Eye movements & psychophysics

INDP Human Cognitive Neuroscience 2024

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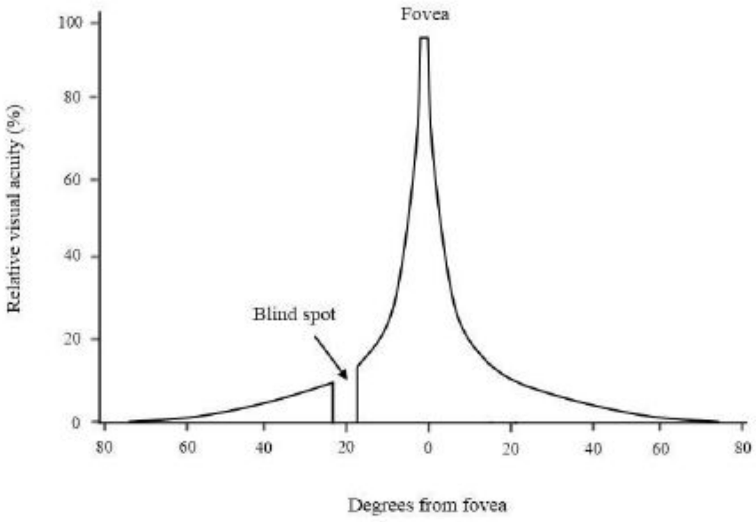
Mainen Lab

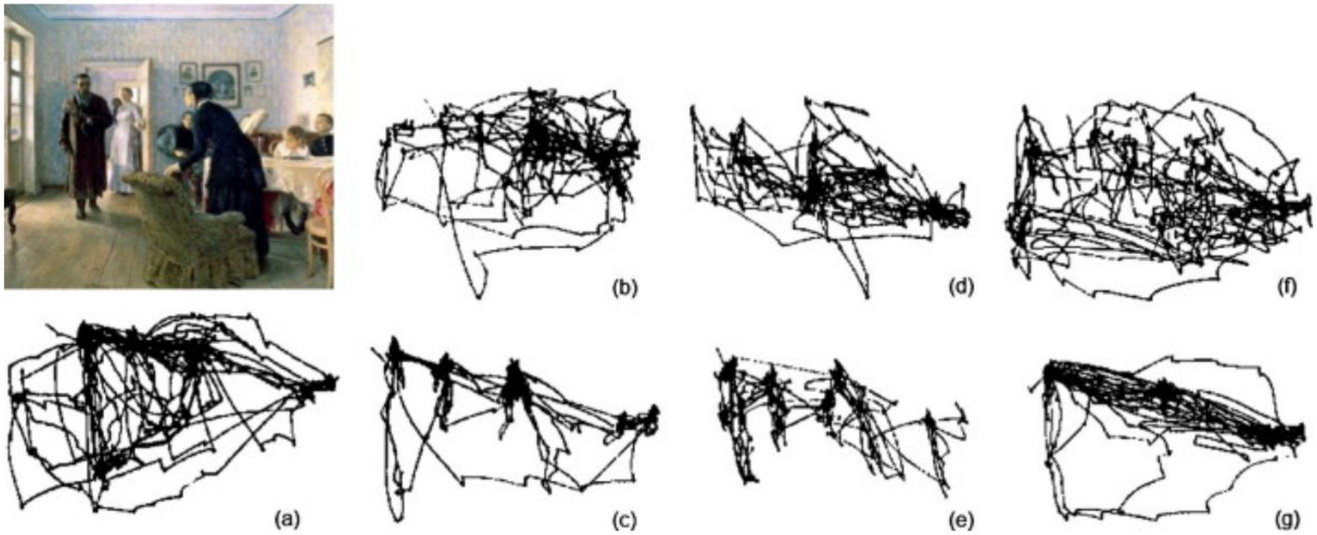
Why do humans need to make eye movements?

Despite a ~180° visual field, good visual acuity in humans is restricted to just 1-5° of visual angle spanned by the fovea.

That's approximately size of your thumbnail held at arm's length.



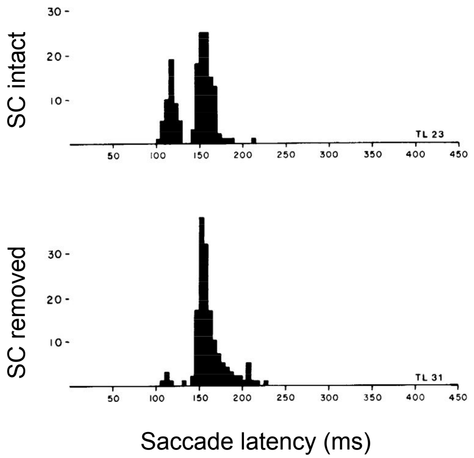
Eye movements in cognitive neuroscience



Yarbus (1967)

“Bottom-up” contributions to eye movements

Superior colliculus ablation abolishes
rapid saccades to a target.



Schiller et al. (1987), Itti & Koch (2000), Parkhurst et al. (2002), White et al. (2017), Basso et al. (2021)

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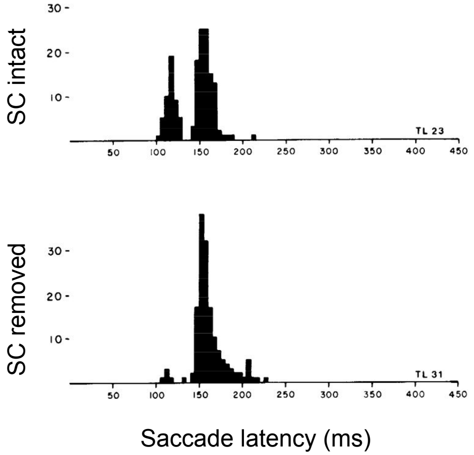
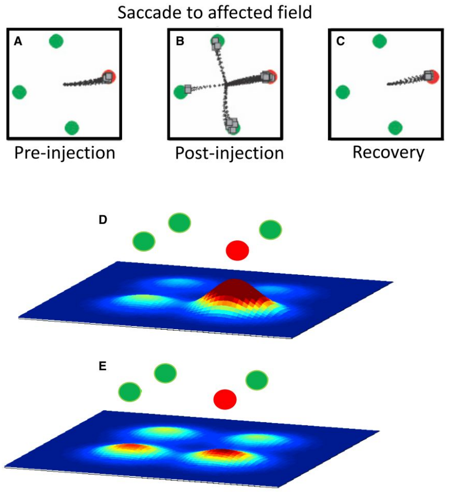


SC ablation hinders the ability to saccade to a target, and topographic SC activity predicts target detection.



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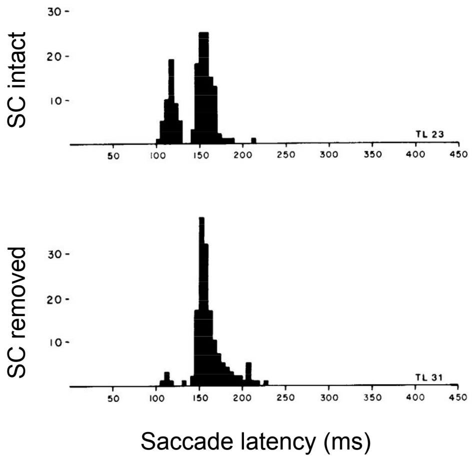

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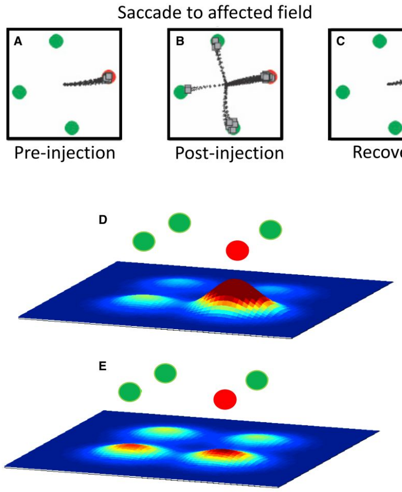
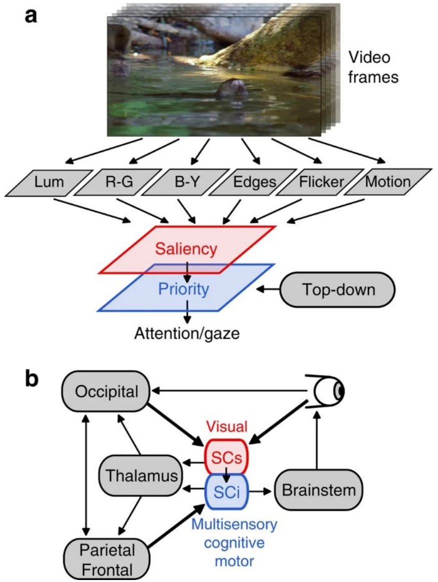


“Saliencey map” models predict fixations when free-viewing a scene and are encoded in SC activity



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“Top-down” contributions to eye movements

Salience models do cannot account for
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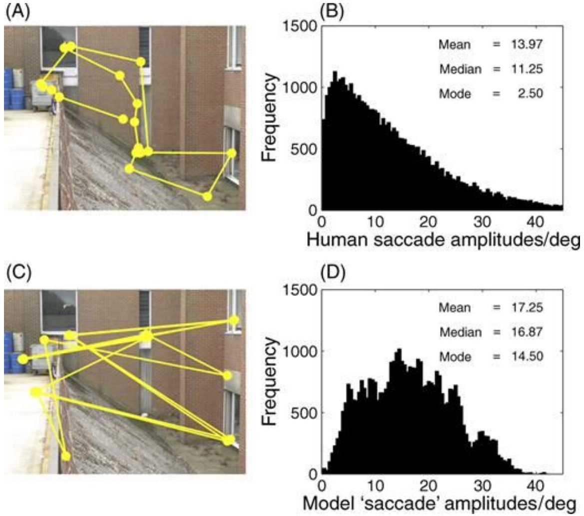

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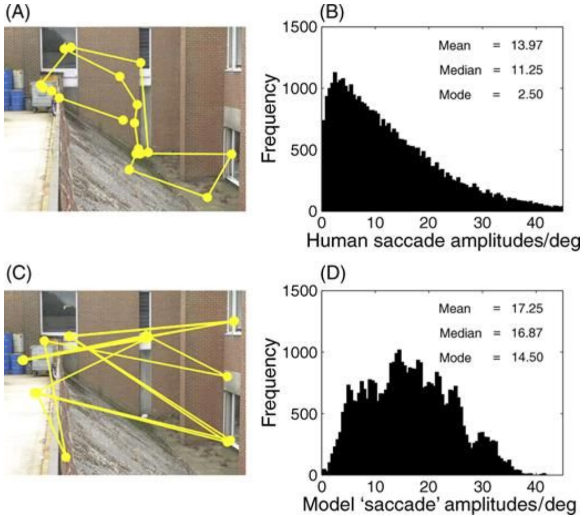
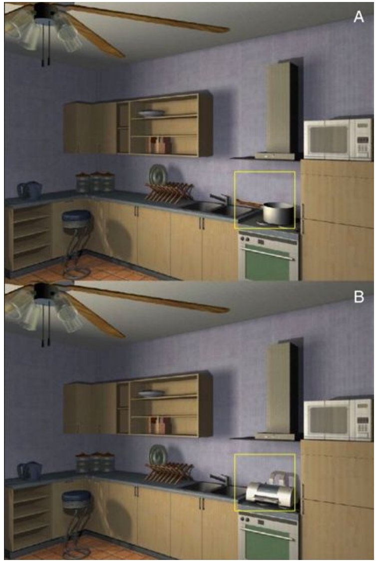
While performing a task, our expectations determine where we look in the scene.





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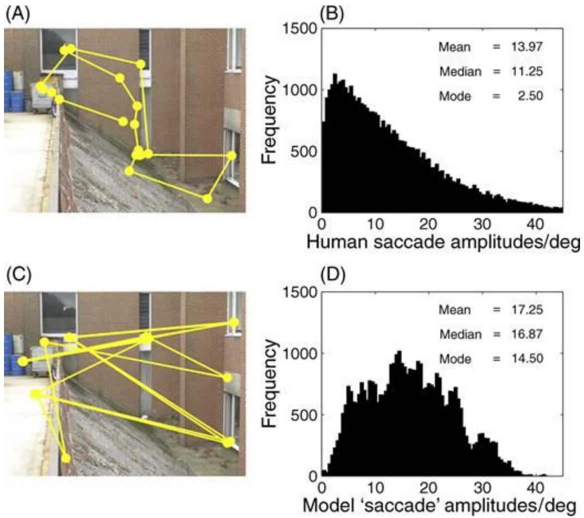

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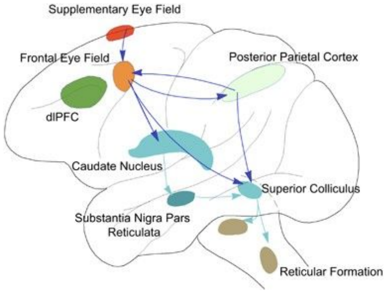

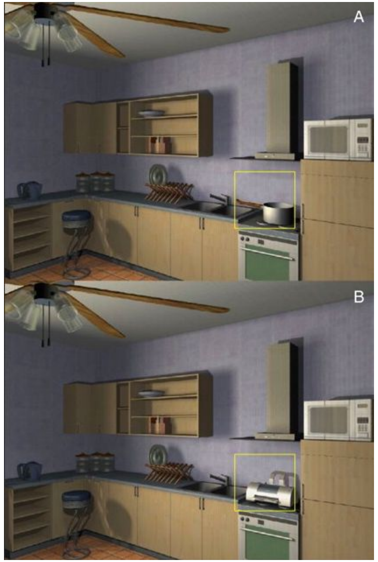

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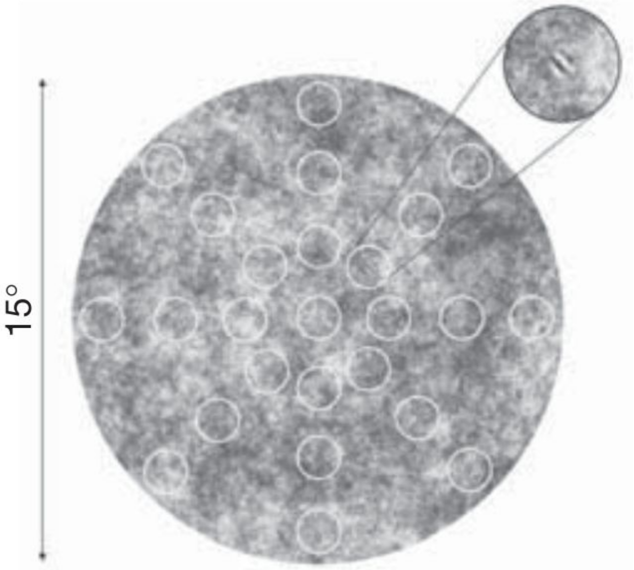
Modeling human visual search

Optimal eye movement strategies in visual search

Jiri Najemnik & Wilson S. Geisler



Najemnik & Geisler (Nature, 2005)

Modeling human visual search

1) Extract a visibility map

2) Simulate a Bayesian searcher

3) Compare simulated searchers to human data

Najemnik & Geisler (Nature, 2005)

1) Quantifying visibility: the psychophysics toolkit

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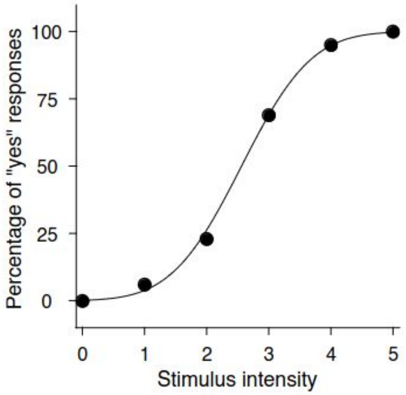
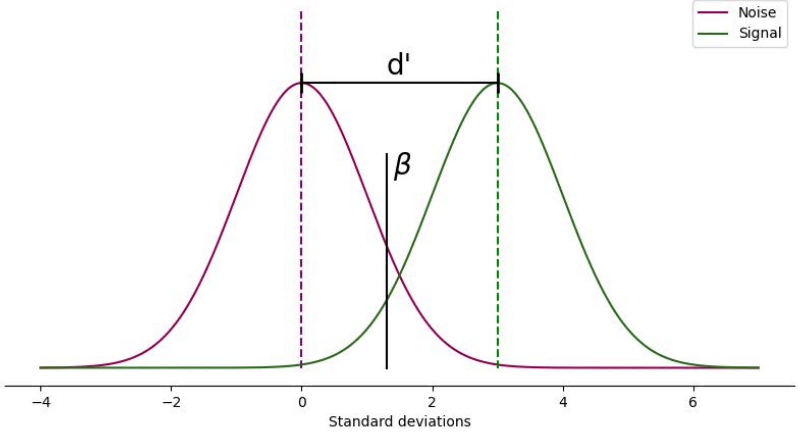
Psychometric functions



$$\psi = \gamma + (1 - \gamma - \lambda) \cdot F(x; \alpha, \beta)$$

Signal detection theory



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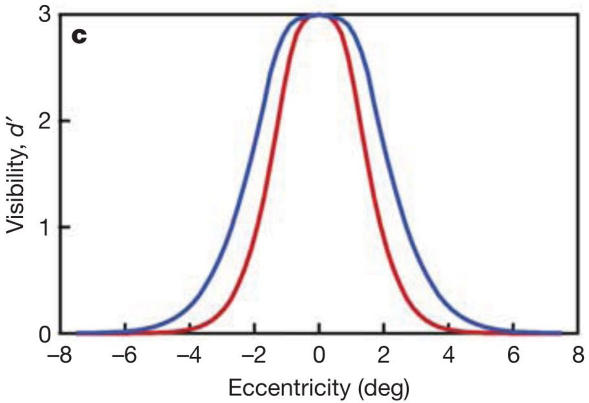

3) Compare simulated searchers to human data

Najemnik & Geisler (Nature, 2005)

2) Where to look next: Bayesian search

1) **Compute sensory evidence** for each point in space by multiplying a hypothetical visual response with the visibility function

2) Where to look next: Bayesian search

$$P(H \mid E) \propto P(E) \cdot P(E \mid H)$$

$P(H \mid E)$

“posterior” → probability that the target is at a particular location, given the sensory evidence

$P(E \mid H)$

“likelihood” → probability of the sensory evidence, given the hypothesis about the target location

$P(E)$

“prior” → probability of the target being at the particular location

2) Where to look next: Bayesian search

a) **Compute sensory evidence** for each point in space by multiplying a hypothetical visual response with the visibility function

b) **Combine the sensory evidence with prior knowledge** using Bayes' law to get the posterior probability of the target for all locations in space

c) **Check if the criterion for identifying the target is met** by comparing the posterior probabilities to a threshold

d) **Make a saccade to a new location** by…?

Modeling human visual search

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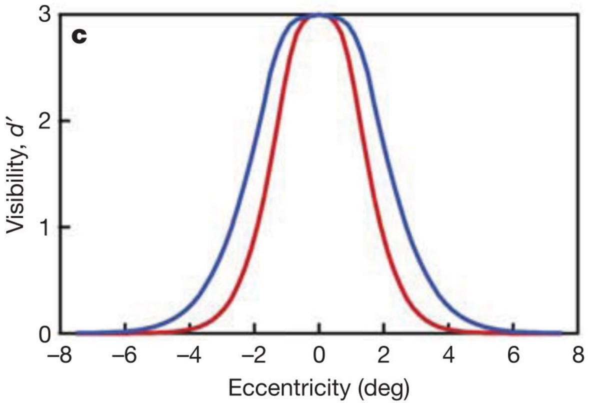

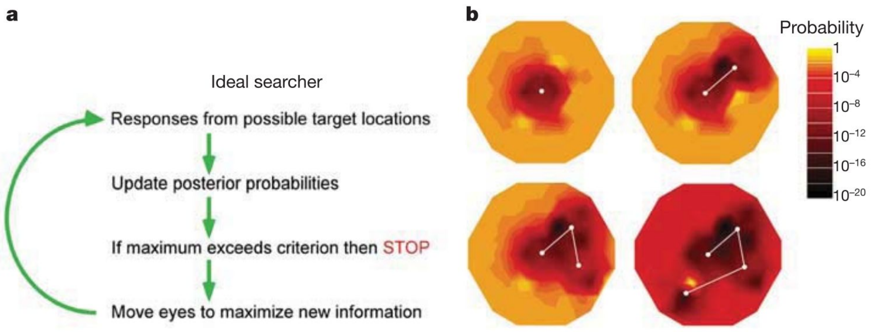

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Modeling human visual search

Characteristics of the Bayesian searcher:

(✅) Parallel information processing for all locations in space

(❓) Perfect integration of information across fixations

(✅) Uses saccades to actively explore the visual space

- (✅) ‘Inhibition of return’ / moderate length saccades
- (✅) ‘Center-of-gravity saccades’
- (❓) ‘Exclusion saccades’