SACCADIC SYSTEM RHYTHMICITY ACCOUNTS FOR BOTH ATTENTIONAL CAPTURE AND INHIBITION OF RETURN IN ATTENTIONAL CUEING

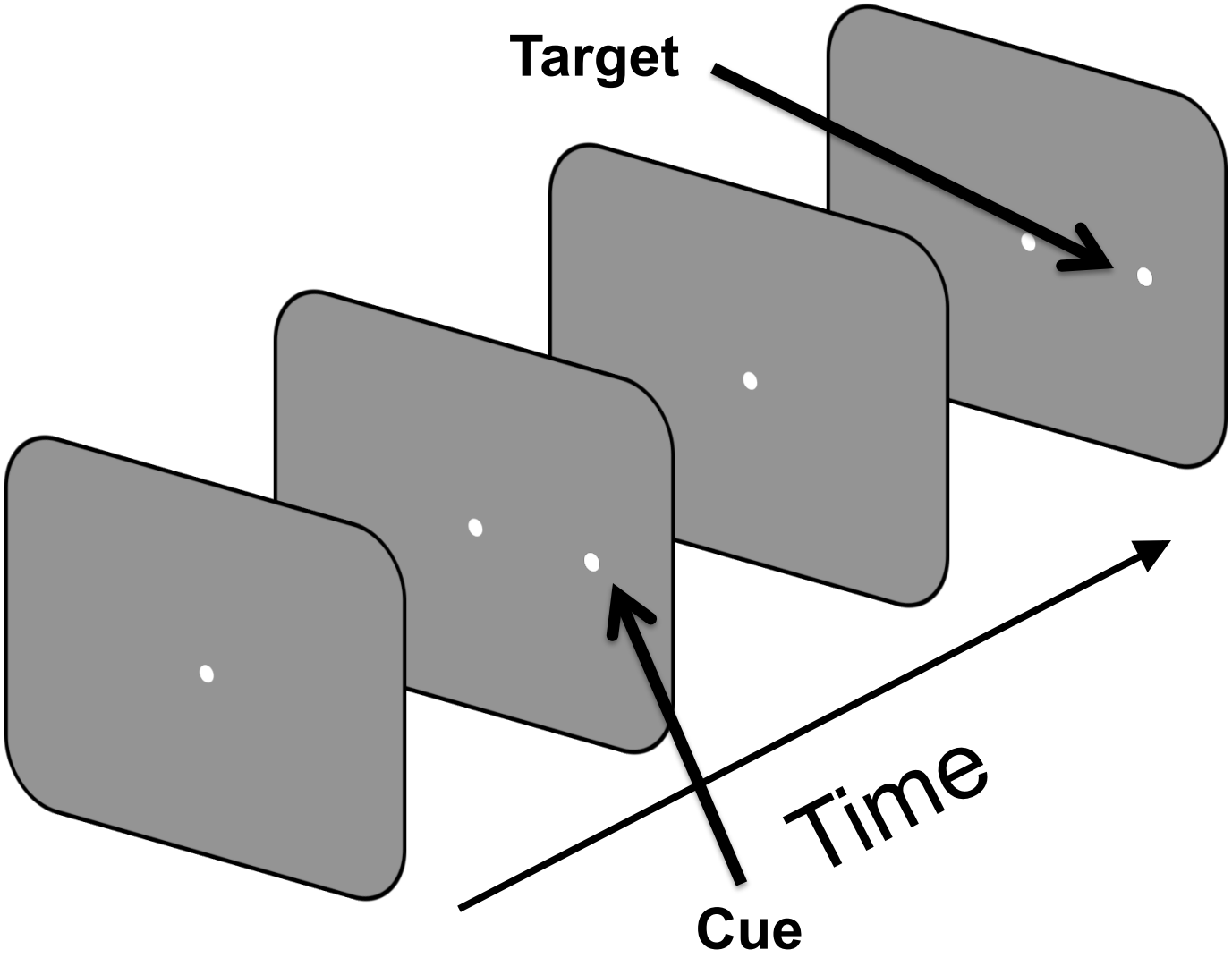
Ziad M. Hafed & Xiaoguang Tian

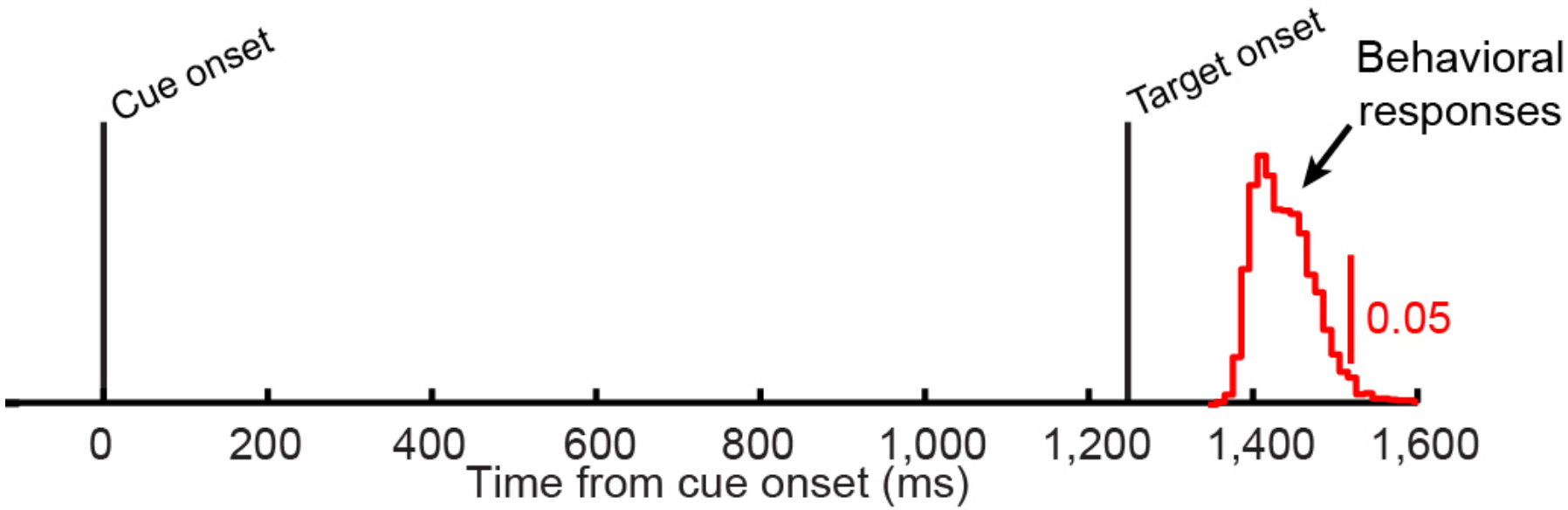
Physiology of Active Vision Lab

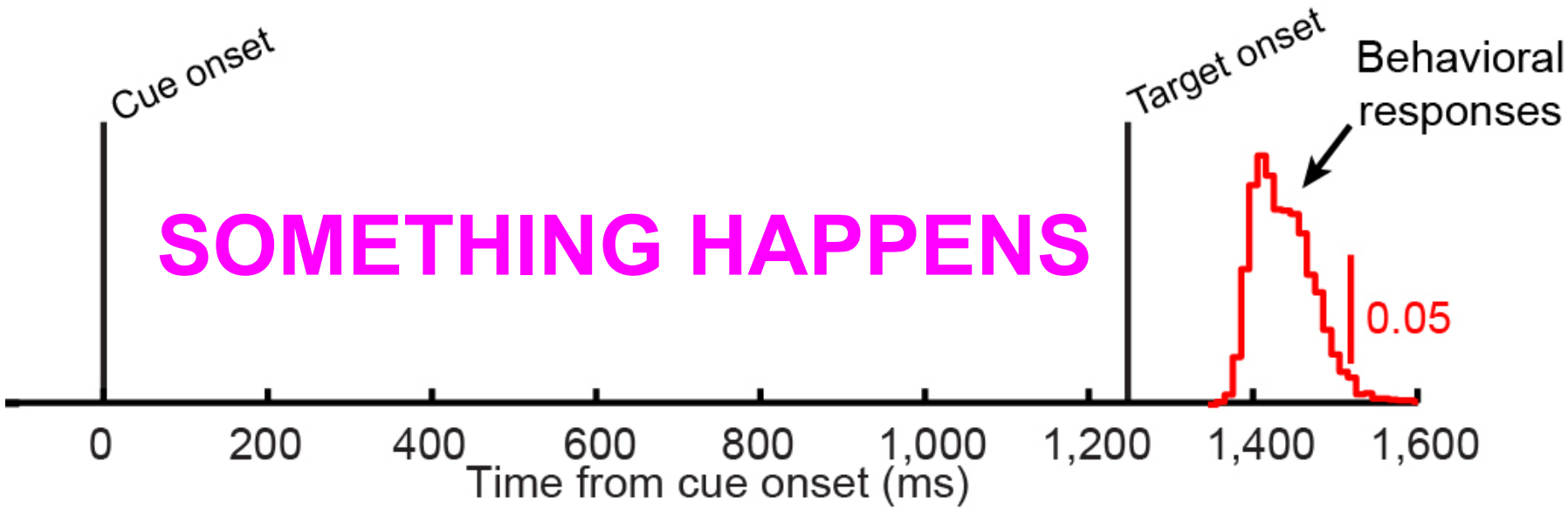
CIN
Werner Reichardt
Centre for Integrative Neuroscience

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

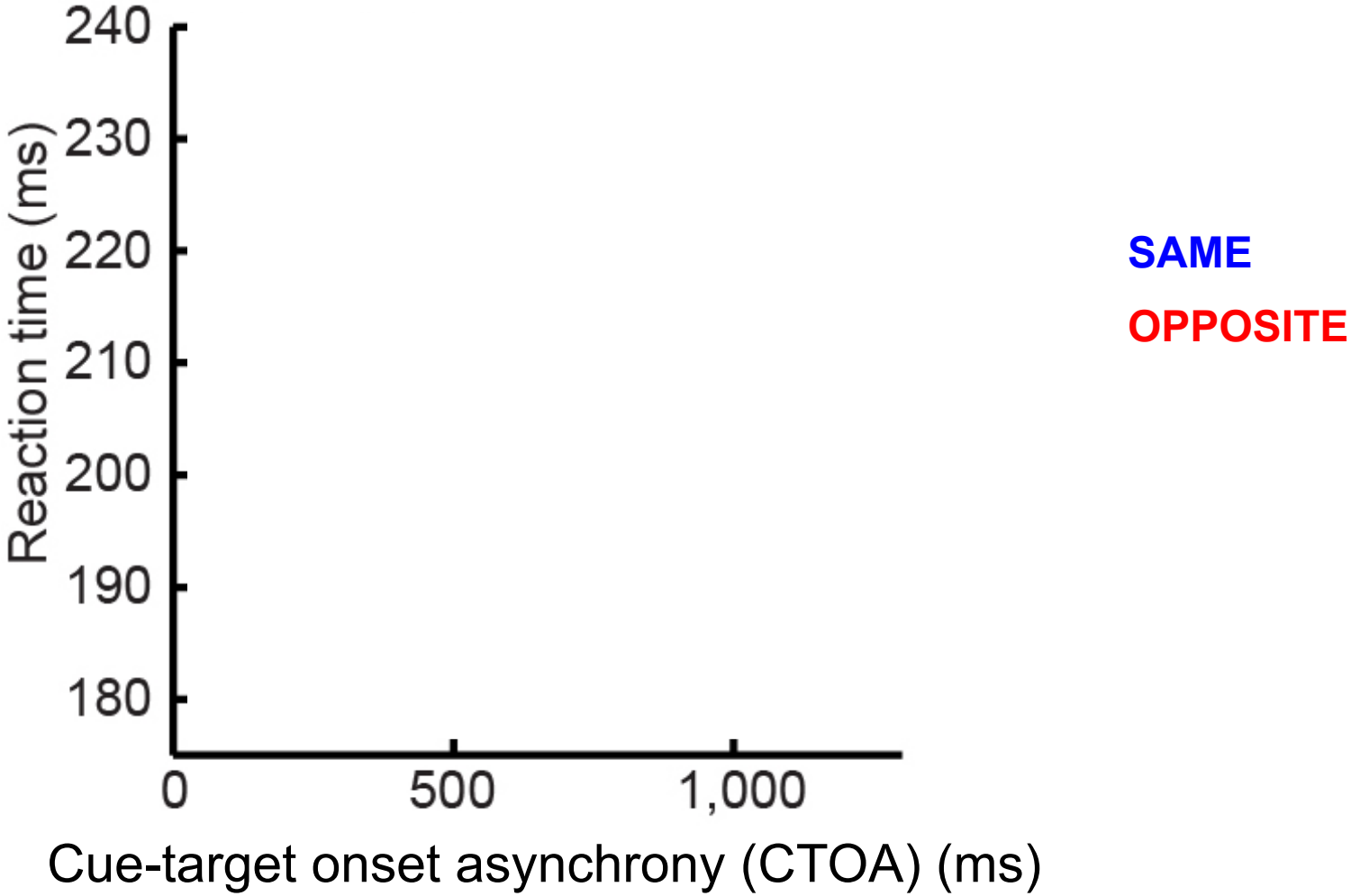
The Posner cueing paradigm



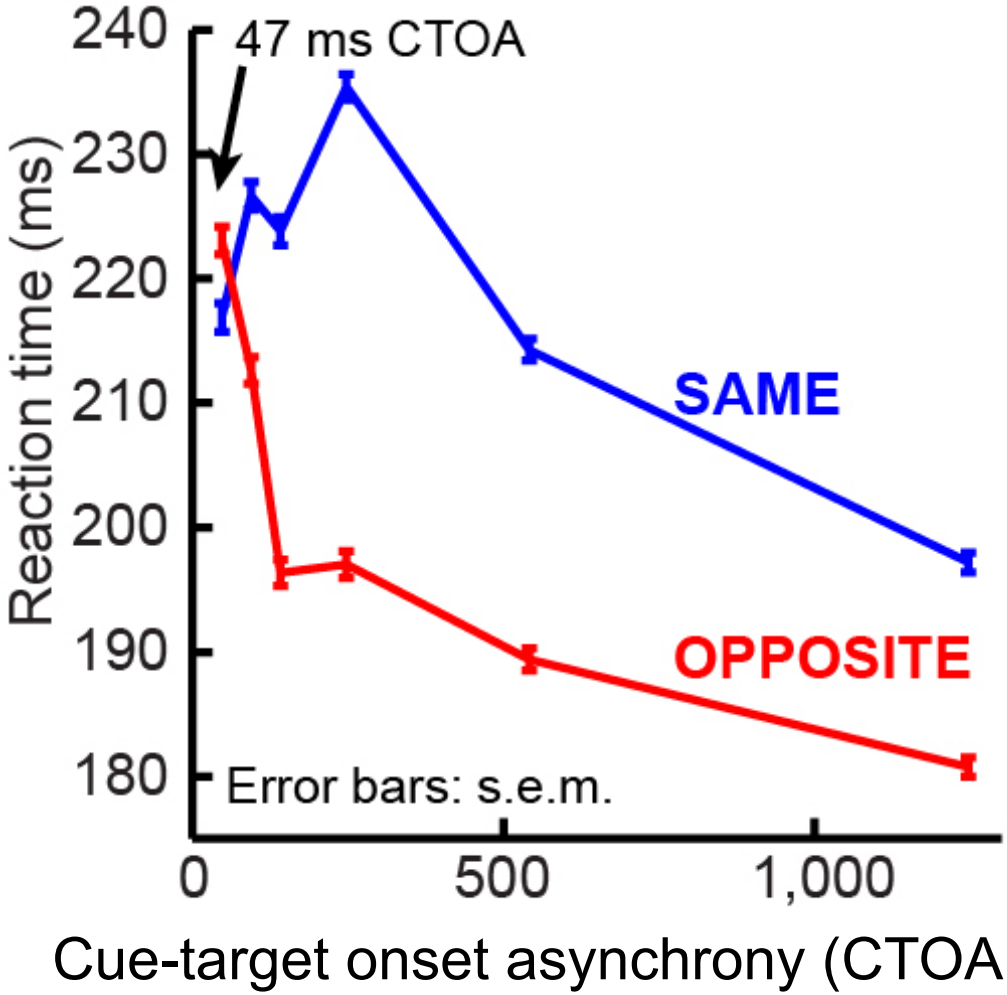

Cue onset
Target onset
Behavioral responses
0.05
0
200
400
600
800
1,000
1,200
1,400
1,600
Time from cue onset (ms)


Cue onset
Target onset
Behavioral responses
SOMETHING HAPPENS
0.05
0
200
400
600
800
1,000
1,200
1,400
1,600
Time from cue onset (ms)

Performance during Posner cueing



Performance during Posner cueing



SAME

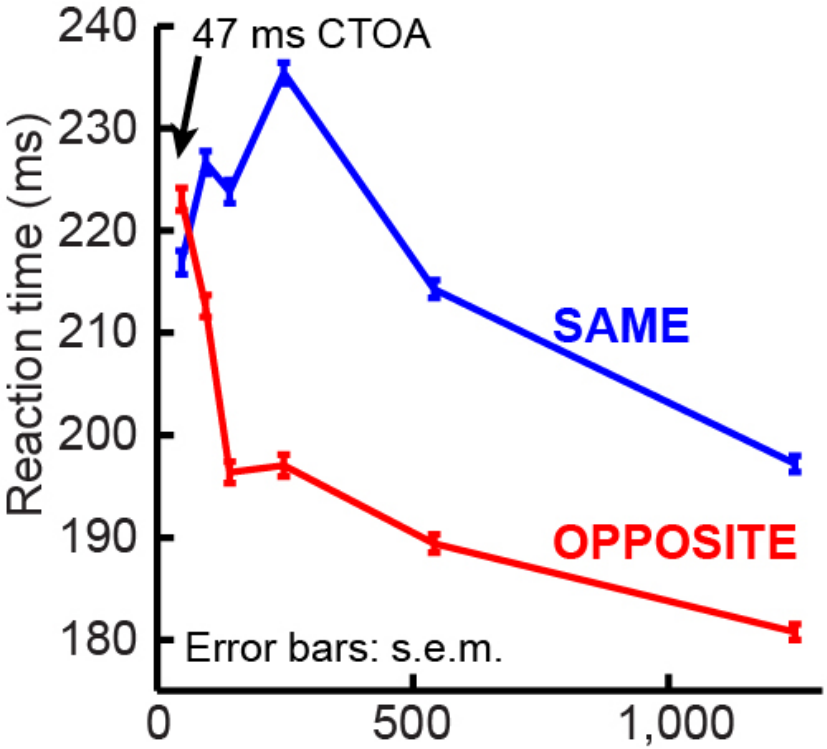
OPPOSITE

Cue onset:

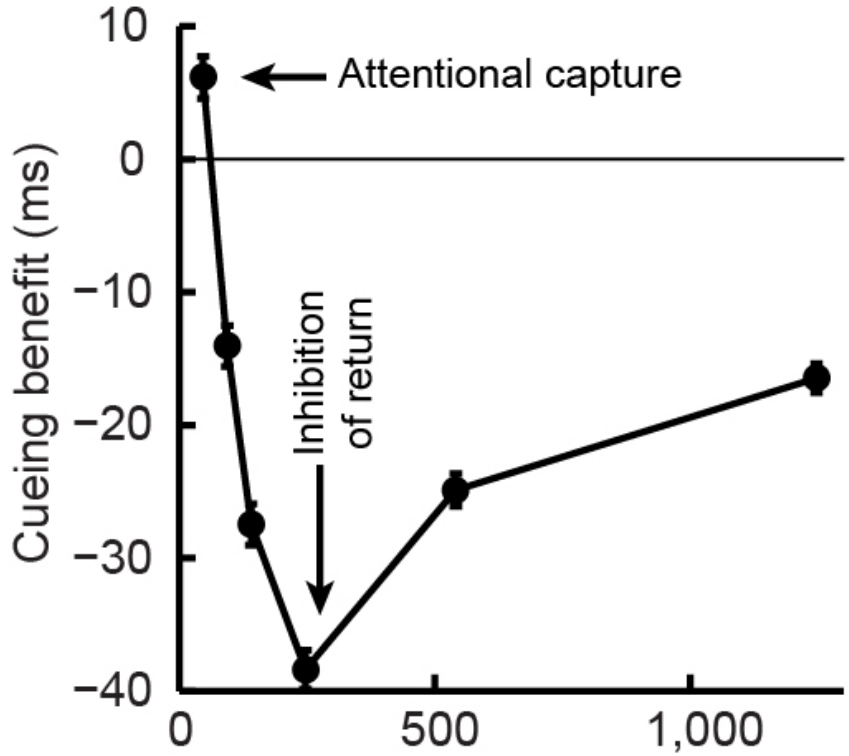
→ attentional capture

→ inhibition of return

Absolute performance

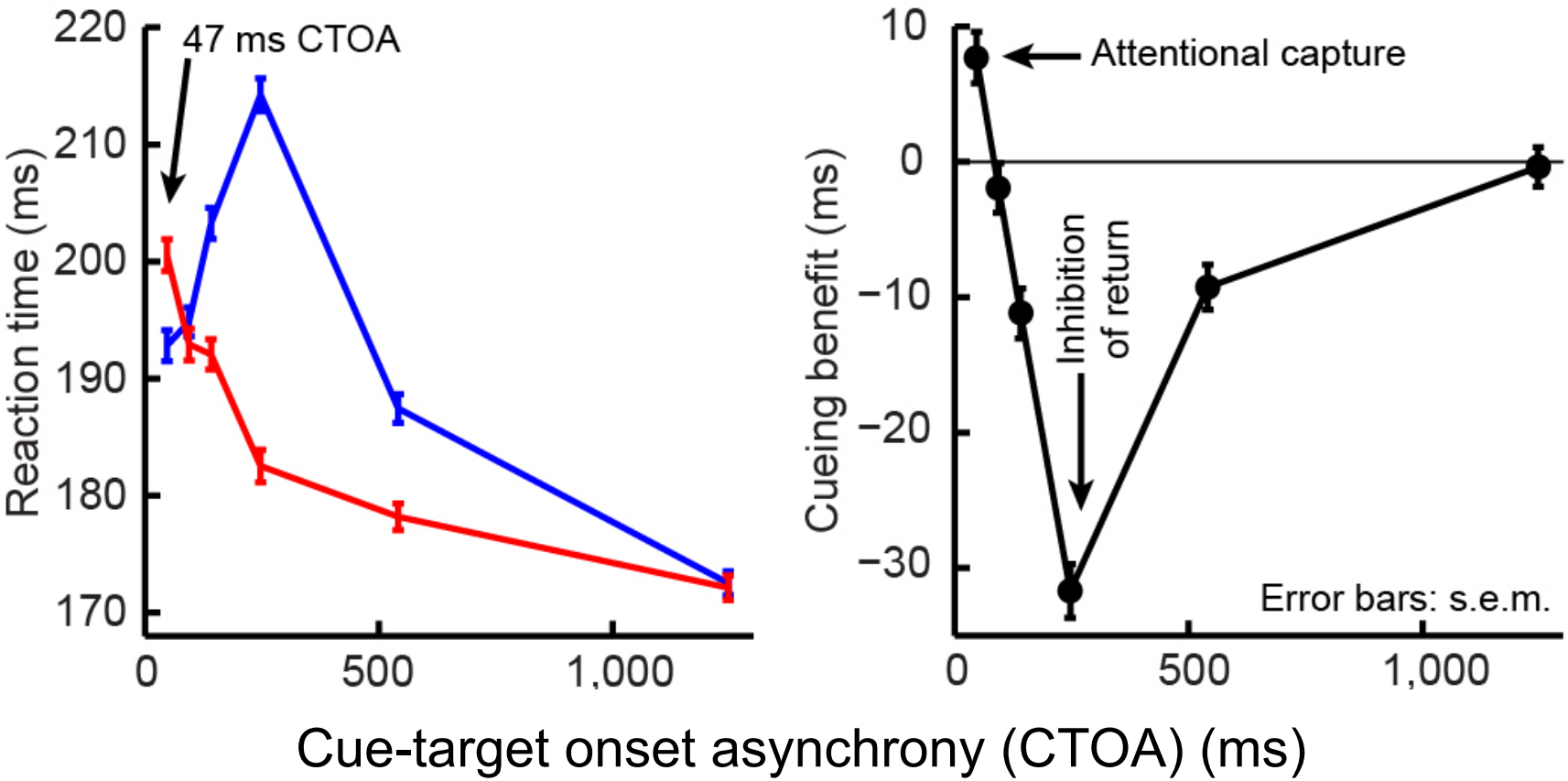


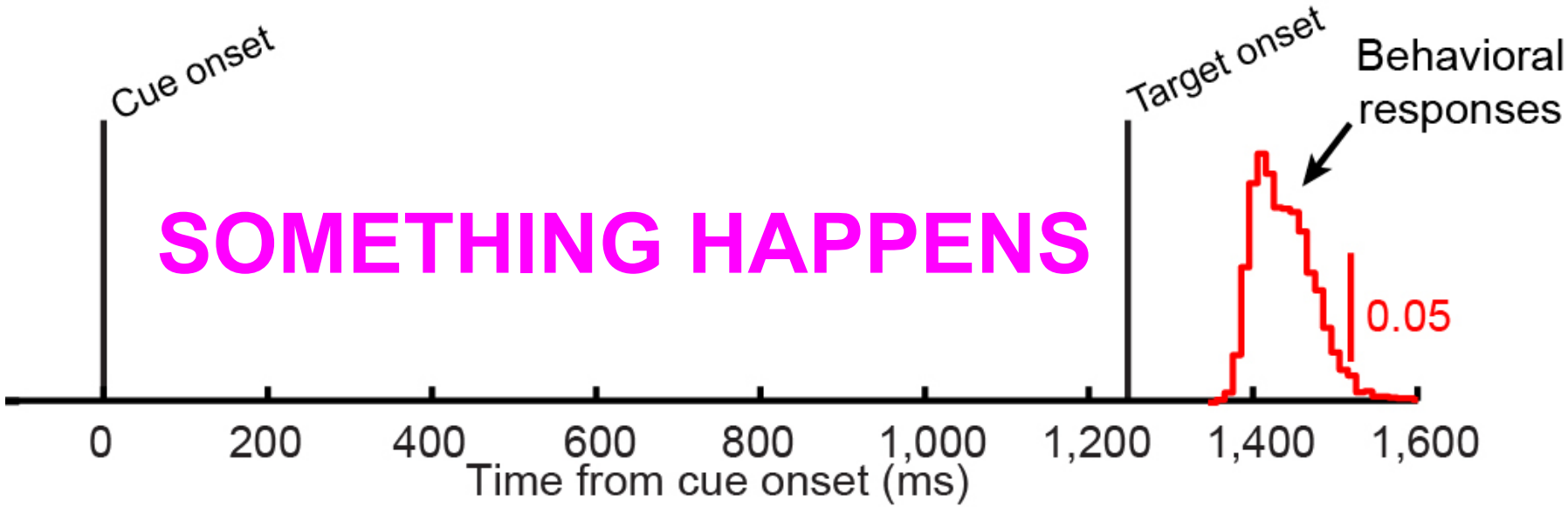
Cueing benefit



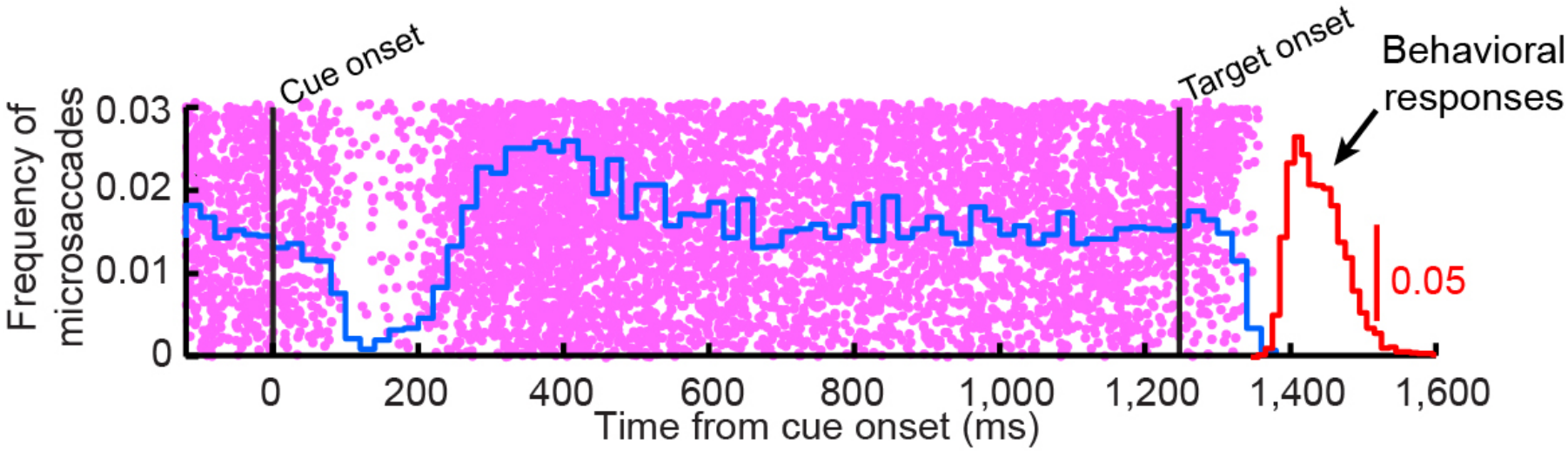
Cue-target onset asynchrony (CTOA) (ms)

Model result

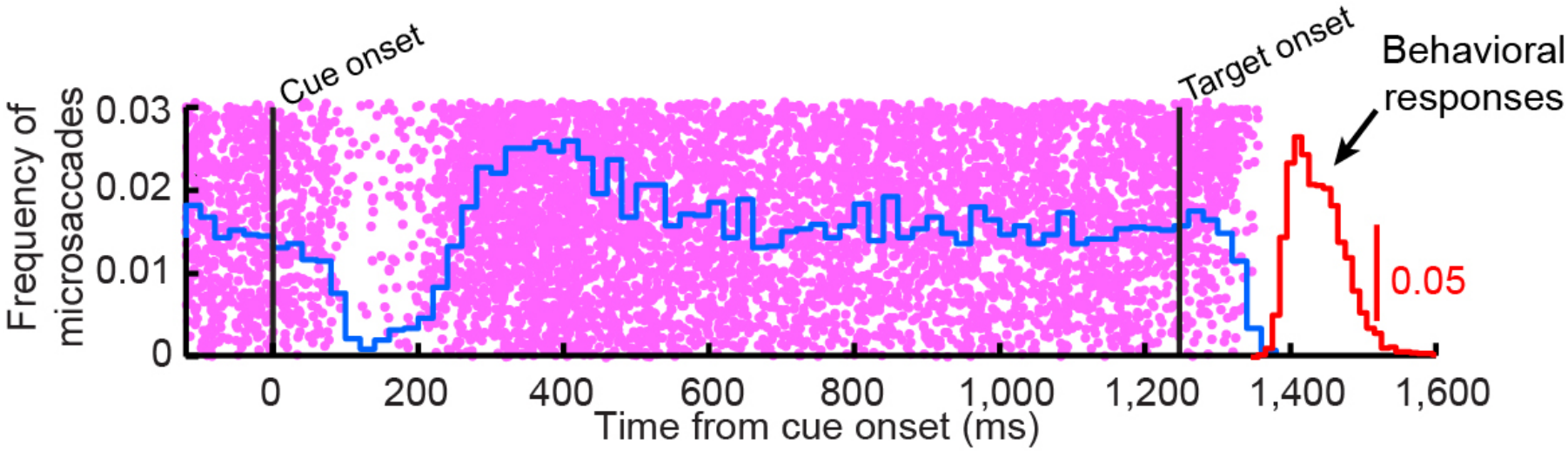



Cue onset
Target onset
Behavioral responses
SOMETHING HAPPENS
0.05
0
200
400
600
800
1,000
1,200
1,400
1,600
Time from cue onset (ms)

Microsaccades during fixation



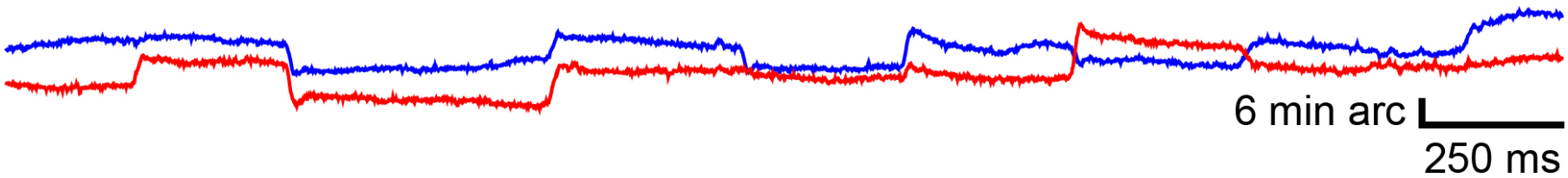
Microsaccades during fixation



- **Many** behavioral outputs rather than only a single one at the end of a trial

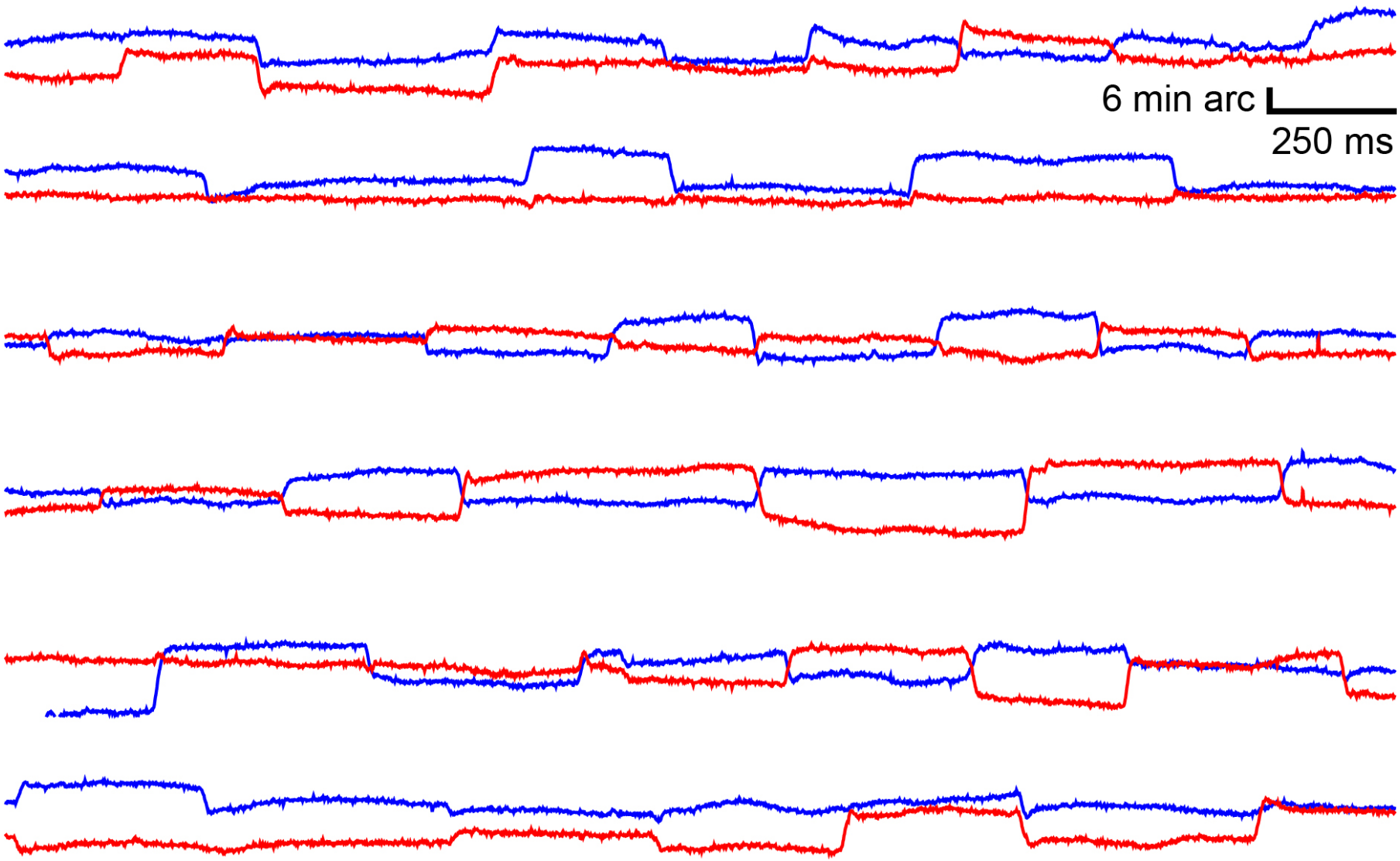
Based on simple properties of these “many” behavioral outputs, is it **possible** to account for performance changes in Posner cueing?

4 basic properties of microsaccades are **sufficient** to account for attentional capture and inhibition of return



Horizontal eye position

Vertical eye position


6 min arc
250 ms

1) Saccades are repetitively generated even during willful fixation (a temporal rhythm)

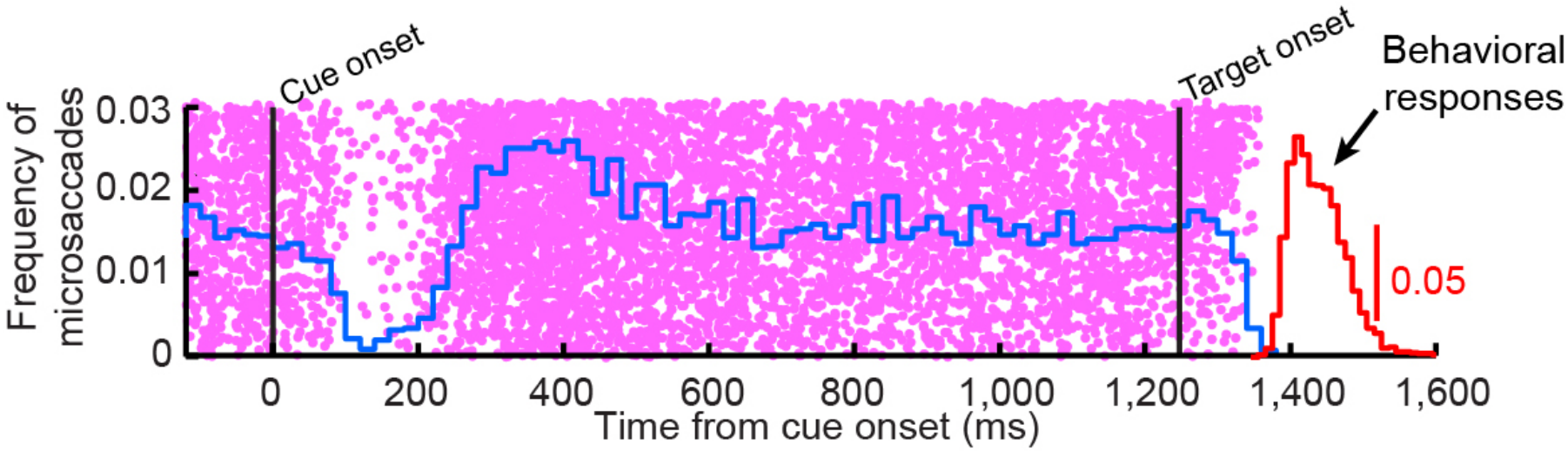
1) Saccades are repetitively generated even during willful fixation (a temporal rhythm)

2) Repetitive saccades are spatially anti-correlated (a spatial oscillation)

What happens if a cue or target appears?

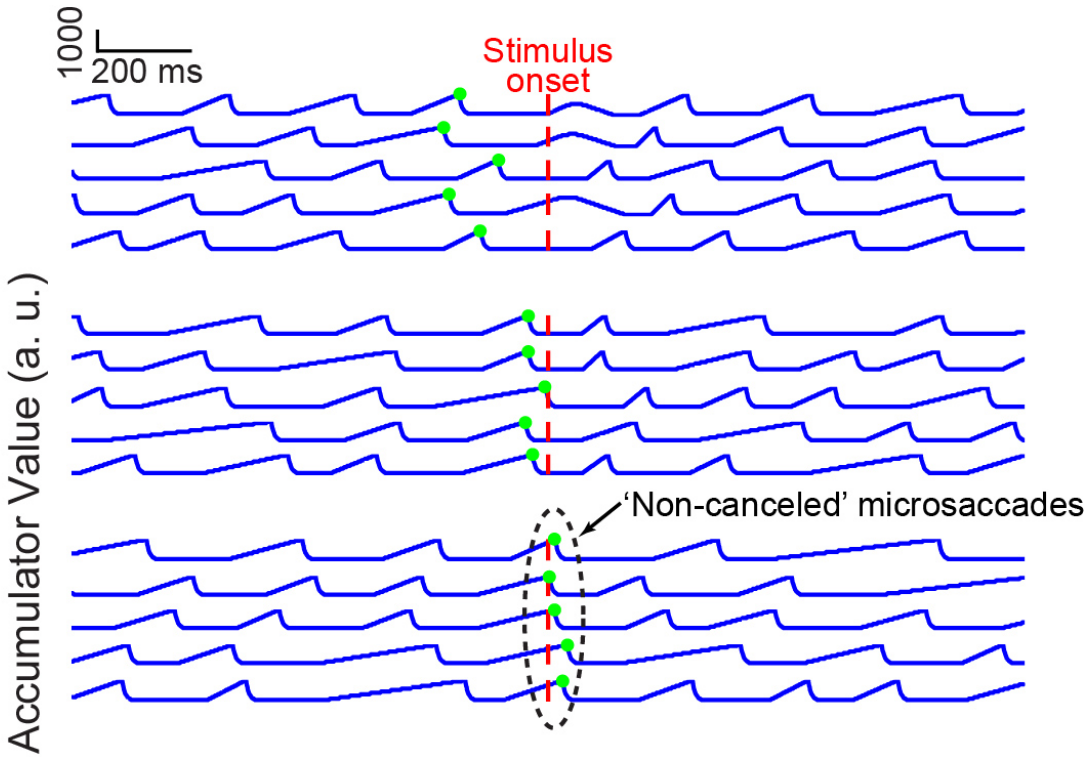
Phase resetting of microsaccades by stimulus onsets

Phase resetting of microsaccades by stimulus onsets



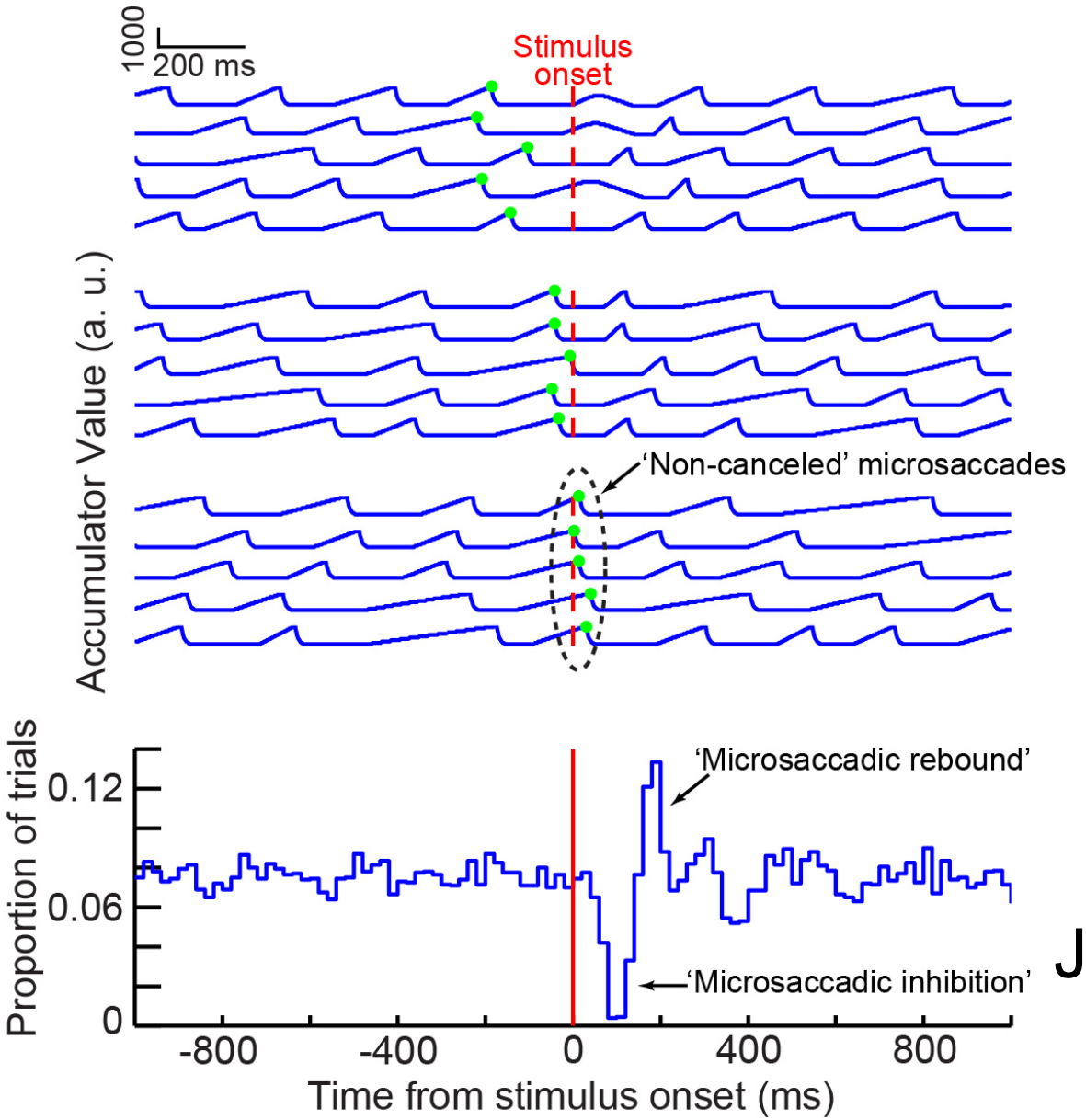
- Previously called “microsaccadic inhibition” or “saccadic inhibition”
- Robust response to ***any*** stimulus transient

Stimulus onset as ‘phase resetting’



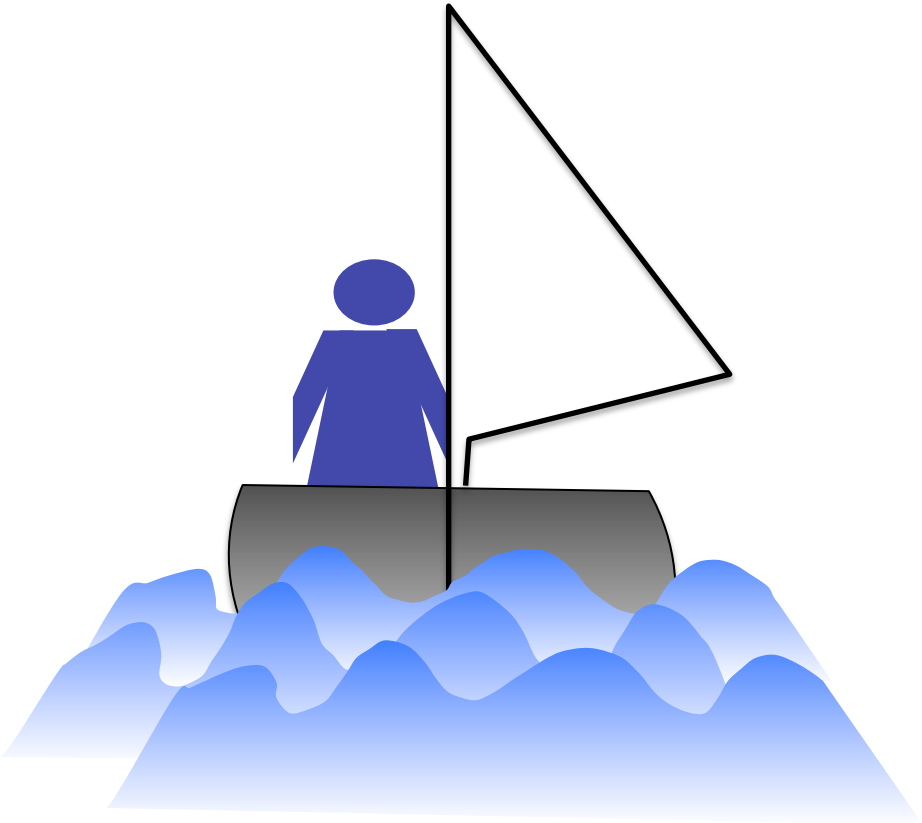
(Hafed & Ignashchenkova, J. Neurosci., 2013)

Stimulus onset as ‘phase resetting’

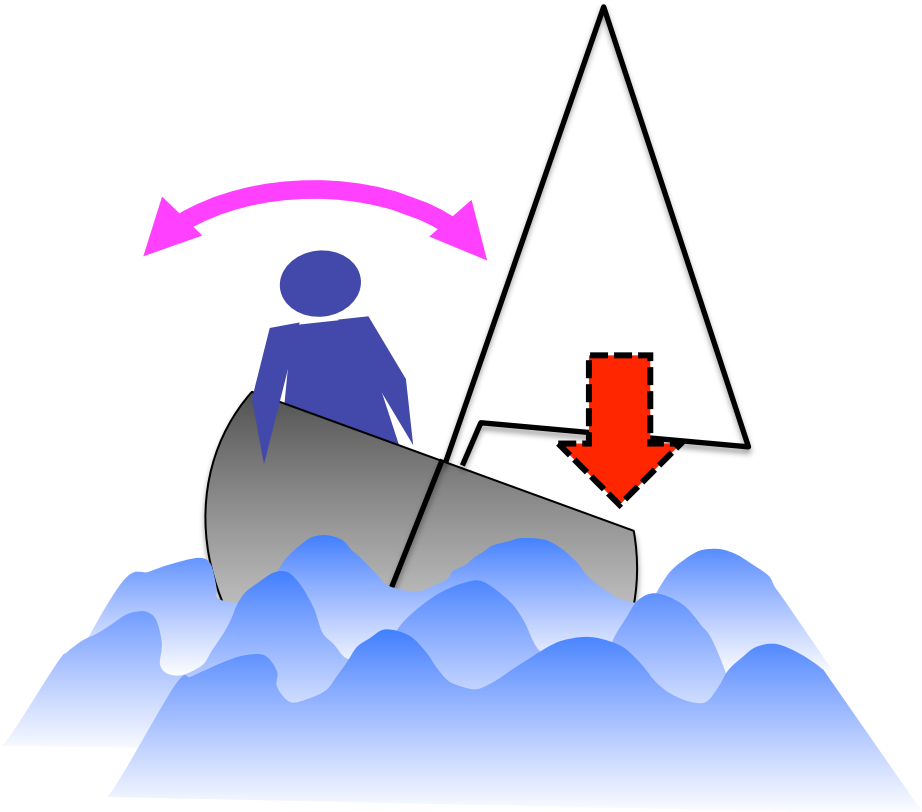


(Hafed & Ignashchenkova, J. Neurosci., 2013)

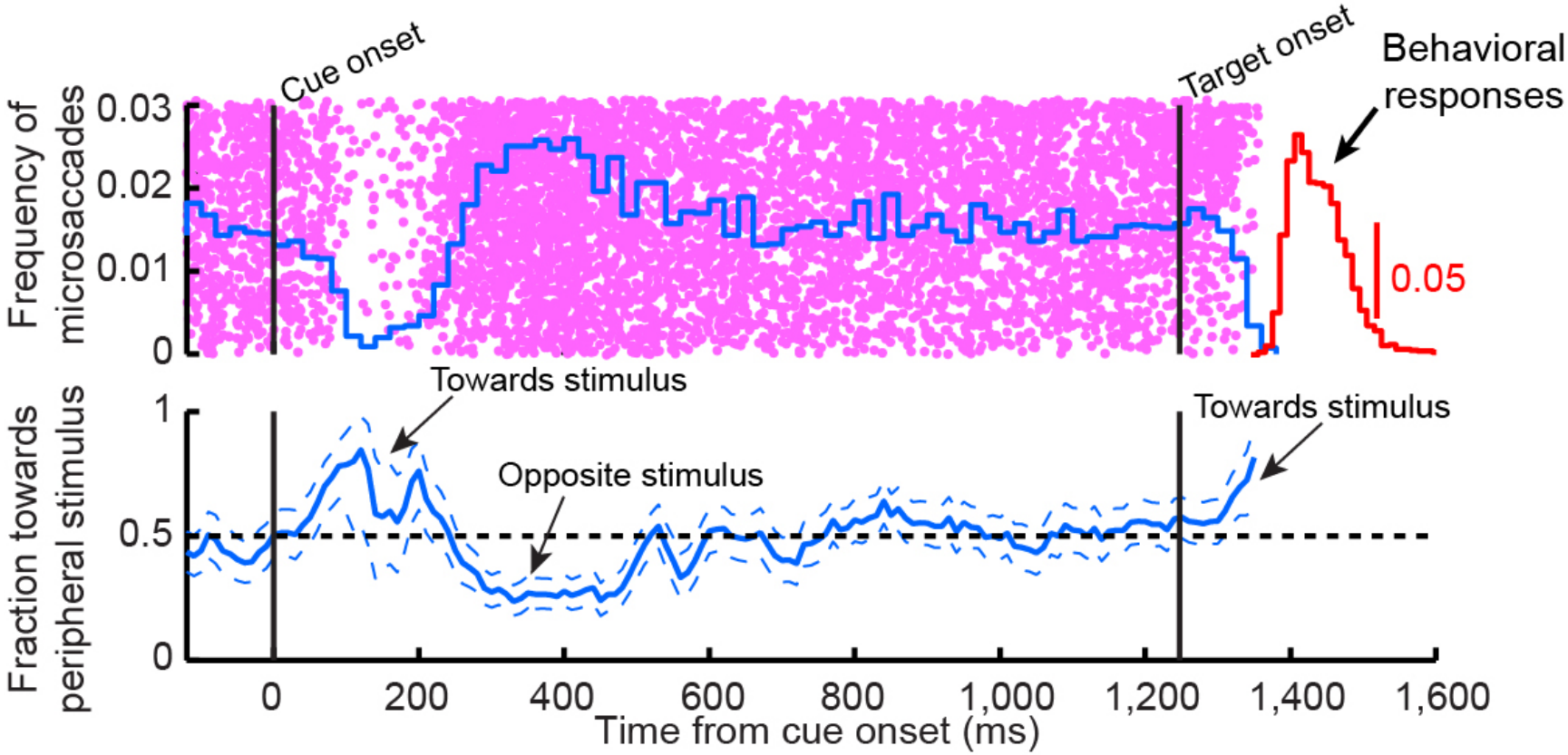
Balance



Transient → Oscillation



Phase resetting of microsaccades by stimulus onsets

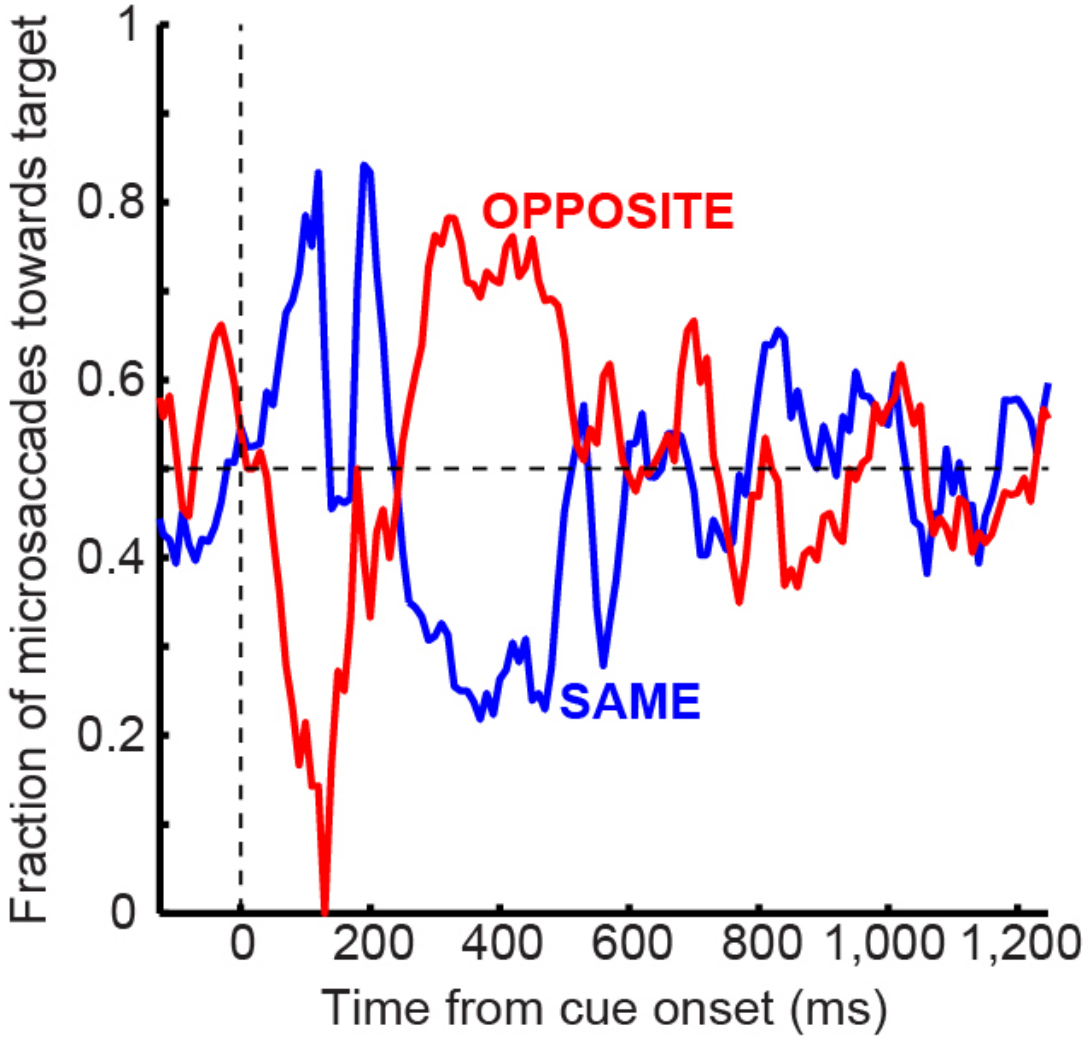


1) Saccades are repetitively generated even during willful fixation (a temporal rhythm)

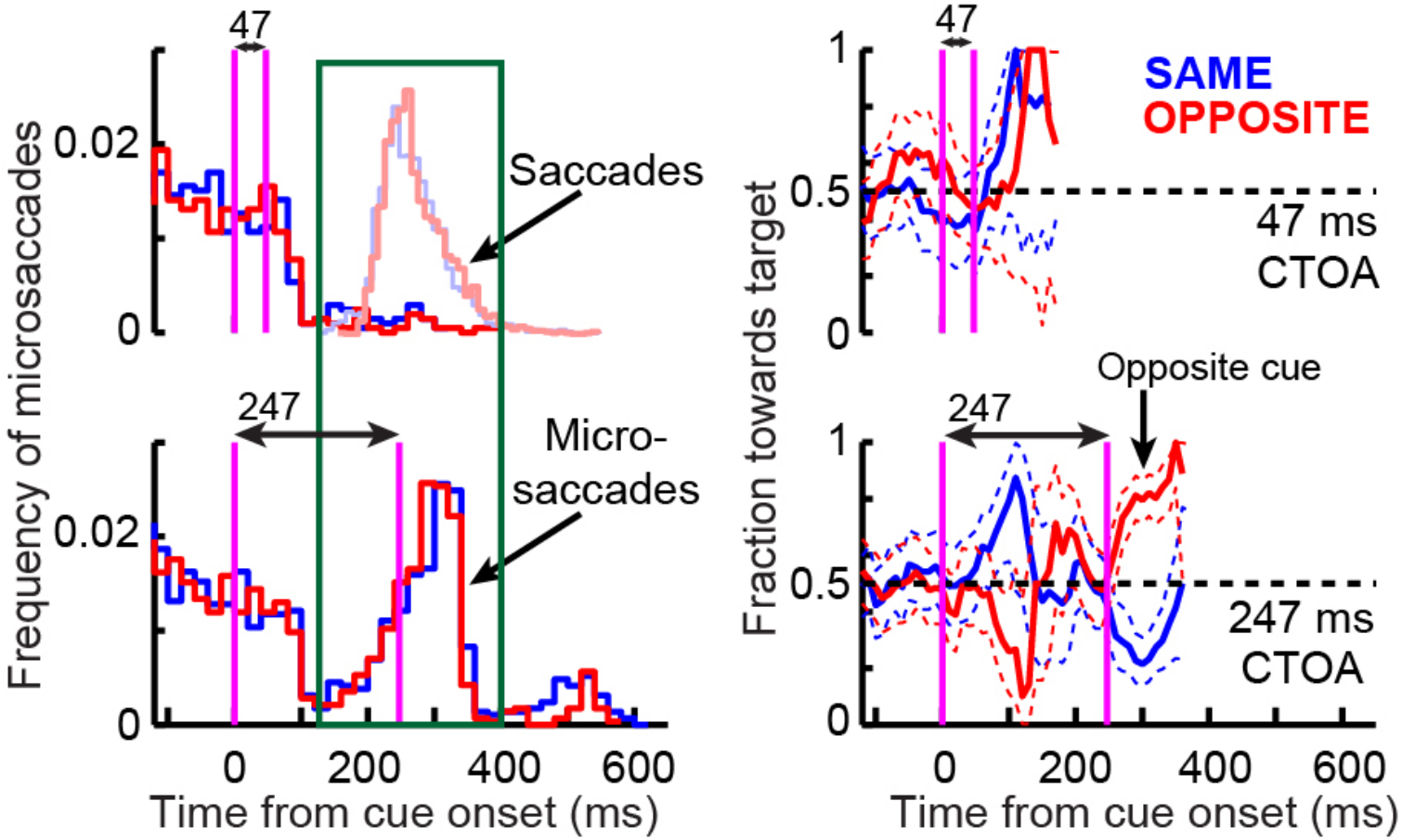
2) Repetitive saccades are spatially anti-correlated (a spatial oscillation)

3) Stimulus transients (like cue and target onset) **reset** microsaccadic rhythms in an automatic manner, resulting in coherent post-cue microsaccade oscillations

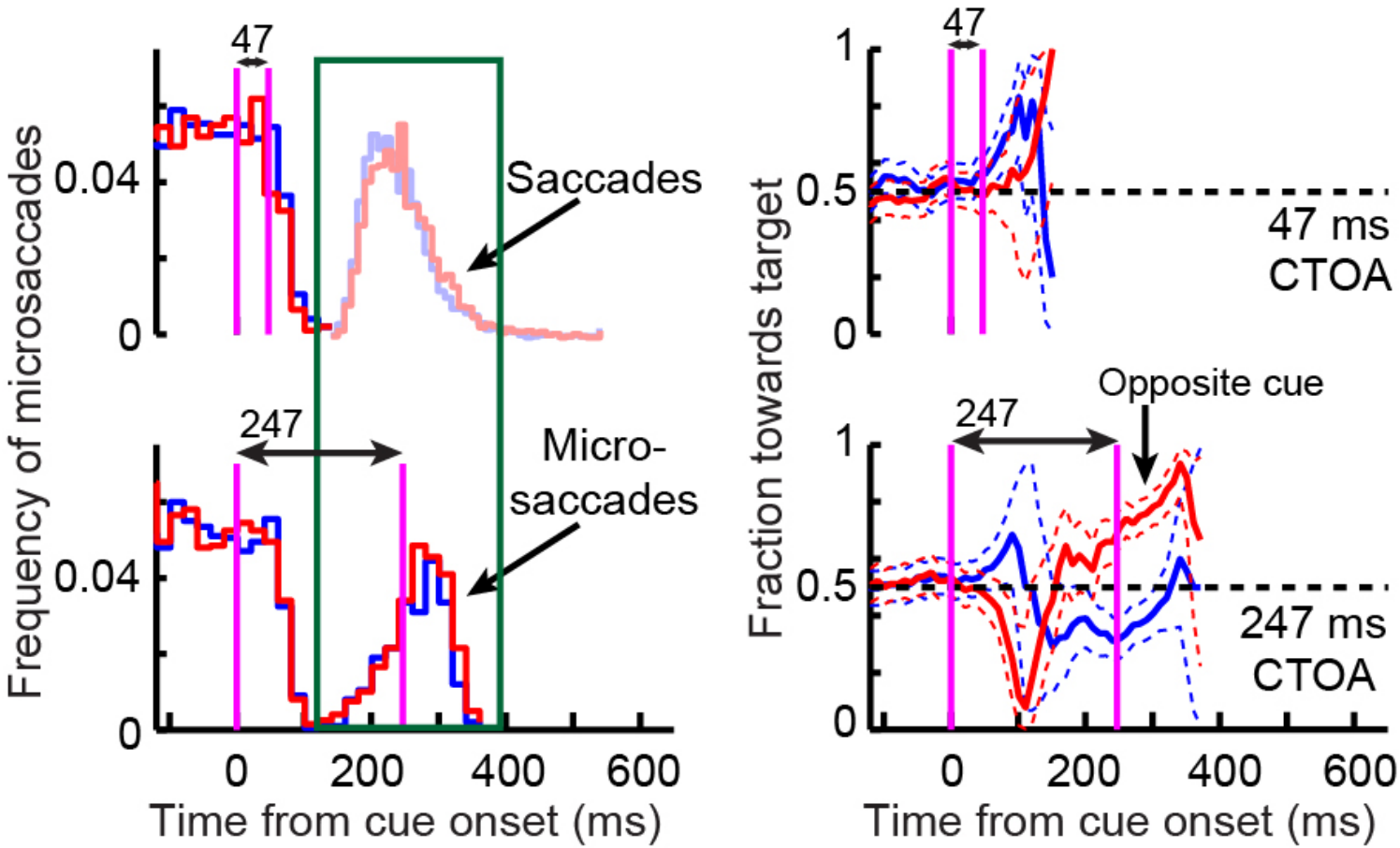
Coherent post-cue microsaccadic oscillations in Posner cueing



Sample CTOA's



Model result



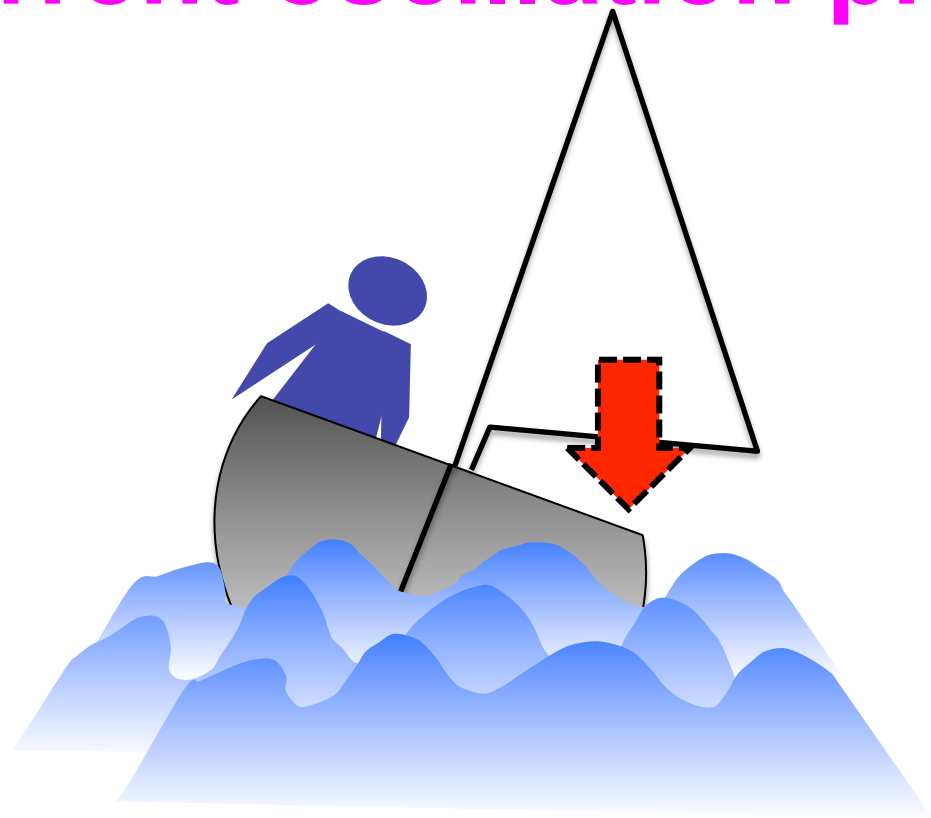
1) Saccades are repetitively generated even during willful fixation (a temporal rhythm)

2) Repetitive saccades are spatially anti-correlated (a spatial oscillation)

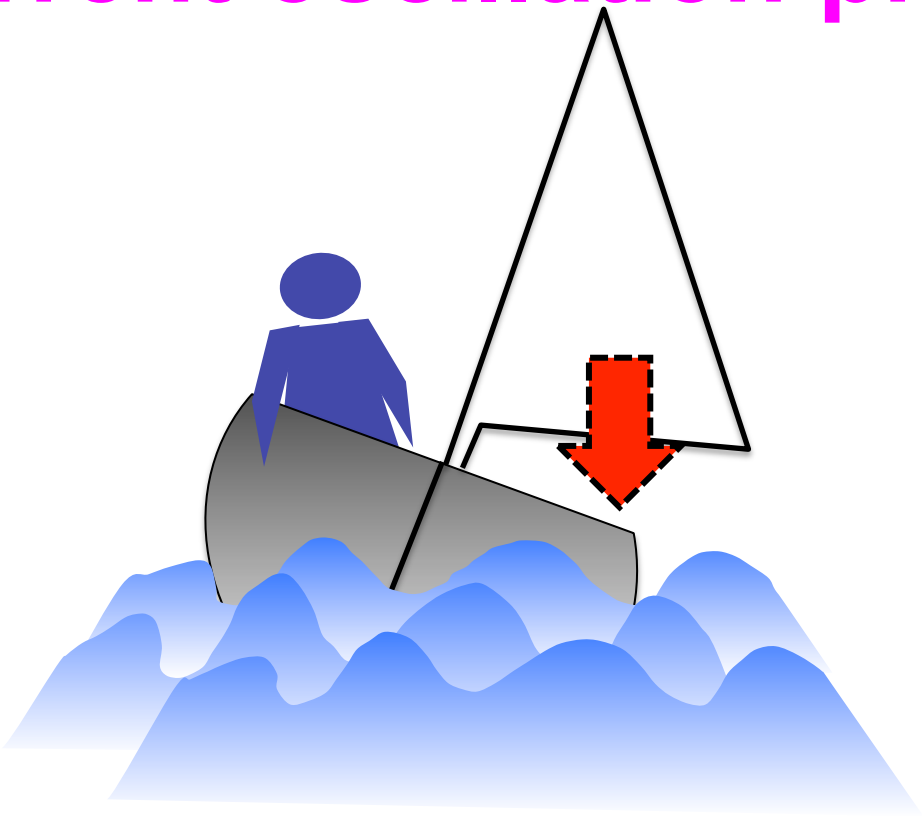
3) Stimulus transients (like cue and target onset) **reset** microsaccadic rhythms in an automatic manner, resulting in coherent post-cue microsaccade oscillations

What happens when the target is presented in Posner cueing?

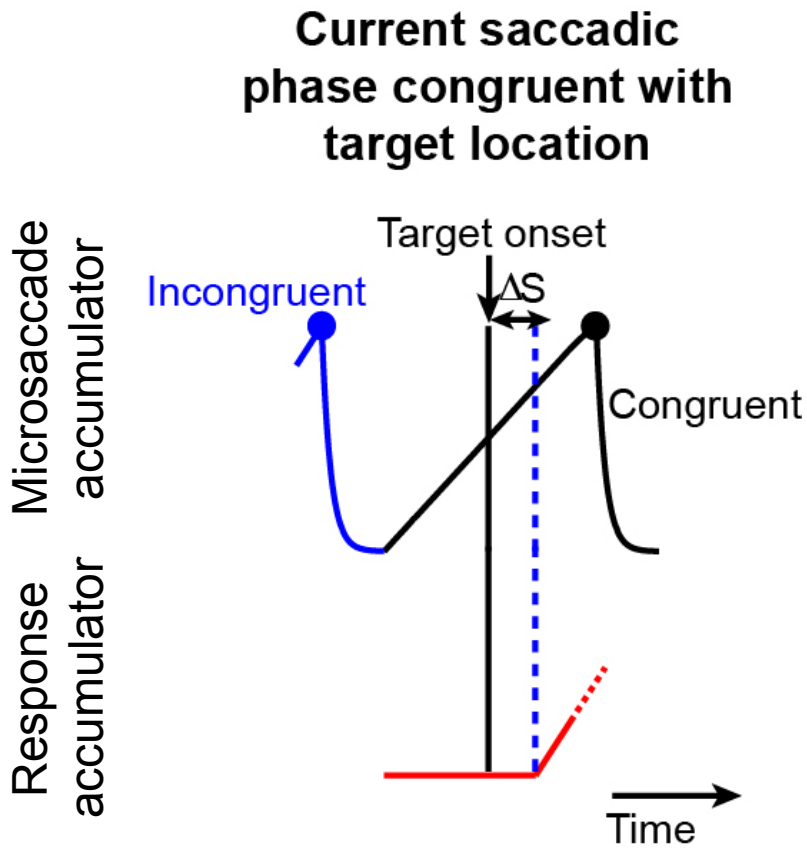
Stimulus comes **congruent** with **current oscillation phase**



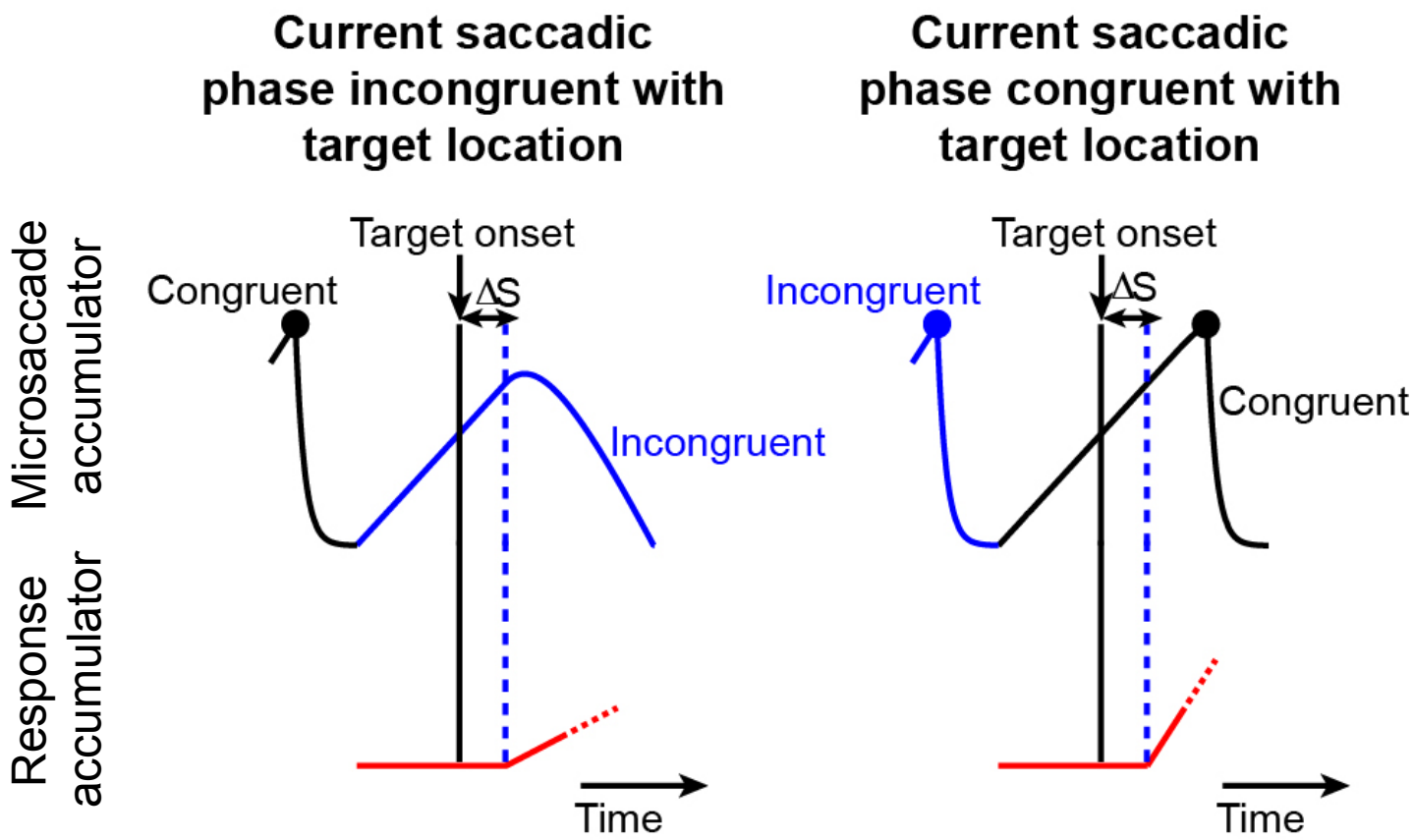
Stimulus comes **incongruent** with **current oscillation phase**



What happens when the target is presented in Posner cueing?



What happens when the target is presented in Posner cueing?

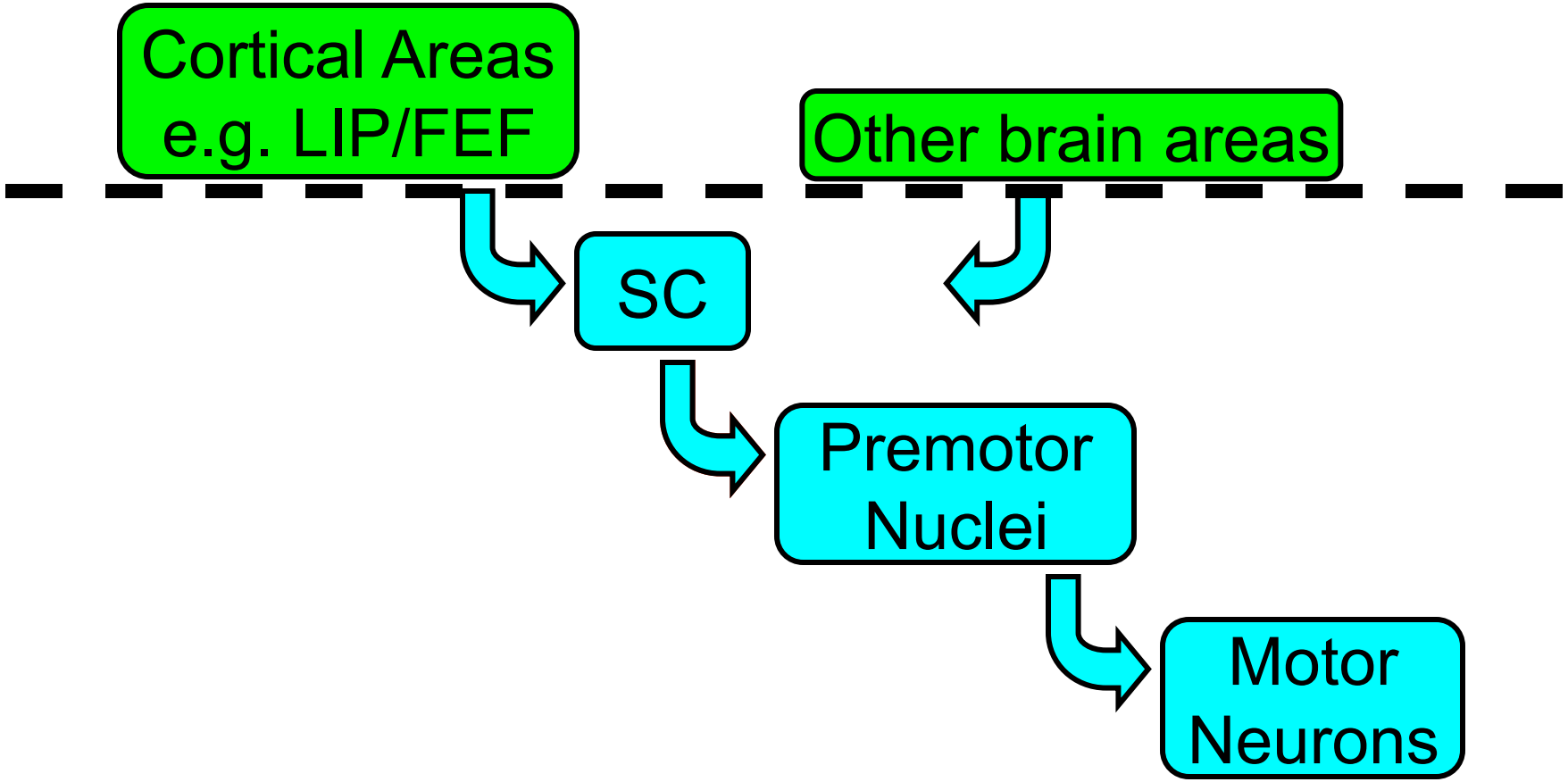


This means that performance in Posner cueing may be modulated at target onset **independent** of prior cueing

The cue resets, and thus unmasks, underlying fluctuations

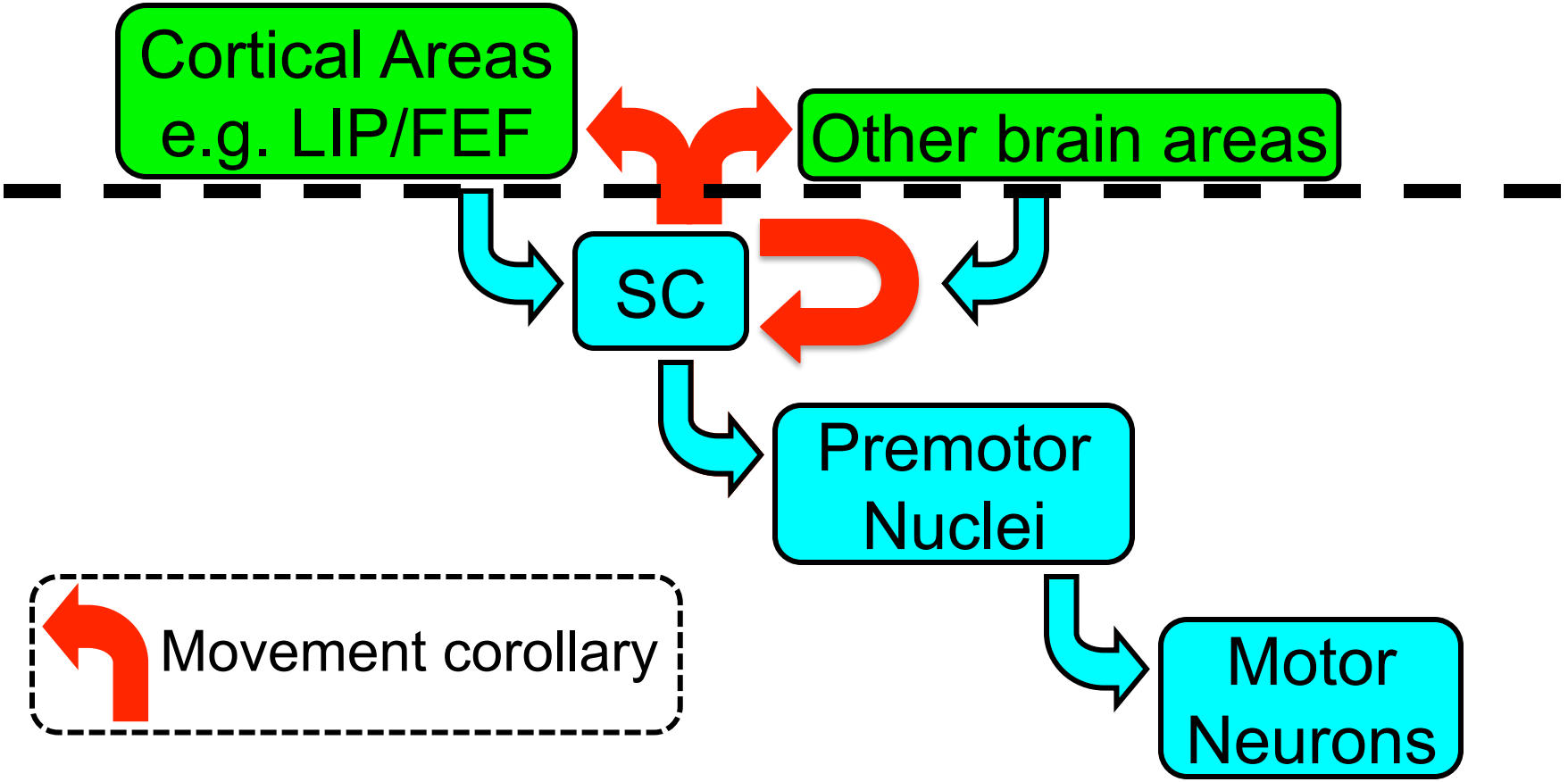
4) Target onset **prior** to a microsaccade **congruent** with target location results in stronger neuronal response gain than target onset prior to a non-congruent microsccade

Hierarchy of microsaccade generation

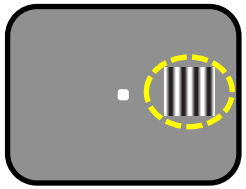


(Hafed et al., Science, 2009; Hafed, Eur. J. Neurosci., 2011)

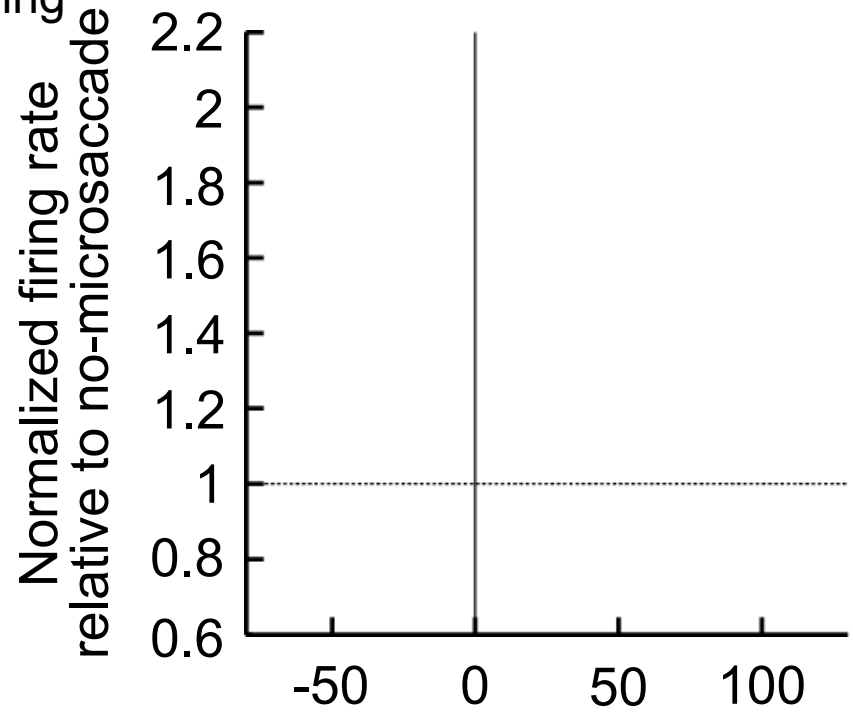
Hierarchy of microsaccade generation



(Hafed et al., Science, 2009; Hafed, Eur. J. Neurosci., 2011)

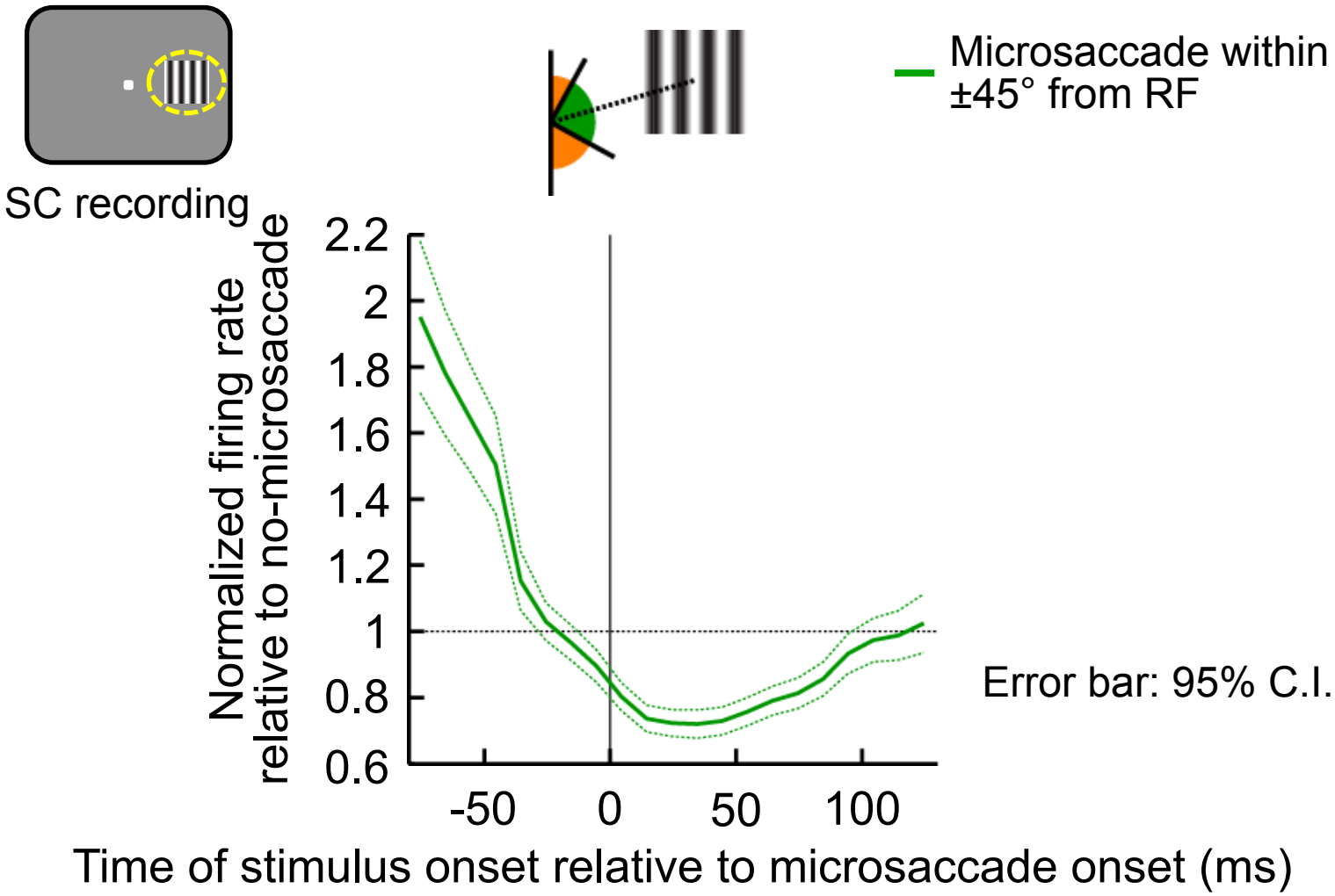


SC recording

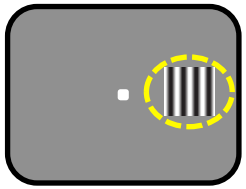


Error bar: 95% C.I.

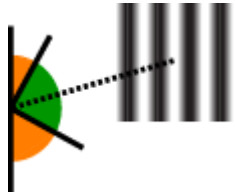
Time of stimulus onset relative to microsaccade onset (ms)


SC recording
Microsaccade within ±45° from RF
Normalized firing rate relative to no-microsaccade
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
-50
0
50
100
Error bar: 95% C.I.
Time of stimulus onset relative to microsaccade onset (ms)

Selective gating of visual response in **pre-microsaccadic** intervals

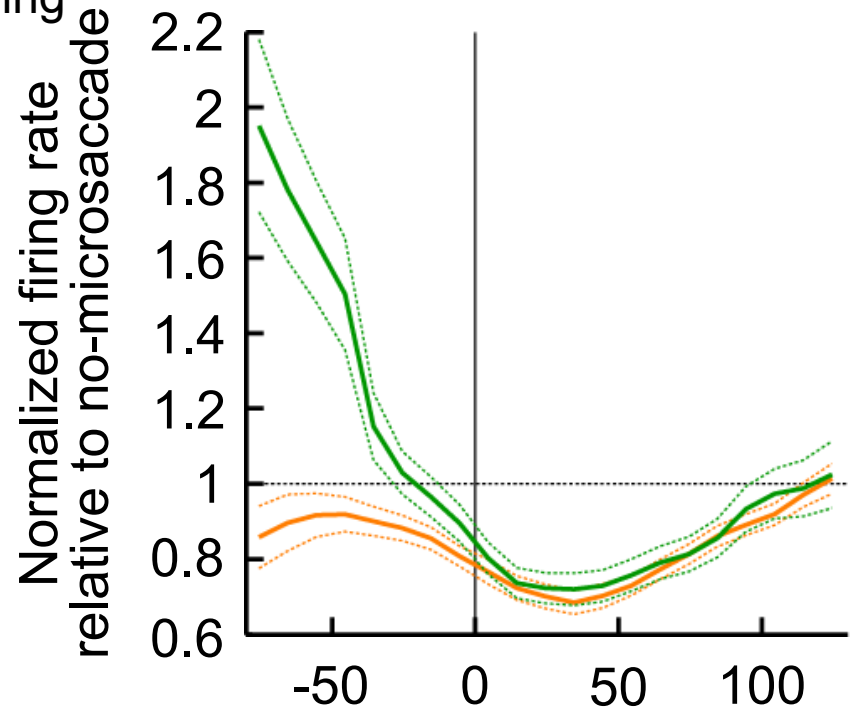


SC recording



Microsaccades within ±45° from RF

Other microsaccades



Error bar: 95% C.I.

Time of stimulus onset relative to microsaccade onset (ms)

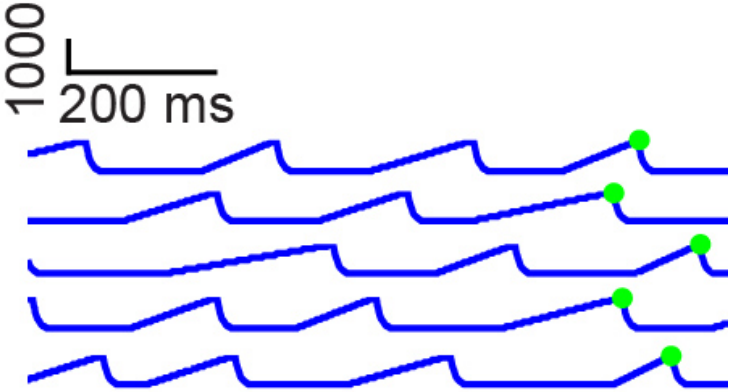
Selective gating of visual response associated with microsaccade directions

(Chen et al., Current Biology, 2015; and also see Hafed, Neuron, 2013)

The model

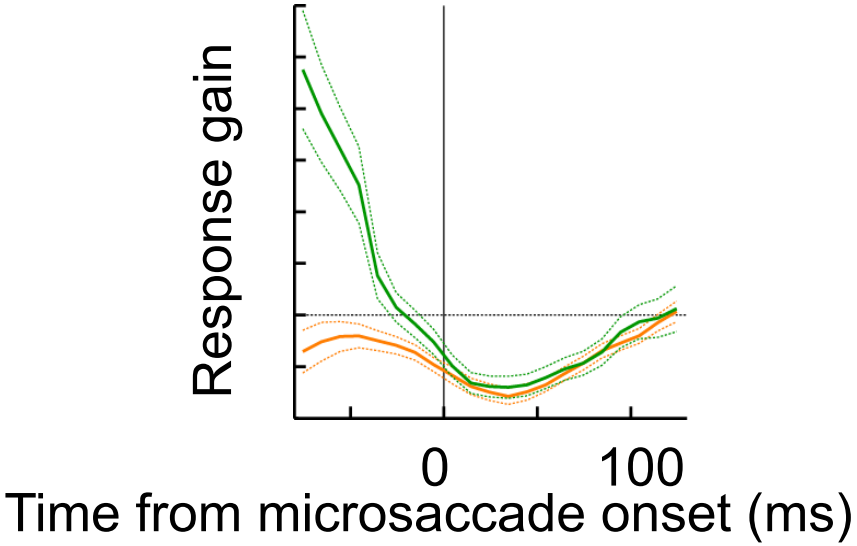
- Repetitive microsaccades

(Hafed & Ignashchenkova, J. Neurosci., 2013)

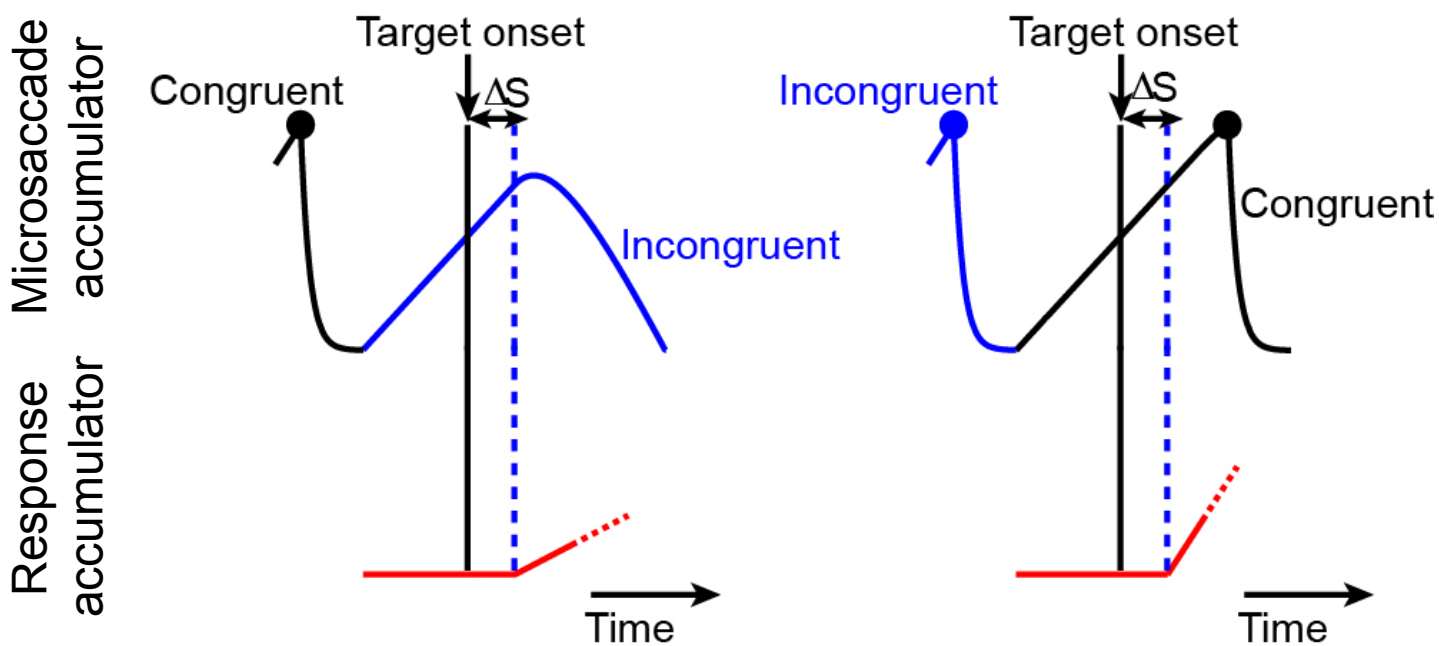


- Pre-microsaccadic modulation of visual bursts for any given microsaccade

(Chen et al., Current Biology, 2015)

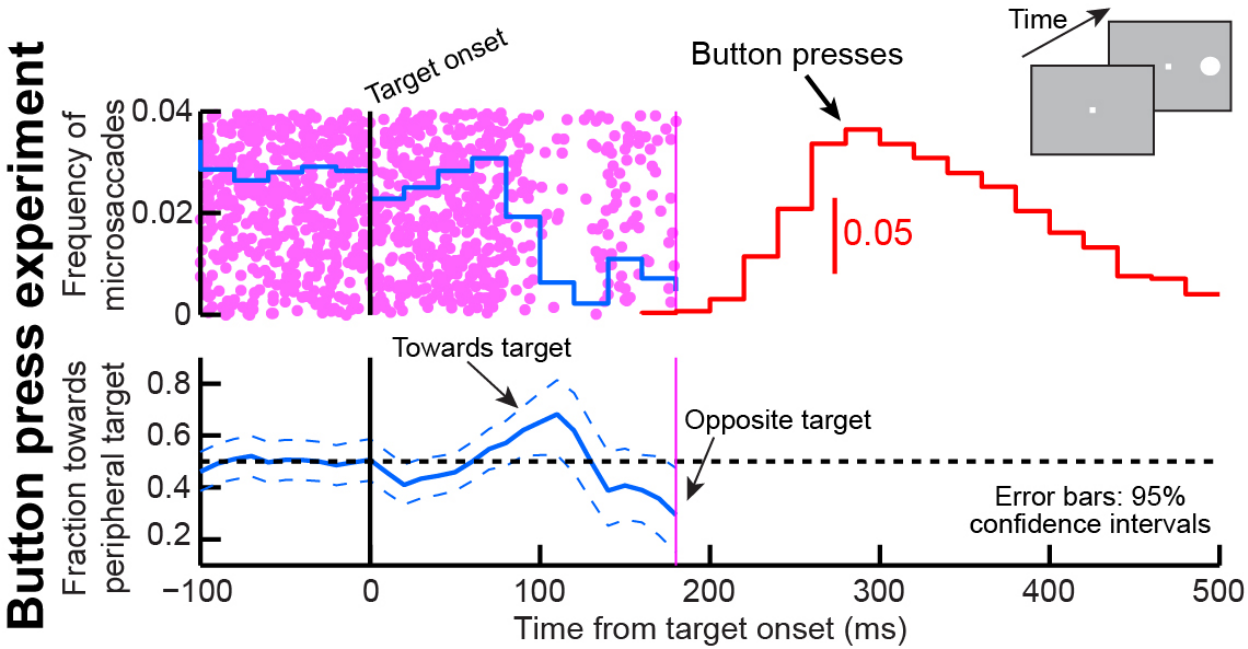


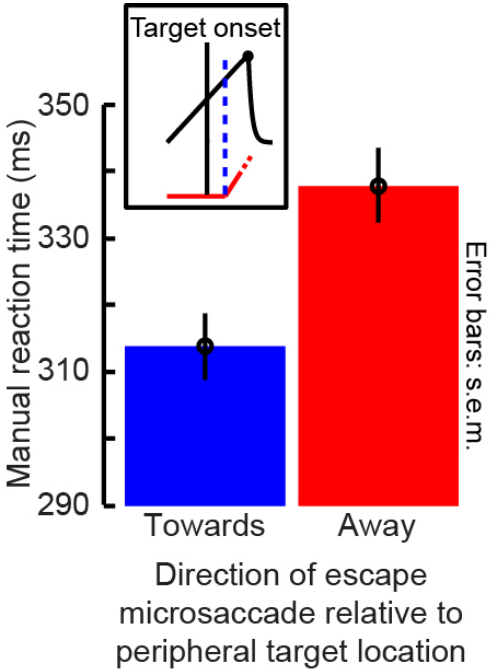
Final model performance is dependent on **current** microsaccadic phase **at target onset**



Performance modulations **without** prior cueing

Performance modulations **without** prior cueing

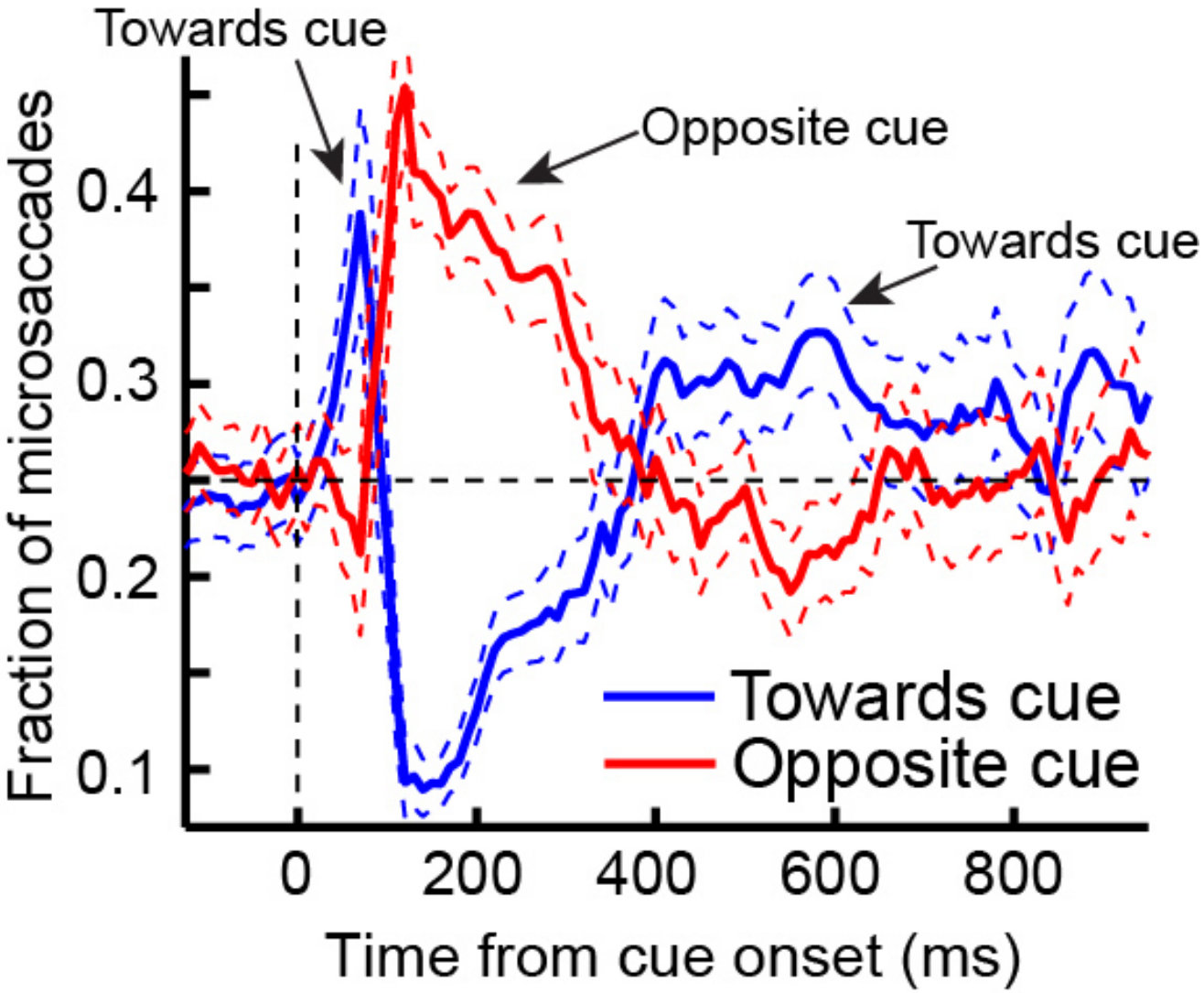




Qualitatively and quantitatively similar behavioral effects without cueing; as a function of target onset relative to microsaccades

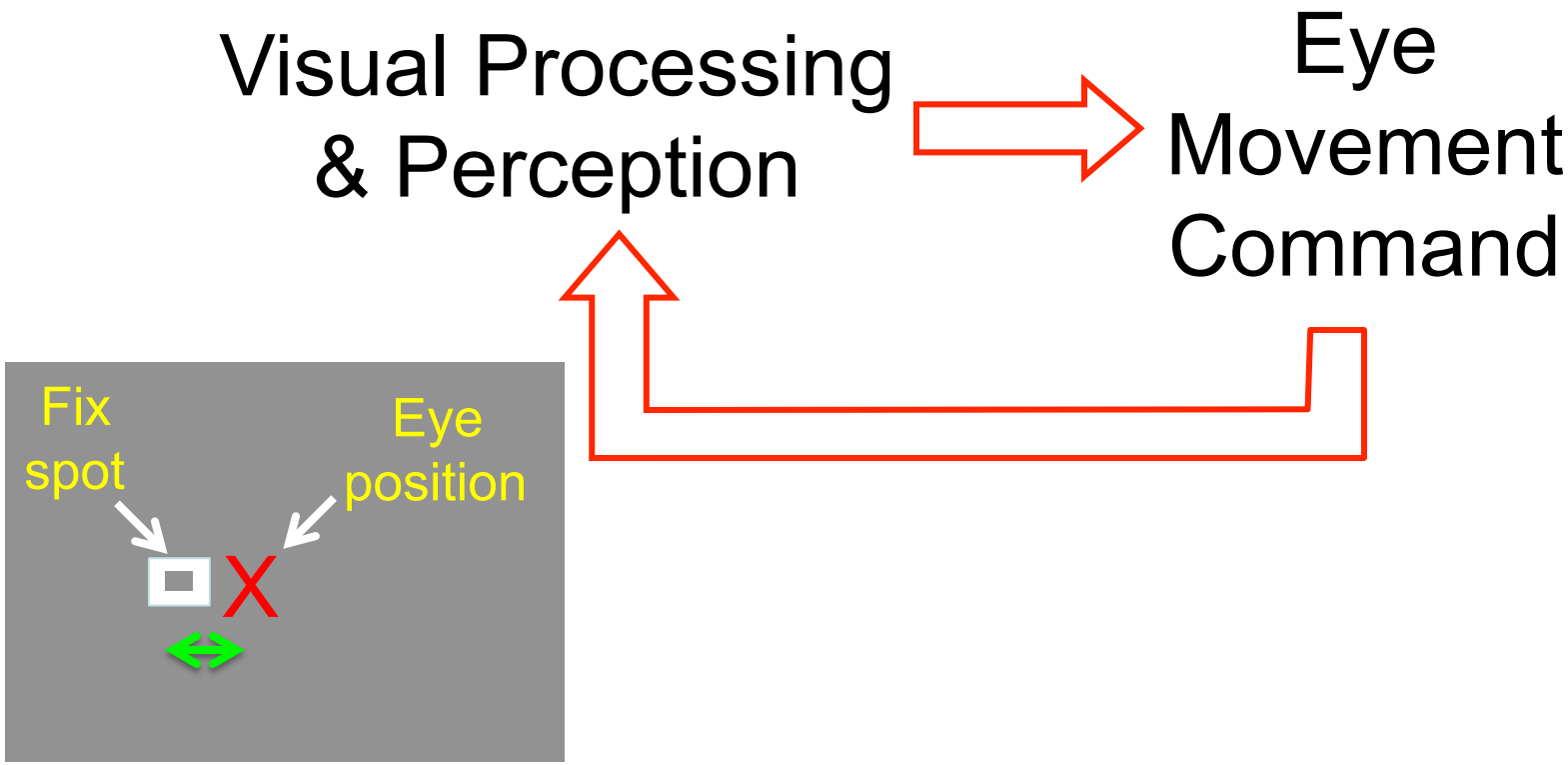
(Also see Chen et al., Current Biology, 2015; and Hafed, Neuron, 2013)

Why do microsaccades behave this way in the first place?

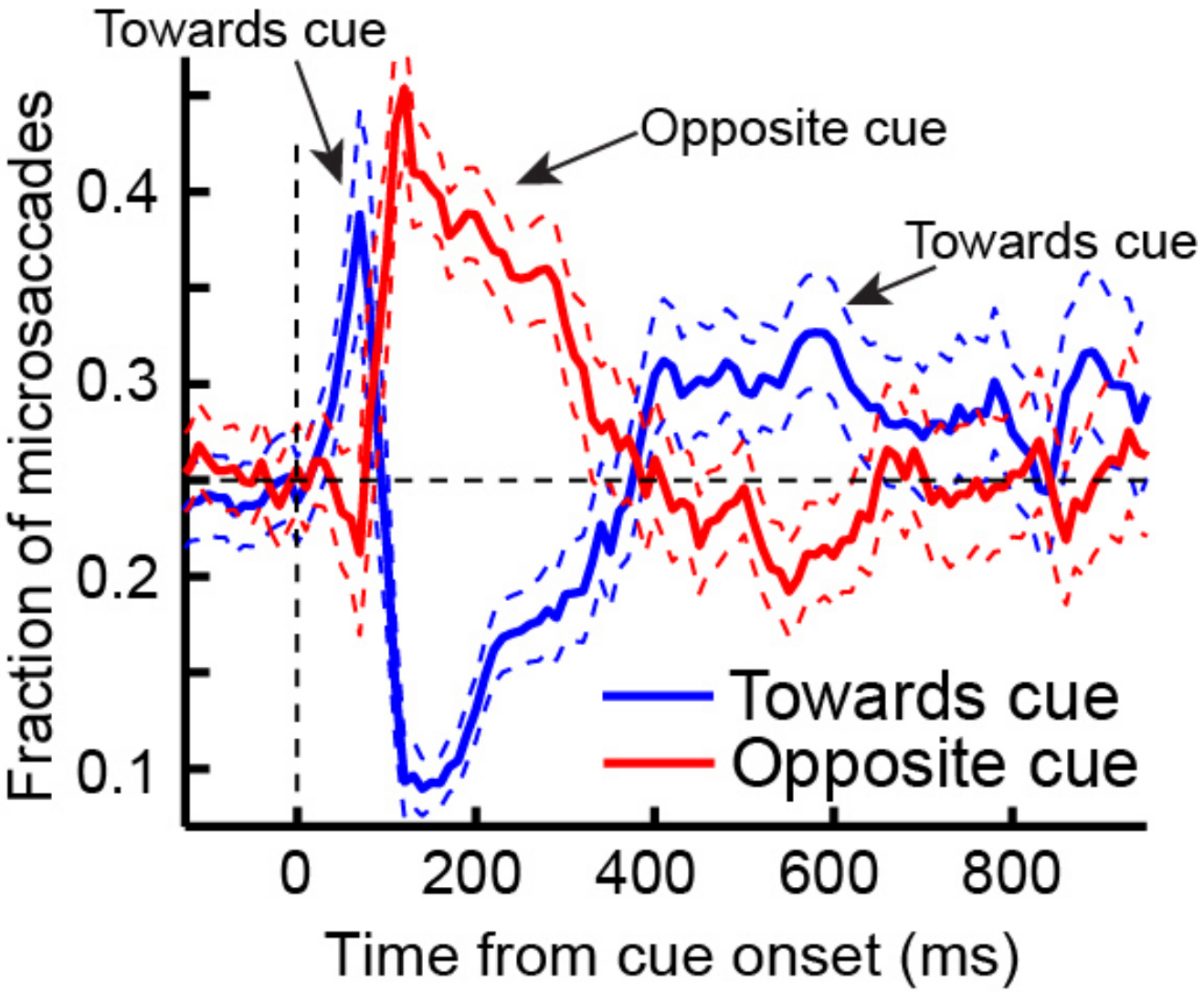

Towards cue
Opposite cue
Towards cue
Fraction of microsaccades
0.4
0.3
0.2
0.1
Towards cue
Opposite cue
0
200
400
600
800
Time from cue onset (ms)

Hypothesis: microsaccadic modulations reflect corrections for tiny foveal motor errors

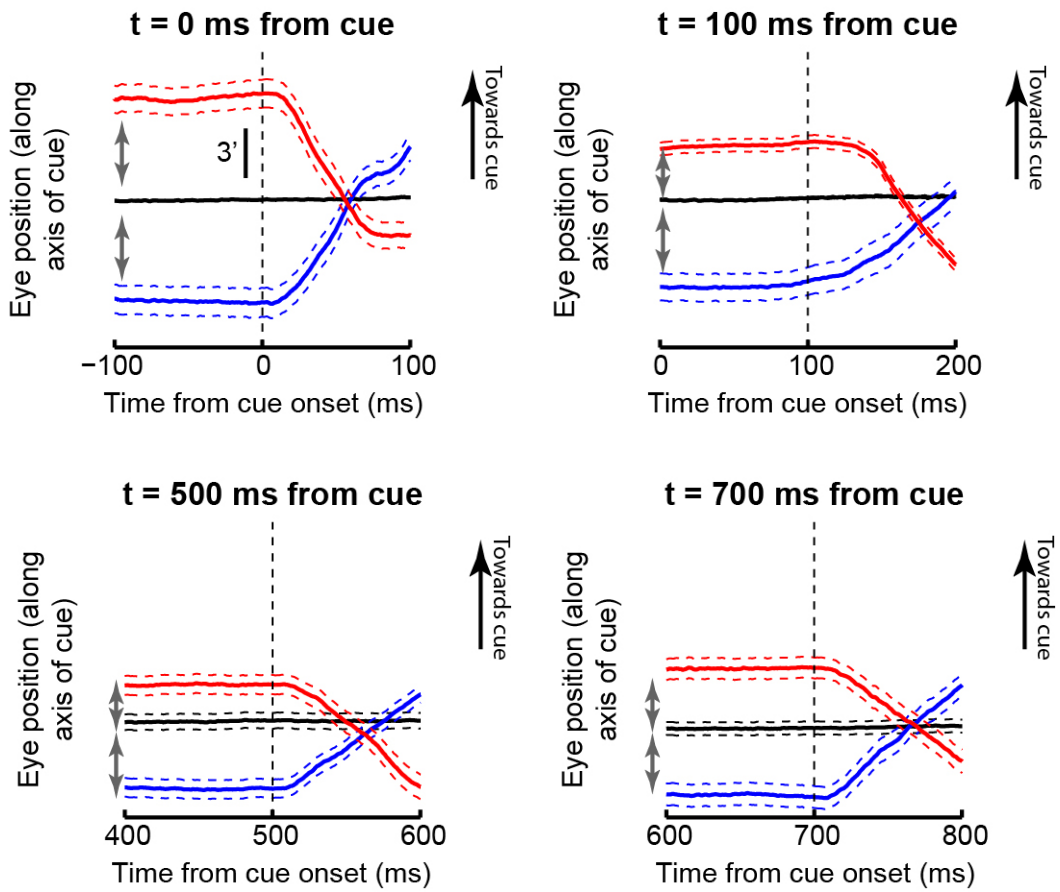
Active vision at the fixation spot



Take slices at different times



Peri-cue microsaccade directions as a function of foveal error



No microsaccades during t +/- 150 ms

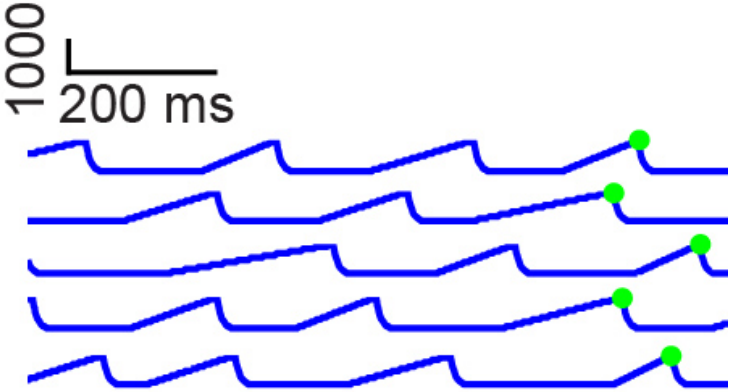
Microsaccades towards cue during t to t+100 ms

Microsaccades opposite cue during t to t + 100 ms

The model

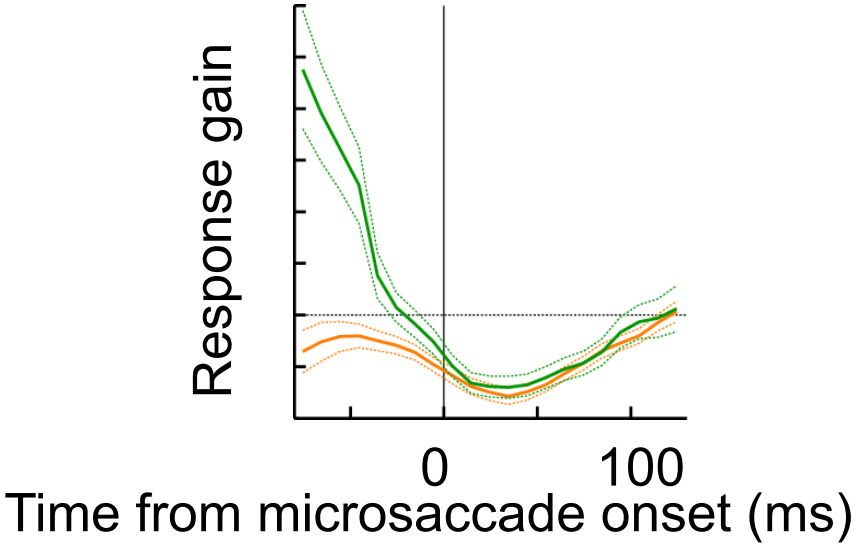
- Repetitive microsaccades

(Hafed & Ignashchenkova, J. Neurosci., 2013)



- Pre-microsaccadic modulation of visual bursts for any given microsaccade

(Chen et al., Current Biology, 2015)



The Posner cueing paradigm