Anticipation and Prediction in the Visual System

from

Cellular Level to System Level

Andrei Barborica

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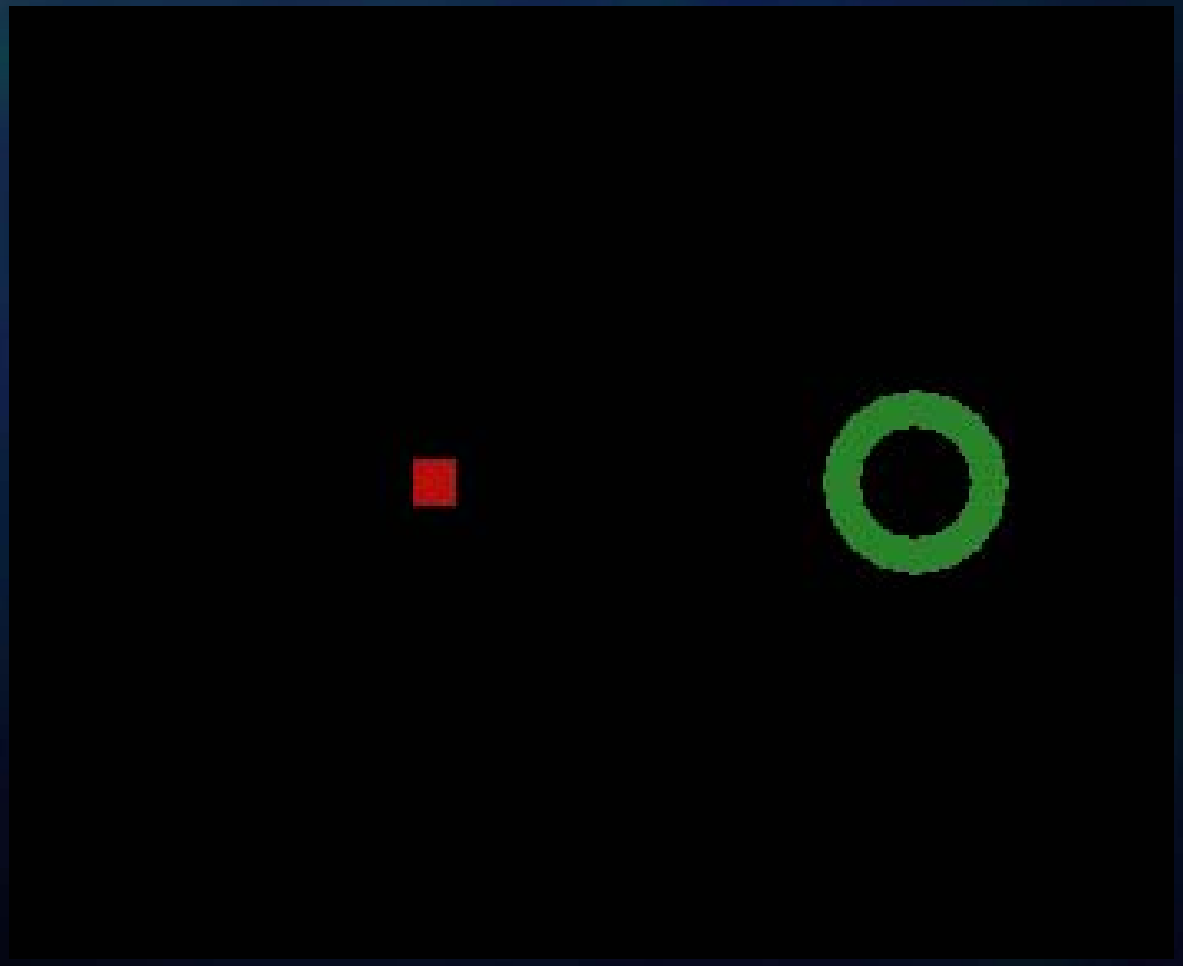
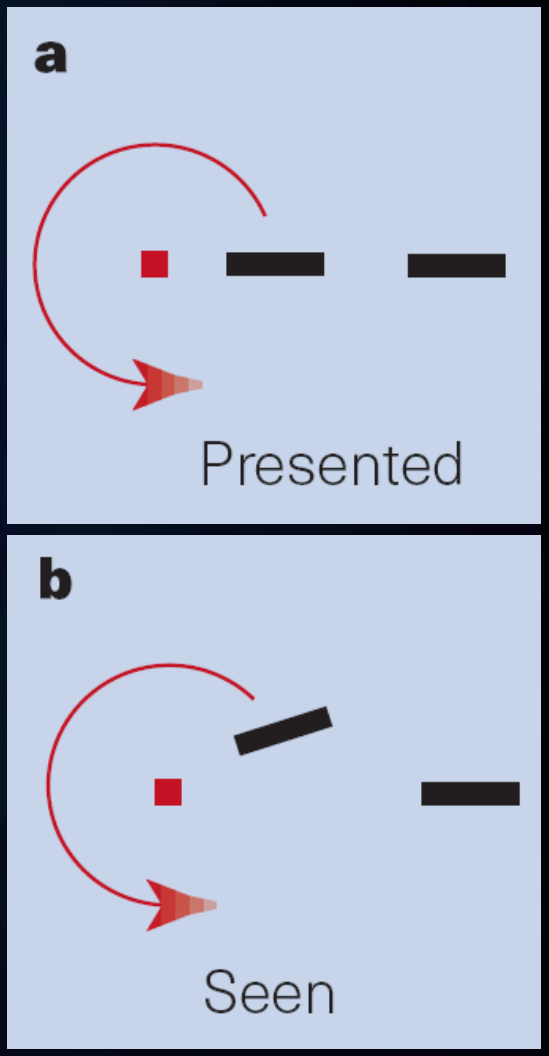
Anticipation?

- Visual Illusions: Flash-Lag Effect





Anticipation?

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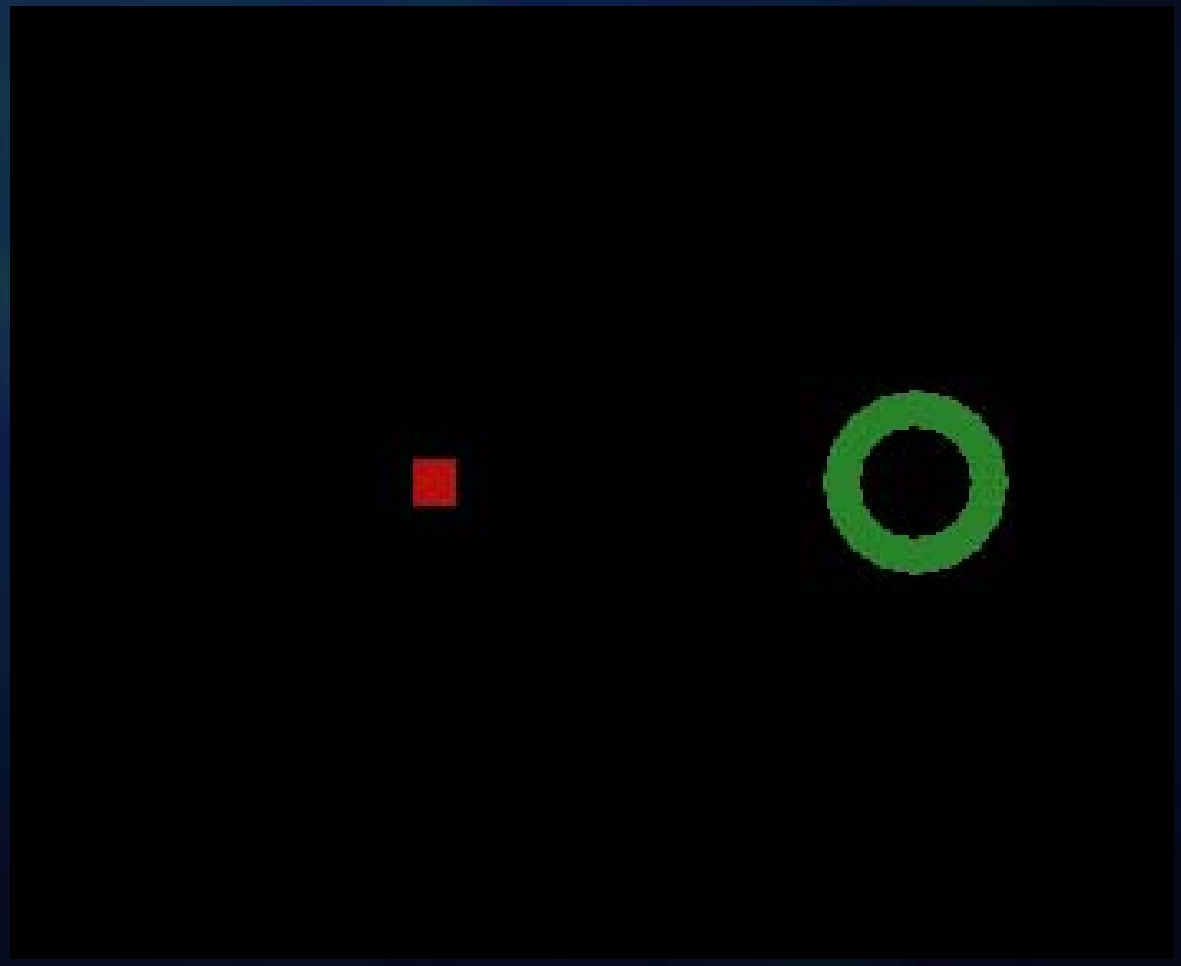
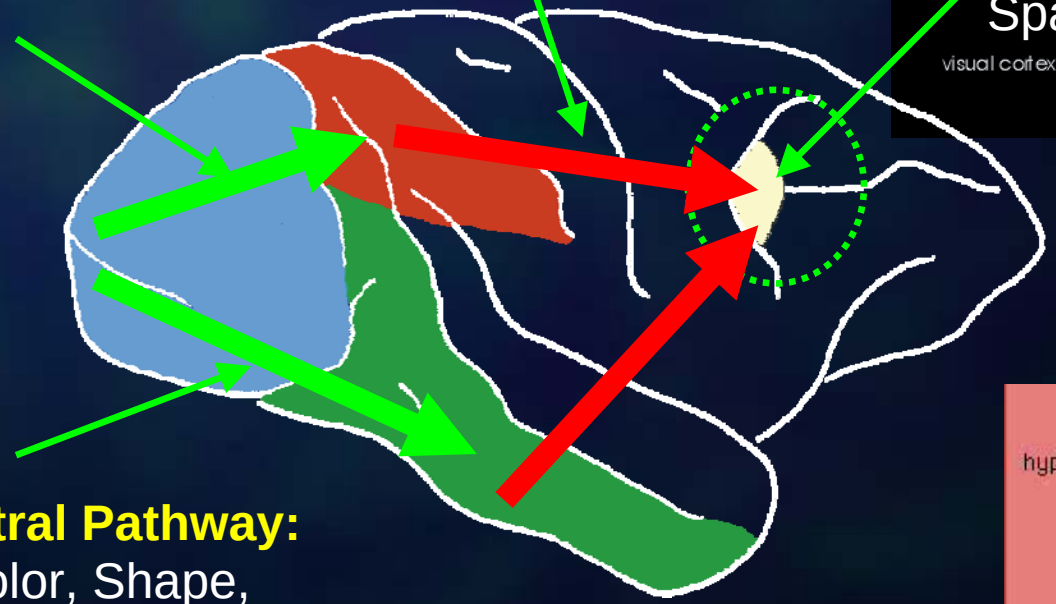


Prediction?

Visual Pathways

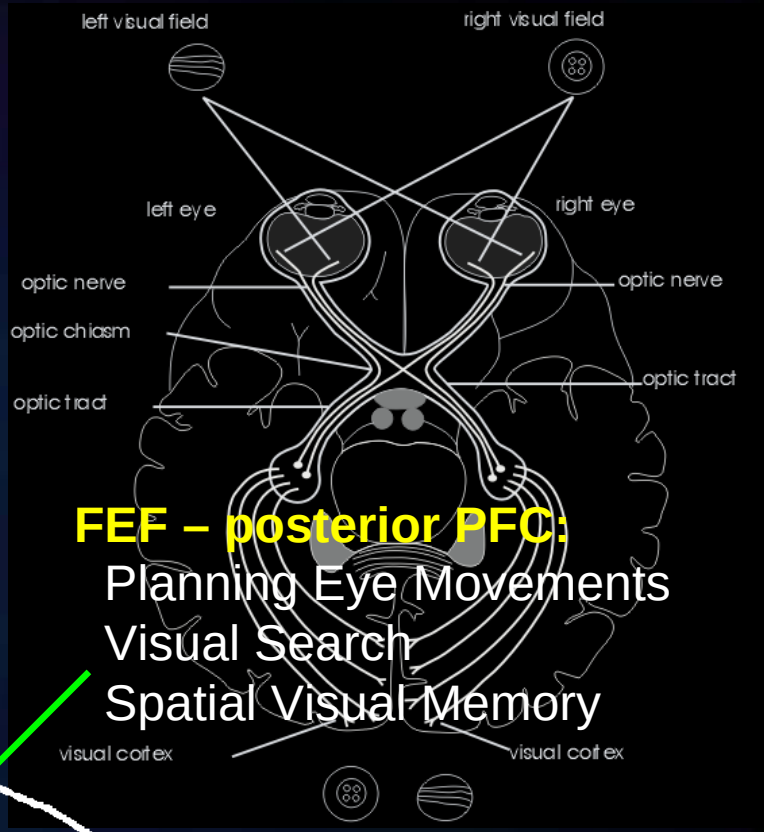
Anatomical Projections From
Parietal Motion Areas
(Schall et al. 1995)

Dorsal Pathway:
Motion, Stereo
Visually-Guided Movement

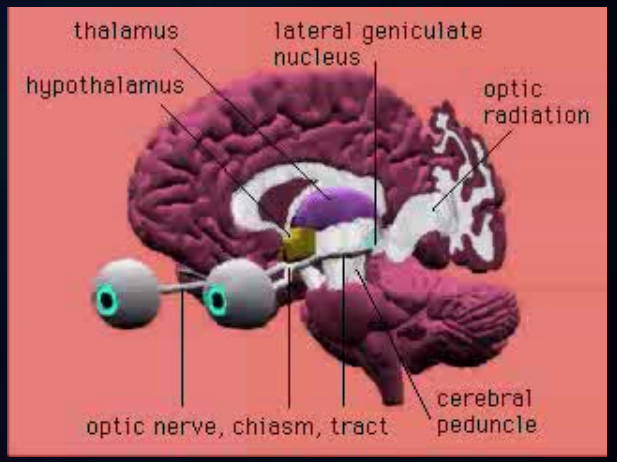


Ventral Pathway:
Color, Shape,
Face Recognition

Macaque Monkey Brain



FEF – posterior PFC:
Planning Eye Movements
Visual Search
Spatial Visual Memory

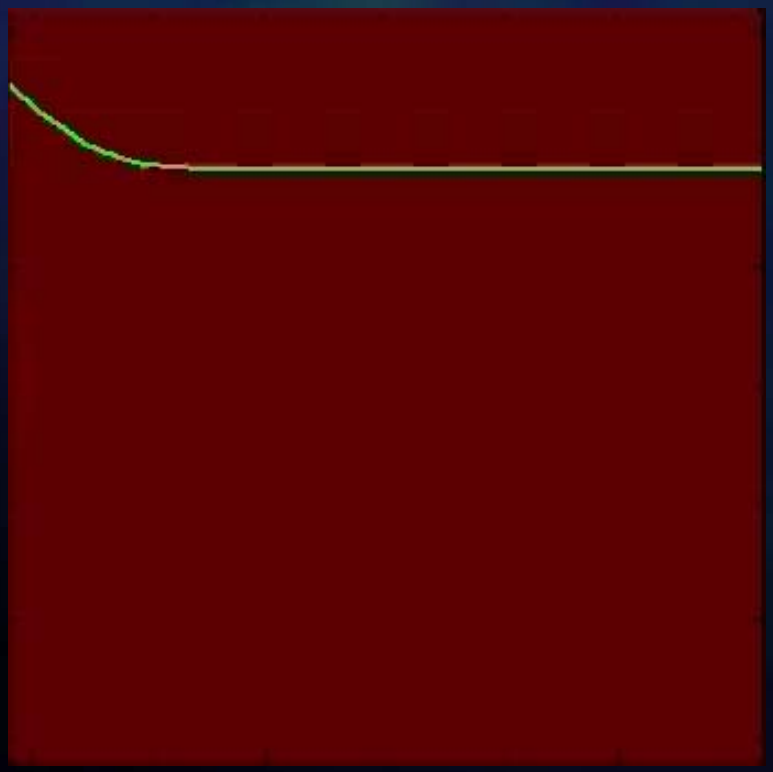


Anticipation and Prediction

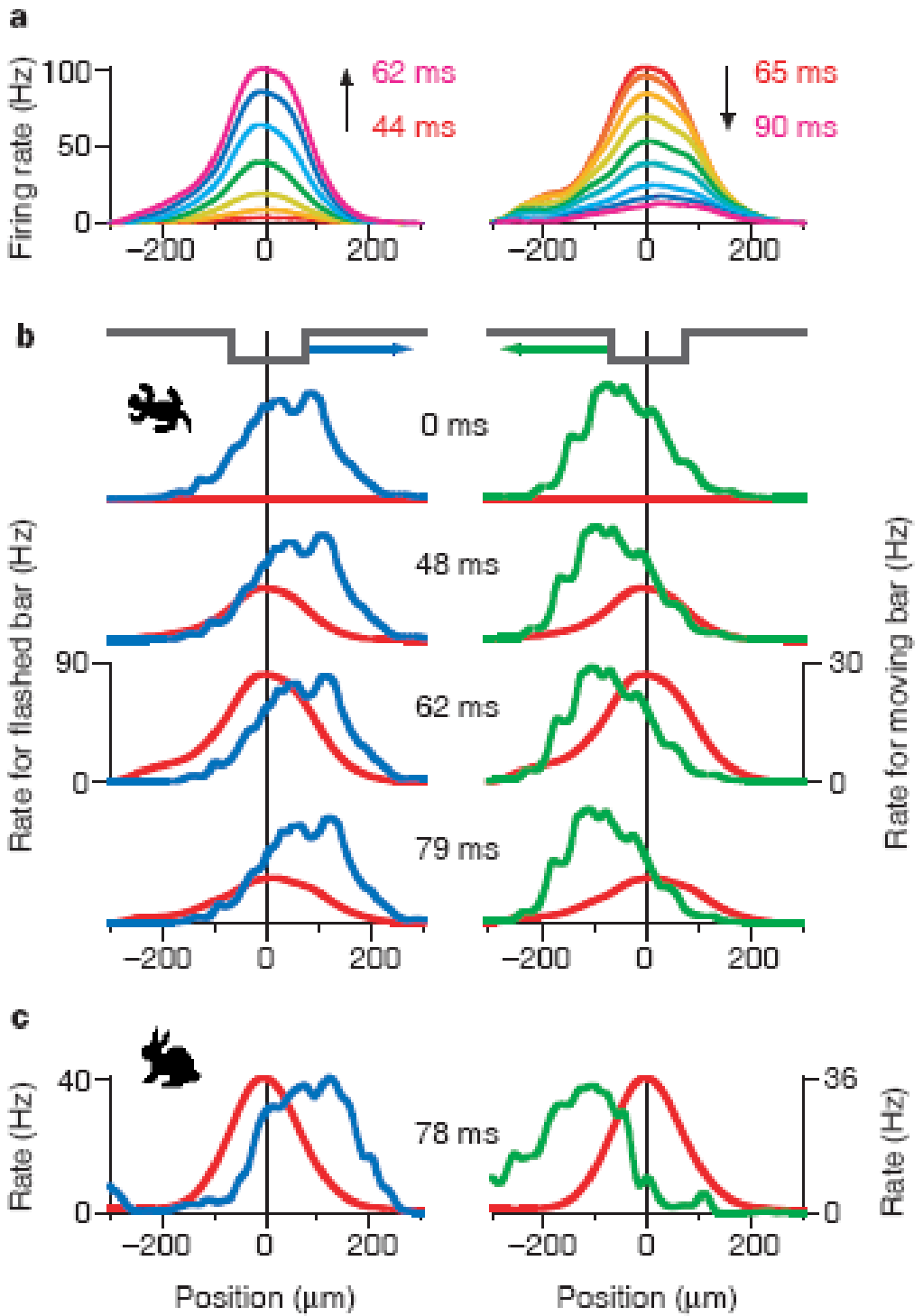
- Anticipation – a simple process taking place at the receptor level or early visual processing areas
- Prediction – a more complex process taking place at the higher order processing areas
- Levels:
  - Receptor level (retina)
  - Visual processing areas (V4)
  - Higher order processing areas – prefrontal cortex (PFC)

Receptor Level

- Anticipation of moving stimuli by the retina



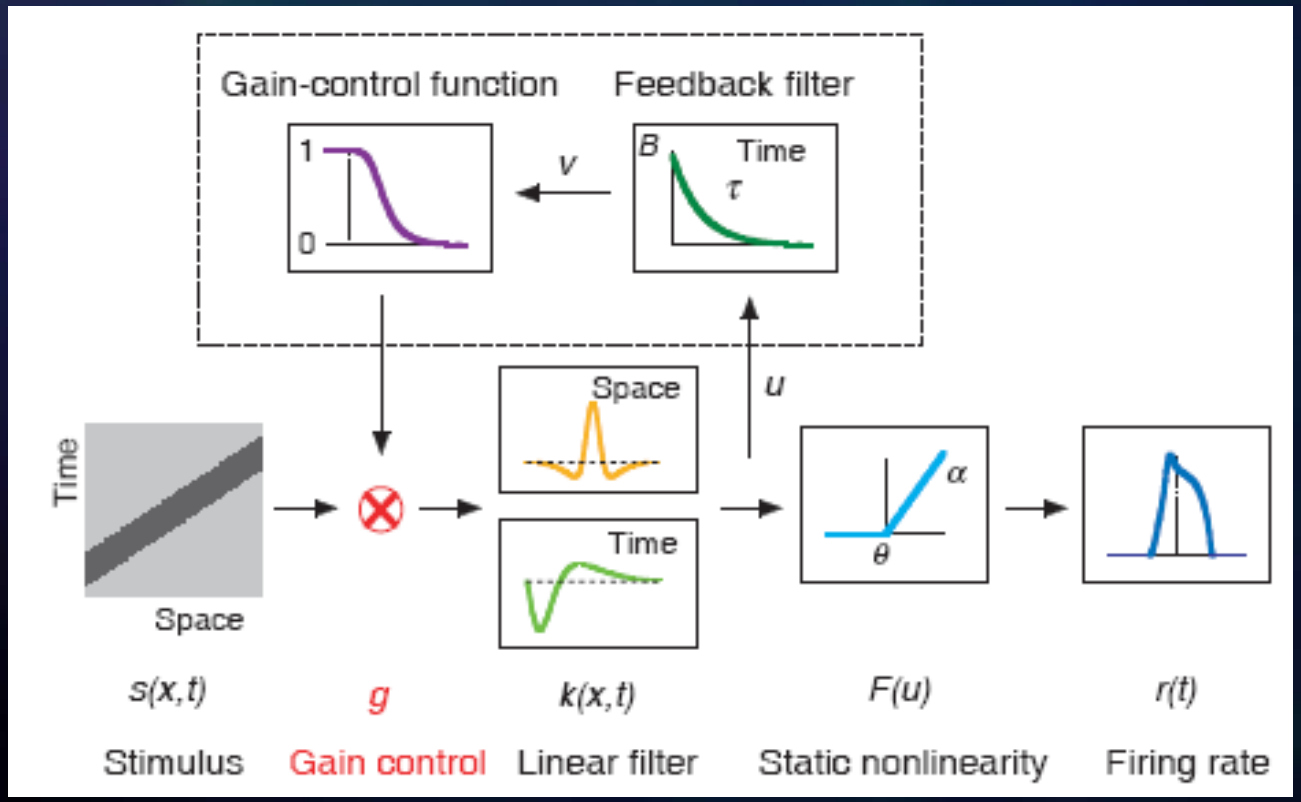
Ferrera VP, Barborica A. (2006) Neuron. 49:327-329



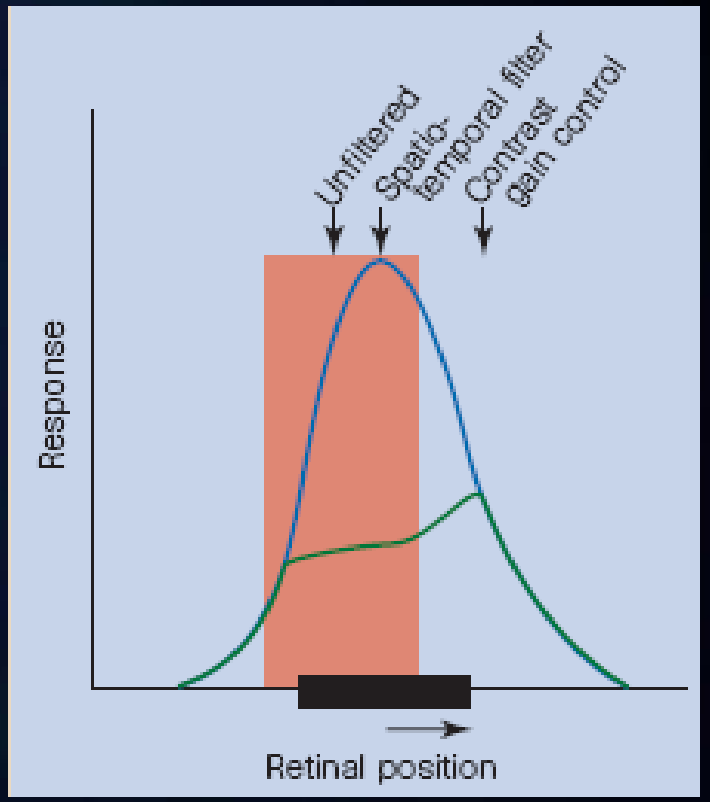
Berry MJ, ***Brivanlou*** IH, Jordan TA, ***Meister*** M (1999) Nature. 398:334-338

Anticipation by Retina

- Linear Model: spatio-temporal filters with contrast gain control (Berry et al, 1999)



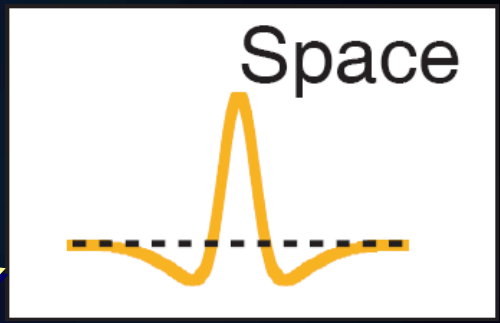
Berry MJ, ***Brivanlou*** IH, Jordan TA, ***Meister*** M (1999) Nature. 398:334-338

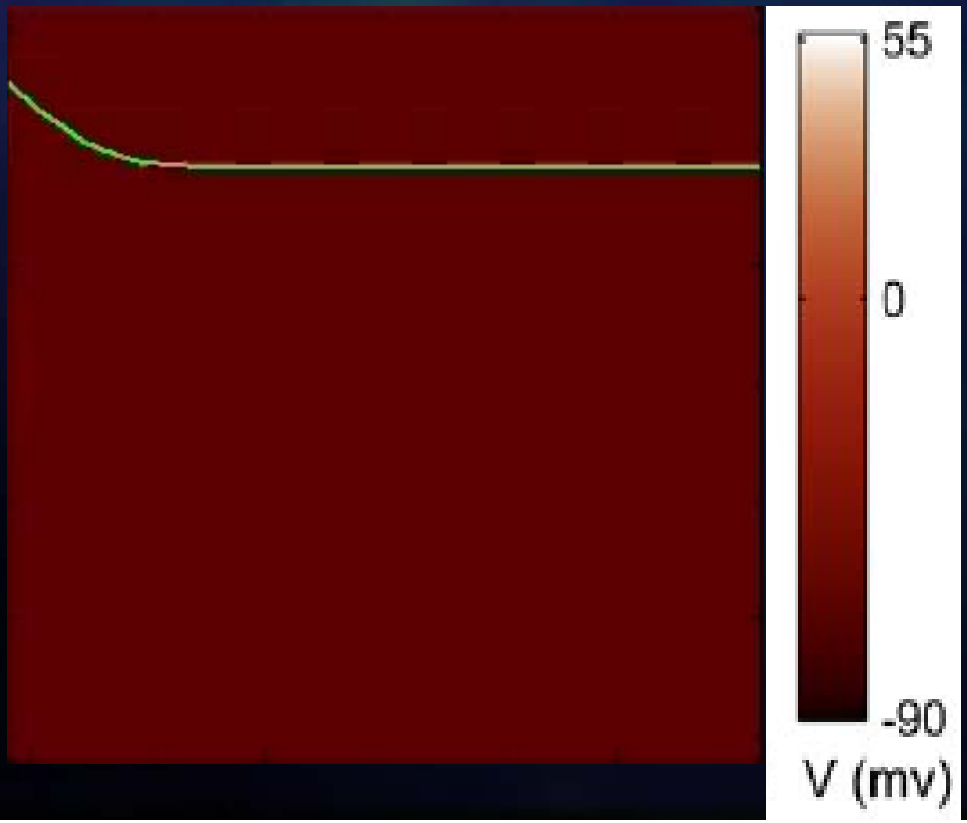


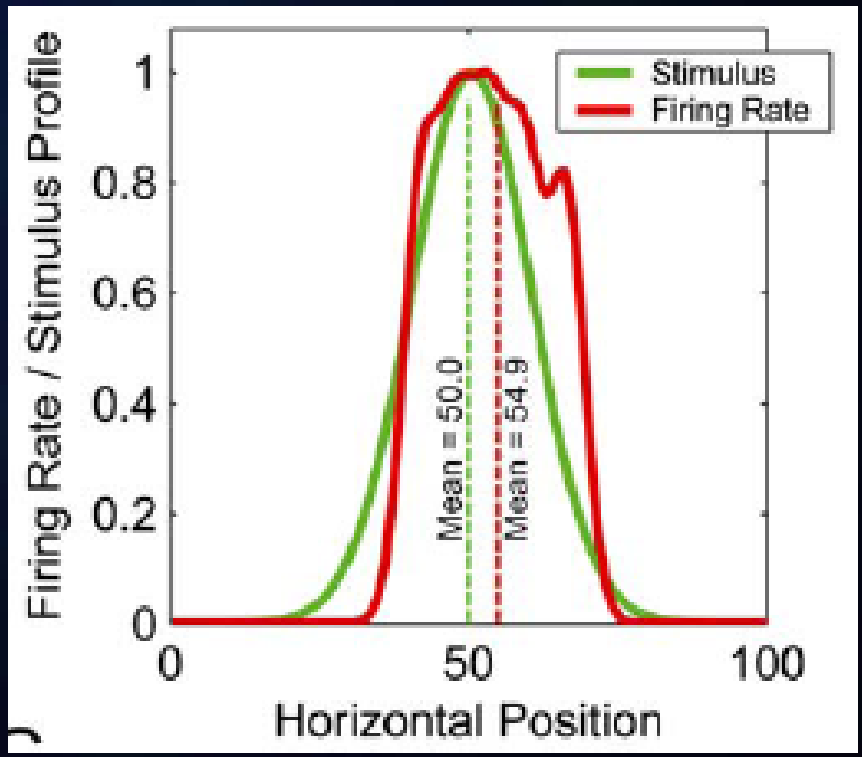
Gegenfurtner K (1999) Nature 398:291-292

Anticipation by Retina

- Network model:
  - 2-D network of Hodgkin-Huxley neurons
  - Lateral interactions – ***Mexican Hat*** function

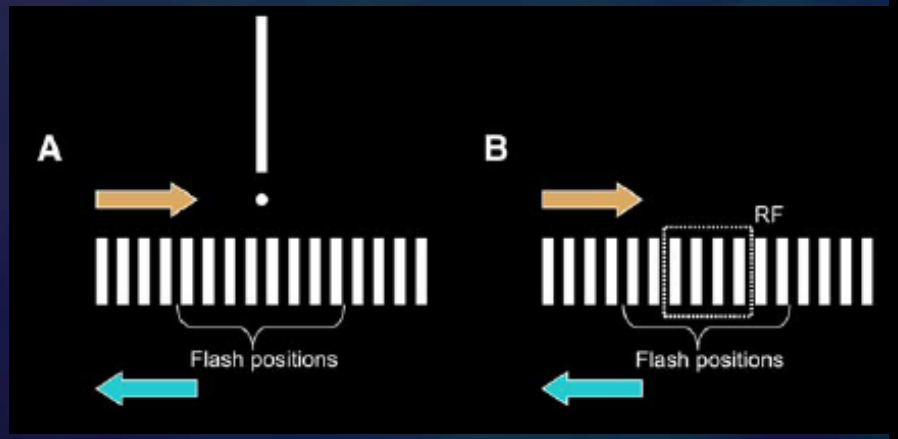


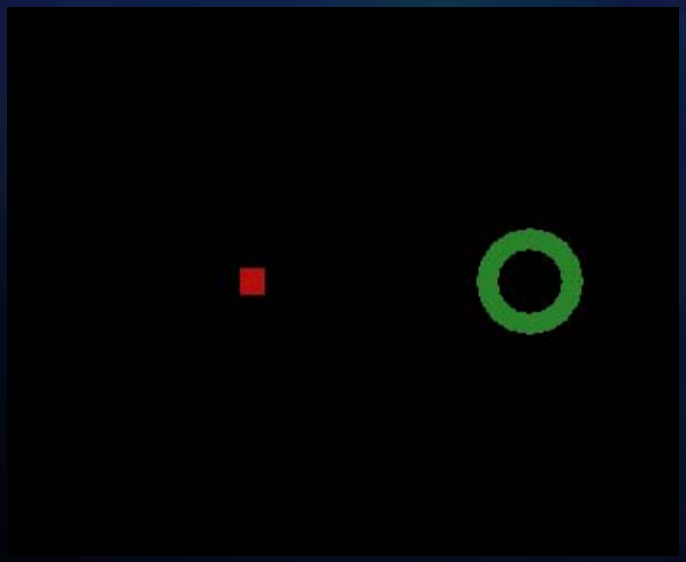


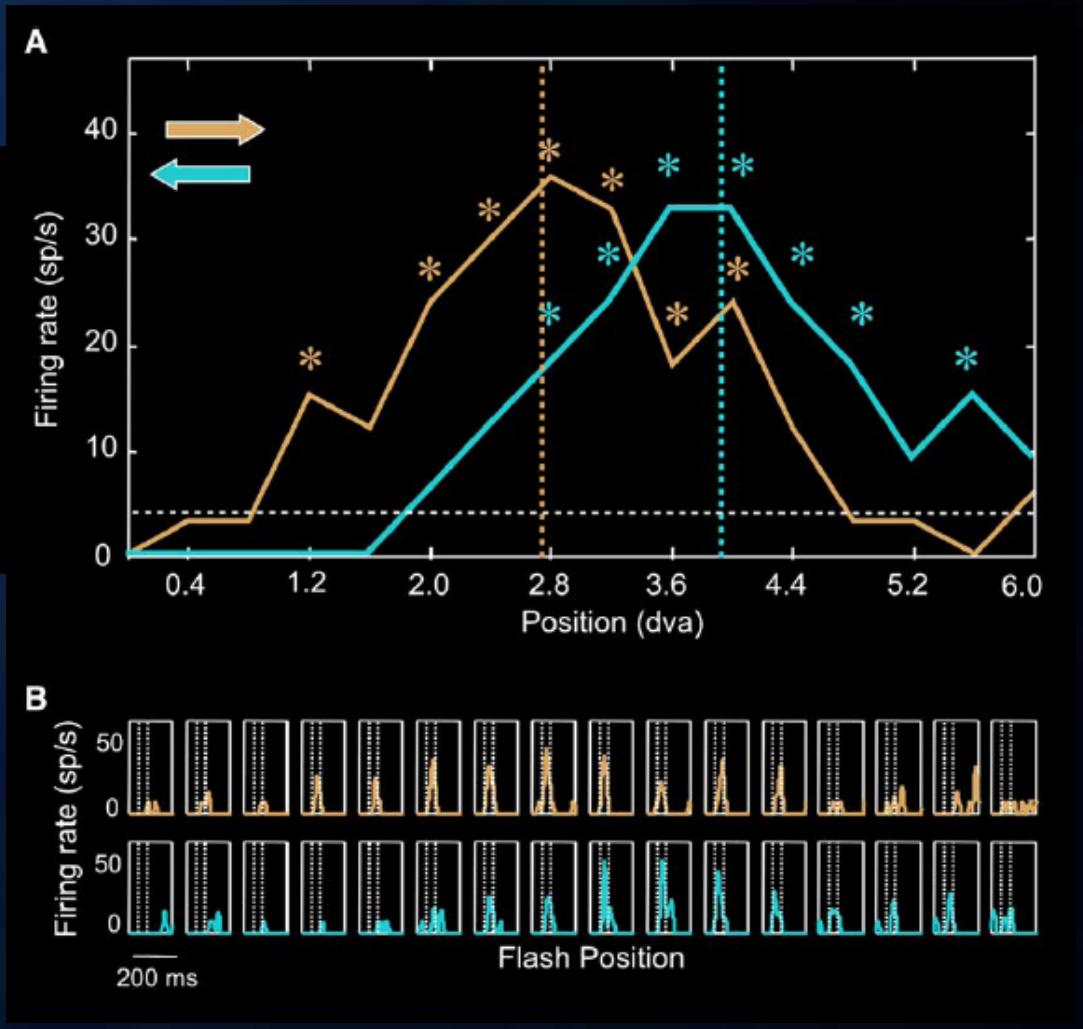


Ferrera VP, Barborica A. (2006) Neuron. 49:327-329

Anticipation in V4



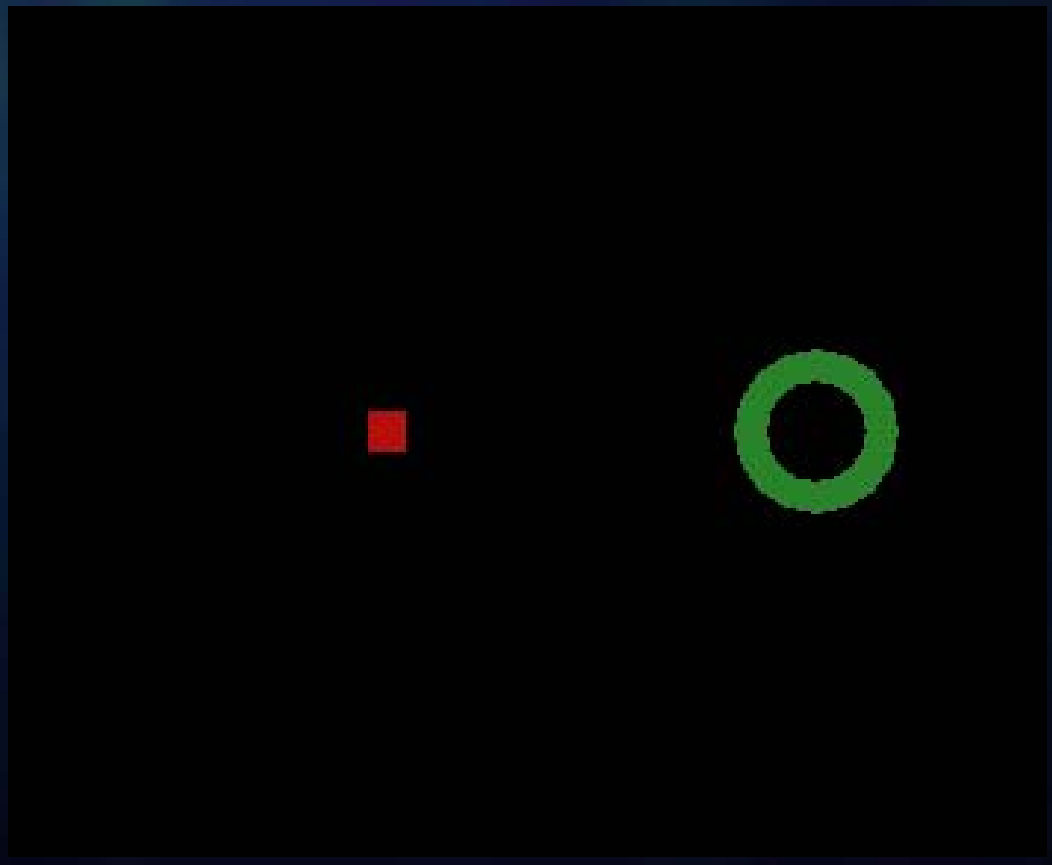




Sundberg KA, Fallah M, Reynolds JH. (2006) Neuron 49:447-457

Psychophysics vs Electrophysiology

- Unexpected finding:
  - In the terminal condition (motion terminated on flash presentation), the lag perceived by humans diminished very much, while the V4 responses showed no change.



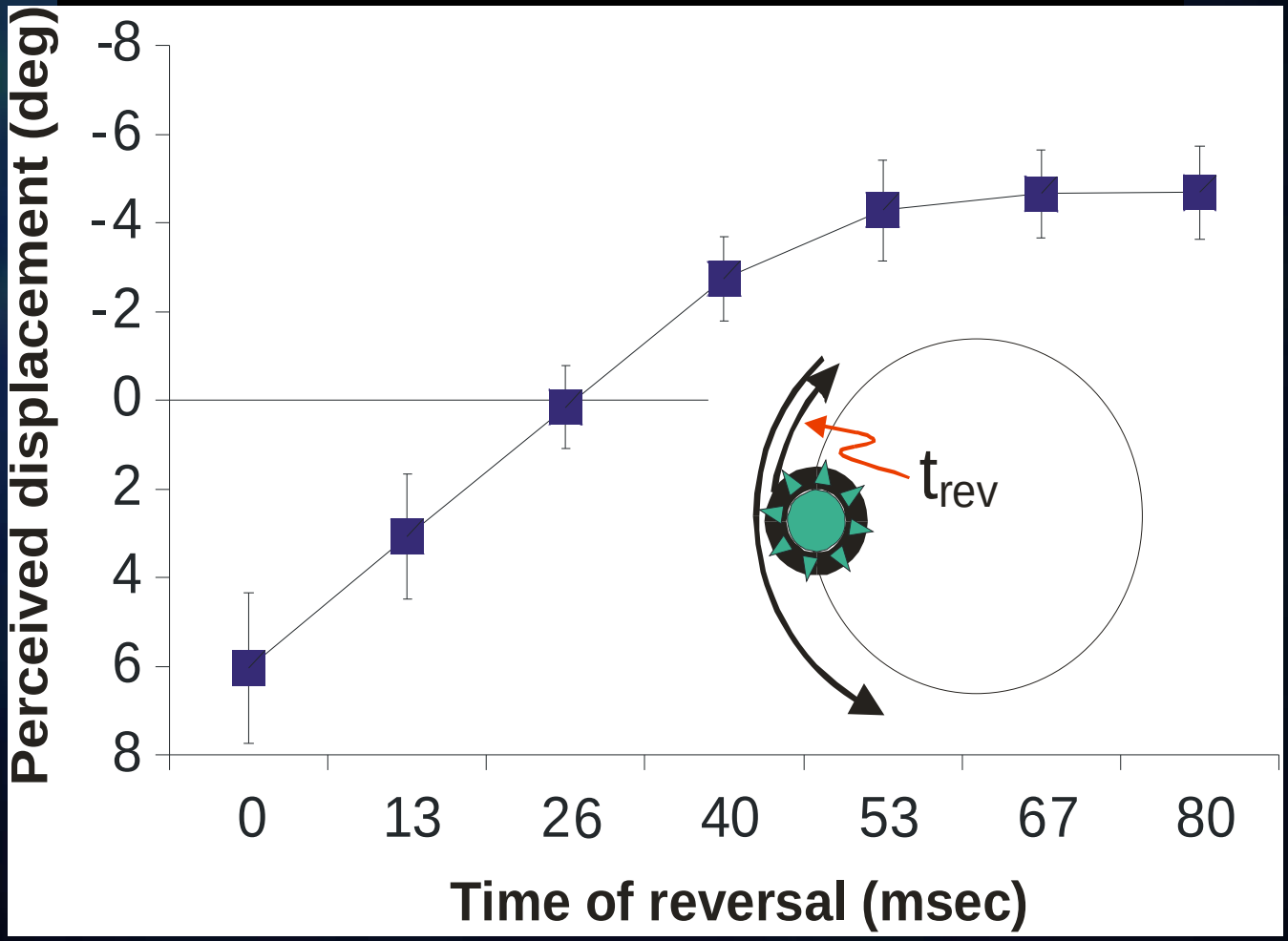
Psychophysics vs Electrophysiology

- Possible explanation for the discrepancy:
  - ***Multiple Drafts*** model of Dennett and Kinsbourne:
    - Consider, first, a Stalinesque mechanism: in the brain's editing room, located before consciousness, there is a delay, a loop of slack like the "tape delay" used in broadcasts of "live" programs which gives the censors in the control room a few seconds to bleep out obscenities before broadcasting the signal. *In the editing room,* first frame A, of the red spot, arrives, and then, when frame B, of the green spot, arrives, some interstitial frames (C and D) can be created and then spliced into the film (in the order A,C,D,B) on its way to projection in the theater of consciousness. By the time the "finished product" arrives at consciousness, it already has its illusory insertion
    - perceptual representations are considered to be a product of the brain's interpretive processes, not a direct reflection of the sequence of events making up those processes
- The multiple drafts model is consistent with the "postdiction" hypothesis (Eagleman & Sejnowski)

Dennett D and Kinsbourne M (1992) Time and the Observer. Behavioral and Brain Sciences, 15, 183-247

Postdiction

- It matters not only what happens ***before*** the flash, but what happens ***after*** the flash as well



Eagleman DM, Sejnowski TJ. (2000) Motion integration and postdiction in visual awareness. Science. 287:2036-8

Flash-lag

- Proposed models:
  - Motion extrapolation – Nijhawan 1994
    - The moving stimuli's position is extrapolated in space
  - Differential latency – Patel & Ogmen 1998, 2000
    - The moving and stationary stimuli follow different processing pathways having different latencies
  - Postdiction – Sejnowski & Eagleman 2000
    - The percept is the result of integrating both stationary and moving stimuli within a certain time window

Prediction

- More complex associations involving (pre)frontal lobes

Prediction: Frontal Eye Fields

Anatomical Projections From
Parietal Motion Areas
(Schall et al. 1995)

Dorsal Pathway:
Motion, Stereo
Visually-Guided Movement

FEF – posterior PFC:
Planning Eye Movements
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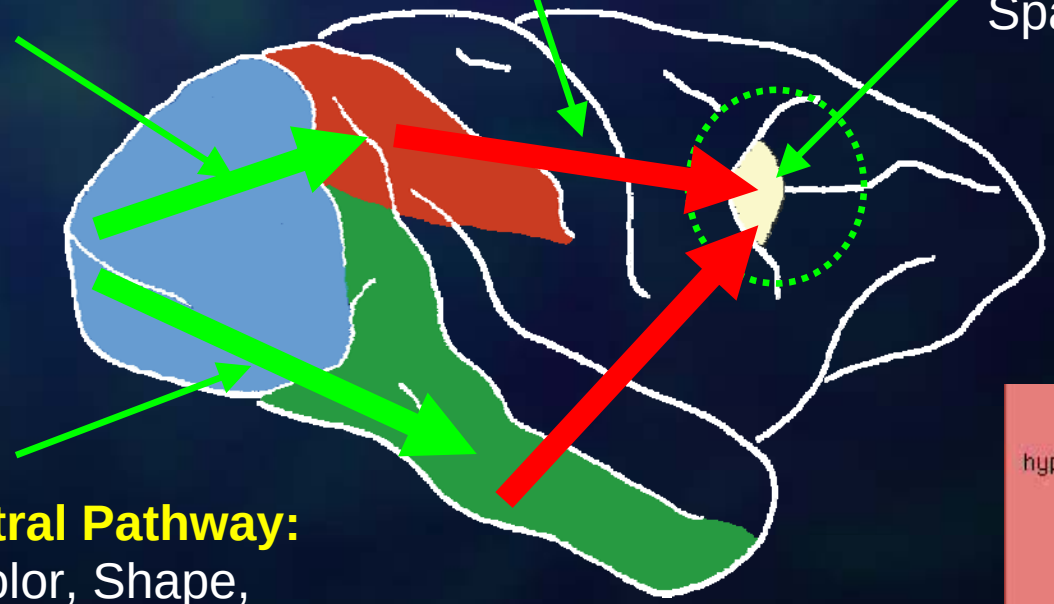
Spatial Memory



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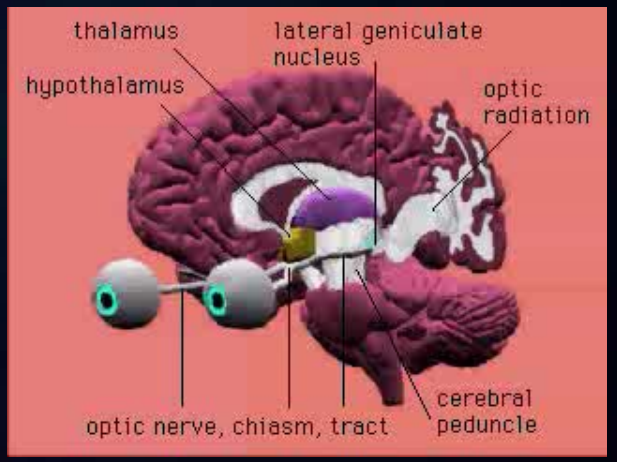
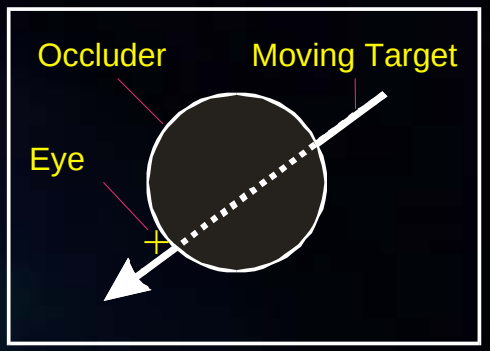


Motion Prediction



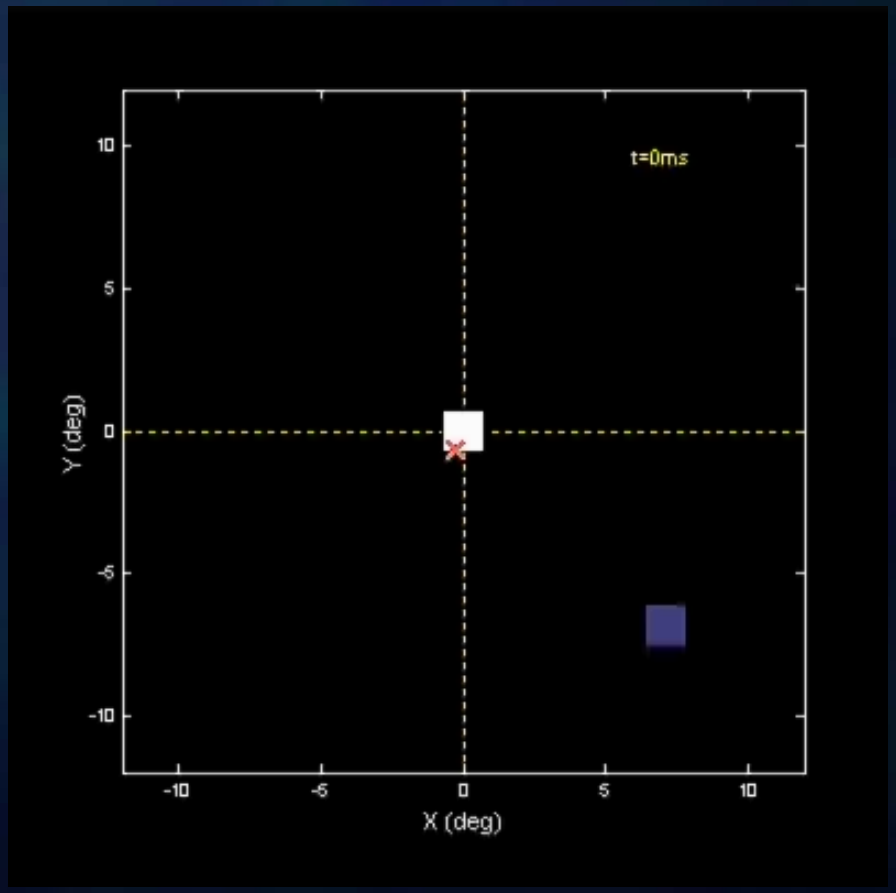
- We trained Macaque monkeys to perform a motion extrapolation task
  - Moving target rendered temporarily invisible
  - Monkeys are trained to execute saccades to the extrapolated location of the target
  - Saccades are performed while target is invisible, without any visual guidance, based on the target speed and direction information when last seen

Temporarily Invisible Objects

- Is there an internal representation of objects that are rendered temporarily invisible ?
- Is there the internal representation updated in a continuous manner ?

Motion Prediction Task

- Visible target
- Invisible target



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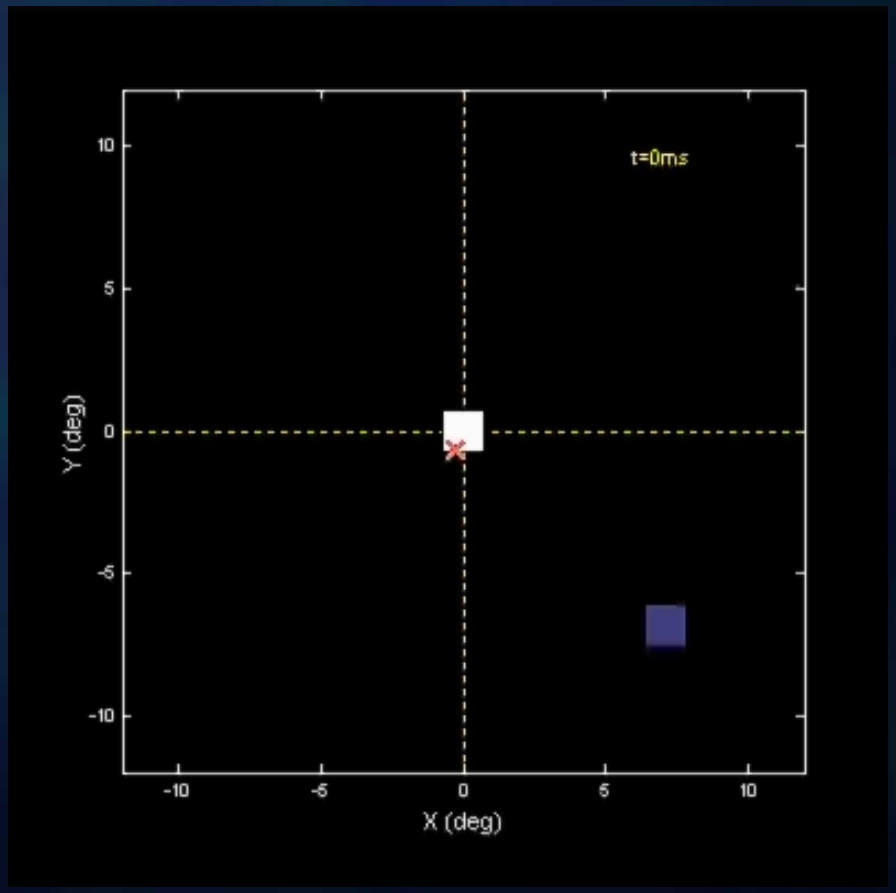
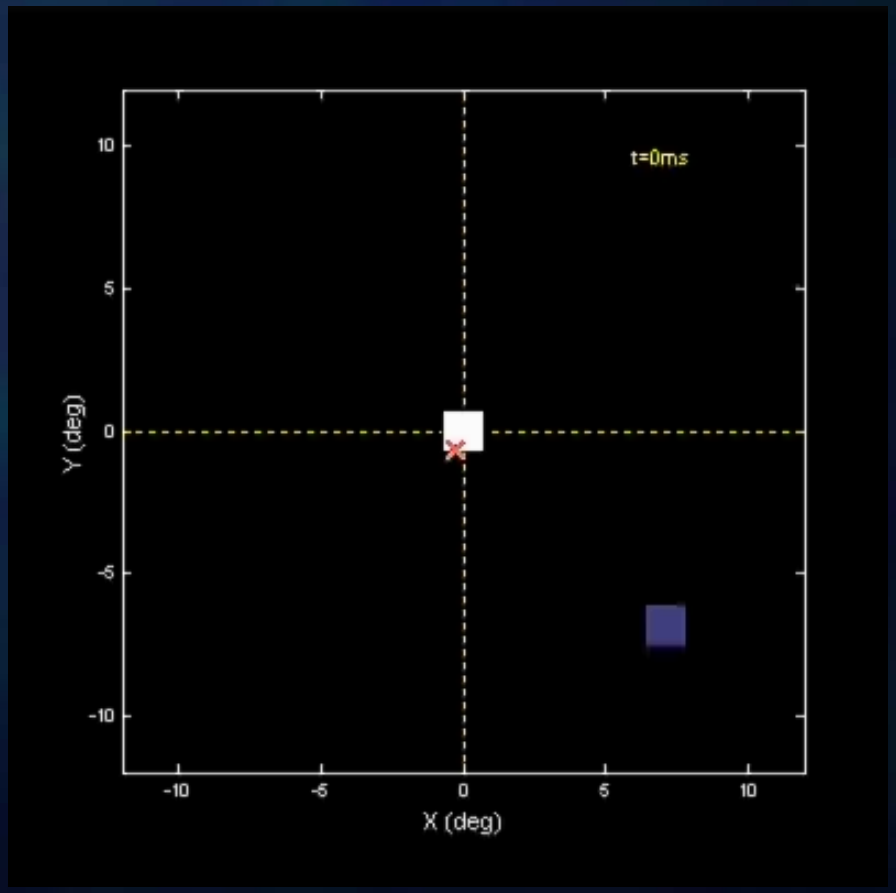


Motion Prediction Task



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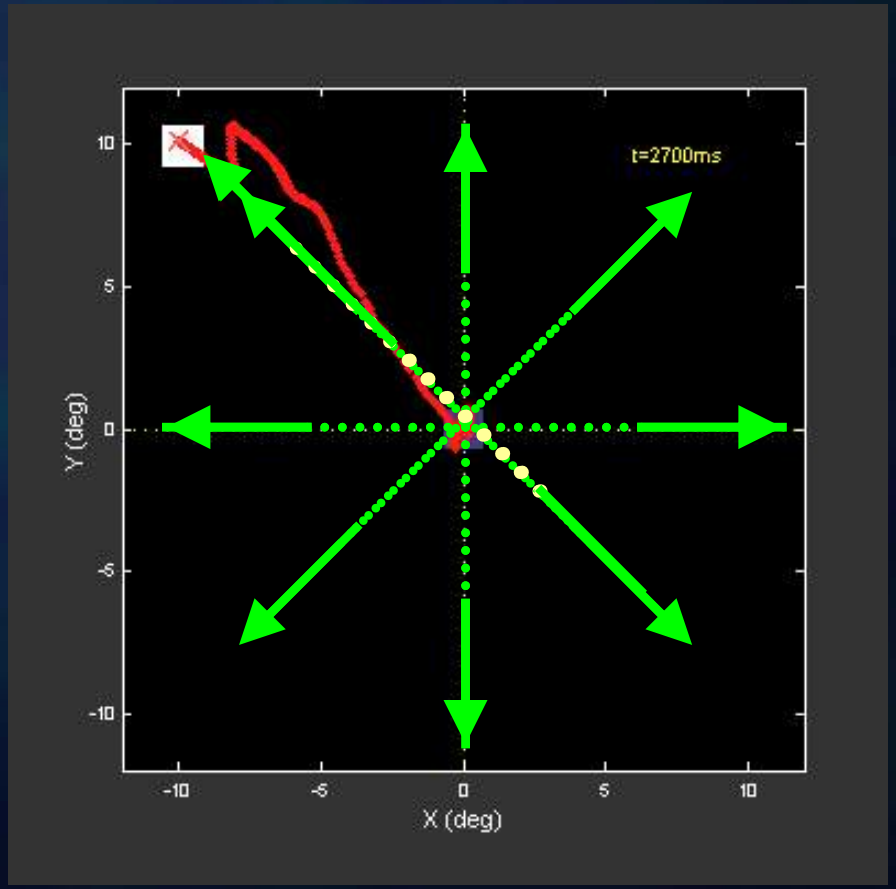
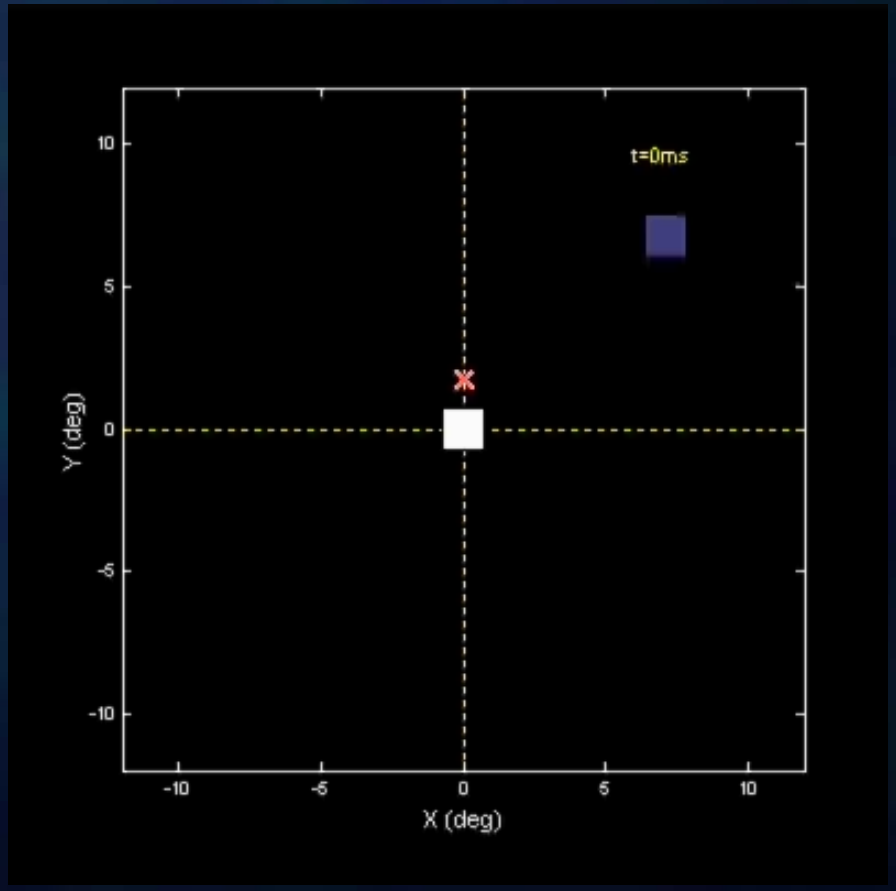


How does the monkey solve this task ?

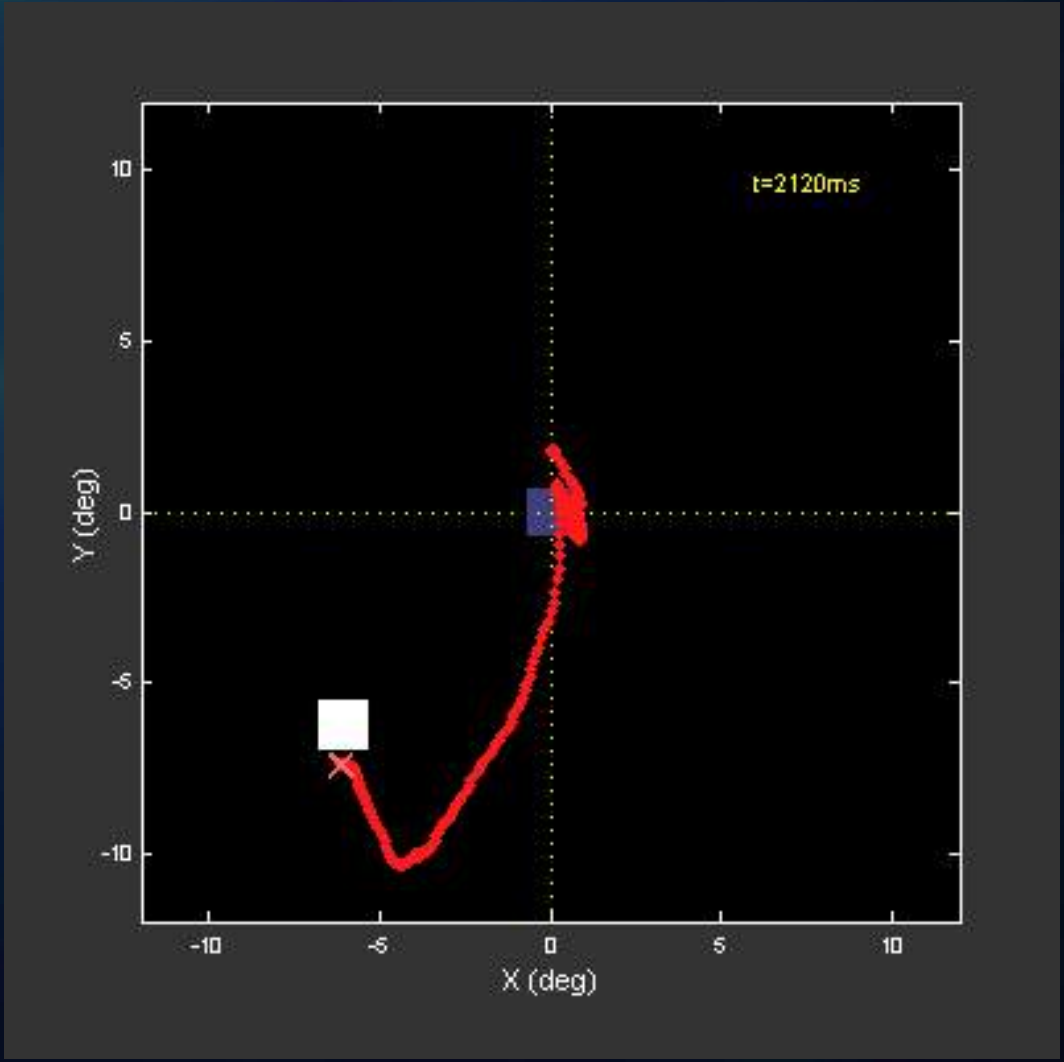
- Hypothesis 1: he updates a mental representation of a moving target

- Hypothesis 2: he learns a complex set of stimulus-response associations

Error correction without visual feedback



Error correction without visual feedback



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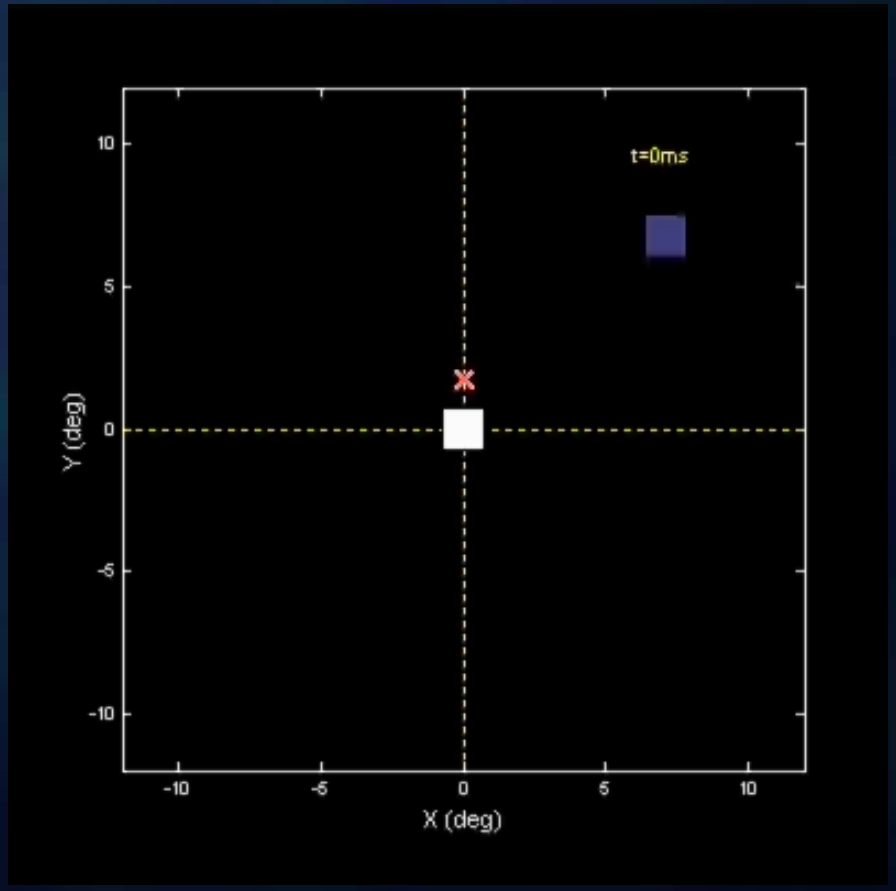

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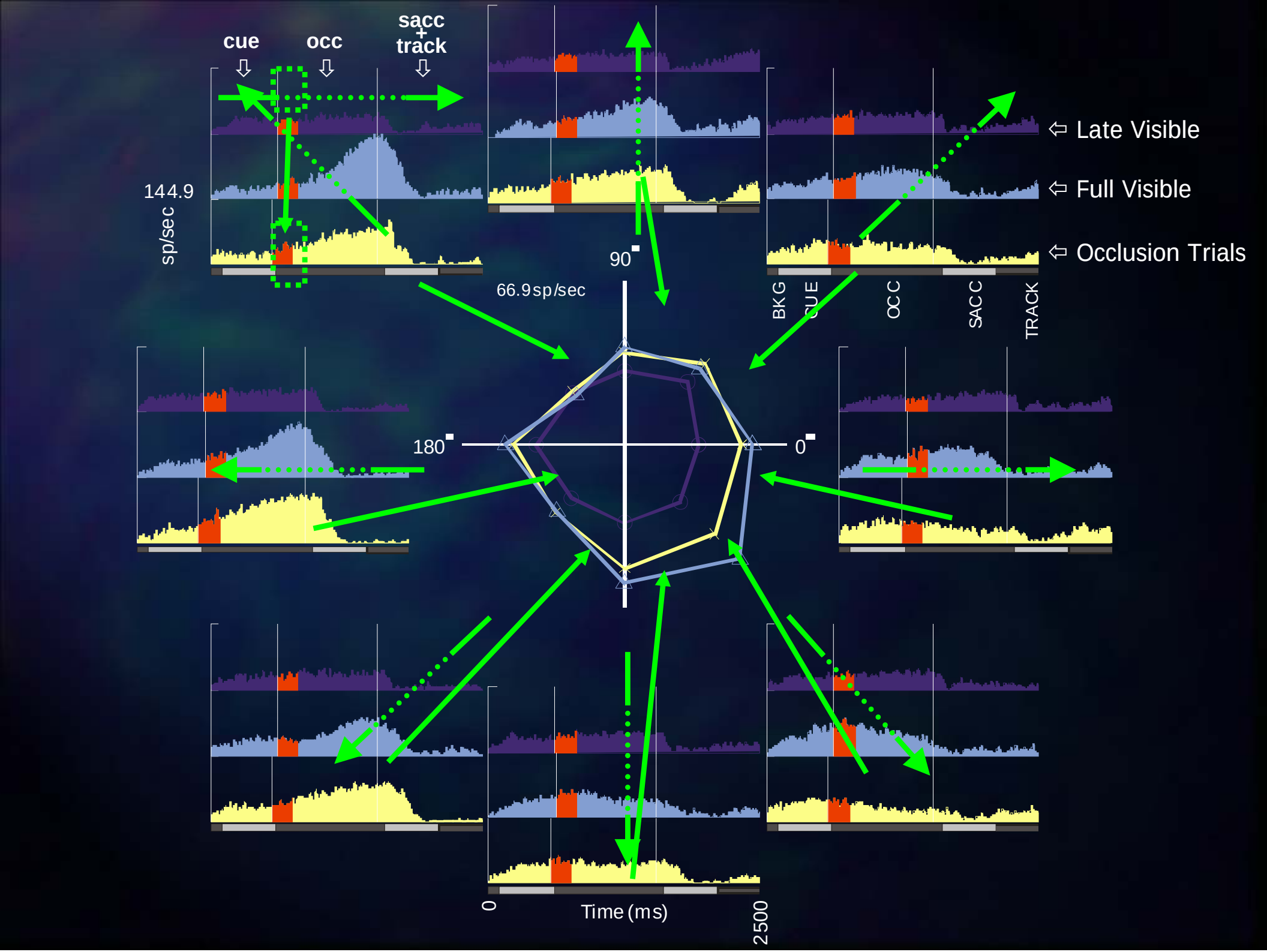
Probing Internal Representations

- I : Neural responses in FEF
- II : FEF electrical microstimulation


cue
occ
sacc + track
144.9
sp/sec
90
66.9sp/sec
180
0
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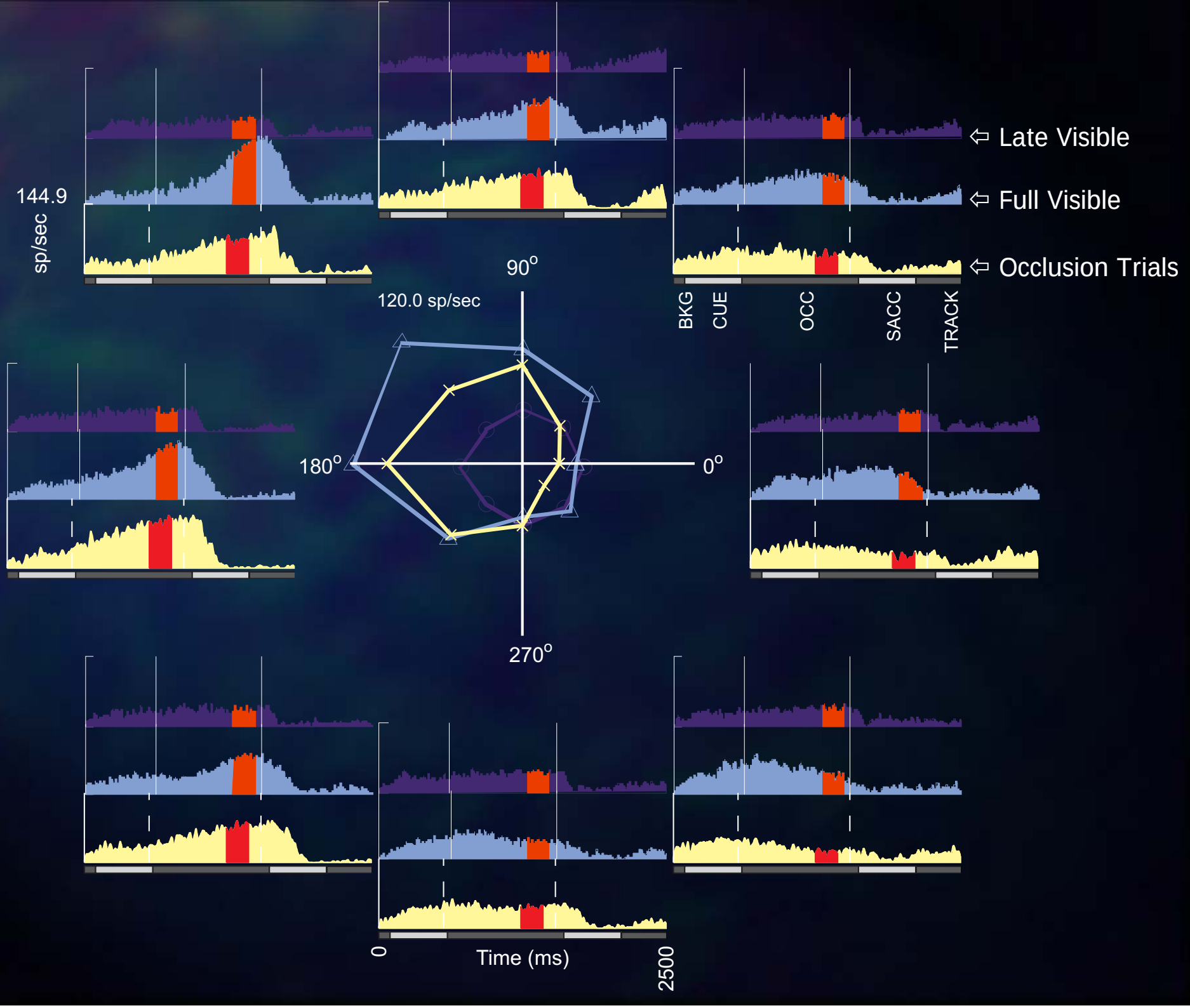
TRACK
⇦ Late Visible
⇦ Full Visible
⇦ Occlusion Trials
0
Time (ms)
2500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⇦ Full Visible
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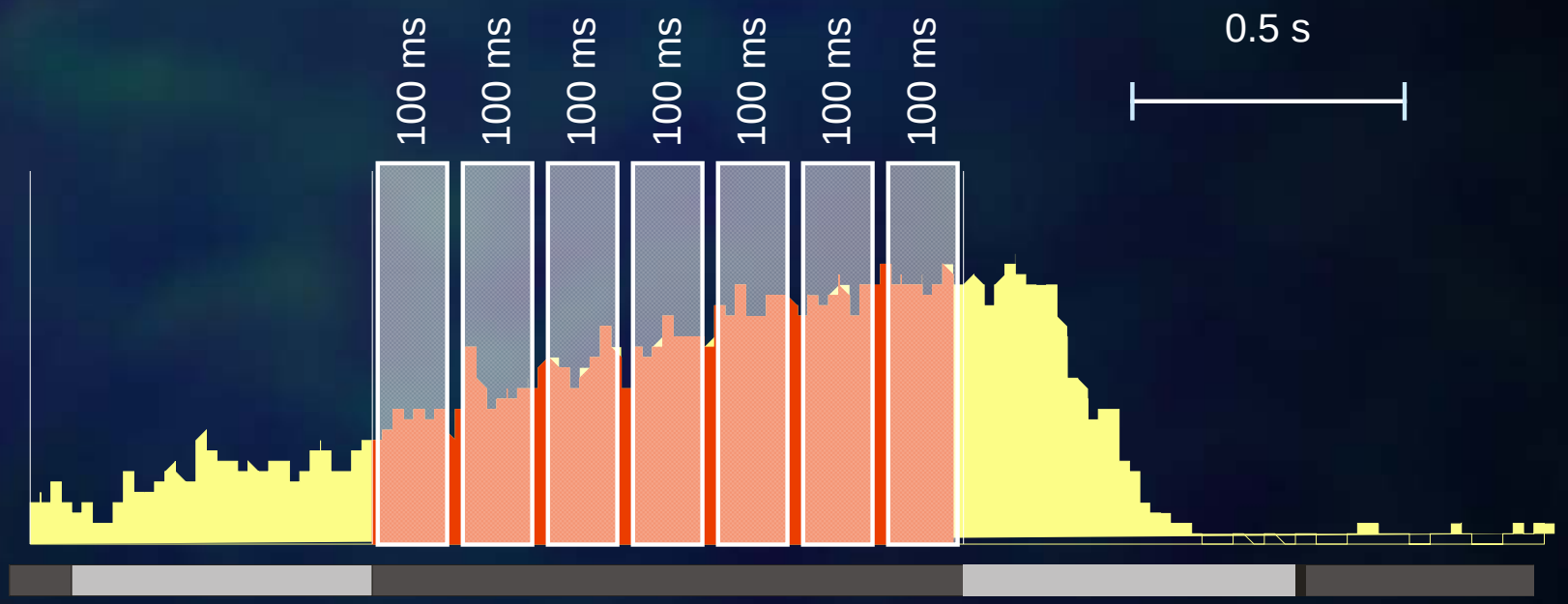
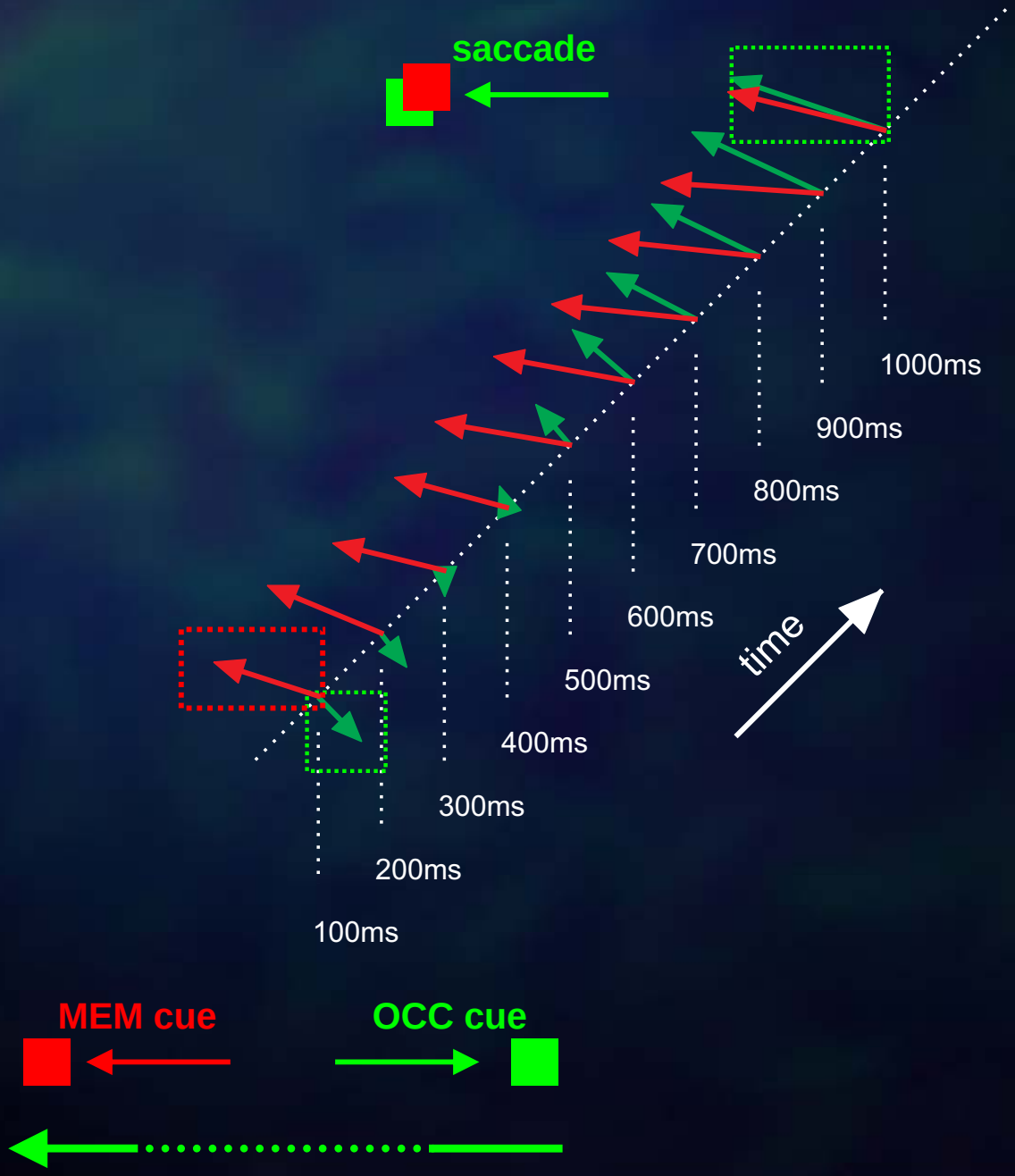
0
Time (ms)
2500

Tuning Dynamics

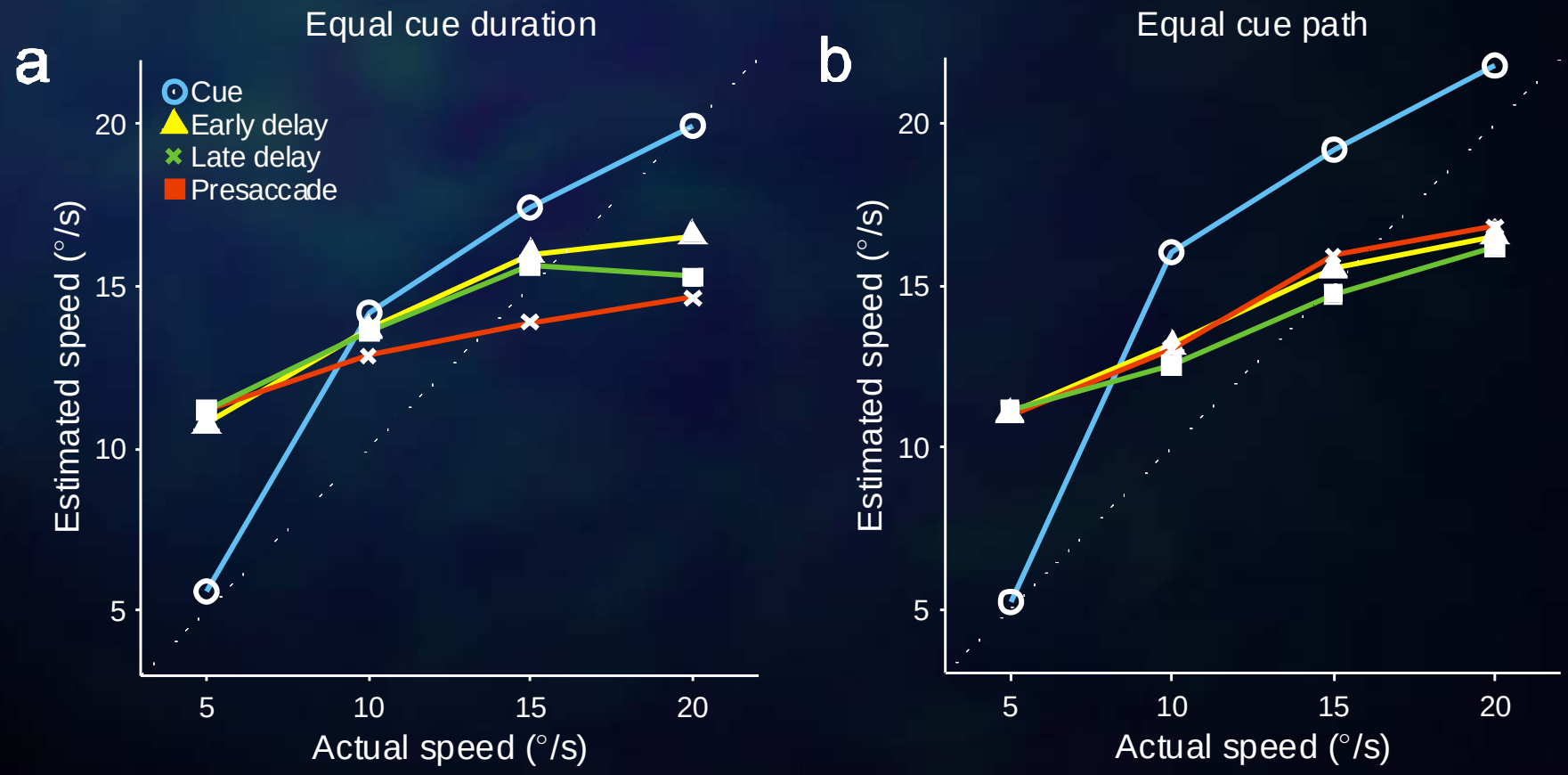


Response tuning rotation



Dynamical features encoding: Target Speed

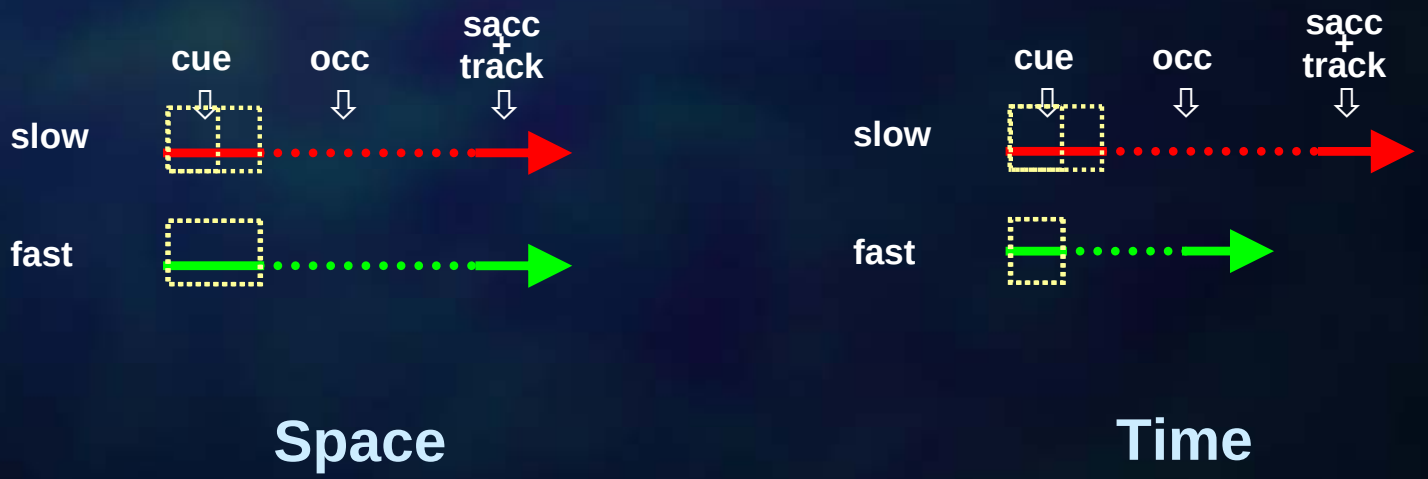
- Motion extrapolation with different target speeds
- Target speed can be reconstructed from neural responses



Barborica A, Ferrera VP. Nat Neurosci. 2003 Jan;6(1):66-74.

Response Intervals

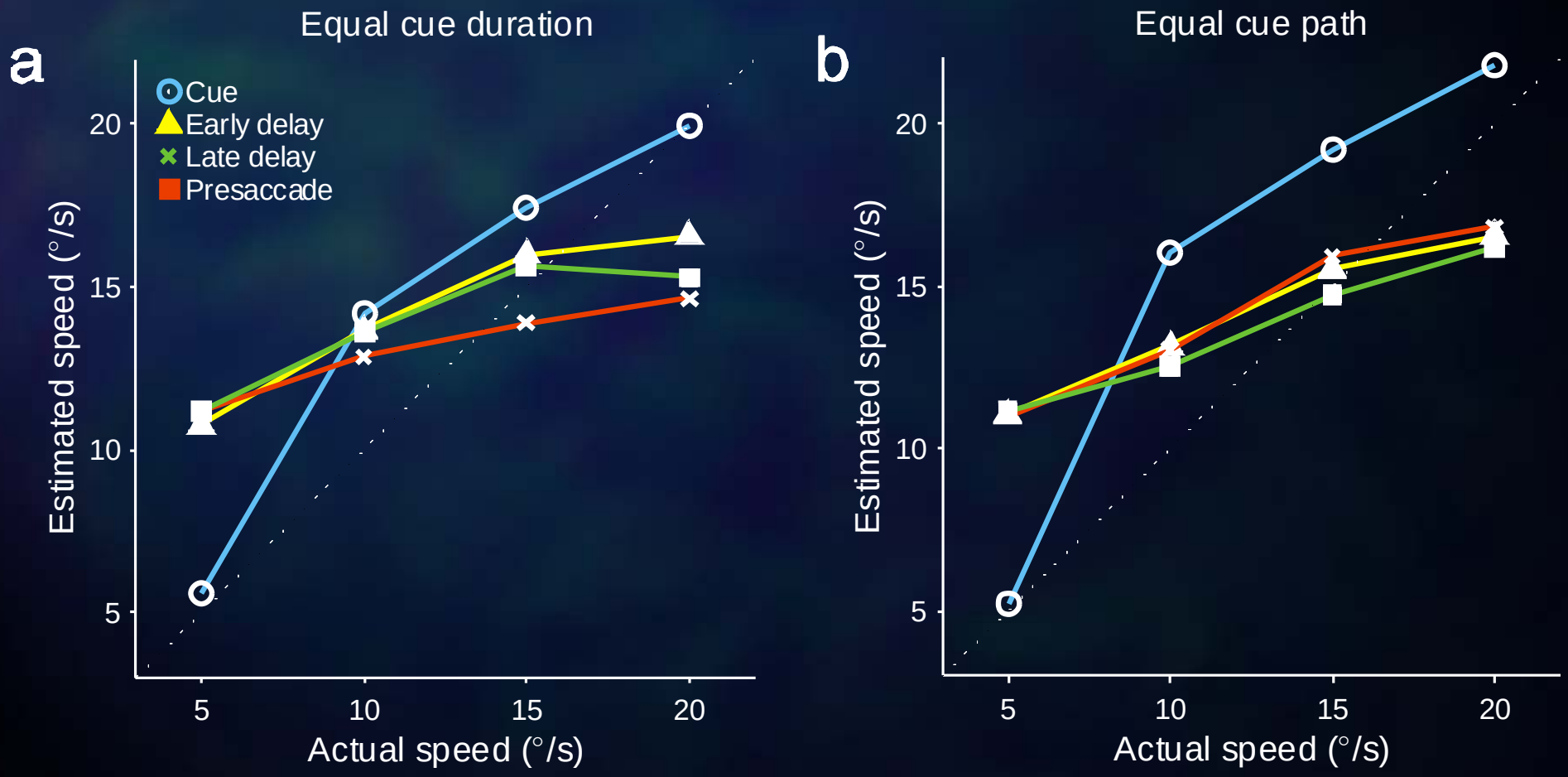
Different paths ⇔ Different durations



Space

Time

Encoding of Target Speed



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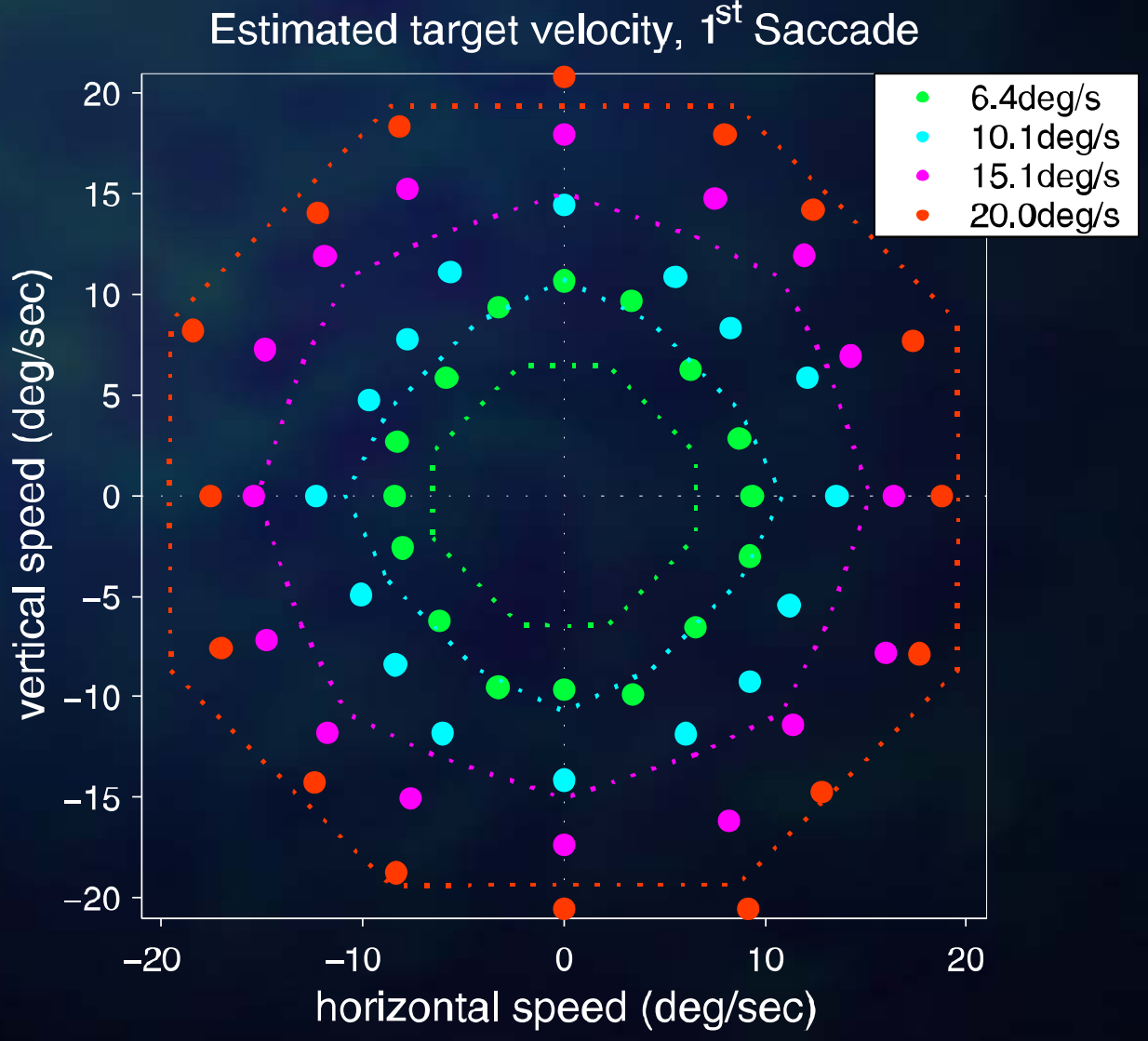
Estimated Target Speed Based On Saccade Amplitude



Probing Internal Representations II FEF Electrical Microstimulation

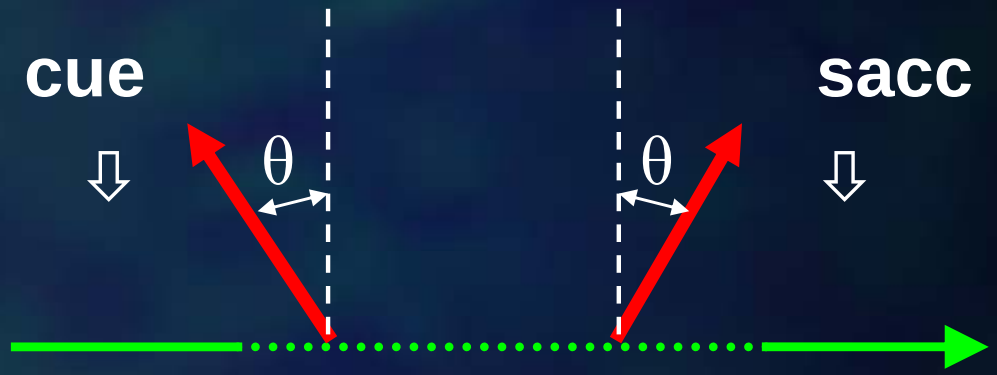
- Evokes spatially accurate eye movements
- Evoked movements are modified by visual cues, motor plan, and locus of attention (Kustov and Robinson 1996)
- ... Are EE saccades modified during covert tracking ?

Experiment

- We selected FEF sites where saccades were evoked by electrical stimulation* during a simple fixation task
- We arranged the target trajectory to be orthogonal to the direction of EE saccades during fixation
- We applied microstimulation at random times during the occlusion interval
- We analyzed the deviation of the EE saccade vectors.

Stimulation: biphasic pulses, t=70ms, f=350Hz, i<=100microamps

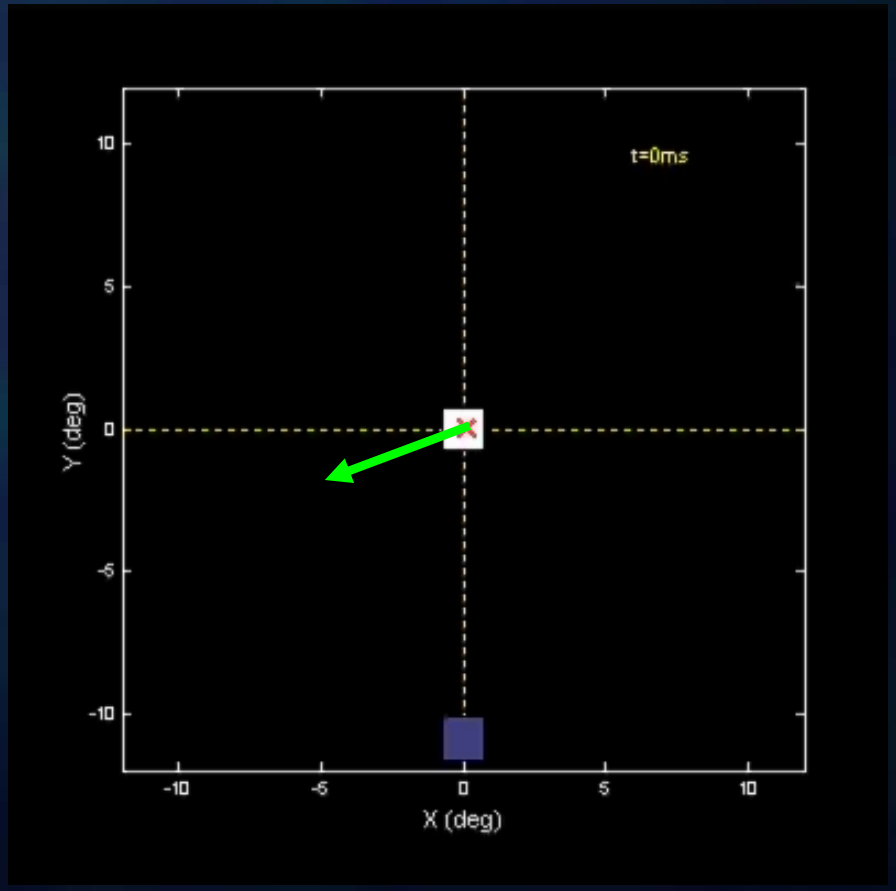
Saccade Deviation



When electrical stimulation was applied:

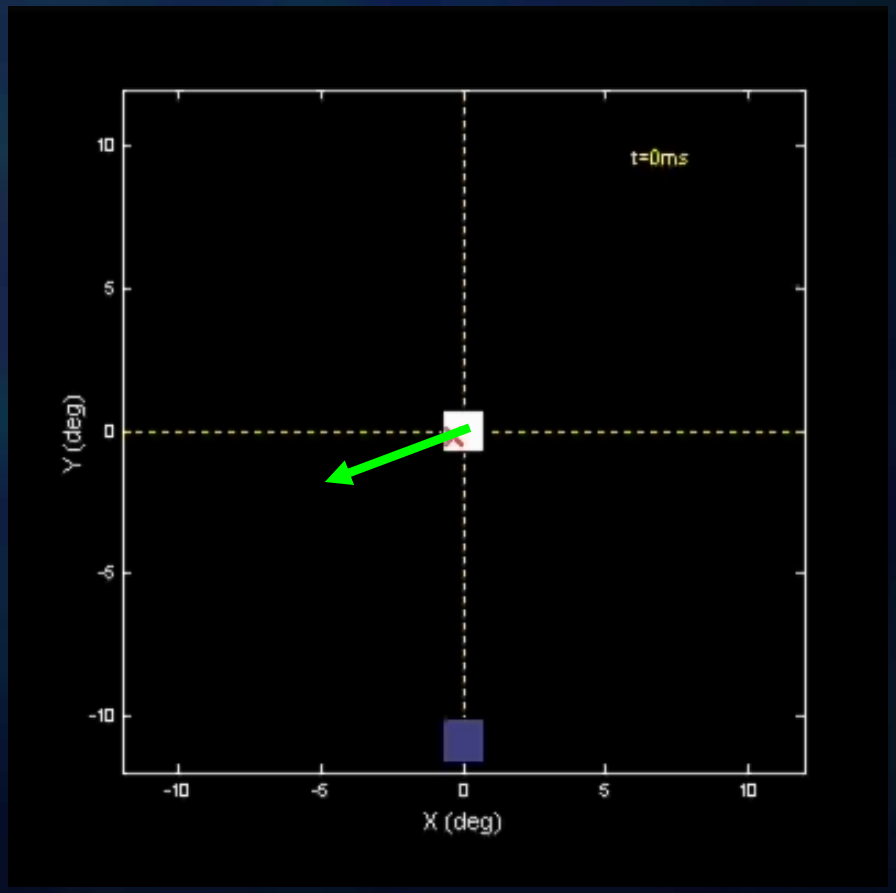
- early during the occlusion interval:
  - EE saccades were deflected towards the cue
- late during the occlusion interval:
  - EE saccades were deflected towards the planned eye movements

Early Stimulation

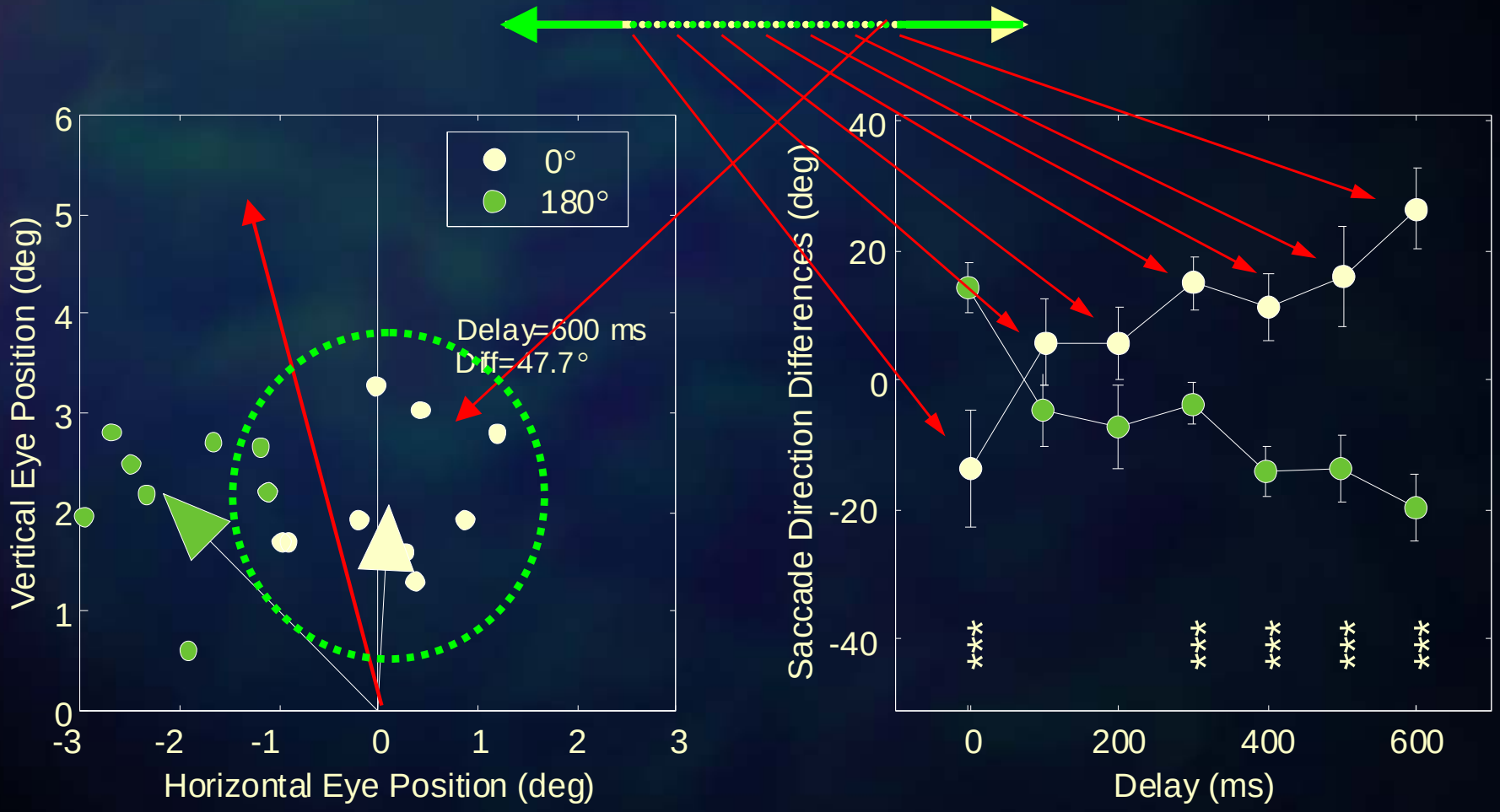


Stimulation during fixation with no moving target: average amplitude **5.2** deg, direction **193** deg.

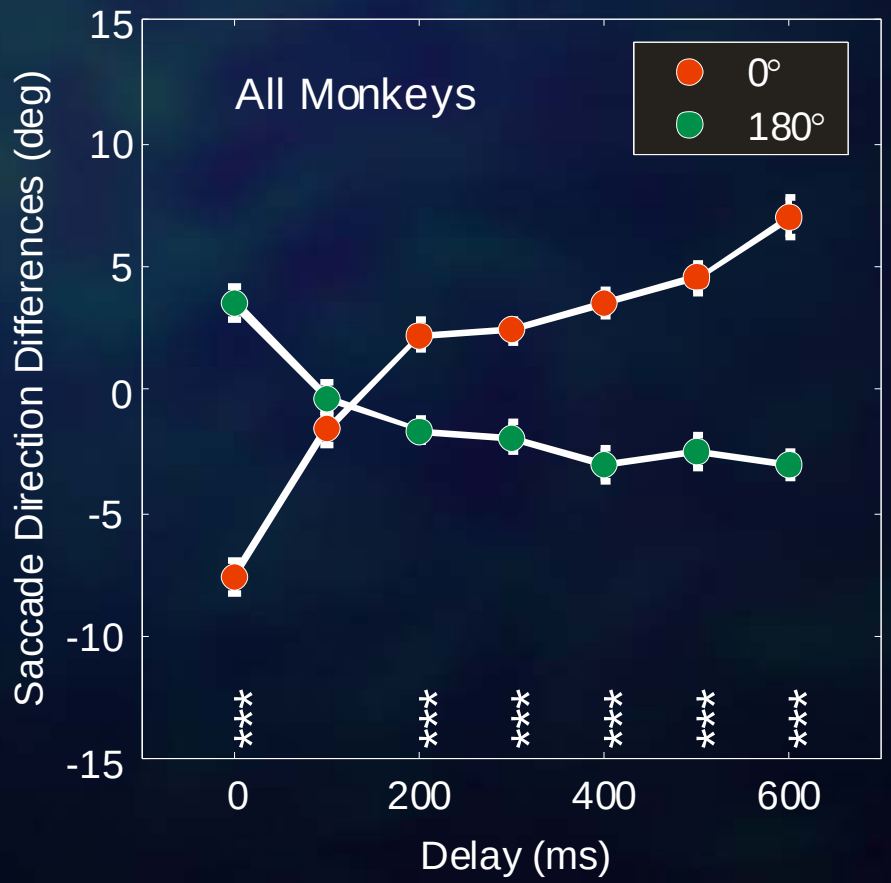
Late Stimulation



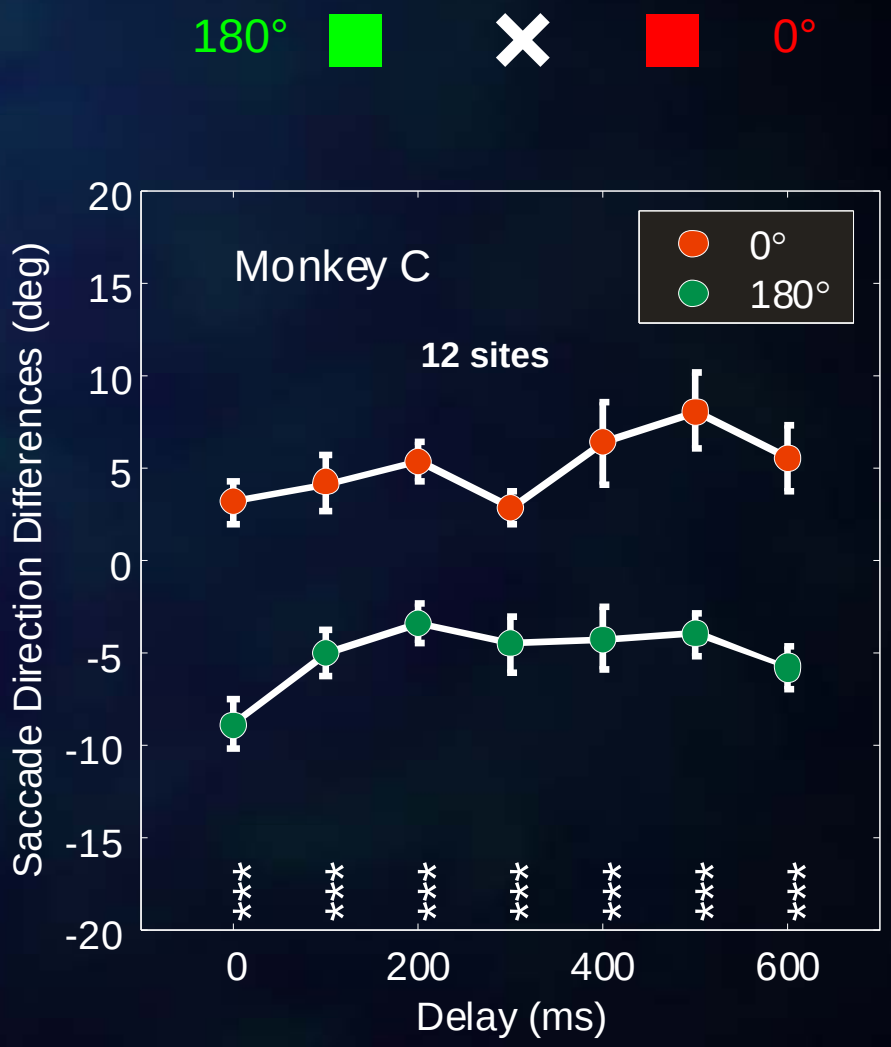
FEF stimulation site



All 110 sites / 2 monkeys



Spatial Memory Task



- No target motion
- Cue and saccade have same location

Dynamic update

- To program saccades to invisible targets different strategies may be used:
  - Static: wait for the GO signal, then combine the available information to execute saccade
  - Dynamic: requiring a continuous update of an internal target representation, then make a catch-up saccade to this mental target

Probing Internal Representations

Conclusions

- FEF responses – the population vector rotation and speed encoding – are consistent with the maintenance of an internal representation of an invisible target hypothesis
- FEF microstimulation may be used to probe internal object representations
- Electrically evoked saccades are modified during covert tracking as if there is a sliding attentional window
- The saccade deviation is quasi-linear, following the constant motion of the invisible target. This suggests that there is a continuous update of an internal representation.

Conclusions

- Anticipation and prediction take place at multiple levels of the visual processing stream
- Simple anticipation starts at the receptor level
- Complex predictions involve higher order processing areas, like FEF

Acknowledgements

- Vincent Ferrera – Columbia Unversity
- Ioan Opris
- Gil Case
- Puiu Balan
- Andrea Rocca
- Jean Willi
- Albert Banta