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

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The Posner cueing paradigm
SOMETHING HAPPENS

Time from cue onset (ms)

Cue onset
Target onset
Behavioral responses

0.05
Performance during Posner cueing

Cue-target onset asynchrony (CTOA) (ms)

Reaction time (ms)

SAME

OPPOSITE
Performance during Posner cueing

Reaction time (ms)

Error bars: s.e.m.

Cue-target onset asynchrony (CTOA) (ms)

47 ms CTOA

SAME

OPPOSITE
Cue onset:
→ attentional capture
→ inhibition of return
Absolute performance

Cueing benefit

47 ms CTOA

SAME

OPPOSITE

Error bars: s.e.m.

Cue-target onset asynchrony (CTOA) (ms)

Reaction time (ms)

Cueing benefit (ms)

Attentional capture

Inhibition of return
Cue-target onset asynchrony (CTOA) (ms)

Model result

47 ms CTOA

Attentional capture

Inhibition of return

Error bars: s.e.m.
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
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
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- 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 $\rightarrow$ Oscillation
Phase resetting of microsaccades by stimulus onsets

Frequency of microsaccades

Fraction towards peripheral stimulus

Time from cue onset (ms)

Cue onset

Target onset

Behavioral responses
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

- Saccades
- Micro-saccades
- Opposite cue

Frequency of microsaccades

Fraction towards target

Time from cue onset (ms)
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 microsaccadic 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?

Current saccadic phase incongruent with target location

Current saccadic phase congruent with target location
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 microsaccade.
Hierarchy of microsaccade generation

Cortical Areas e.g. LIP/FEF

SC

Premotor Nuclei

Other brain areas

Motor Neurons

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Movement corollary

Normalized firing rate relative to no-microsaccade

Time of stimulus onset relative to microsaccade onset (ms)

Error bar: 95% C.I.
Normalized firing rate relative to no-microsaccade

Time of stimulus onset relative to microsaccade onset (ms)

Error bar: 95% C.I.

SC recording

Microsaccade within ±45° from RF

2.2
2
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-50 0 50 100
Selective gating of visual response in pre-microsaccadic intervals

SC recording

Normalized firing rate relative to no-microsaccade

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

Button press experiment

Frequency of microsaccades

Fraction towards peripheral target

Error bars: 95% confidence intervals

Towards target

Opposite target

Target onset

Time

Manual reaction time (ms)

Towards

Away

Direction of escape microsaccade relative to peripheral target location
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?
Hypothesis: microsaccadic modulations reflect corrections for tiny foveal motor errors
Active vision at the fixation spot

Visual Processing & Perception → Eye Movement Command

Fix spot
Eye position
Take slices at different times
Peri-cue microsaccade directions as a function of foveal error

- Microsaccades towards cue during t to t+100 ms
- Microsaccades opposite cue during t to t + 100 ms
- No microsaccades during t +/- 150 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