The Normalization Model of Attention Extended to Realistic Dynamics and Stages of Processing

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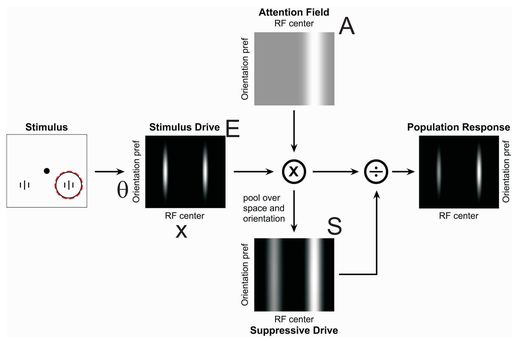
Normalization Model of Attention
Reynolds&Heeger 2009



$$R(x,\theta) = | [A(x,\theta)E(x,\theta)] / [S(x,\theta) + \sigma] |$$
$$S(x,\theta) = s(x,\theta) * [A(x,\theta)\,E(x,\theta)]$$

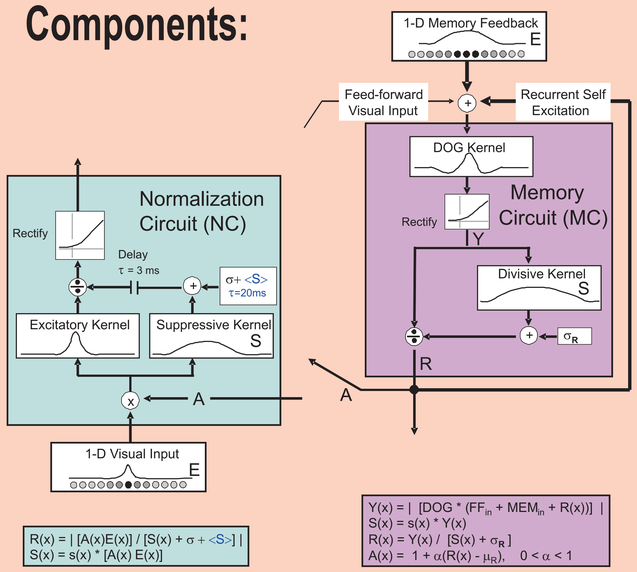
This earlier model explains most forms of attention-dependent modulation of rate:

1) competive interactions within the RF
2) shifts in the contrast response curve
3) multiplicative gain of the constrast response and of the orientation tuning curve

Extended Model's Goals:

1) Realistic temporal response dynamics
2) Dynamics of attention / feedback signals
3) Extended to multiple layers of processing

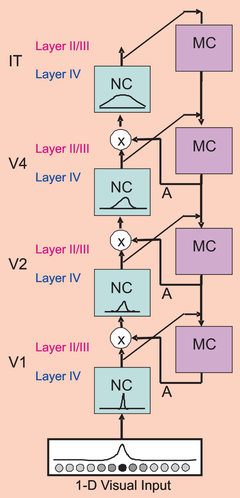
Extended Model's Components:



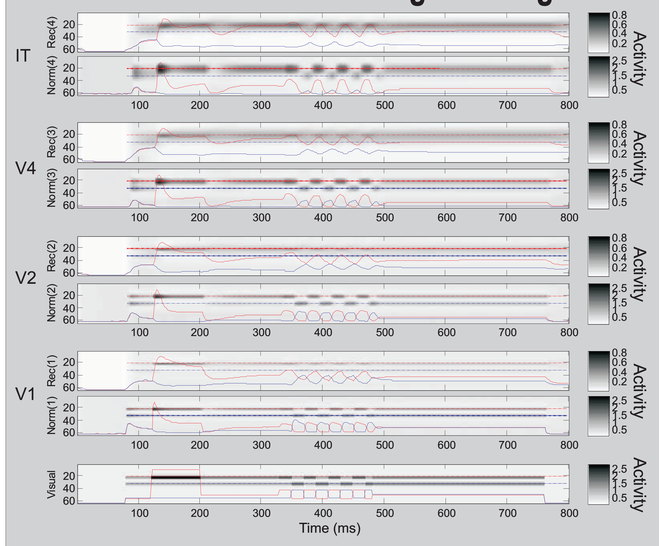
$$R(x) = | [A(x)E(x)] / [S(x) + \sigma + \langle S \rangle] |$$
$$S(x) = s(x) * [A(x)\,E(x)]$$

$$Y(x) = |\ [DOG * (FF_{in} + MEM_{in} + R(x))]\ |$$
$$S(x) = s(x) * Y(x)$$
$$R(x) = Y(x) / [S(x) + \sigma_R]$$
$$A(x) = 1 + \alpha(R(x) - \mu_R), \quad 0 < \alpha < 1$$

Extended Model's Layered Architecture:



The extended model filters out responses to non-atteded stimuli at its highest stages:



See caption to the right panel for figure format

The extended normalization model tracks attended stimuli through brief visual interruptions/occlusion:

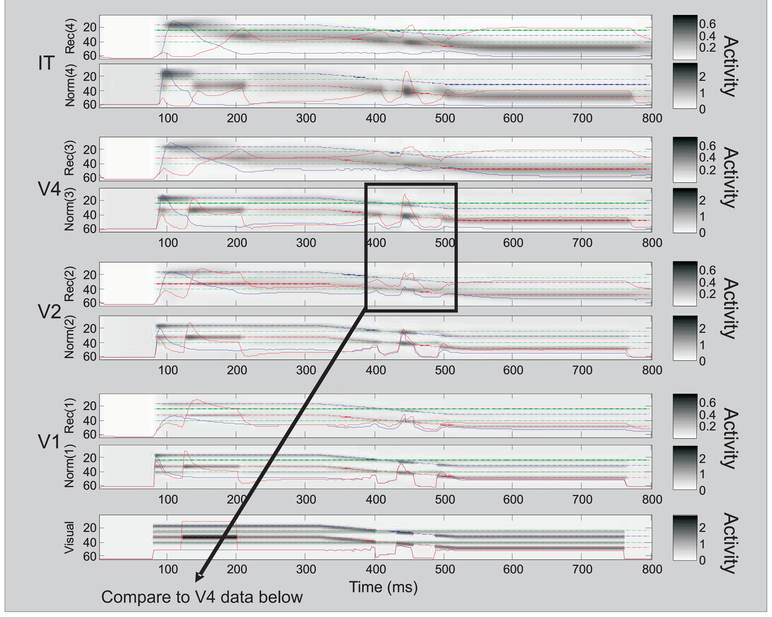
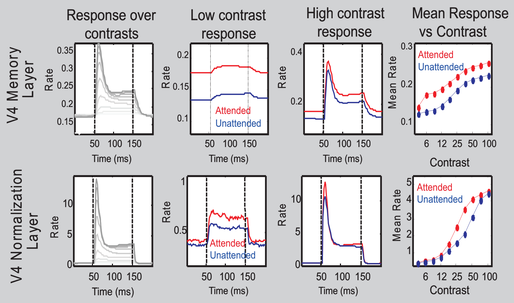


Figure format:

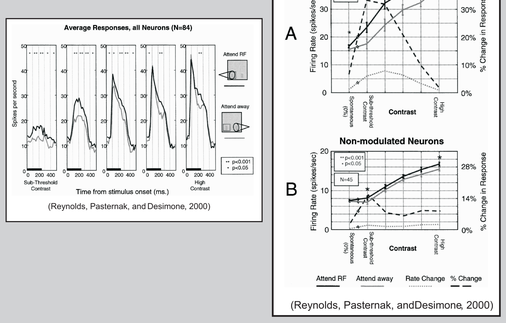
The activity of each array in the layered model is depicted across time (x axis) and spatial location (y axis) for the Input, V1, V2, V4, and IT normalization and memory arrays in gray scale (activity legend on right). Superimposed on the activity arrays the trace for two select locations are shown in red and blue (locations marked by dashed red and blue lines in the arrays). Each trial begins with the presentation of two targets in the input, after which one target is cued by a contrast increase resulting in that location being selected by the highest memory layer as the attended target. To the left, location is fixed over the trial and both targets are temporally modulated. Above, the targets remain stationary and then move behind two occluding targets (green dashed lines).

Realistic response dynamics to stimuli varying in contrast:

Model:

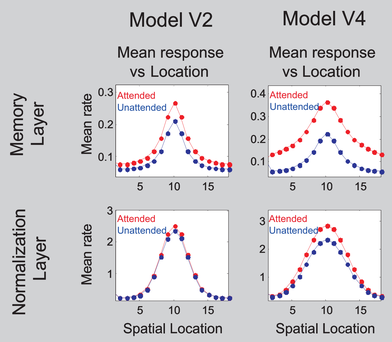


Data:

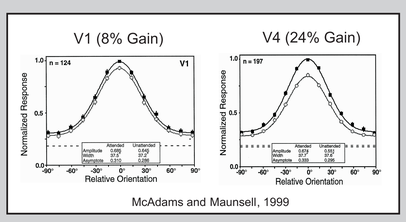


Exhibits multiplicative gain for an attended stimulus alone in the RF:

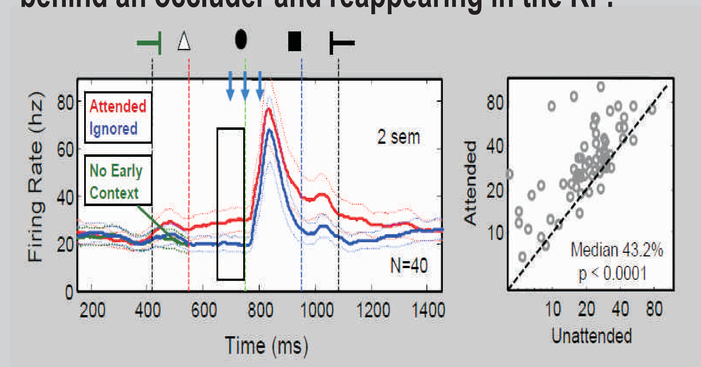
Model:



Data:



Mean V4 neuronal response to target moving behind an occluder and reappearing in the RF:



Conclusions

1) Exhibits realistic modulation of temporal responses for different contrast stimuli
2) Exhibits progressively stronger attention modulation from lower to higher areas.
3) Predicts more additive changes in rate in cortical layers II/III (memory circuits) vs gain changes in layer IV (normalization circuit).

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References

1. Reynolds JH and Heeger DJ (2009) The normalization model of attention. Neuron 61(2):168-85.
2. Mitchell JF and Zipser D (2003) Sequential memory-guided saccades and target selection: a neural model of the frontal eye fields. Vision Res. 43(25):2669-95.