Binocular Rivalry: Waves, Hysteresis & Perceptual Memory

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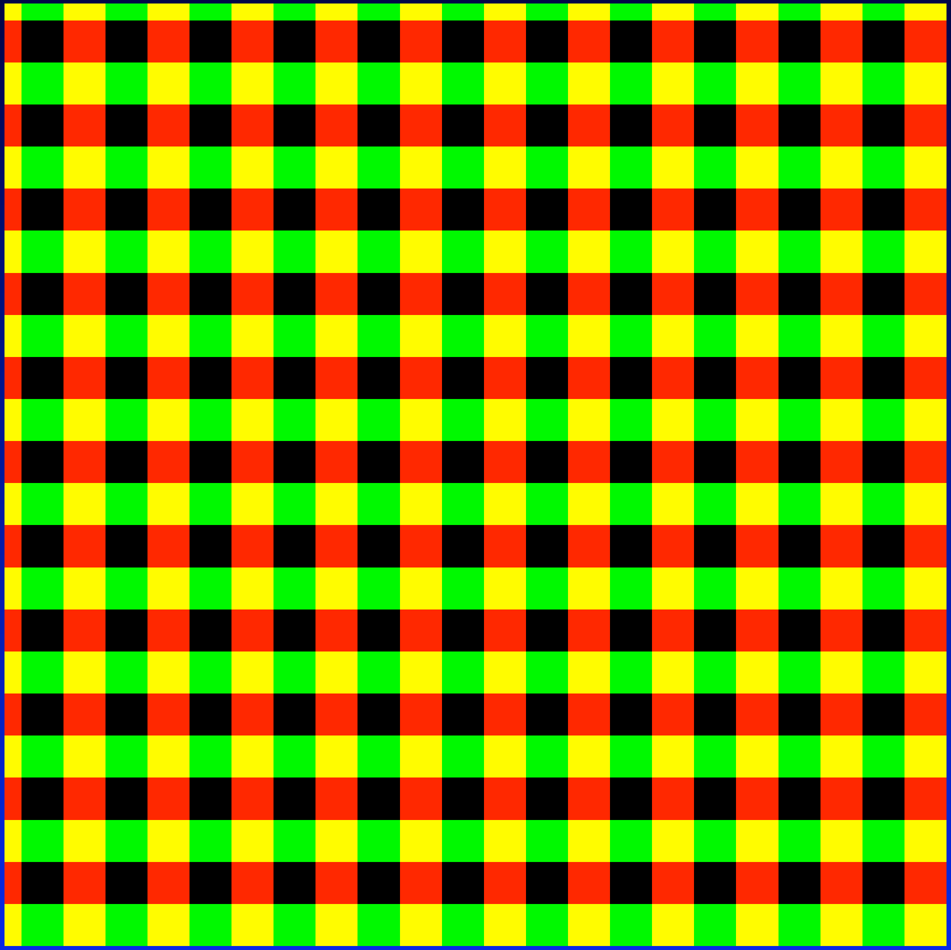
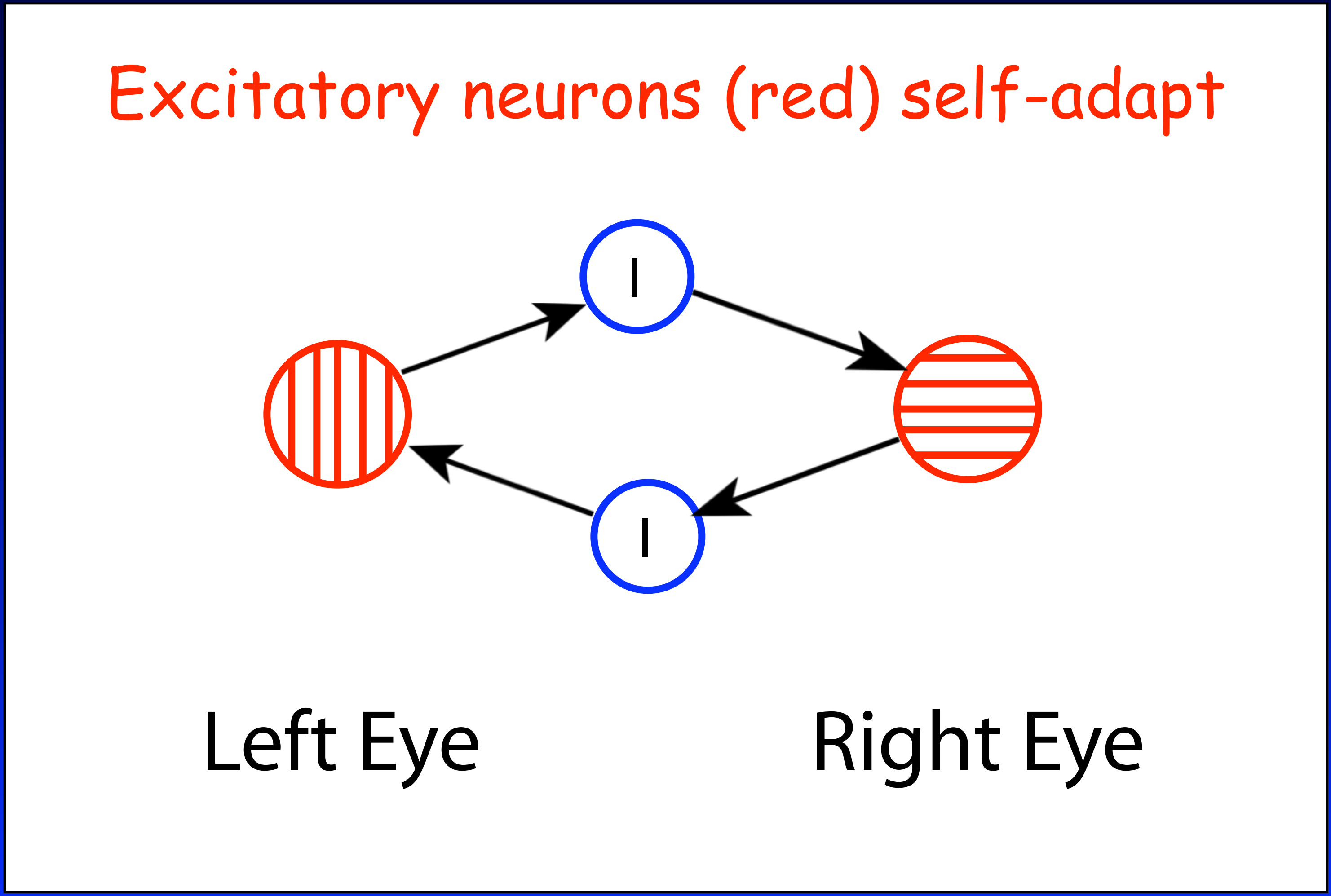
History of Binocular Rivalry

- Porta (1593): "Place a partition between the eyes, to divide one from the other, and place a book before the right eye, and read; if another book is placed before the left eye, not only can it not be read, but the pages cannot even be seen, unless the visual virtue is withdrawn from the right eye and changed to the left."

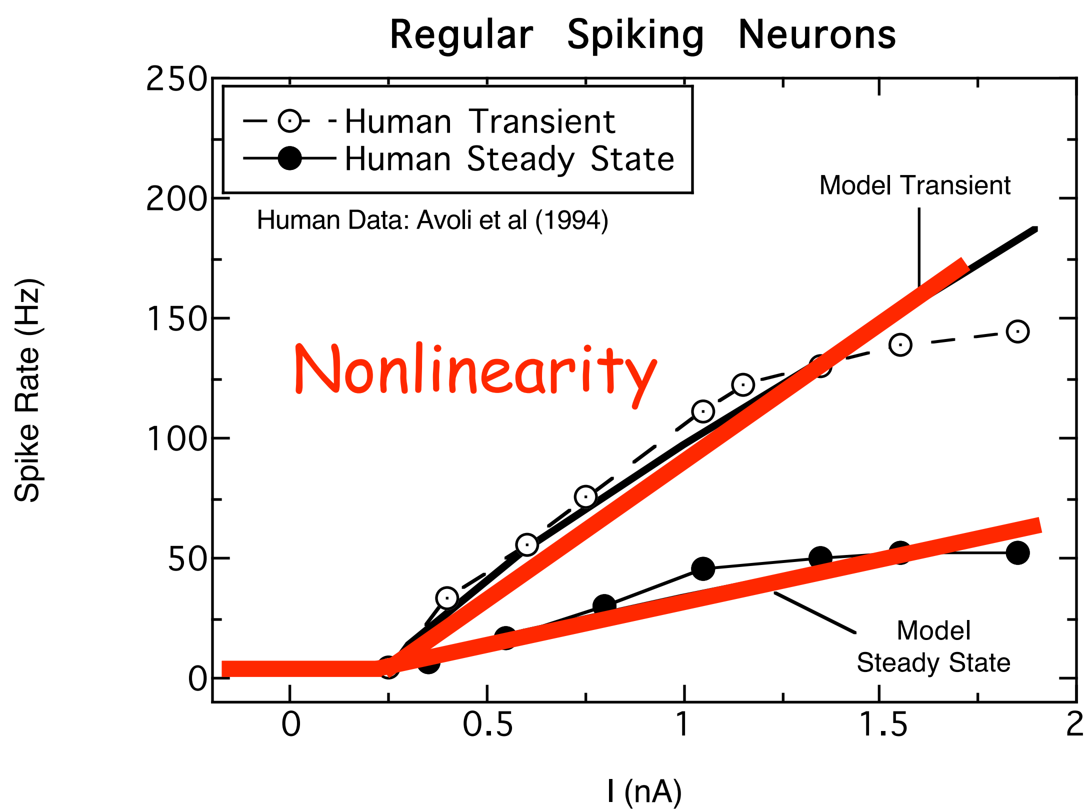
Large Field Binocular Rivalry



Simplest Rivalry Network



Model Firing Rates



Simplified Rivalry Model

$$\tau \frac{dE_L}{dt} = -E_L + [L - a E_R - g H_L]_+$$

$$\tau_H \frac{dH_L}{dt} = -H_L + E_L$$

$$\tau \frac{dE_R}{dt} = -E_R + [R - a E_L - g H_R]_+$$

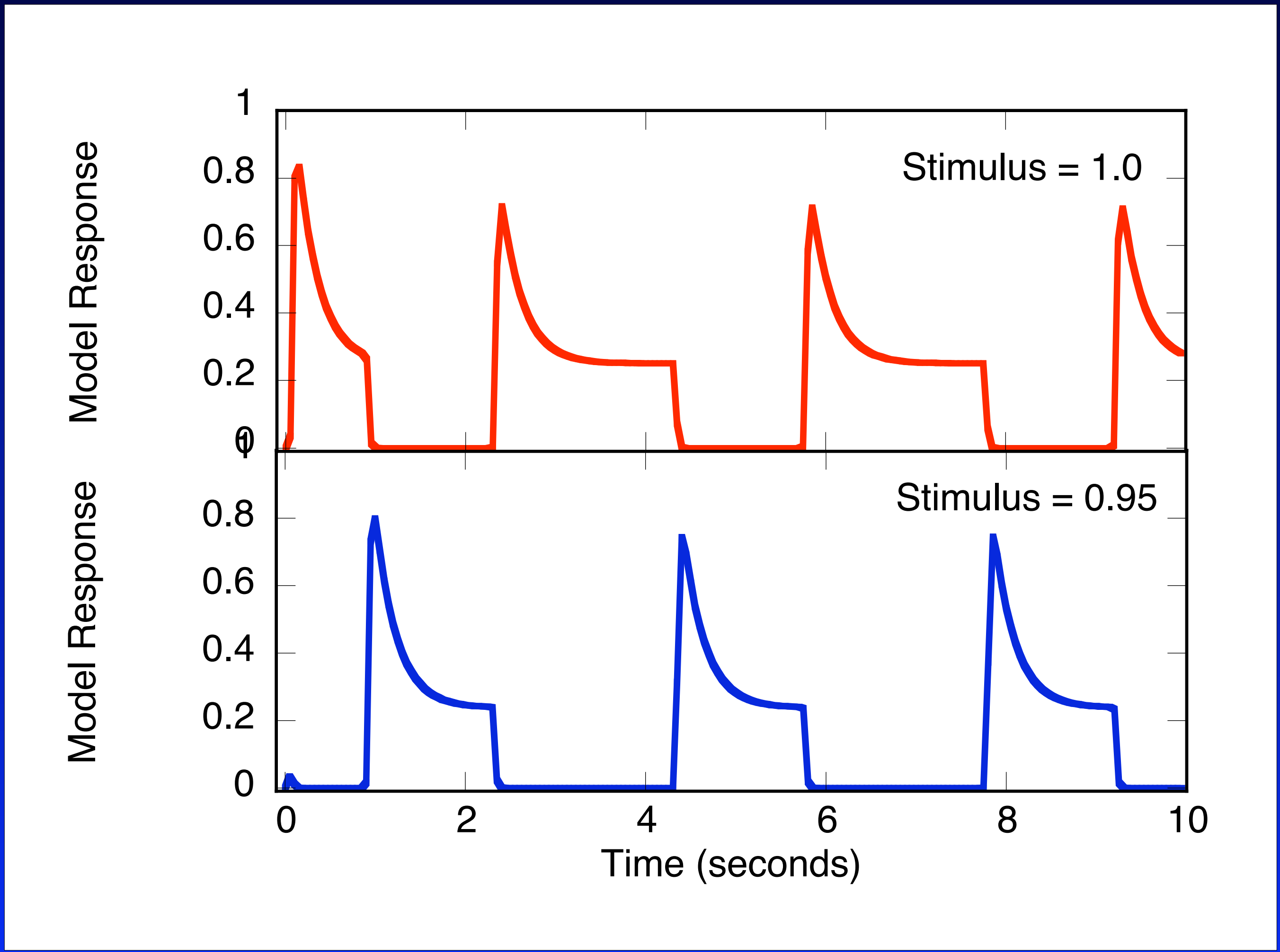
$$\tau_H \frac{dH_R}{dt} = -H_R + E_R$$

- a: inhibition strength
- g: Ca++/K+ hyperpolarization
- $\tau_H \gg \tau$ (20 ms vs 900 ms)

Requirements for Oscillation

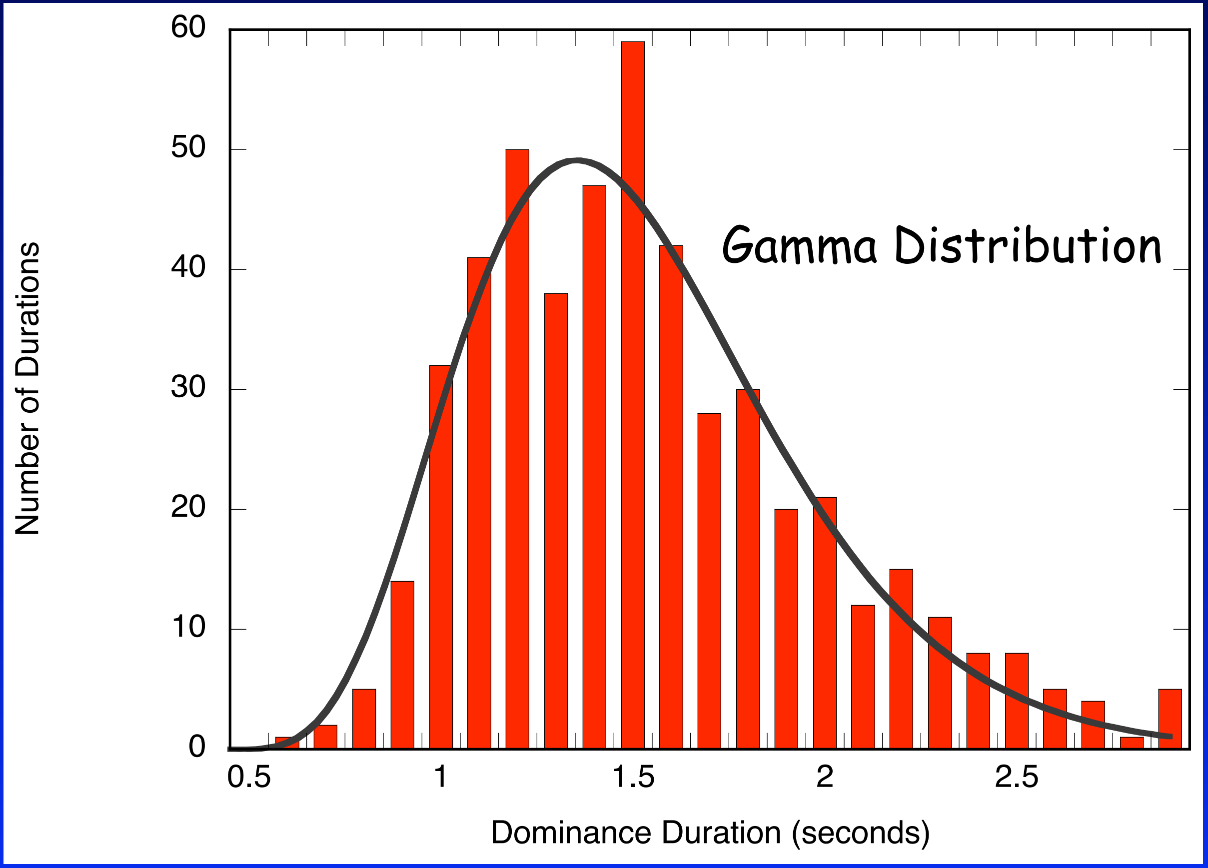
- Inhibition strong so $E1 = E2$ is unstable
- $a > 1$
- Self-adaptation strong to release suppressed neuron from inhibition
- $g > a - 1$

Two Neuron Alternation



Spike Rate Model with Noise

- Add noise to dH/dt equations in model
- Distribution fit by gamma or lognormal



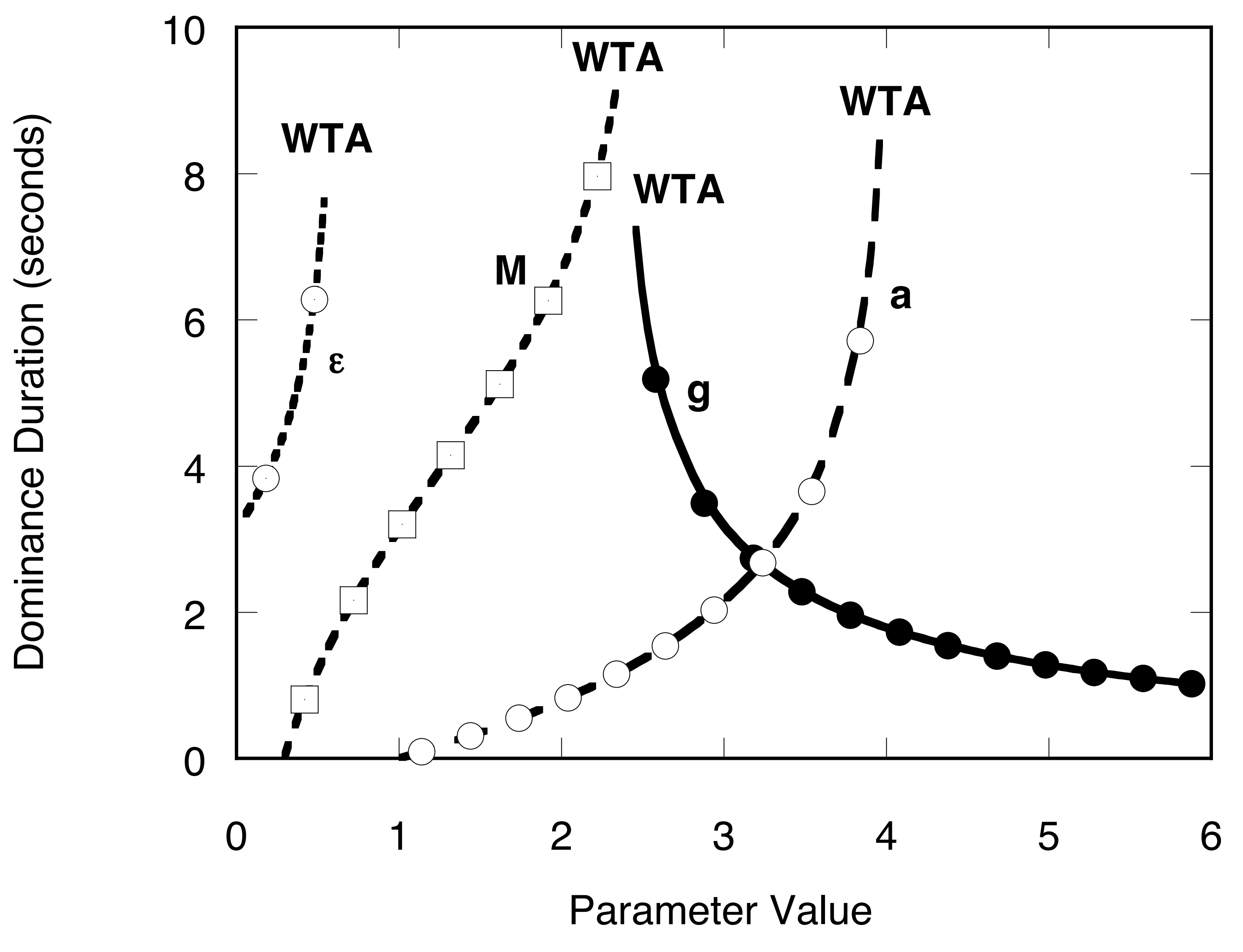
Solution for Dominance Durations

- Approximation: neurons fully self-adapt during dominance

$$T_L = \tau_H \ln\left(\frac{g}{1/M + g - a\,L/R}\right)$$

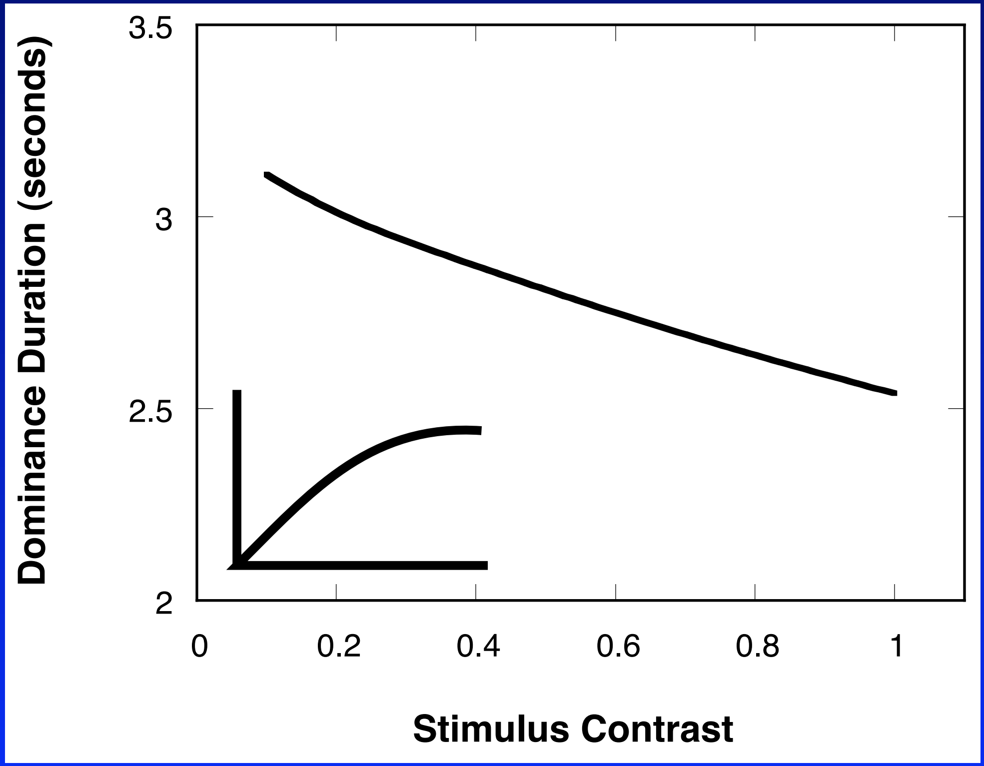
Reciprocal ratio for other eye

Effects of Rivalry Parameters

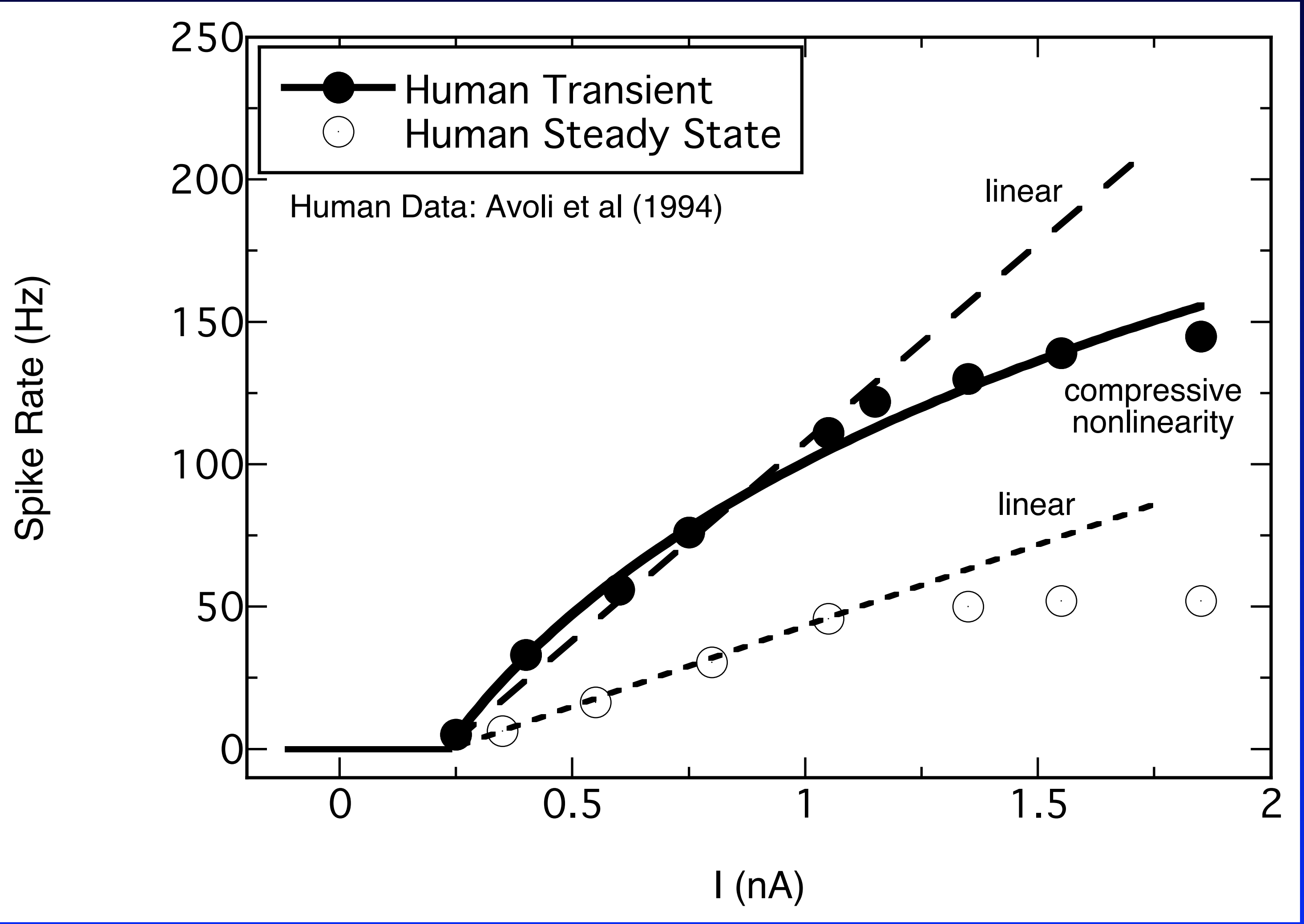


Levelt's 4th Law

- Dominance durations shorten as contrast increases
- Compressive nonlinearity: average M decreases with increasing contrast

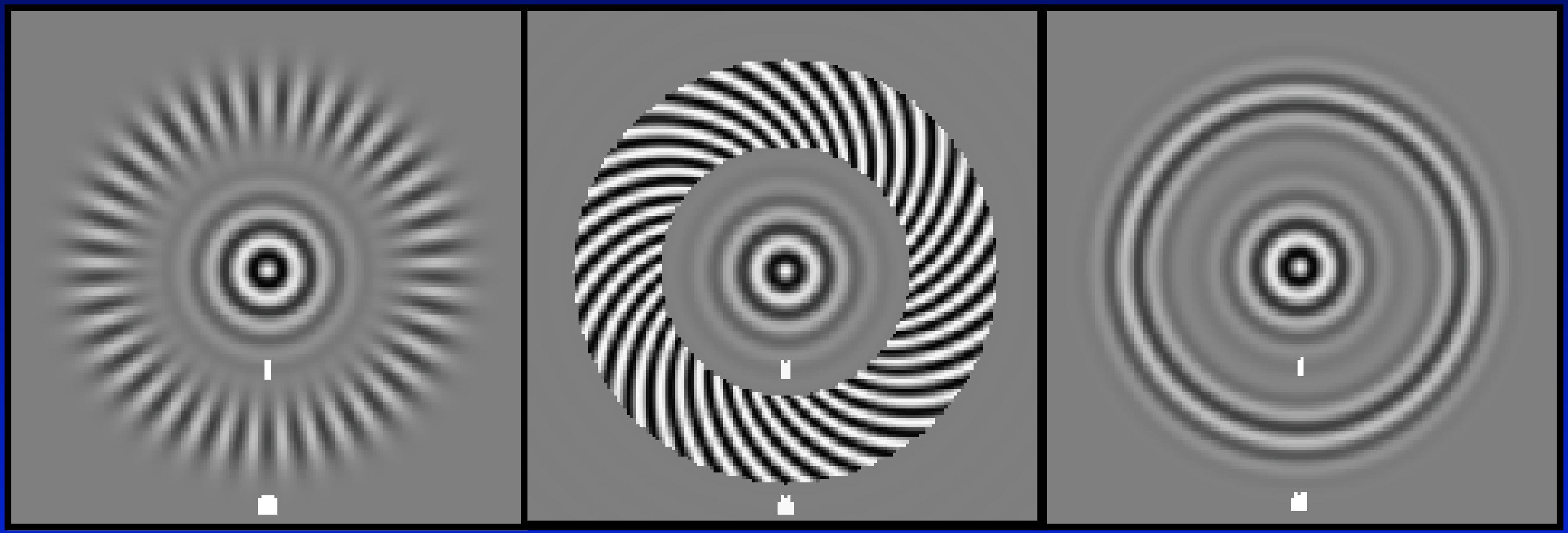


Compressive Nonlinearity



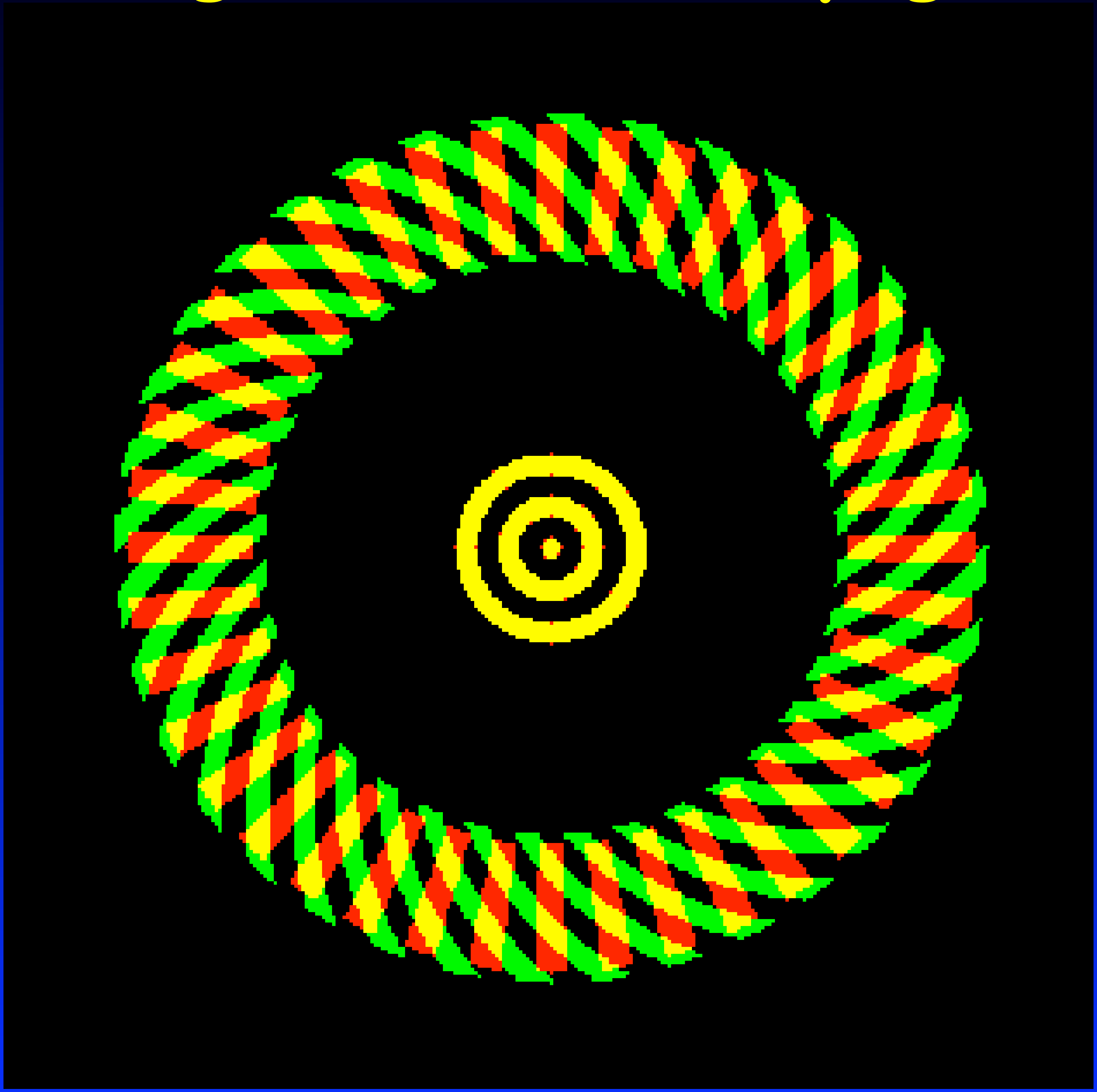
Stereogram

a

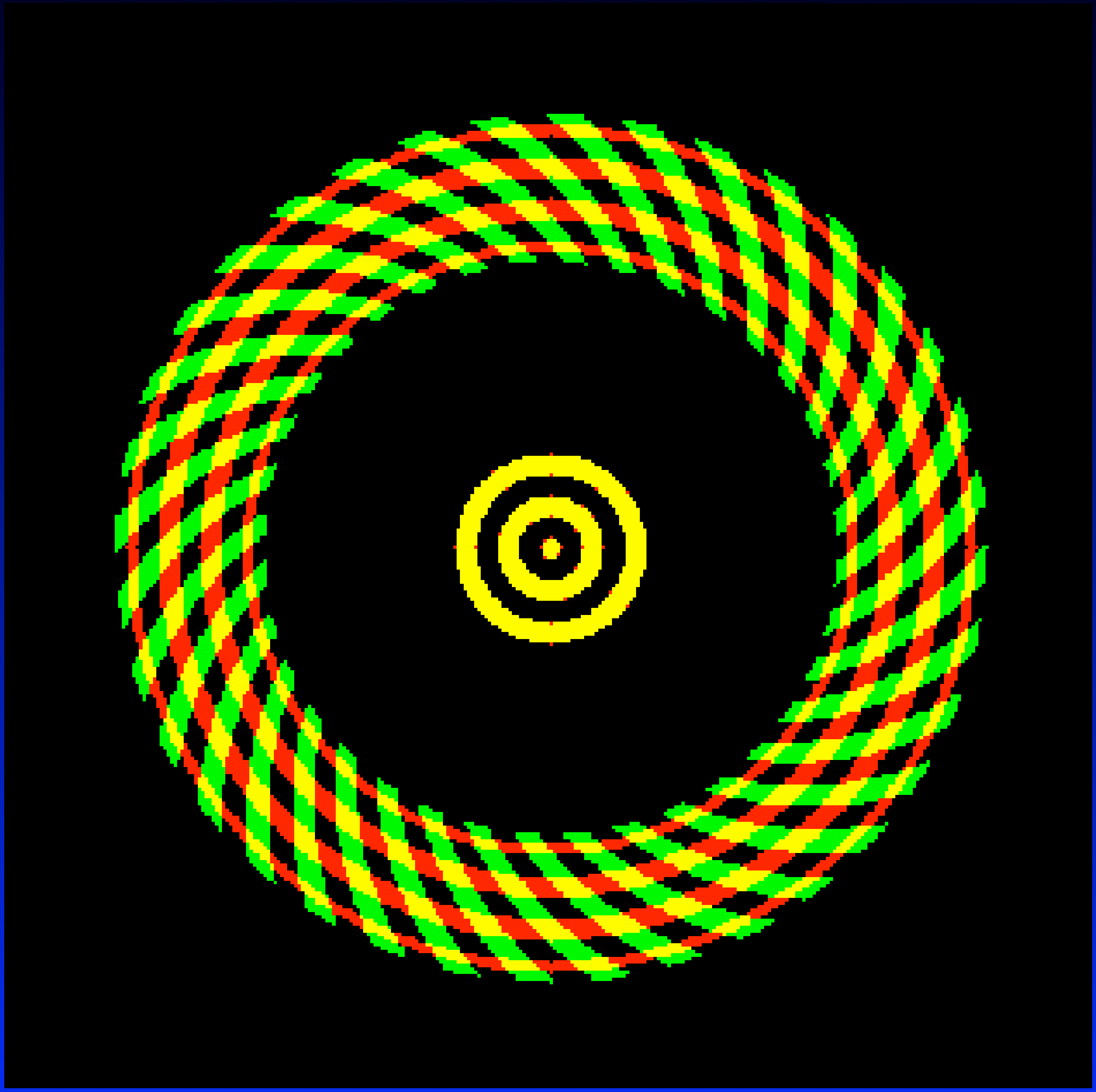


Wilson, Blake & Lee, Nature, 2001

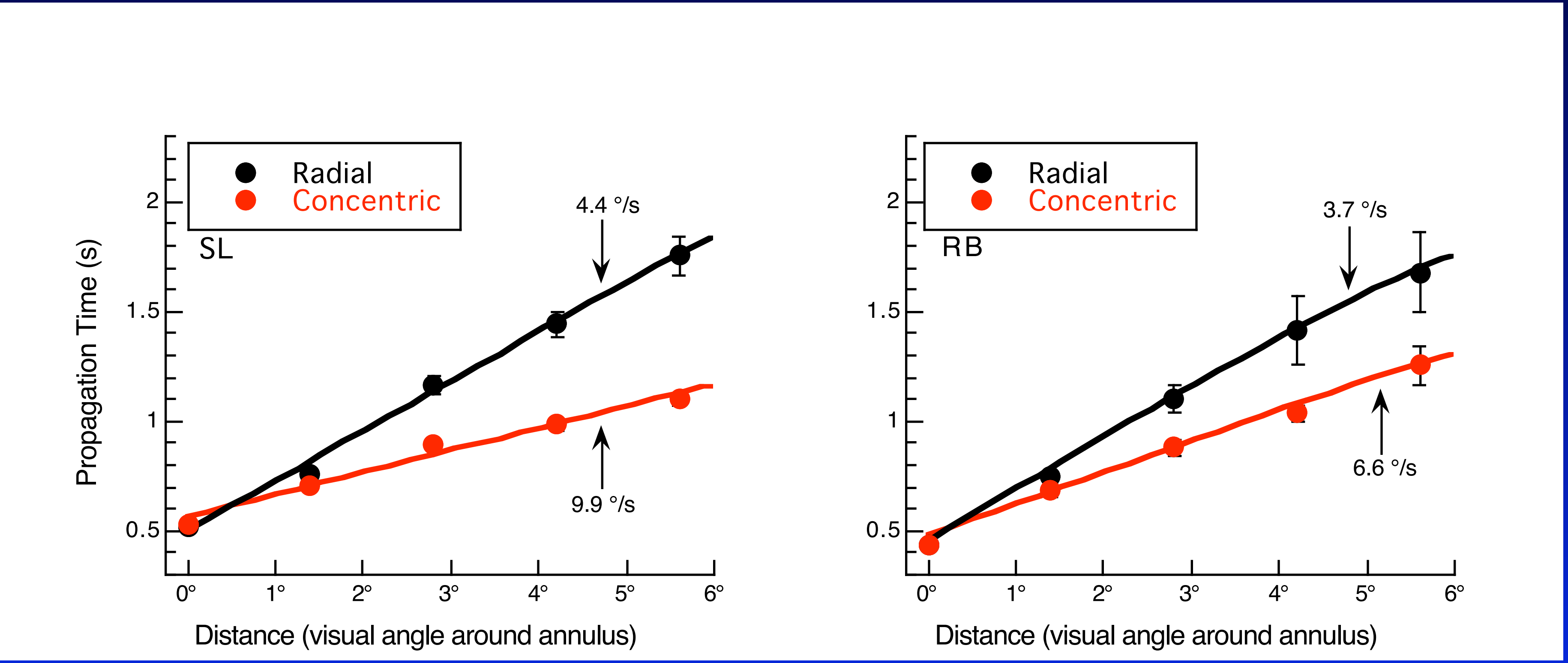
Orthogonal Wave Propagation



Collinear Wave Propagation

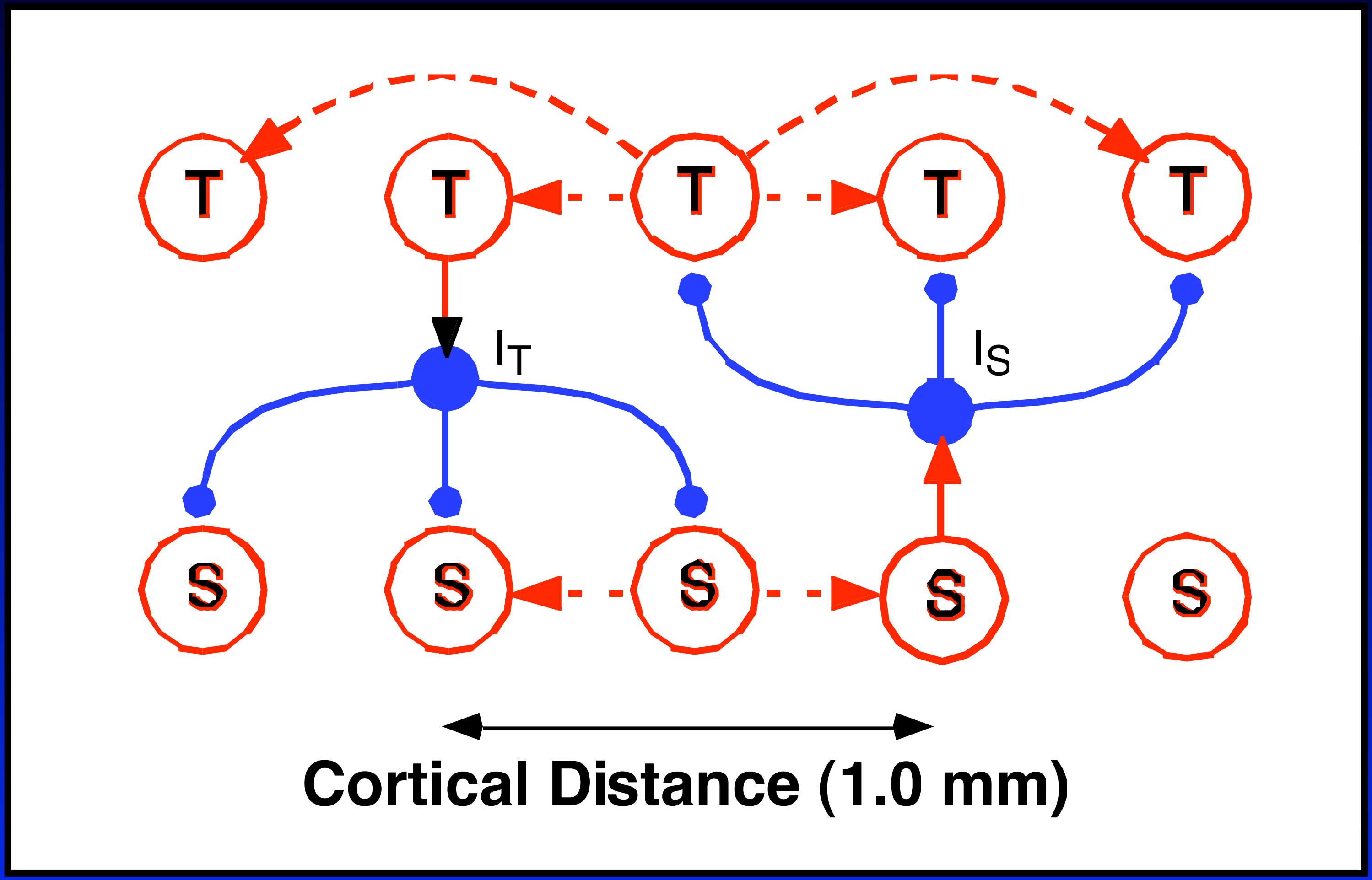


Results



Collinearity doubles propagation speed!

Model Schematic



Short range inhibition, long range weak excitation

Neural Model

- Two circular arrays of mutually inhibitory neurons: Spiral (S) & Target (T)
- Inhibition extends to adjacent ocular dominance columns (1.0 mm in humans, Hitchcock & Hickey, 1980)
- Excitatory neurons exhibit spike frequency adaptation
- Longer range excitatory connections for collinear facilitation only

Equations

$$\tau \frac{dT_n}{dt} = -T_n + \frac{100 P_+^2}{(10 + H_{Tn})^2 + P_+^2}, \qquad \tau = 20ms$$

where

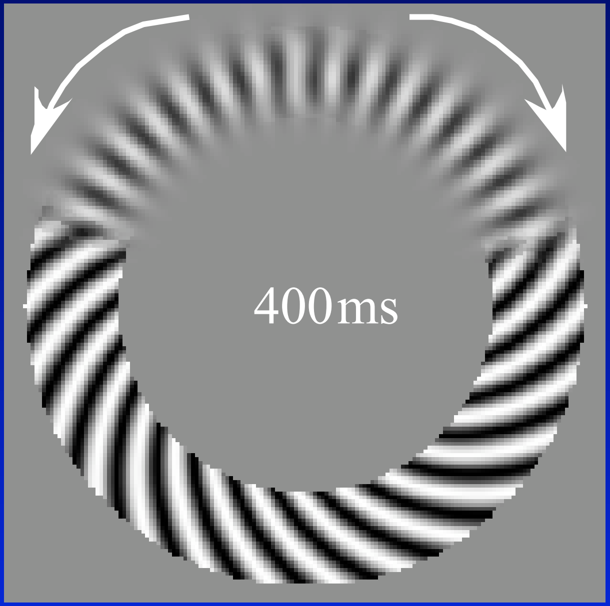
$$P = E_T - 0.27 \sum_k I_{Sk} \exp\left(-x_{nk}^5 / \sigma^5\right) + \underbrace{g \sum_{k \neq n} T_k \exp\left(-x_{nk}^5 / (2\sigma)^5\right)}_{\text{collinear facilitation term}}$$

Inhibition

$$\tau_I \frac{dI_{Tn}}{dt} = -I_{Tn} + T_n, \qquad \tau_I = 11ms$$

$$\tau_H \frac{dH_{Ln}}{dt} = -H_{Tn} + 2T_n, \qquad \tau_H = 900ms$$

Simulation Percept

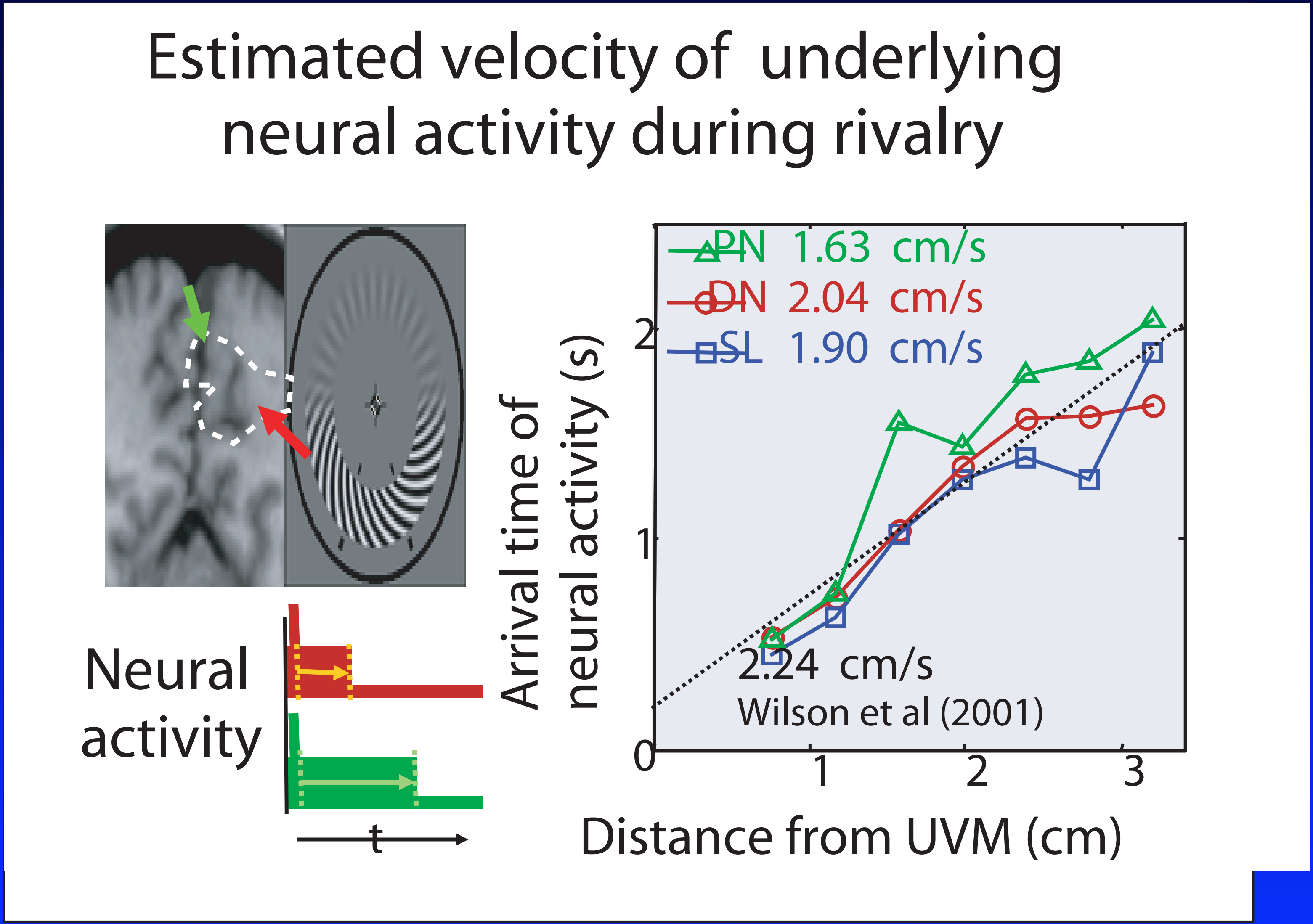


Simulation Results

- Radial pattern (no collinearity) produced wave speed of 2.24 cm/sec.
- Concentric pattern (collinear) produced wave speed of 4.48 cm/sec.
- Model reproduced gap-jumping results.
- Waves propagate by disinhibition.
- Must occur in retinotopic area (V1), NOT in higher visual cortical area

fMRI Evidence for Rivalry Waves

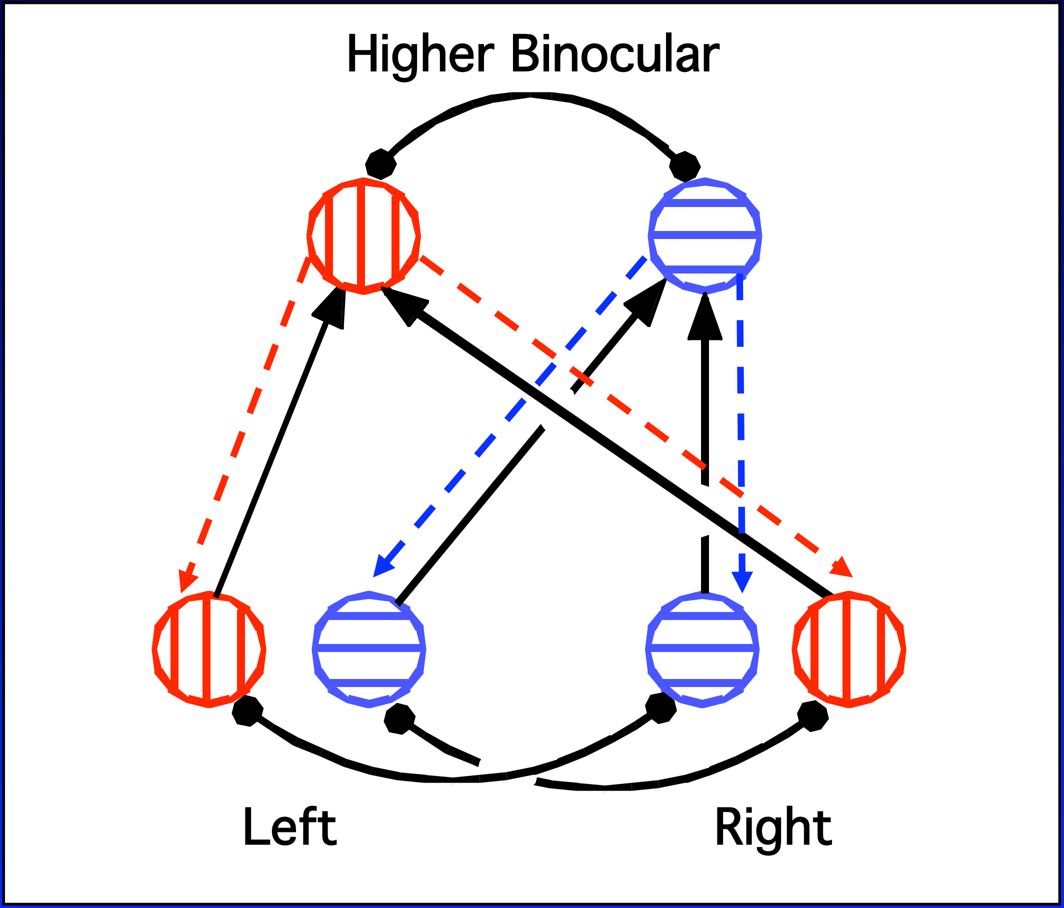
Lee, Heeger & Blake, Nat. Neurosci. 2005



Evidence for Rivalry Hierarchy Logothetis et al (1996)

- On/off flickered gratings at 18 Hz
- Swapped between eyes every 333 ms (1.5 Hz)
- Result: Mean dominance interval was 2.3 sec, equivalent to 7 eye switches
- **Cannot be explained by inter-ocular rivalry!**

Hierarchic Model



Weak positive feedback increases dominance duration 12%

Dynamical Synthesis (demo)

- There are two or more hierarchic stages at which rivalry occurs.
- Except in special circumstances V1 **Interocular Rivalry** dominates with un-fusable stimuli.
- By removing V1 inhibition dynamically, higher cortical rivalry is revealed.

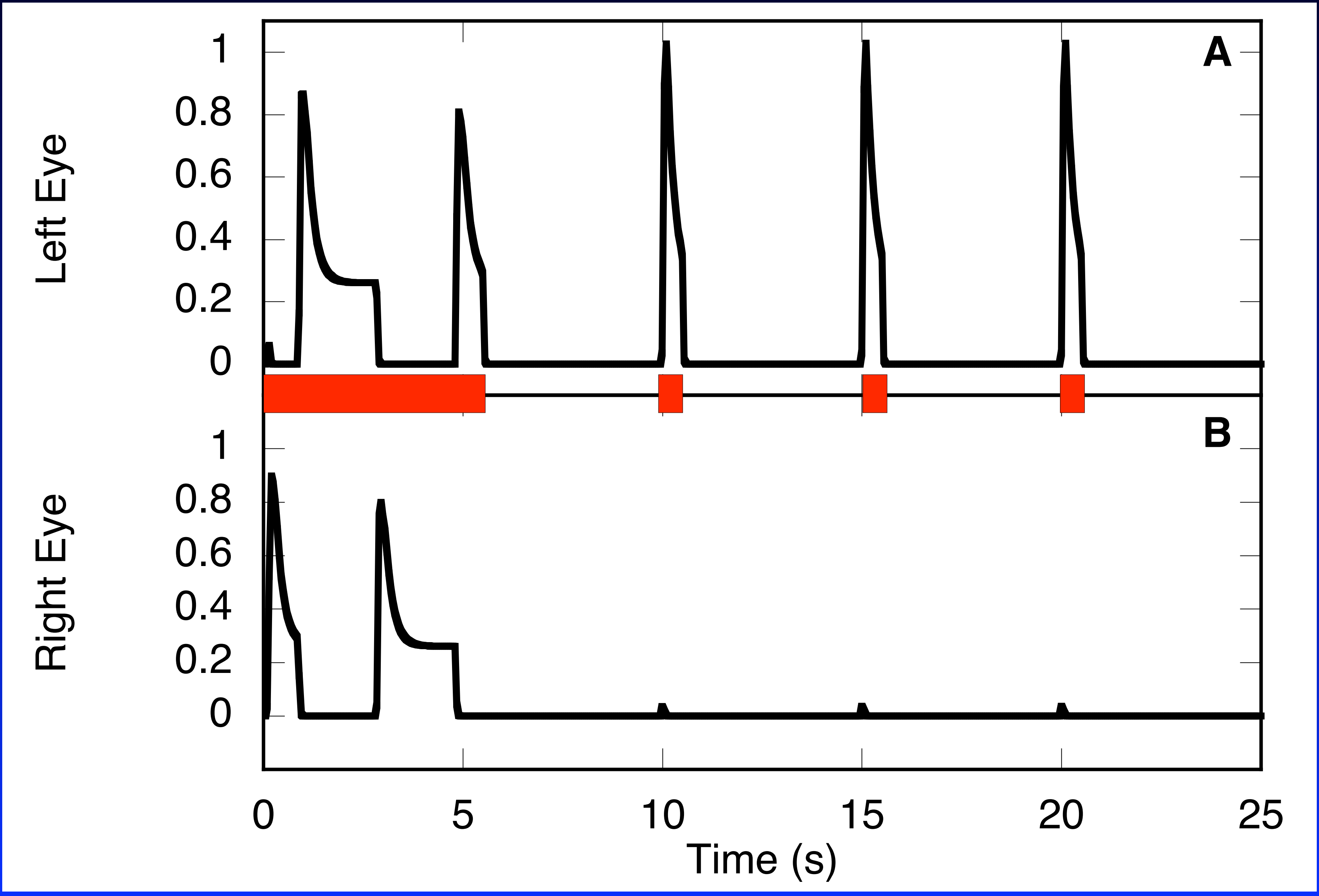
Perceptual Memory in Rivalry

- Within 0.7 sec after appearance of one monocular stimulus: switch off both stimuli
- Wait up to 5-6 sec with no stimuli
- When stimuli re-appear, same stimulus is dominant
- Repeat multiple times: same stimulus remainsdominant

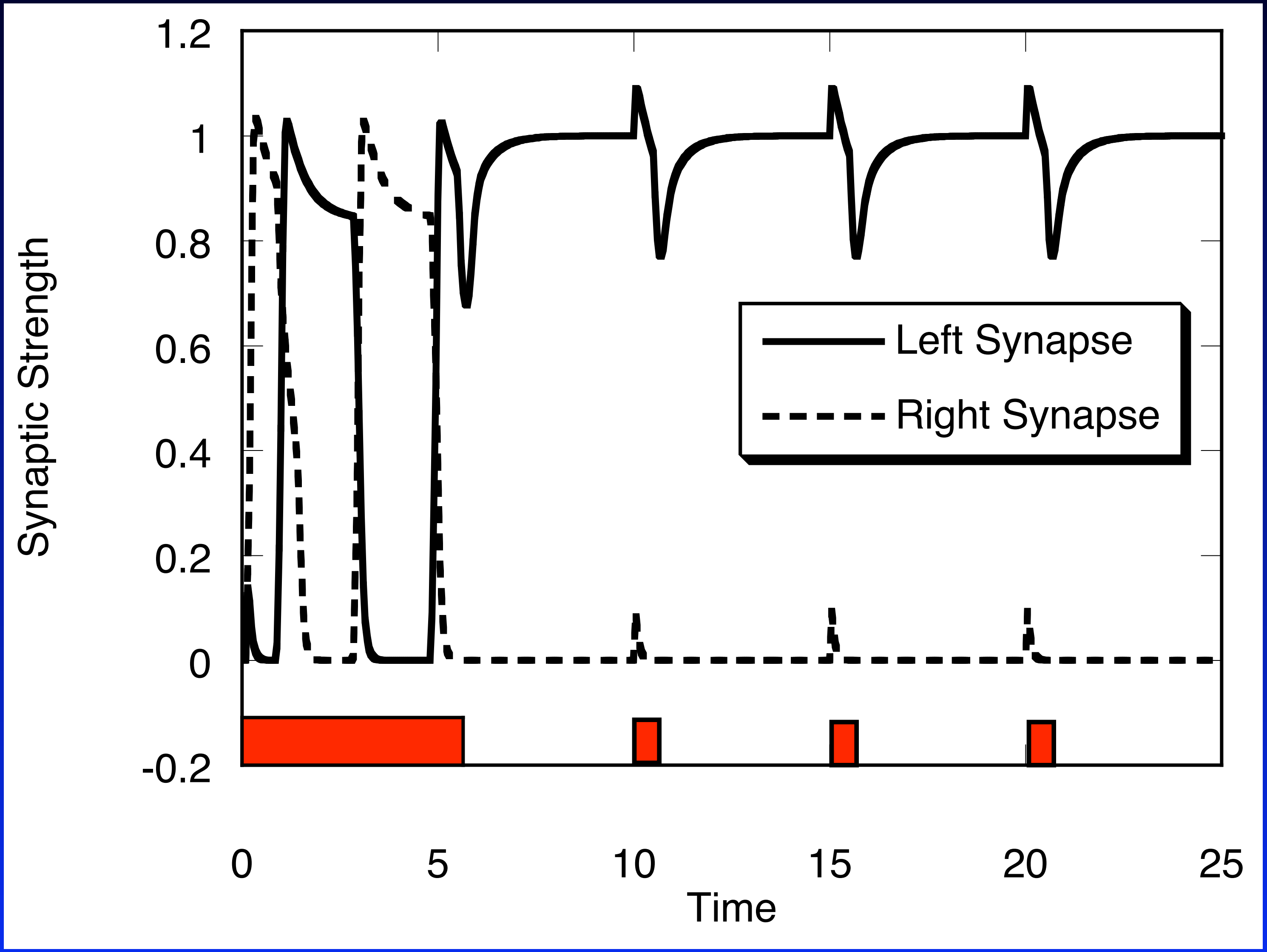
Model of Rivalry Memory

- Hypothesis: initial firing causes rapid & temporary augmentation of E-E synapses
- Could be due to rapid vesicle docking
- Synapse returns to normal state after about 2.0 sec. of firing

Perceptual Memory in Rivalry



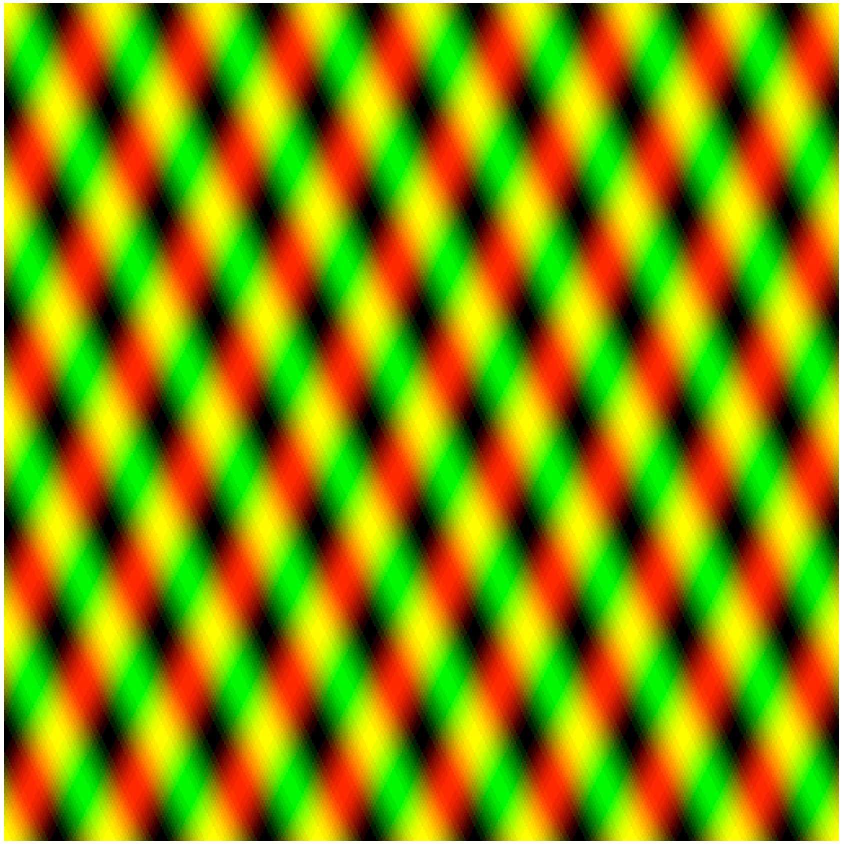
Perceptual Memory & Synapses



Hysteresis Experiments

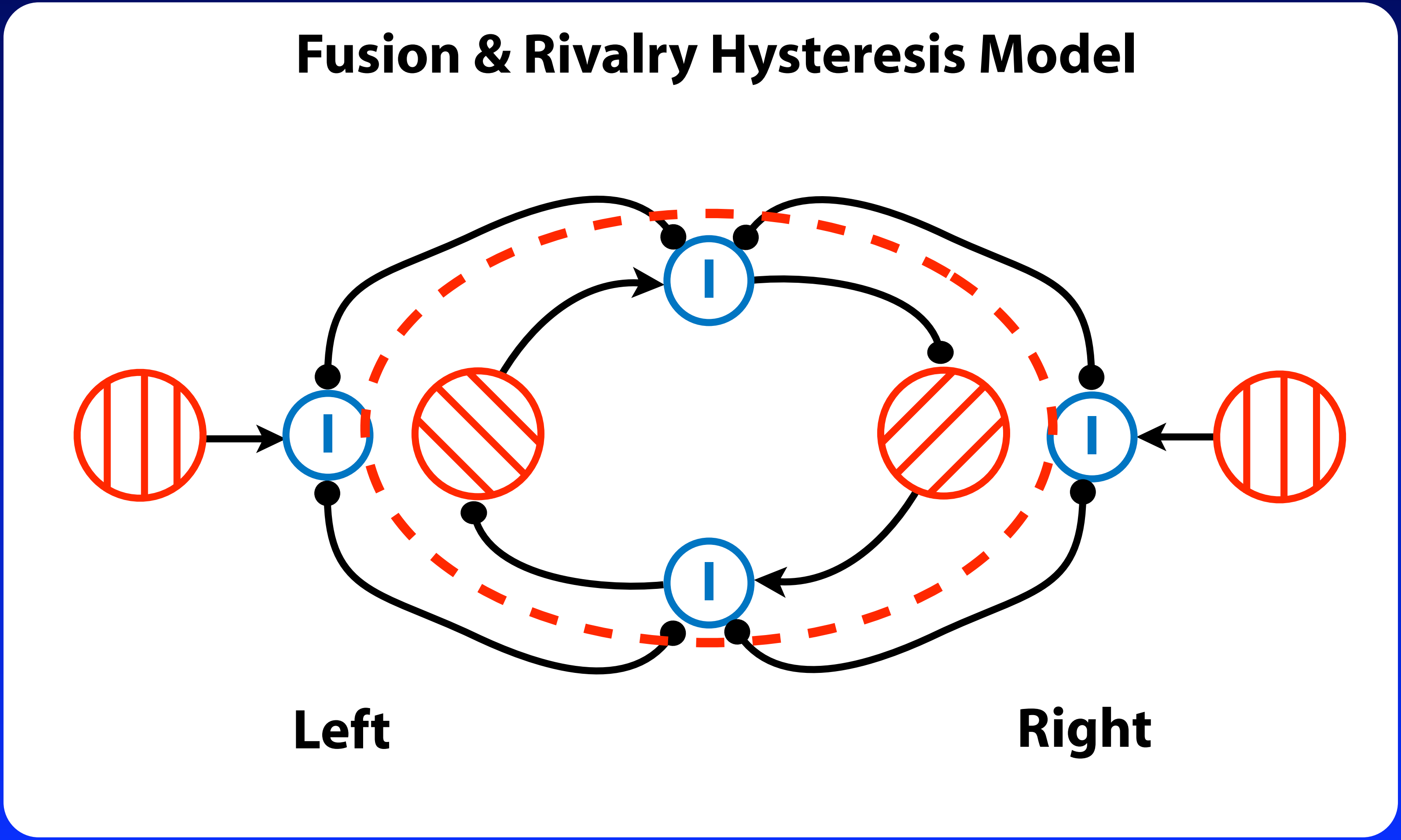
- Video of gratings rotating from vertical to ±20°
- Locate transitions from fusion & slant to rivalry

Hysteresis Stimuli

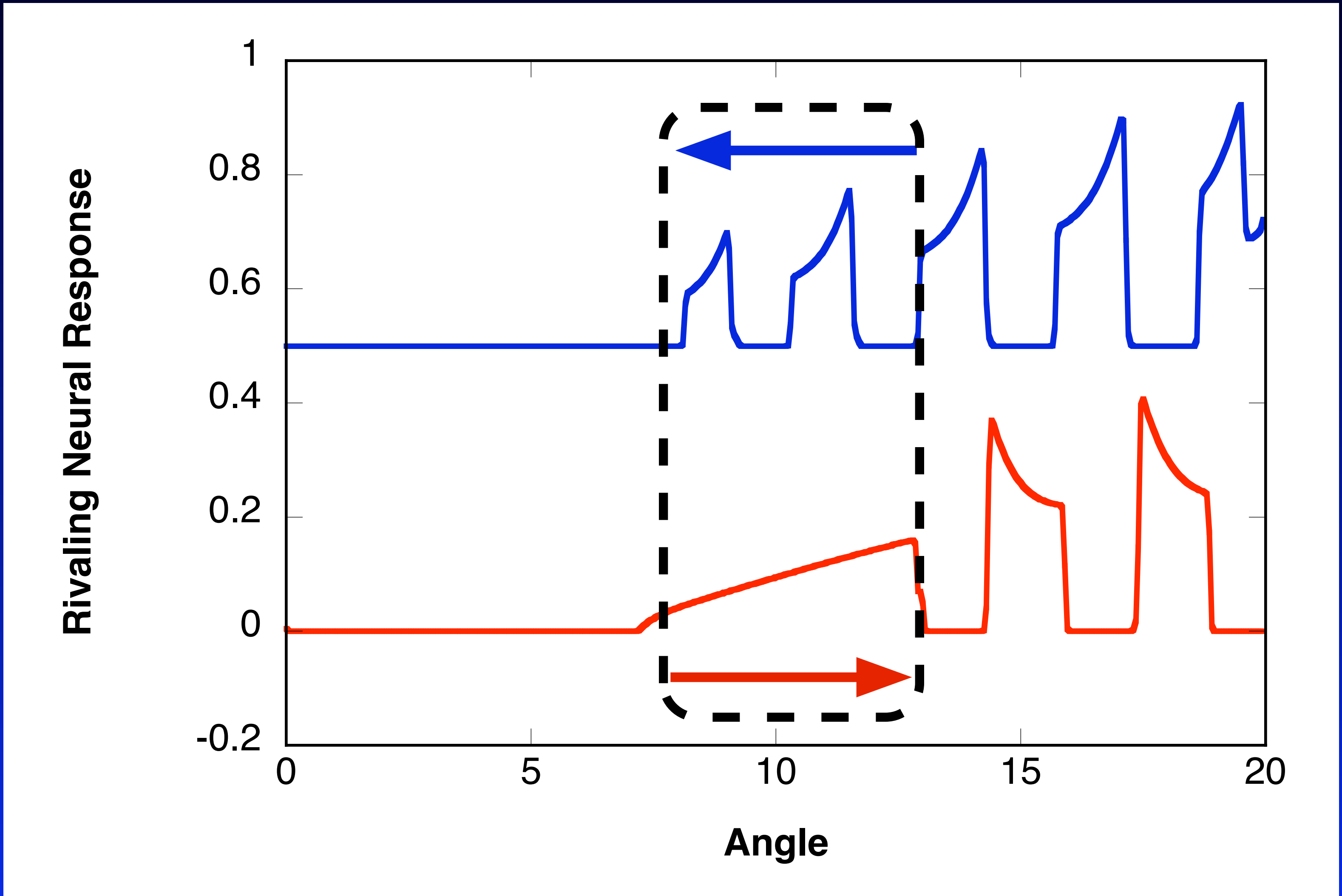


Hysteresis & Rivalry

- Combine rivalrous & fusible orientations
- Mutual inhibition reduces inhibitory strength



Model Rivalry Hysteresis



Predictions & Issues for Future

- Continued importance of simplified, spike rate (Wilson-Cowan) neural dynamics
- Complex multi-level feedback networks
- Multiple adaptation time constants
- Networks with partially random connectivity (Abbott, Sompolinsky)

Thank You!