Spatiotemporal normalization incentivizes selective attention across space and time

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Background

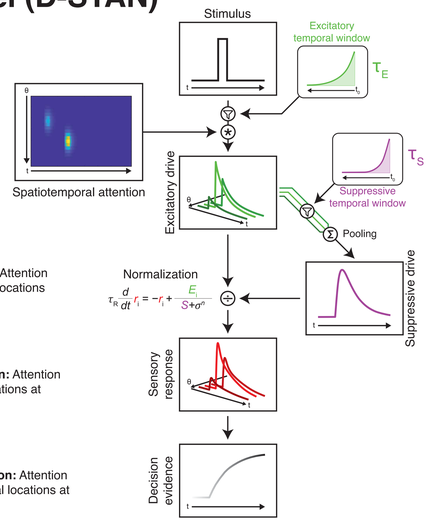
- Visual attention can be deployed to spatial locations[1] or points in time[2], enhancing processing of attended information and impairing processing of unattended information
- Such tradeoffs are thought to reflect competition among stimuli for limited attentional resources[3]
- Normalization-based models implement attention by enhancing neural excitation prior to divisive suppression[4], but do not explain why tradeoffs arise

Question

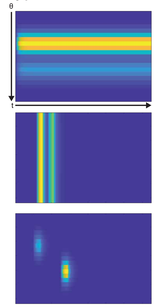
Can normalization incentivize trade-offs in attentional allocation without appeal to an explicit limited resource?

Dynamic Spatiotemporal Attention and Normalization Model (D-STAN)

D-STAN[5] is a computational model with sensory and decision layers consisting of model neurons that undergo attentional modulation and normalization, producing responses in real time



Types of attentional modulation

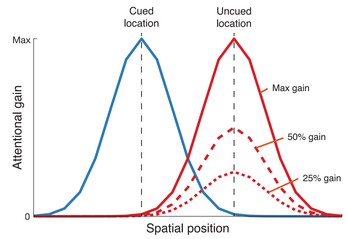


Pure spatial attention: Attention enhances some spatial locations over others

Pure temporal attention: Attention enhances all spatial locations at specific points in time

Spatiotemporal attention: Attention enhances specific spatial locations at specific points in time

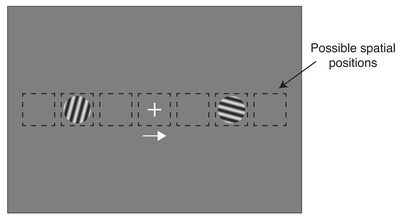
Modulating attentional gain



- Attentional gain was always maximum for the cued location or time
- Attentional gain to the uncued location/time was varied from zero to maximum.

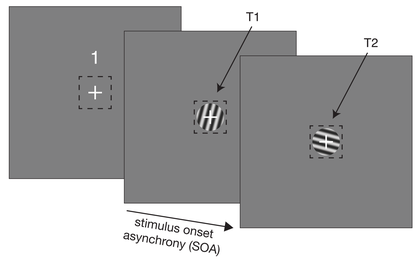
Attentional cueing tasks

Spatial attention task



- Two stimuli were presented simultaneously for 50 ms equidistant from the central fixation
- One location was cued with 75% validity
- Performance was measured by model evidence for CW vs CCW judgements

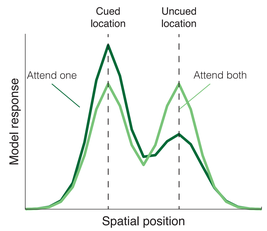
Temporal attention task



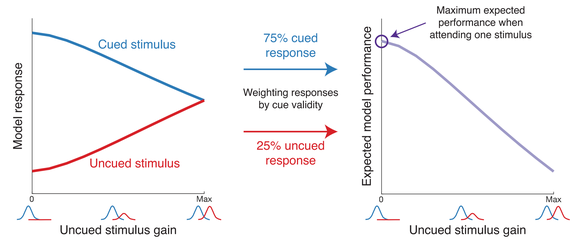
- Two stimuli were presented sequentially for 50 ms at fixation
- One timepoint was cued with 75% validity

Trade-offs in attention across space

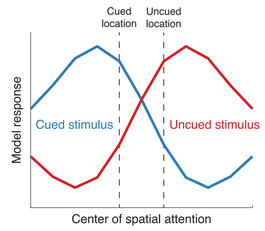
Optimal gain allocation under normalization leads to focused attention



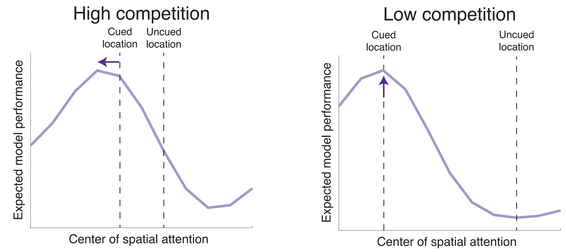
- Attending the uncued location reduces responses to the cued stimulus due to normalization
- Model performance is maximized when attending only to the cued stimulus



Optimal focus of attention shifts under high spatial competition

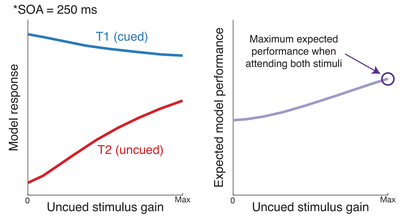


- Spatial proximity induces competition between stimulus responses
- Competition results in biased attention away from the cued location to maximize performance, consistent with prior findings[6,7]



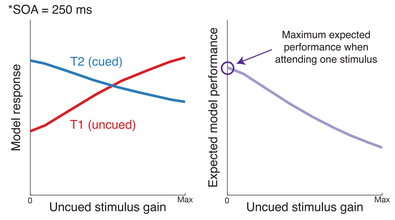
Trade-offs in attention across time

Cueing T1 allows attention to both stimuli



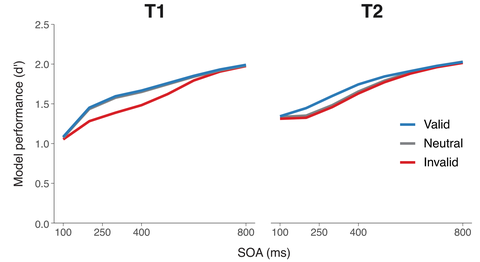
- Attending to the uncued time only slightly decreases responses to the cued time
- Model performance is maximized by attending fully to both times

Cueing T2 promotes focused attention at that time



- Attending the uncued stimulus decreased responses to the cued stimulus
- Model performance is maximized by attention only the cued time

Attentional trade-offs over time depend on temporal competition



- We manipulated temporal competition between stimuli by varying the SOA
- Optimal attention settings were identified for each SOA
- Attentional trade-offs were observed for a range of intermediate SOAs (200-500 ms), consistent with empirical findings[8]

Conclusions

- Normalization with an optimal attention policy leads to attentional trade-offs across space and time, despite no limited resource
- Optimal allocation of attention depends on the degree of stimulus competition
- **Normalization suffices to incentivize selective spatial and temporal attention**

References

1. Carrasco (2011). Vis Res, 51, 1484-1525.
2. Denison (2024). Nat Rev Psychol, 3, 261-274.
3. Desimone, Duncan (1995). Ann Rev Neurosci, 18, 193-222.
4. Reynolds, Heeger (2009). Neuron, 61, 168-185.
5. Chapman, Denison (2025). PLoS Biol, 23(12), e3003546.
6. Chapman, Chunharas, Störmer (2023). Sci Rep, 13, 6487.
7. Mehrpour, Martinez-Trujillo, Treue (2020). Nat Comm, 11, 2128.
8. Denison, Heeger, Carrasco (2021). Nat Hum Behav, 5, 1674-1685.

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