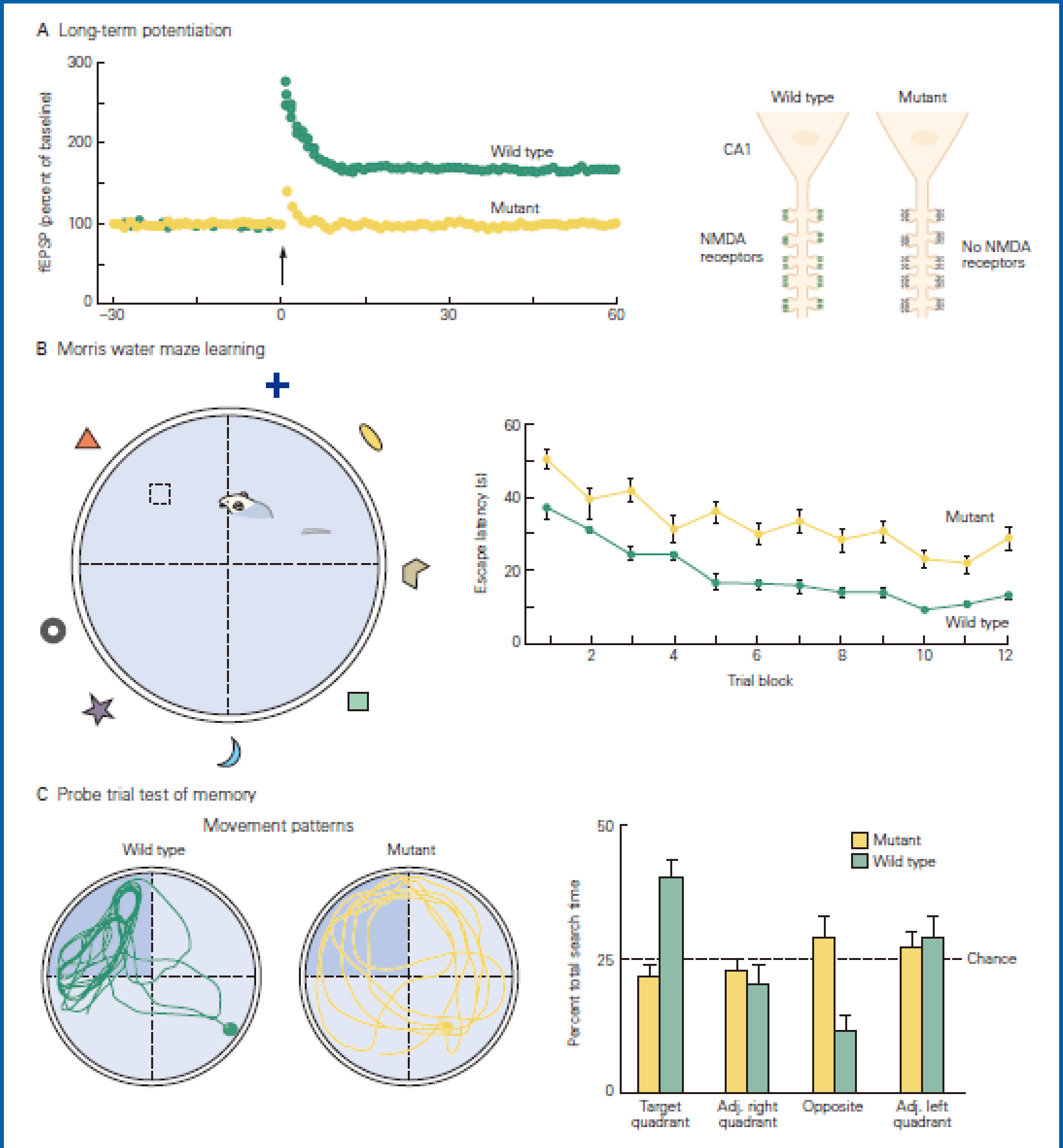
The prefrontal cortex maintains a working memory (short-term memory)



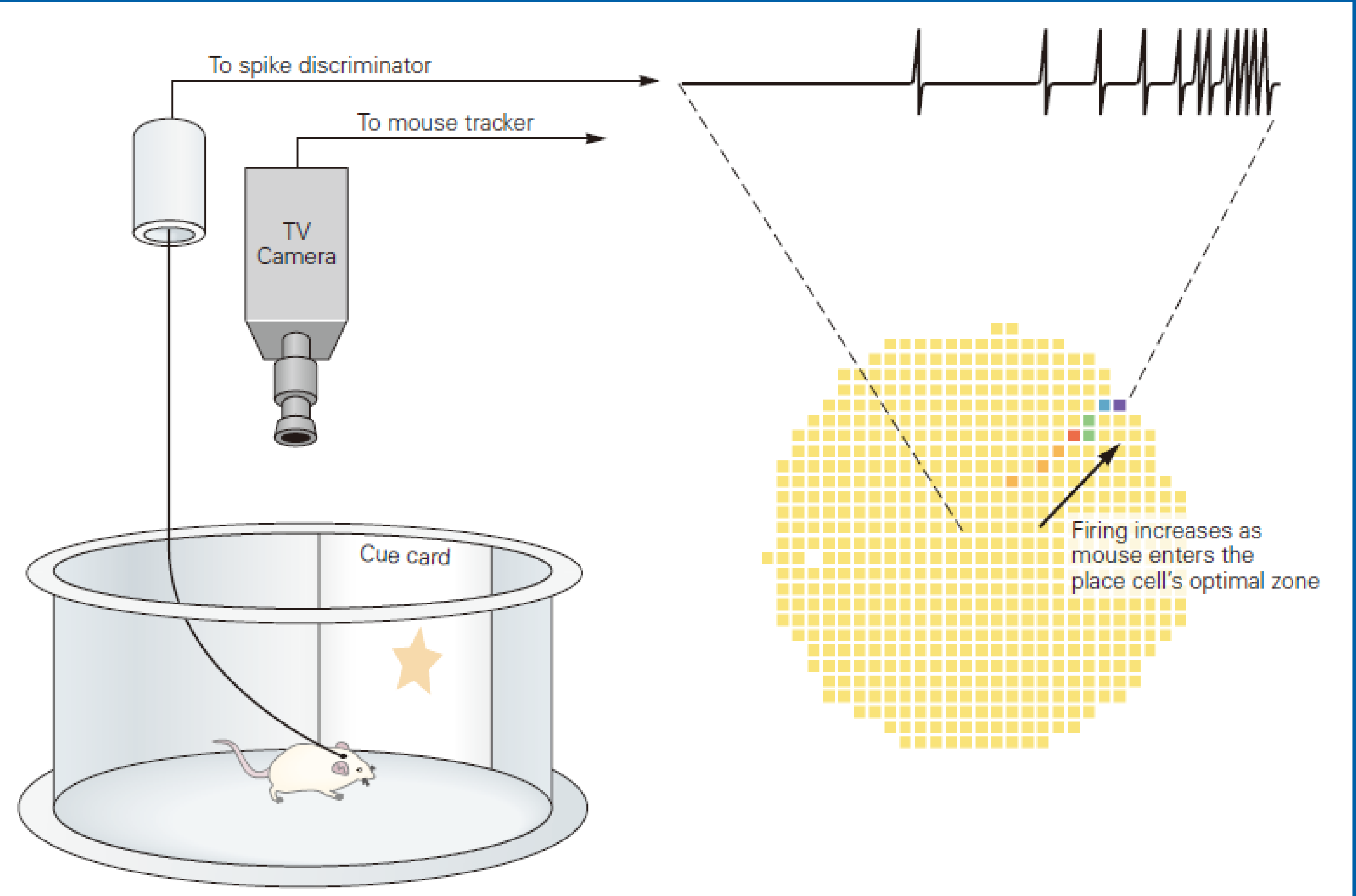
A model for the molecular mechanisms of early and late phase of long-term potentiation



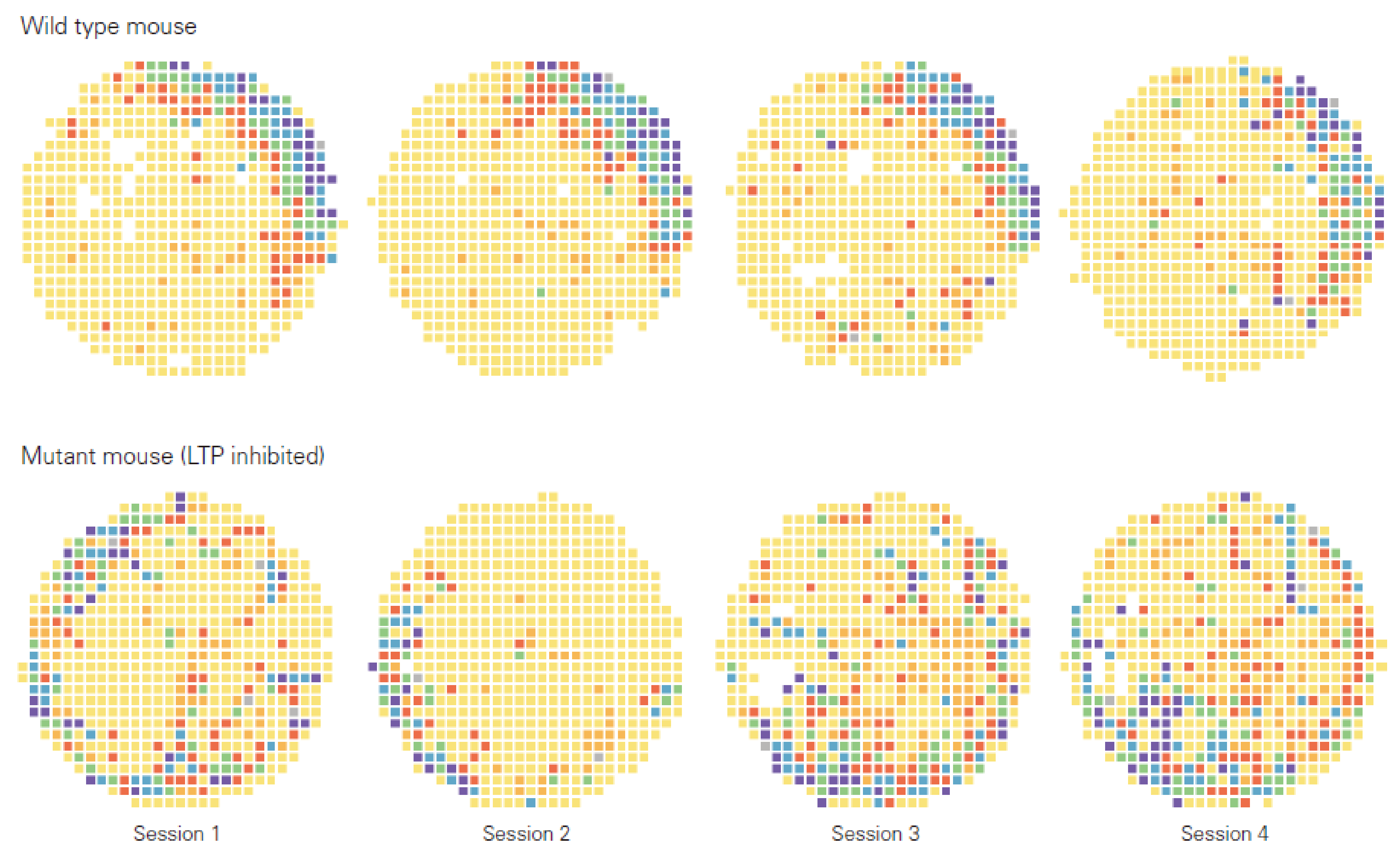
Long-term potentiation, and spatial learning and memory are impaired in mice that lack of the NMDA receptor in the CA1 region of hippocampus



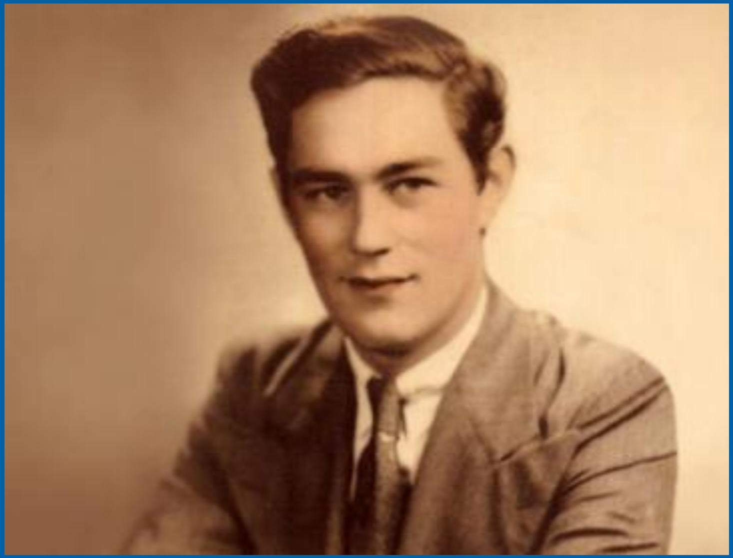
The firing patterns of pyramidal cells in hippocampus create an internal representation of the animal's location in its surroundings



Disruption of long-term potentiation alters the stability of spatial representation in hippocampal cells



Loss of function to form new memories



Henry Gustav Molaison (February 26, 1926 – December 2, 2008), known widely as H.M., was an American memory disorder patient who had a bilateral medial temporal lobectomy to surgically resect the anterior two thirds of his hippocampi, parahippocampal cortices, entorhinal cortices, piriform cortices, and amygdalae in an attempt to cure his epilepsy. Although the surgery was partially successful in controlling his epilepsy, a severe side effect was that he became unable to form new memories.

Memory loss—the Alzheimer's and dementia

Summary

- Often memory is understood as an informational processing system with explicit and implicit functioning that is made up of a sensory processor, short-term (or working) memory, and long-term memory.
- The sensory processor allows information from the outside world to be sensed in the form of chemical and physical stimuli and attended to with various levels of focus and intent.
- Working memory serves as an encoding and retrieval processor. Information in the form of stimuli is encoded in accordance with explicit or implicit functions by the working memory processor. The working memory also retrieves information from previously stored material.
- Finally, the function of long-term memory is to store data through various categorical models or systems.

Outline

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We face alternations every day

Which way to go?

Five steps to good decision making

- Step 1, Identify Your Goal: One of the most effective decision making strategies is to keep an eye on your goal.

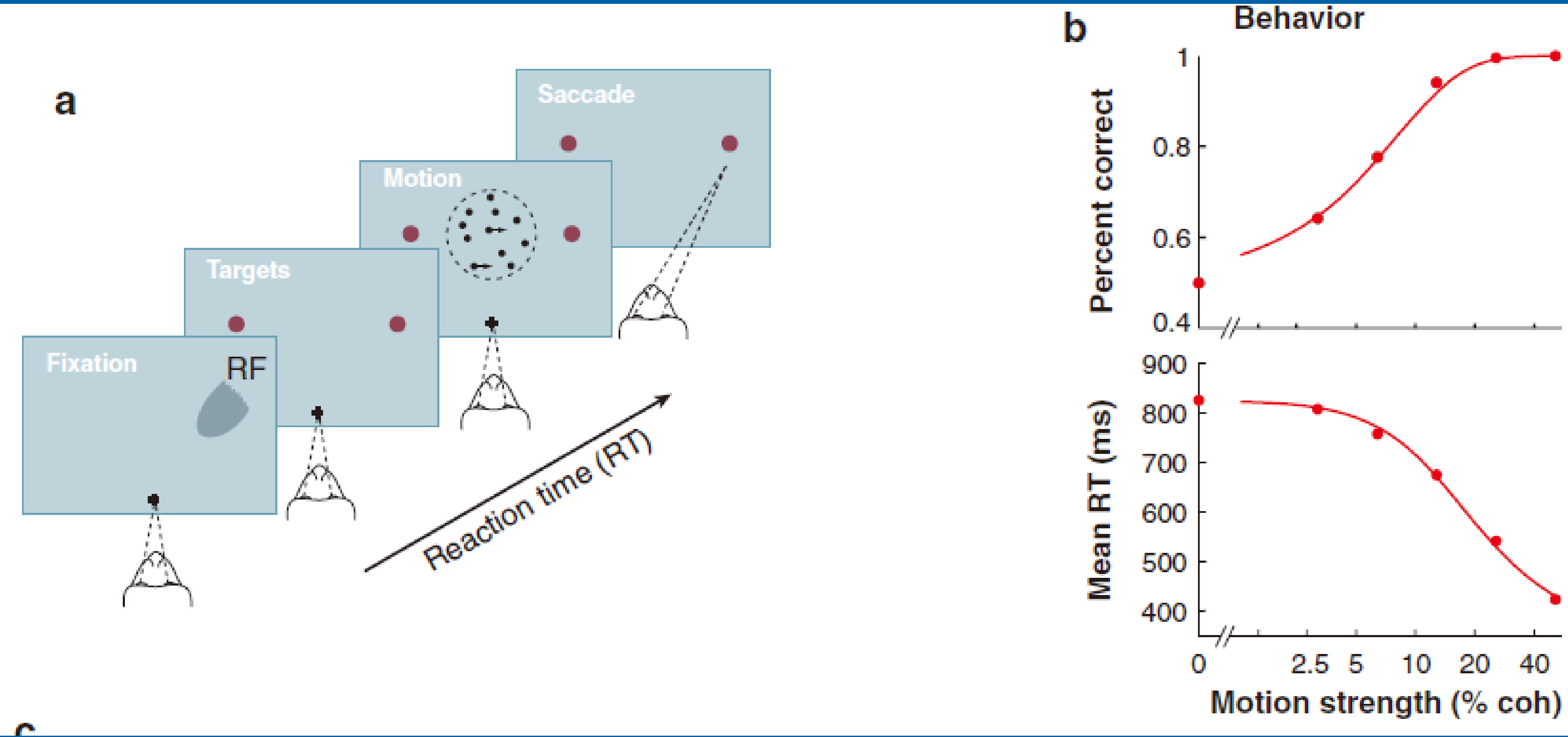
- Step 2, Gather Information for Weighing Your Options: When making good decisions it is best to gather necessary information that is directly related to the problem.

- Step 3, Consider the Consequences: it will help you determine how your final decision will impact yourself, and/or others involved. In this step, you will be asking yourself what is likely to be the results of your decision.

- Step 4, Make Your Decision: it is time to make a choice and actually execute your final decision.

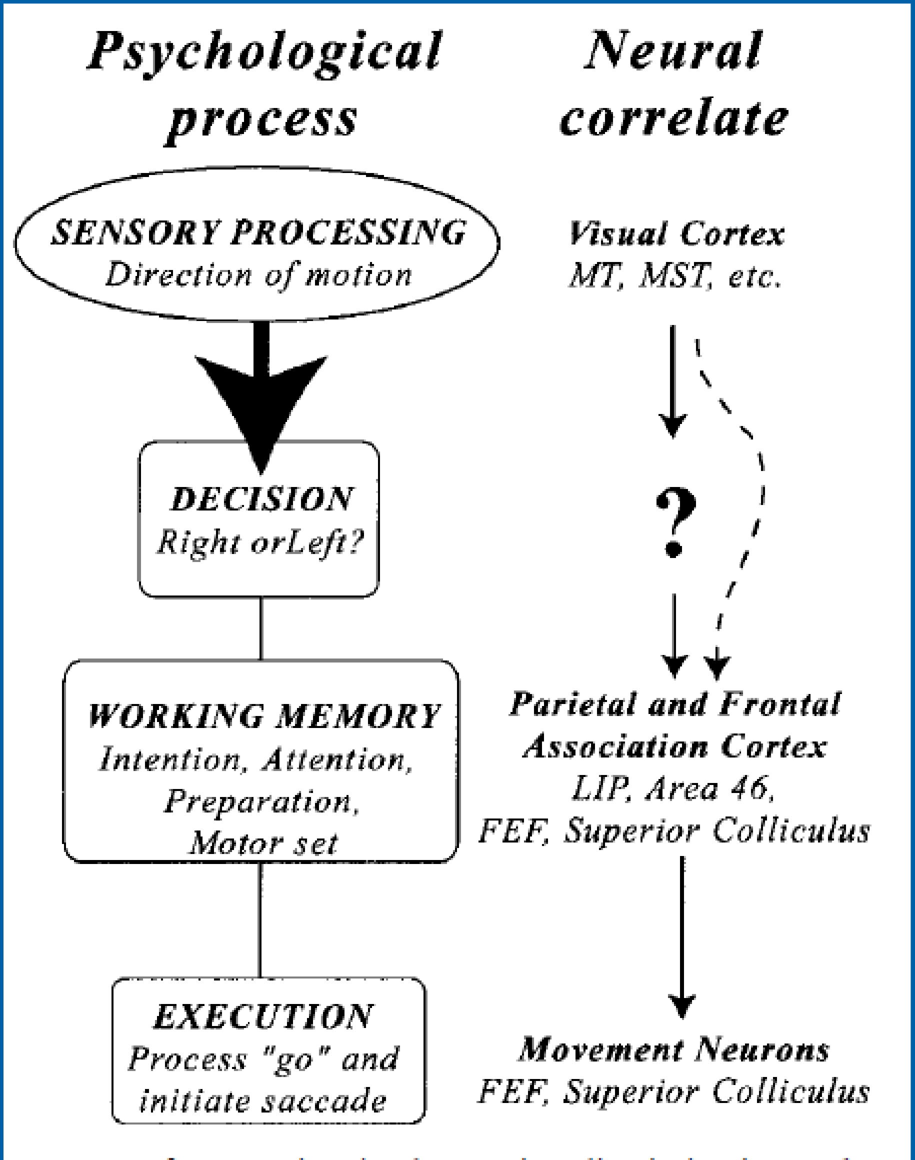
- Step 5, Evaluate Your Decision: it is necessary to evaluate the decision and the steps you have taken to ensure that it works.

Exploring the neural mechanisms of decision-making in laboratory

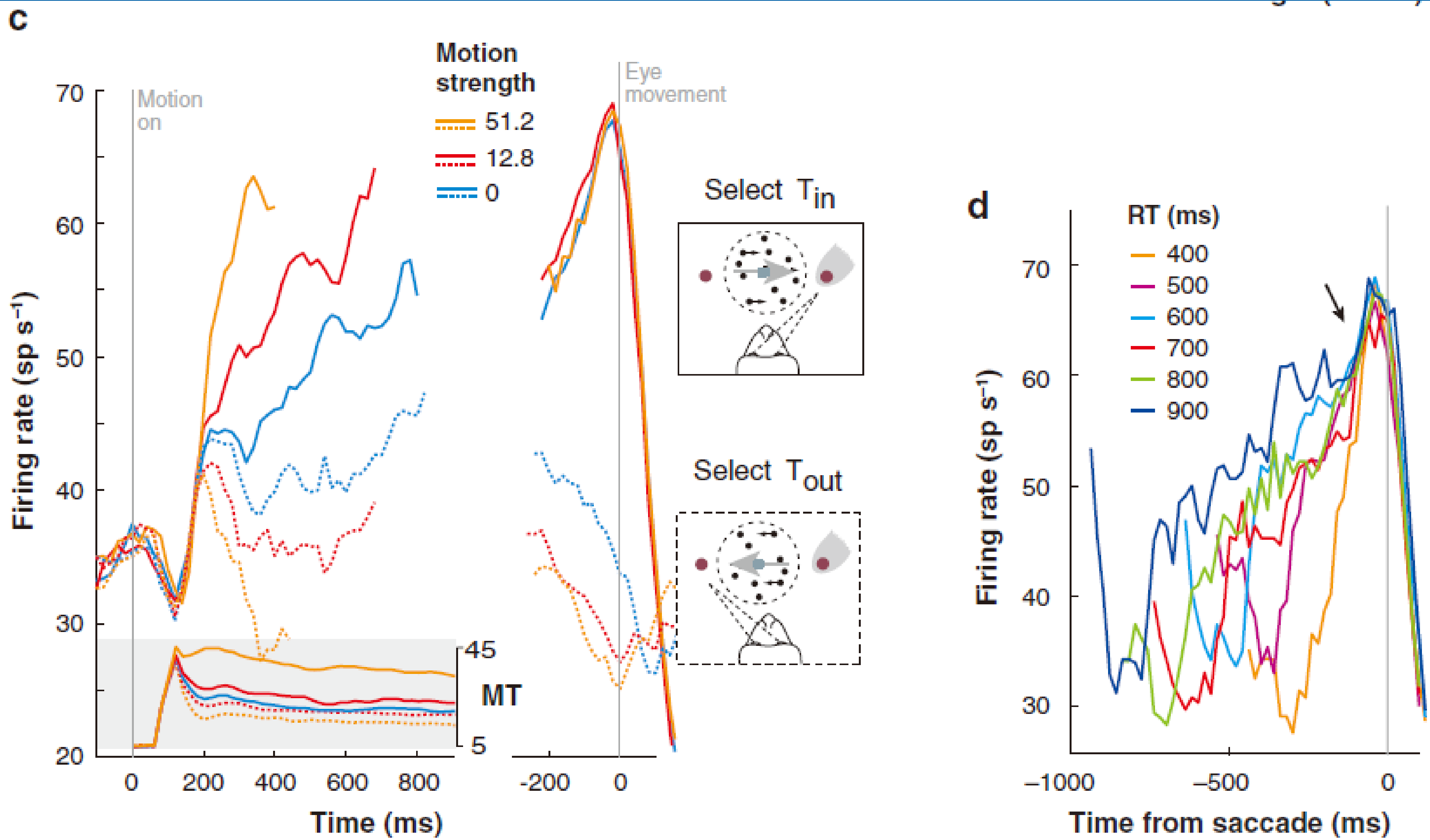


Gold and Shadlen, 2007

Stages of processing in the motion-discrimination task and their putative neural correlates



Decision-making related activity in LIP



Summary

- In psychology, decision-making (also spelled decision making and decisionmaking) is regarded as the **cognitive process** resulting in the selection of a belief or a course of action among several alternative possibilities.
- Every decision-making process produces a final choice, which may or may not prompt action.
- Decision-making is the process of identifying and choosing alternatives based on the values, preferences and beliefs of the decision-maker.
- Decision-making correlated neural activity has been found in neocortex of primates

Outline

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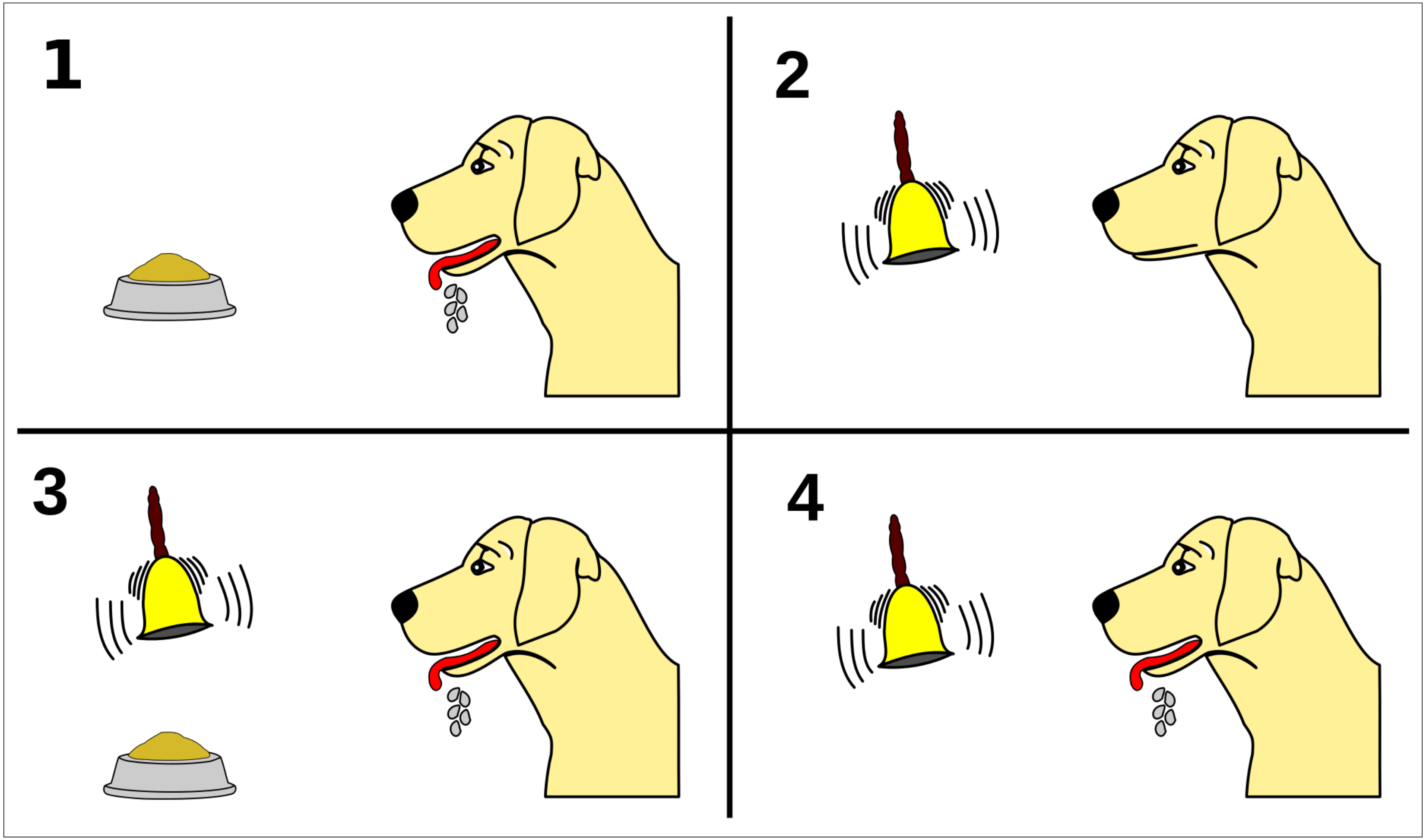
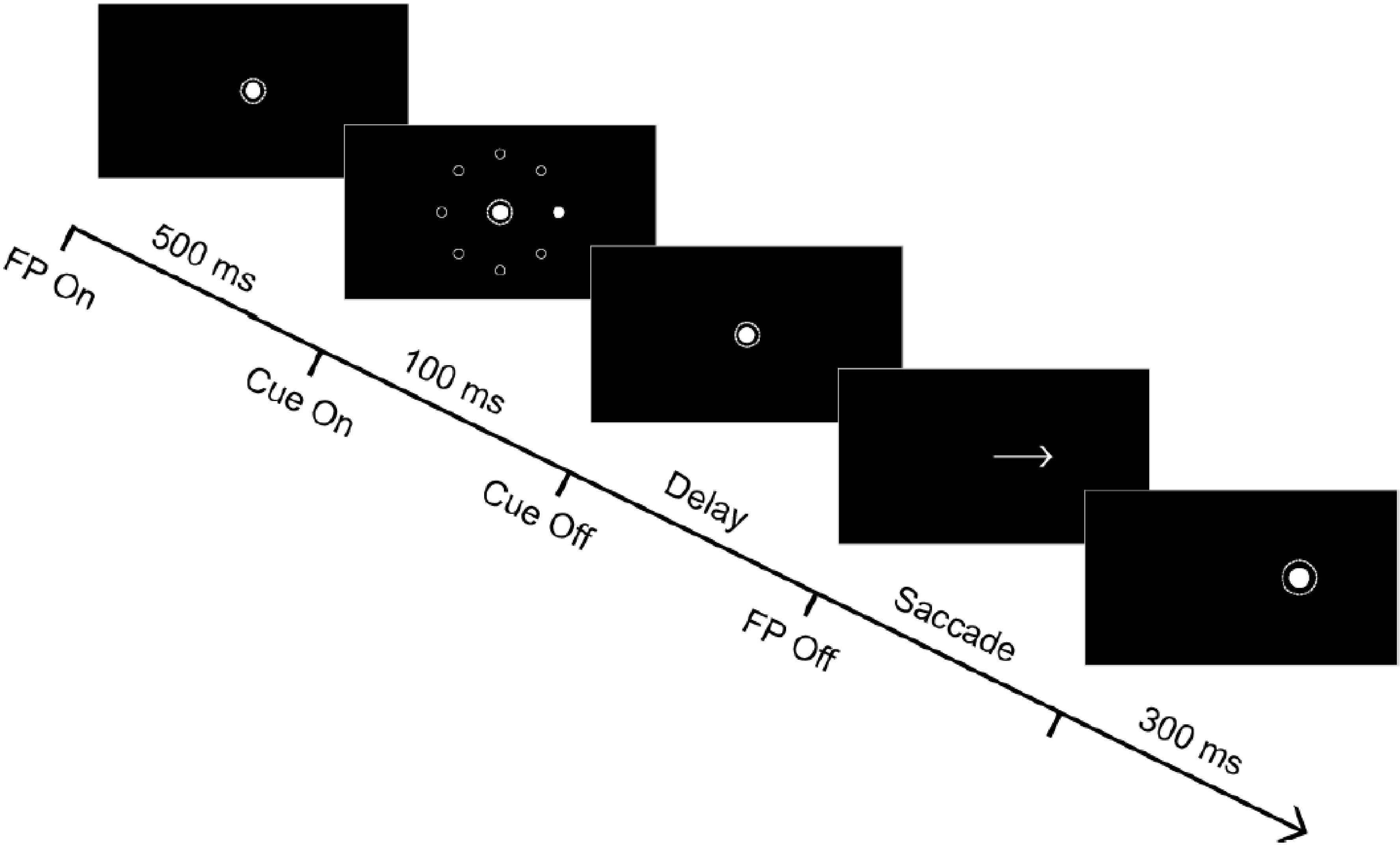
Adaptive animals develop the capability to predict the future events

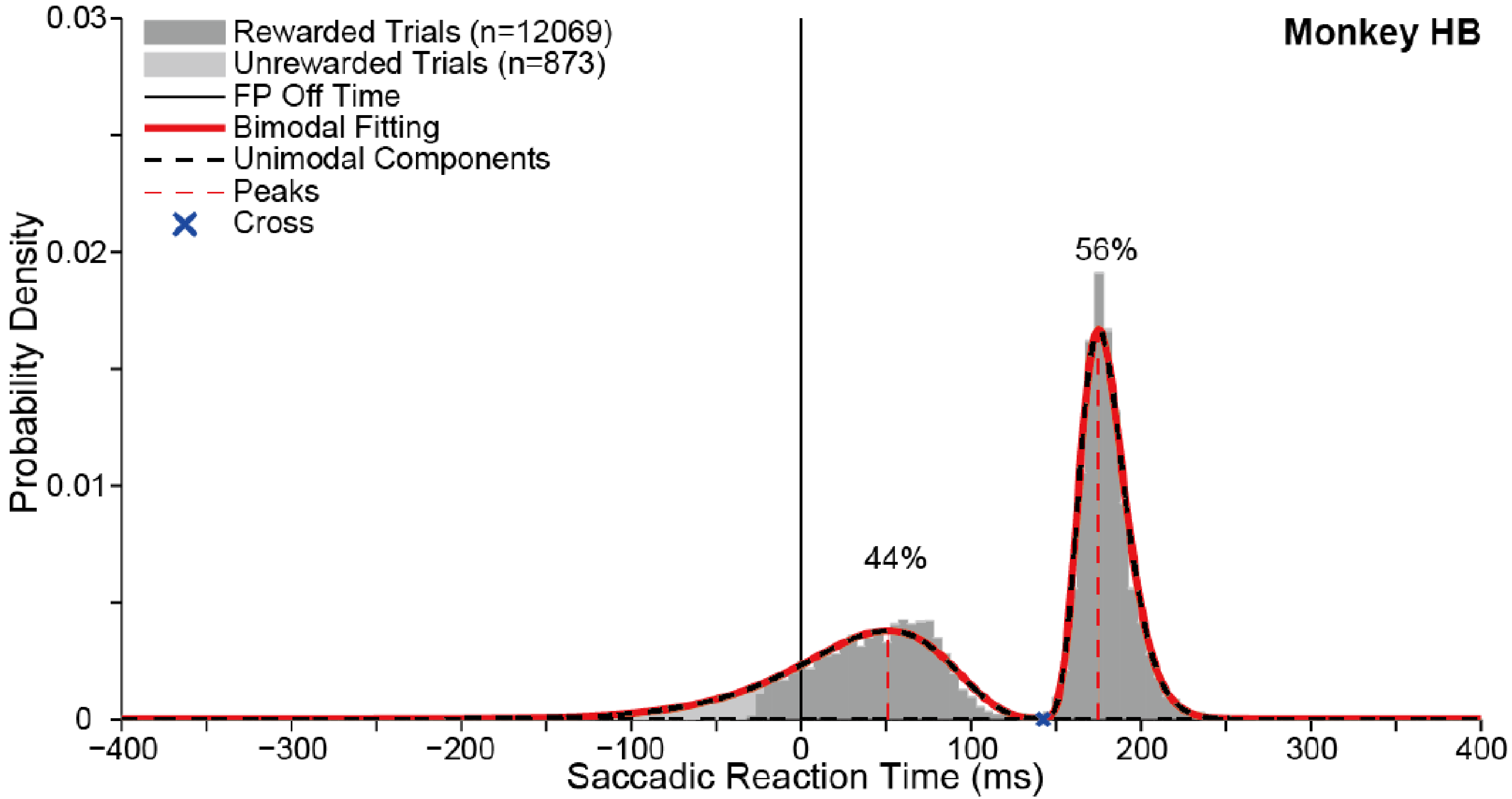
Association learning plays crucial role in forming prediction



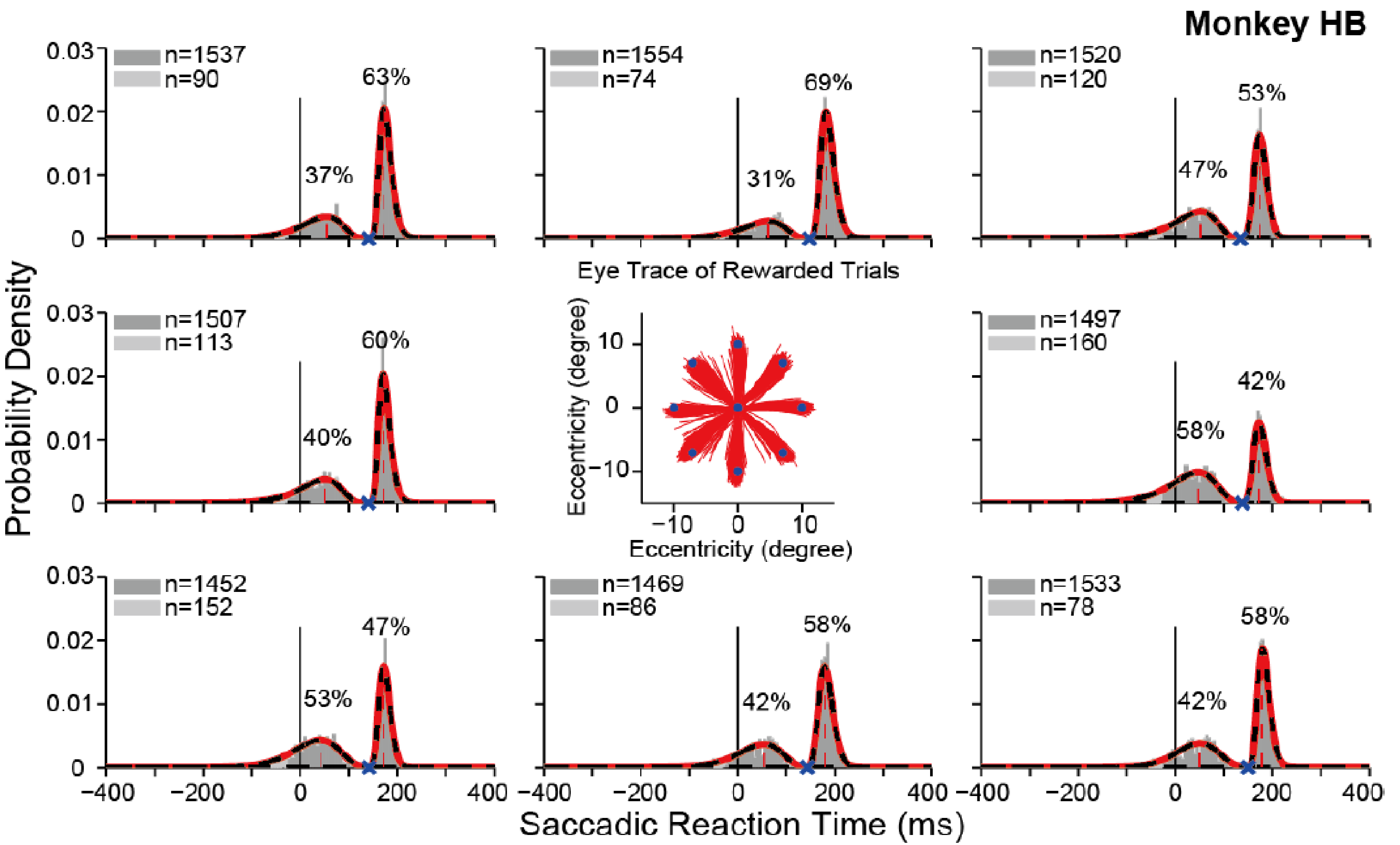
Study prediction in laboratory



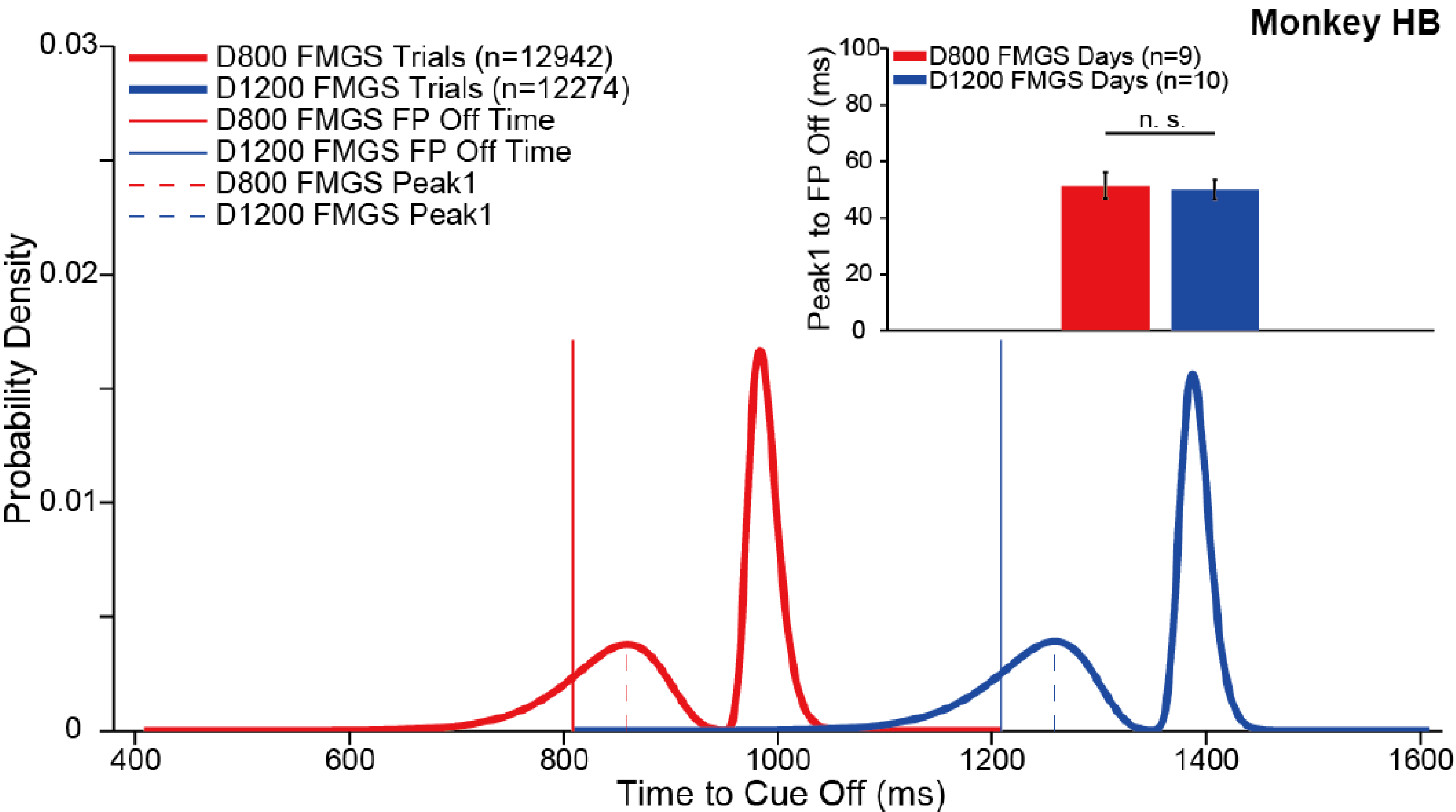
Predictive and reactive saccade



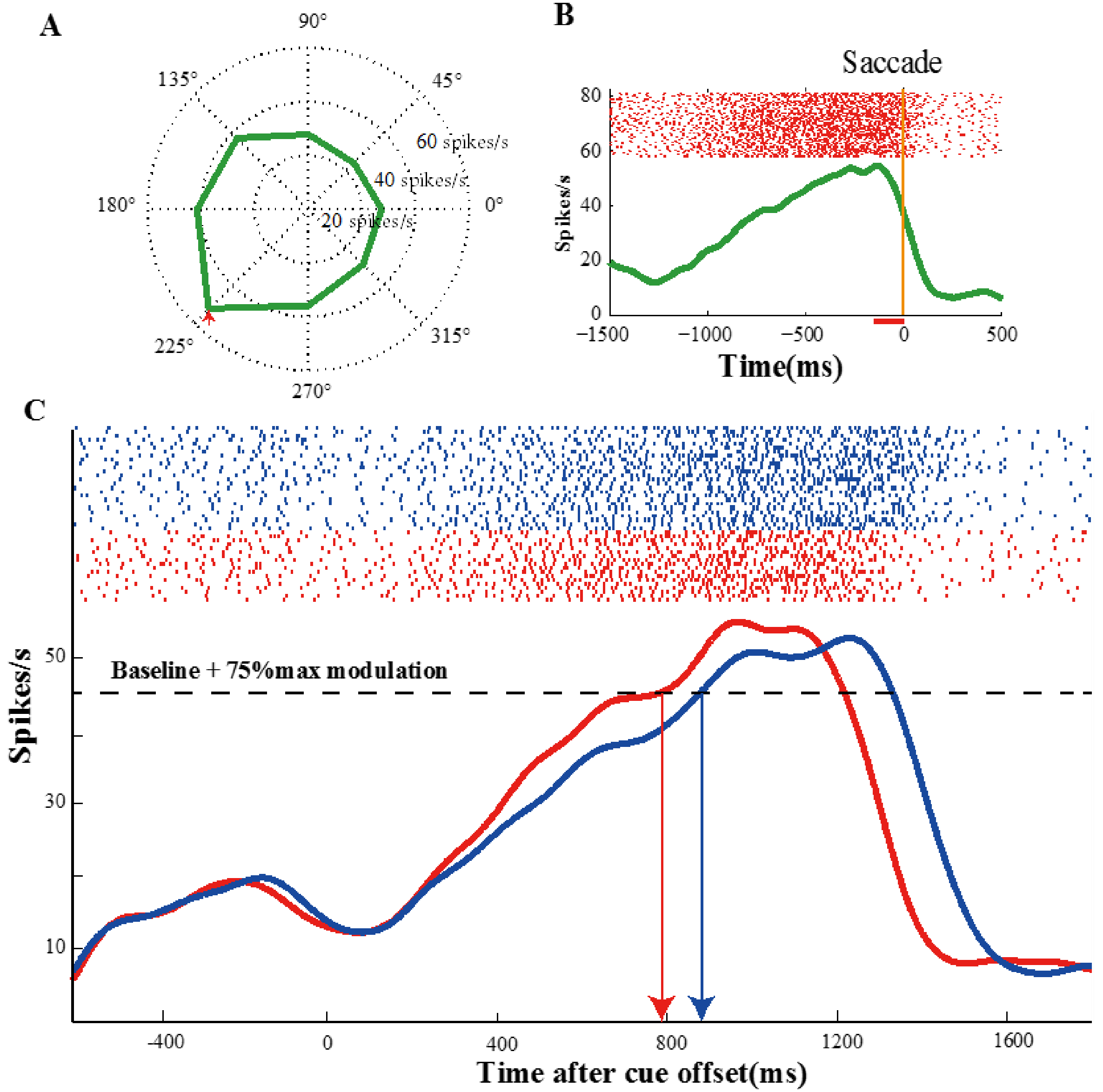
Predictive saccade occurs in all directions



The distribution pattern of predictive saccade remains similar between different delay trials



Predictive related activity in PFC



Summary

- Prediction shortens the signal process from sensory input to motor output, its reflection in behavior is to shorten the reaction time (latency).
- Both cortical (prefrontal cortex) and subcortical (basal ganglia) regions are involved in making prediction.
- There are many unknown questions regarding the neural mechanisms of prediction.

Human brain control artificial arm