Is attentional gain modulation optimal at gamma frequencies?

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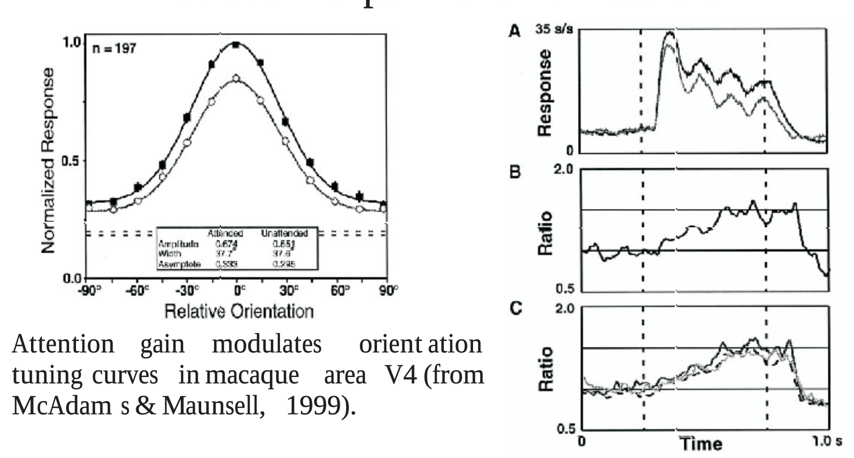
Introduction

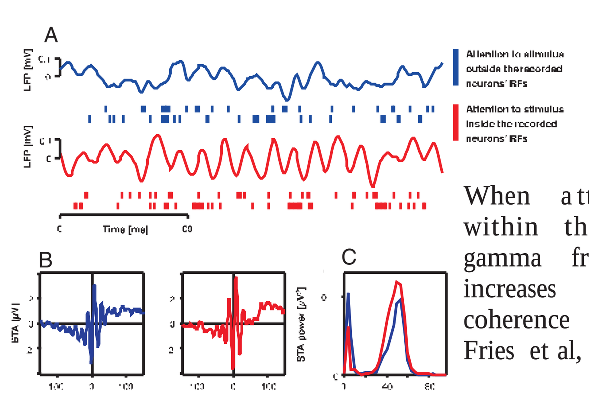
Attention modulates the mean firing rate as well as the synchrony of neuronal responses to sensory stimulation (McAdams & Maunsell (1999); Steinmetz et al (2000); Fries et al (2001)). Here we explore the hypothesis that inhibitory synchrony is a mechanism for attentional modulation. We show that inhibitory synchrony can modulate the gain of neurons and that the modulation is most effective for gamma-frequency range inputs.

Previous experimental results



Attention gain modulates orientation tuning curves in macaque area V4 (from McAdams & Maunsell, 1999).

Attentional effects in macaque area V4 increase during the course of the trial (from McAdams & Maunsell, 1999).



When attention is focused within the receptive field, gamma frequency coherence increases but theta frequency coherence decreases (from Fries et al, 2001).

Methods

Model neurons had Hodgkin-Huxley type sodium and potassium currents and a leak current (Wang & Buzsaki (1996)). Inhibitory synaptic inputs were modeled as exponentially decaying conductance pulses, decay time was 10 ms. Model implementation was as in Tiesinga & Jose (2000). The input spike train consisted of synchronized volleys of inhibitory pulses (Tiesinga et al 2002). Three parameters were varied, the number of pulses per volley, f_{inh}, their temporal dispersion $_{inh}$, and the period between two consecutive volleys, $1/f_{osc}$. Here f_{osc} is the oscillation frequency. Experimental recordings from rat prefrontal cortex neurons were performed using dynamic clamps in Destexhe et al (2001).

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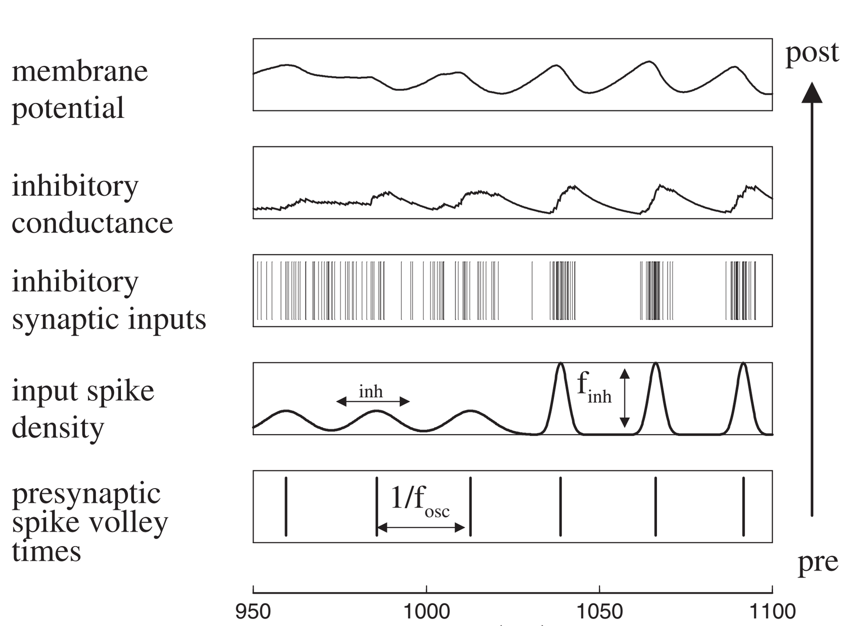

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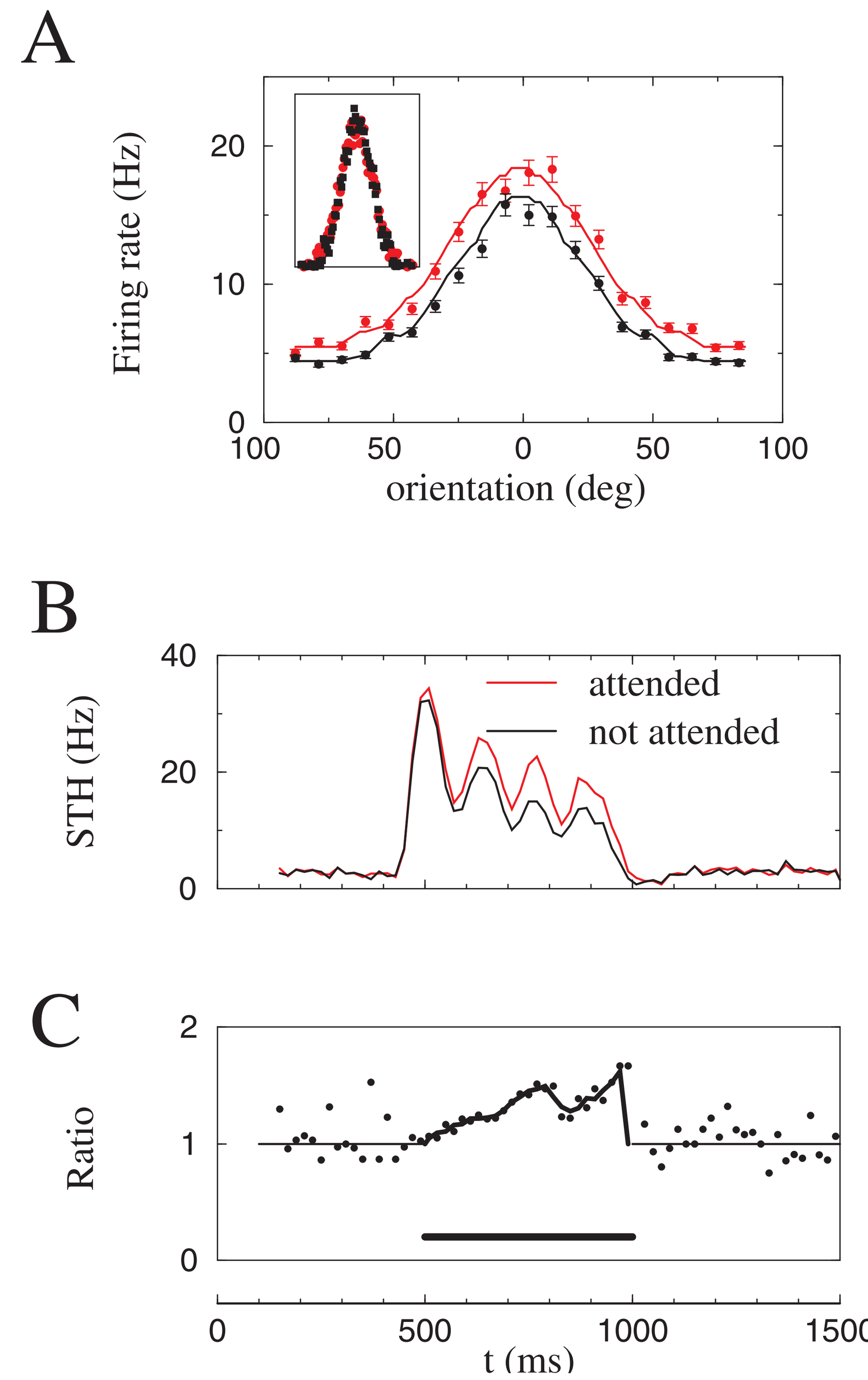

Attention-induced changes in the coherence and activation of interneuron networks in the model reproduced results by McAdams & Maunsell (1999). (A) Mean firing rate as a function of orientation when the stimulus in the receptive field is attended to (red) or not (black). Inset: scaled curves, the asymptotic firing rate was substracted before scaling. (B-C) Time course of attentional effects.

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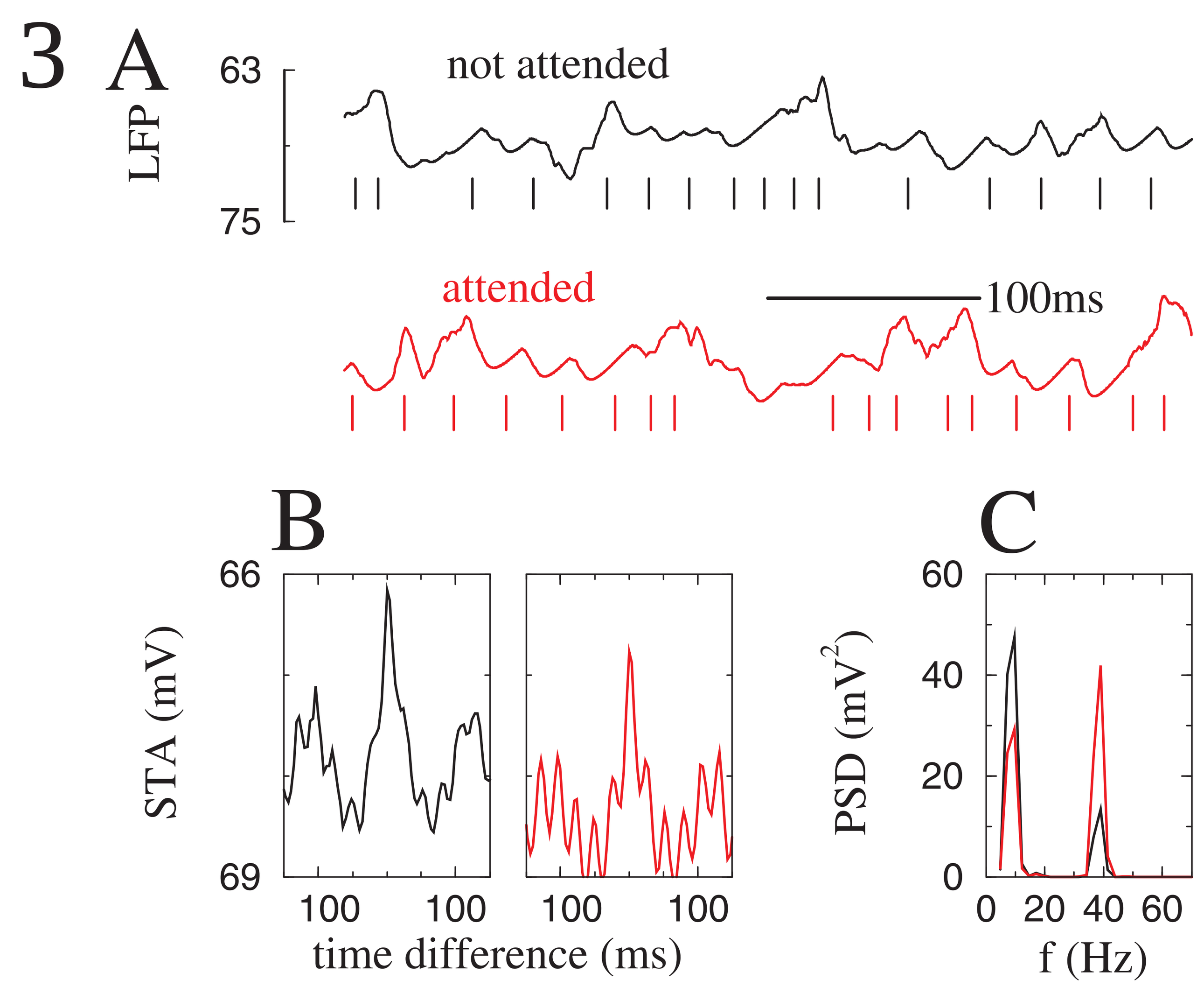

Attention-induced changes in the coherence and activation of interneuron networks in the model reproduced results by Fries et al (2001). (A) Local field potential (LFP) and output spike trains, (B) Spike triggered average (STA) of LFP and (C) power spectrum of the STA. Two conditions are shown (black) with attention focused outside or (red) inside the receptive field. Time course of LFP was estimated as the membrane potential of a neuron receiving theta-frequency excitatory and gamma-frequence inhibitory synaptic drive.

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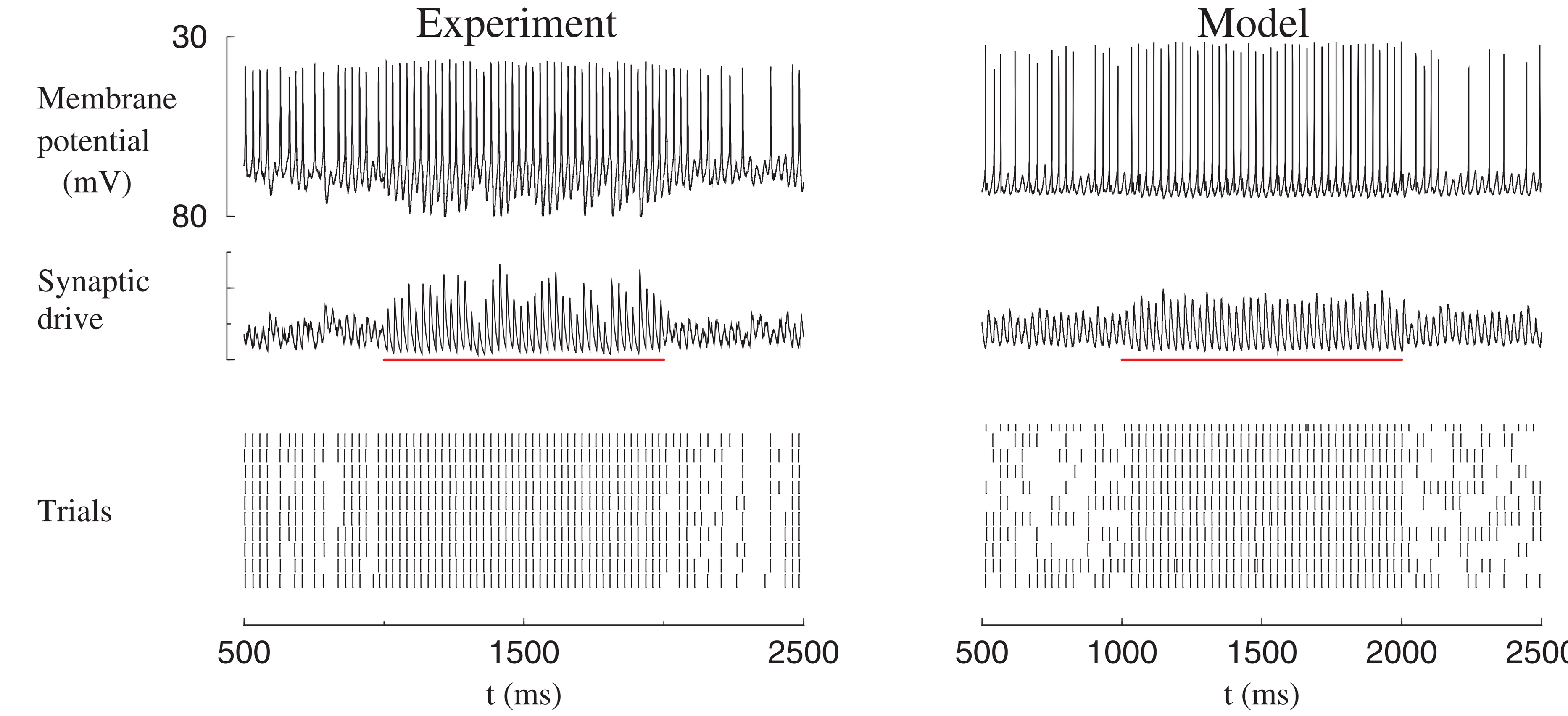

Transient increase in synchrony led to increased output firing rate in recorded and simulated neurons. Left panel: Experiment, layer V pyramidal cell in rat prefrontal cortex, recorded in vitro using dynamic clamp, right panel: Model. In each panel are shown: the membrane potential during the first trial, injected inhibitory conductance waveform and the rastergram for 10 trials.

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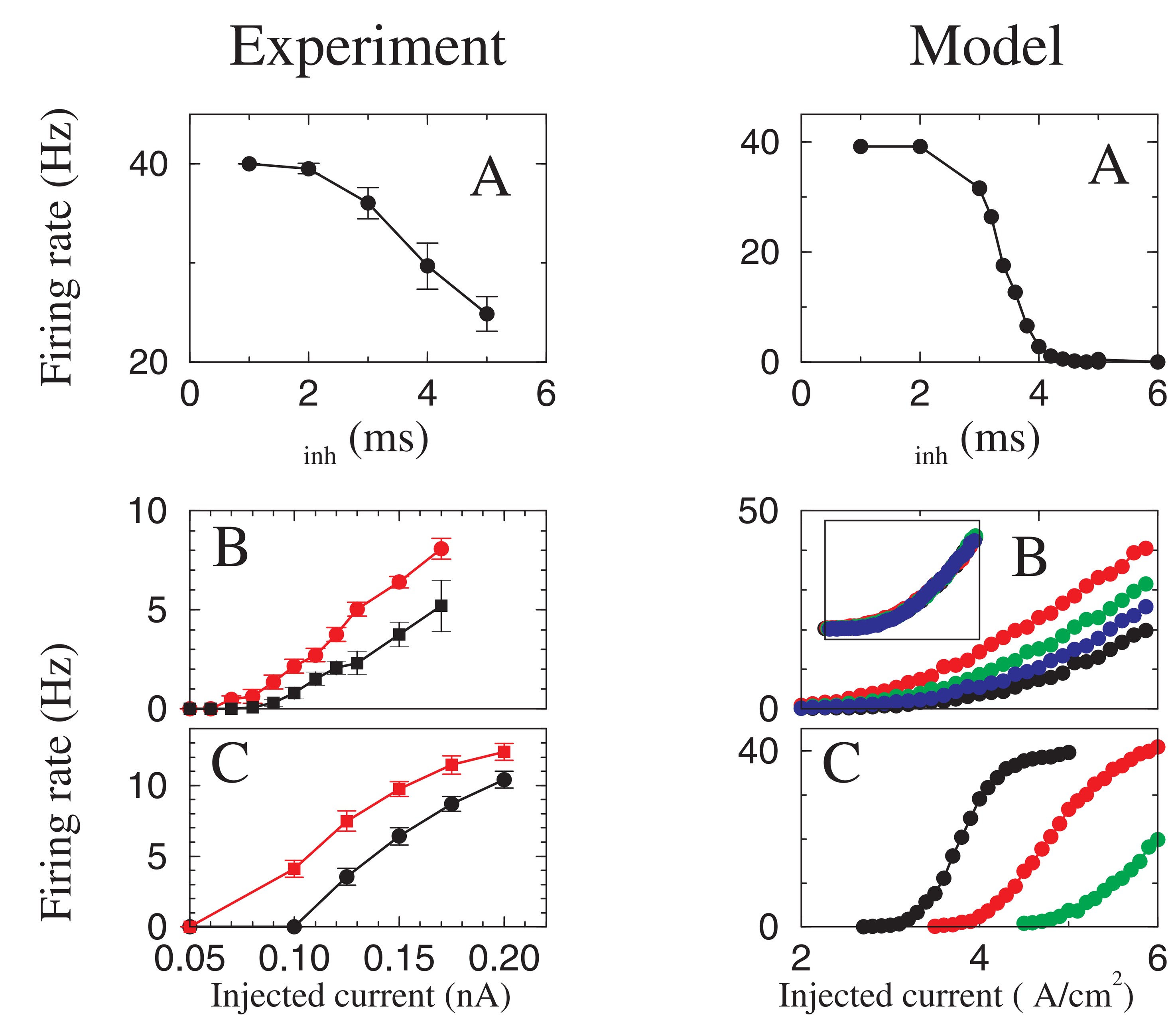

Inhibitory synchrony modulated the gain of the neuron. Left panel: experiment; right panel: Model. Firing rate versus (A) input jitter, (B-C) injected current. Parameters. Experiment: A, f_{inh}=25; B-C, f_{inh}=20, (red) $_{inh}$=1 ms and (black) $_{inh}$= 4 ms. Model: A, f_{inh}=250; B, f_{inh}=25, $_{inh}$=(red) 5, (green) 6, (blue) 7, (black) 10 ms; C, f_{inh}= 50, $_{inh}$= (black) 1, (red) 3, (green) 5 ms.

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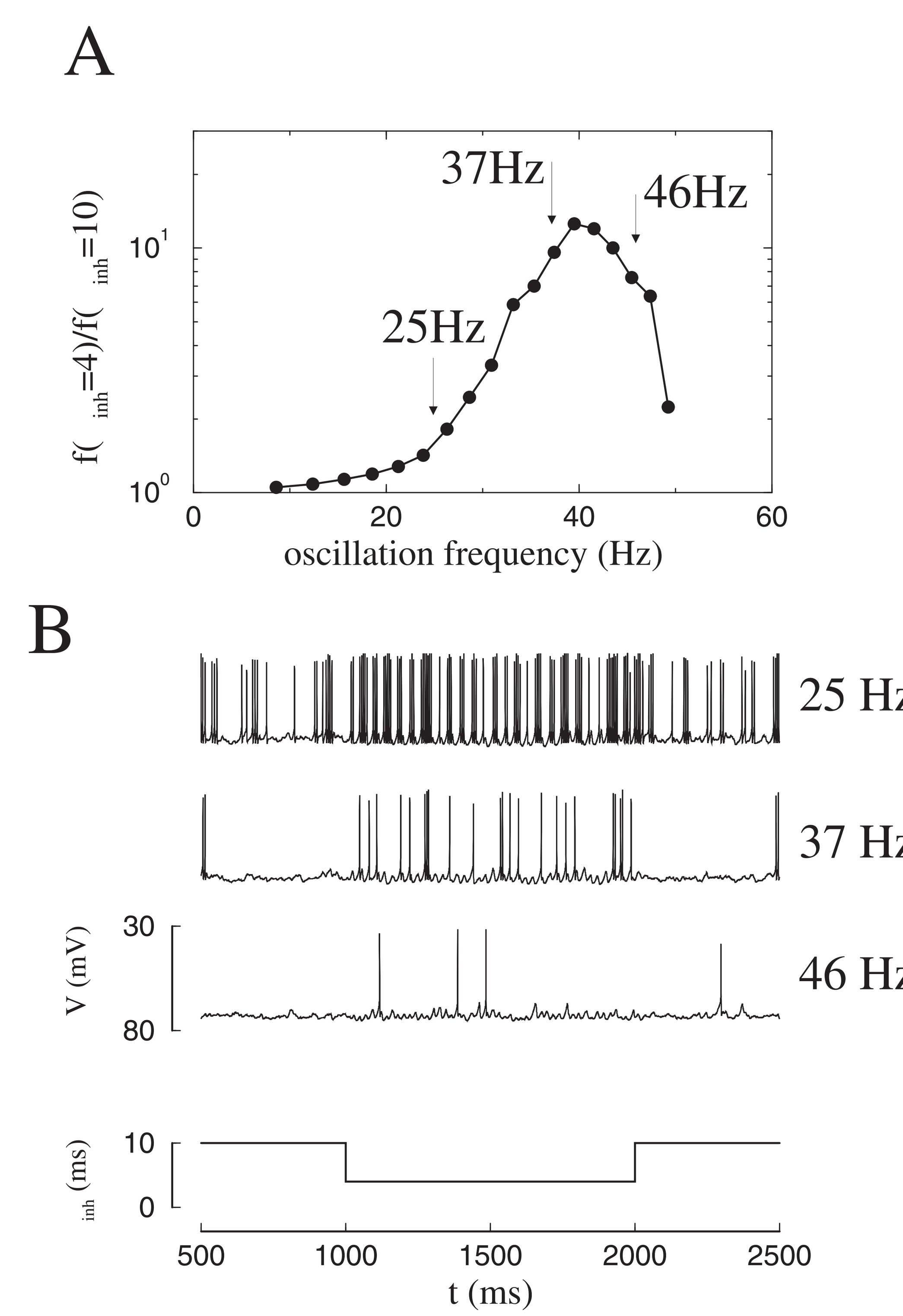

Dynamic range of the modulation of output rate by synchrony was optimal at gamma frequency inputs. (A) The firing rate, f, during high synchrony, $_{inh}$=4ms divided by f for $_{inh}$=10ms as a function of the oscillation frequency of the input spike train. (B) Spike trains corresponding to the frequencies indicated by the arrow in (A), f_{osc} values are on the right. During a period between t=1 and 2 s, $_{inh}$ was transiently decreased from 10ms to 4ms.

Summary

- Modeling the effect of attention as changes in inhibitory synchrony can account for the experimental results of McAdams & Maunsell and Fries and coworkers.
- Inhibitory synchrony has part a multiplicative and substractive effect on the firing rate versus current curves.
- Dynamics range of attentional gain modulation is optimal for oscillatory inhibitory inputs in the gamma-frequency range.

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