Oscillations bias rule-based action in a laminar model of PFC

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Introduction

- Rules are context-specific behavioral guides flexibly coded in Prefrontal Cortex (PFC) to assist action selection based on a set of condition-response mappings.
- Rule-coding cell assemblies exhibit beta-frequency oscillations [1].
- How network oscillations contribute to rule-based action is unknown.
- We adapted an experimentally-constrained biophysical PFC model [2] to investigate how network rhythms may contribute to context-dependent pathway biases serving rule-based action.

Rhythms and resonance in network oscillators

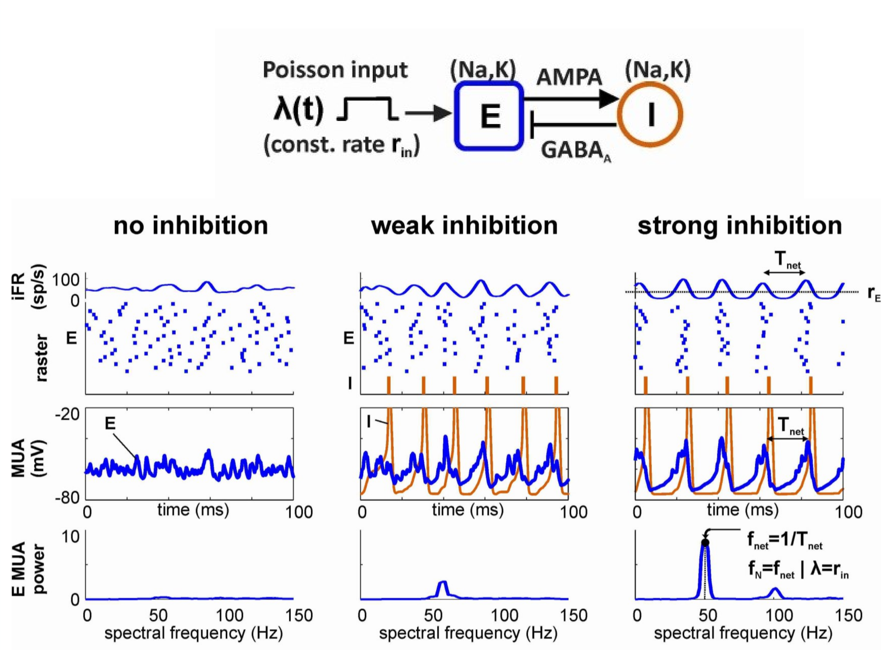
Minimal Hodgkin-Huxley E/I Network

Def: Natural frequency (f_N)

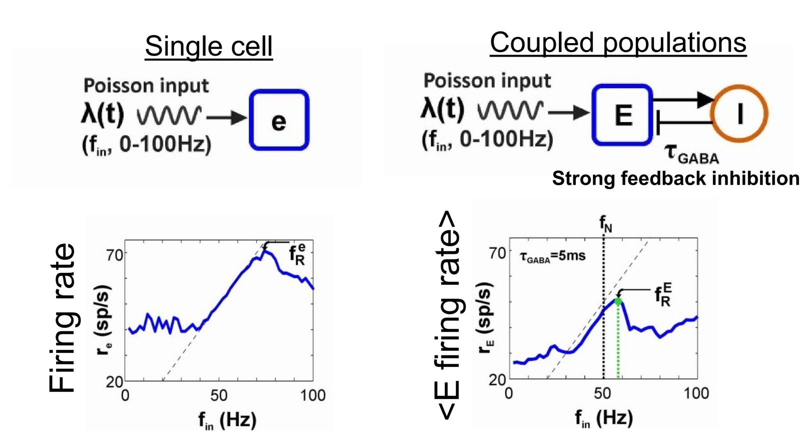
f_N = network freq. given const.-rate async. input.

FR resonant frequency (f_R)

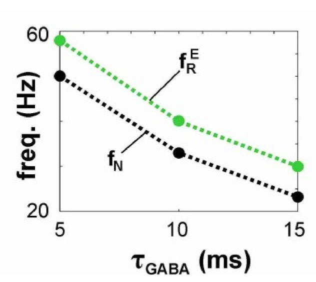
f_R = rhythmic input freq. producing maximal output.



Natural network oscillation emerges under strong feedback inhibition.



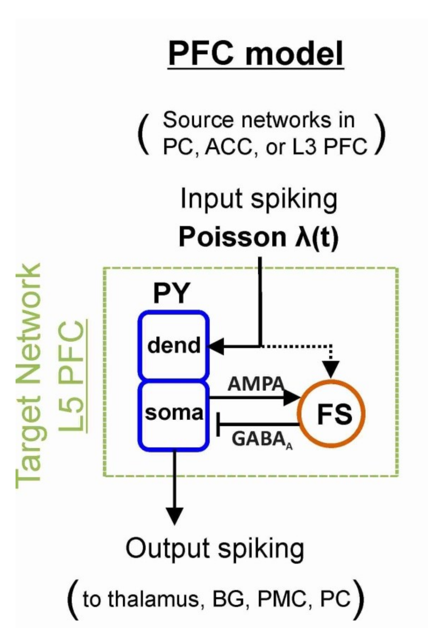
FR resonance differs for single cells and network

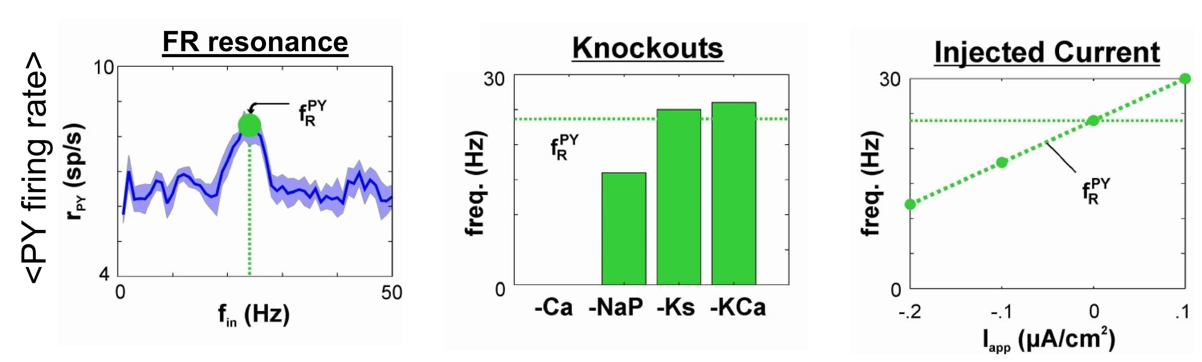


Natural and resonant frequencies can differ, and they depend on duration of inhibition.

PFC L5 PY/FS Network

PY: two-compartment pyramidal cell (NaF, KDR, NaP, Ks, Ca, KCa)
FS: fast spiking interneuron (NaF, KDR)

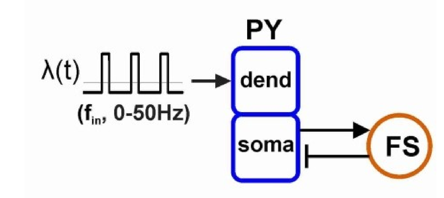




All the conclusions for the HH E/I network hold for the PFC network.

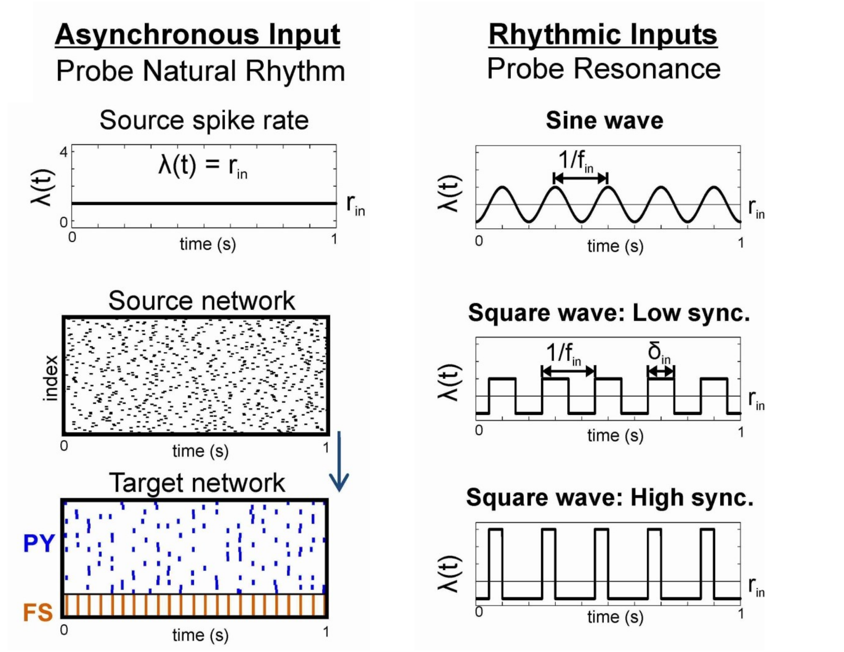
Intrinsic membrane currents contribute to resonant properties only by effects on baseline levels of excitation. Together, they reduce the natural and resonant frequencies of the PFC network to high beta / low gamma frequencies.

PFC network resonance



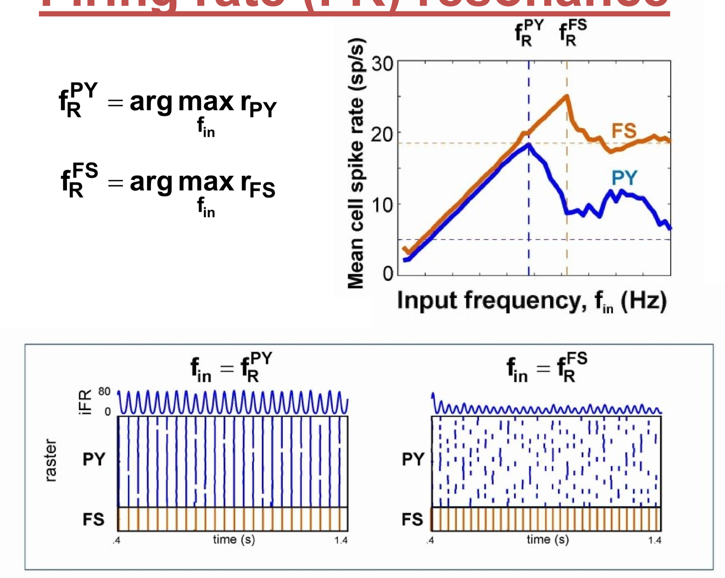
What is Network Resonance?

Inputs from source network



Outputs of target network

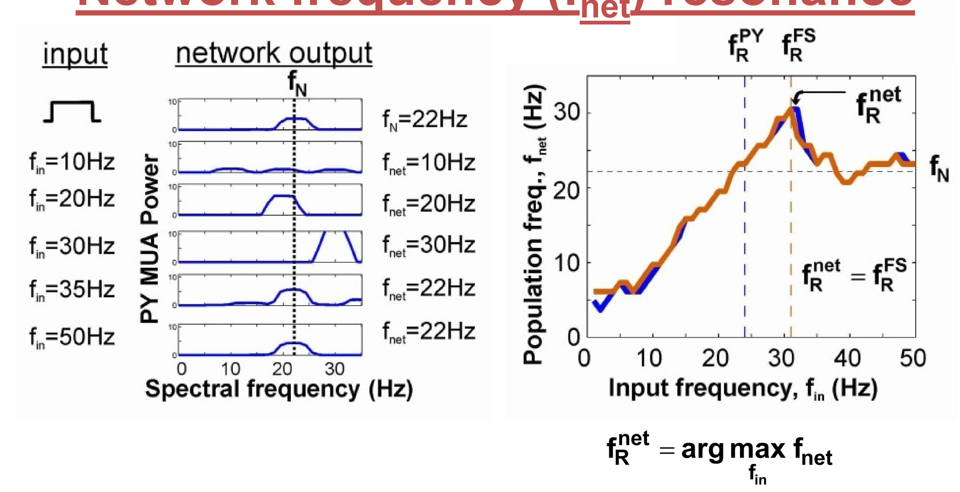
Firing rate (FR) resonance



Def: f_{net} = spectral freq. of net. activity with max power

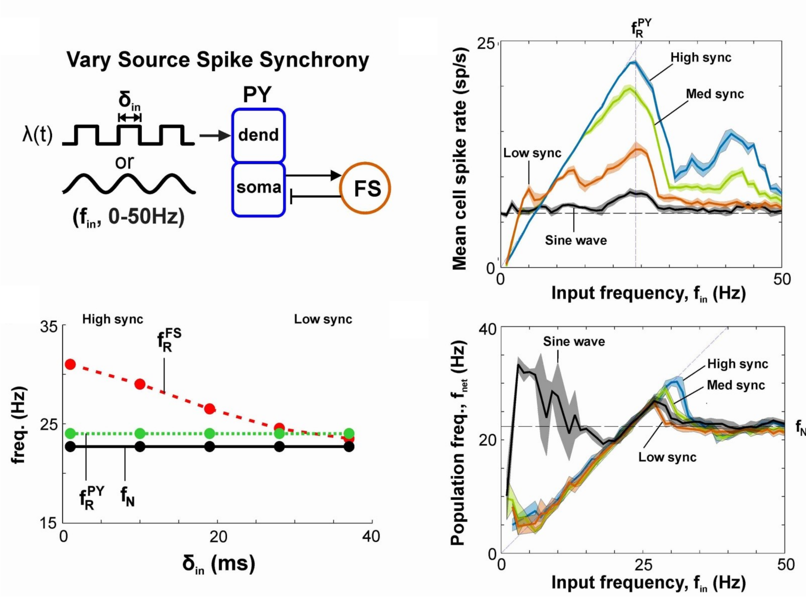
Network freq. is maximal for inputs at the FS pop. firing rate resonant freq.

Network frequency (f_{net}) resonance



Target resonance depends on source spike statistics

Effects of input synchrony

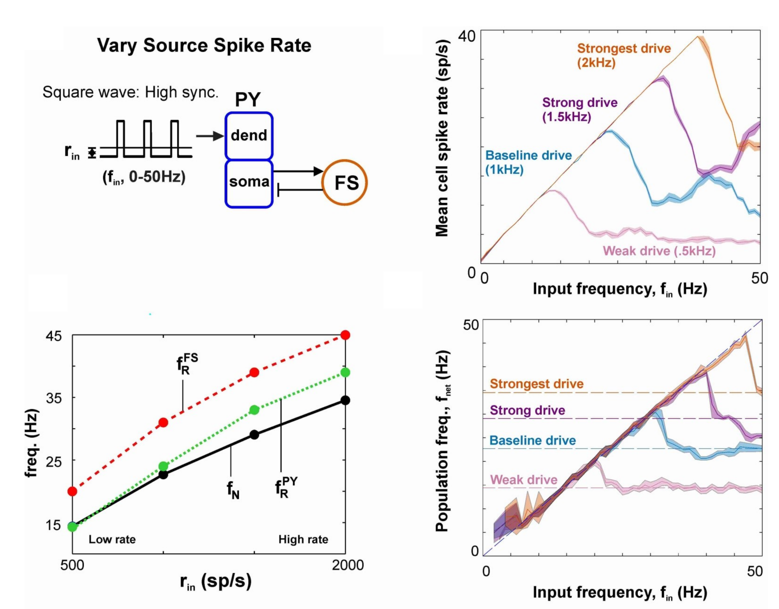


Increased input synchrony increases:

- max output FR of all pops
- FR resonant freq. of FS pop

Does not affect natural freq.

Effects of input strength



Increased input strength increases:

- max output FR of all pops
- FR resonant freq. of all pops
- Natural freq. of network

References
1. Buschman, Denovellis, Diogo, Bullock, Miller. Neuron 2012.
2. Durstewitz, Seamans. Neural Networks 2002.

Acknowledgements
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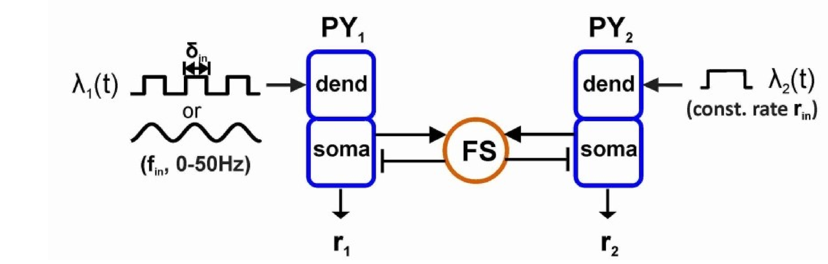
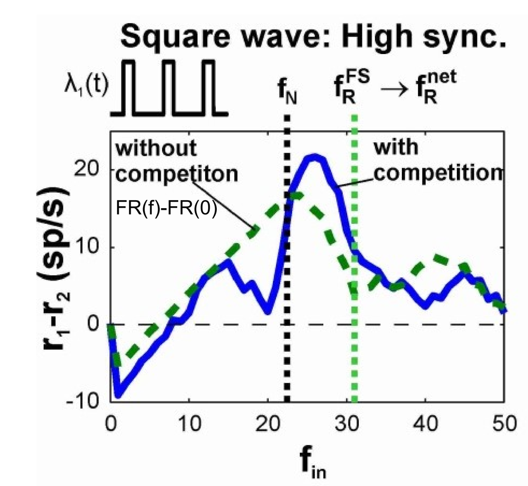
Rhythm-mediated biased competition

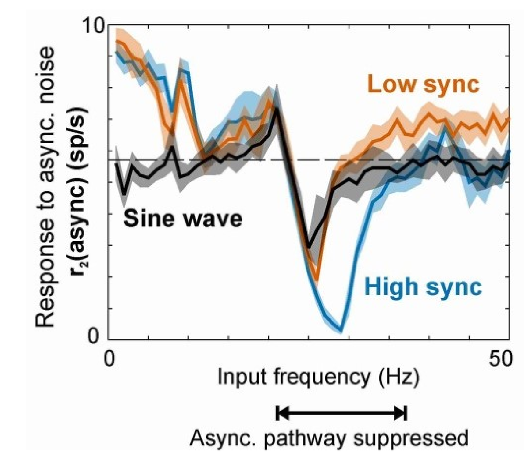
Rhythms can select context-dependent S→R mappings

Competitive Network Dynamics





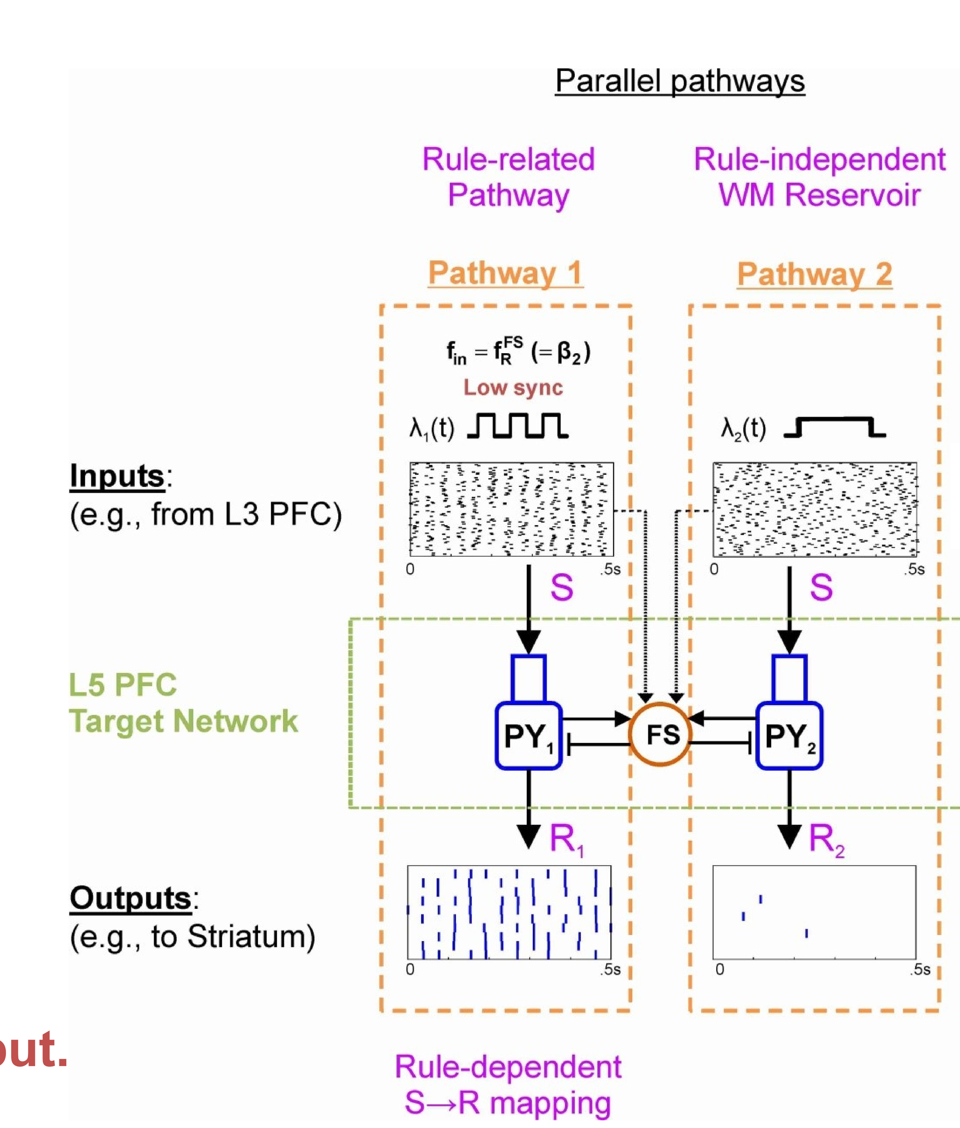
For inputs near natural freq., the assembly with faster net. freq. is suppressive.



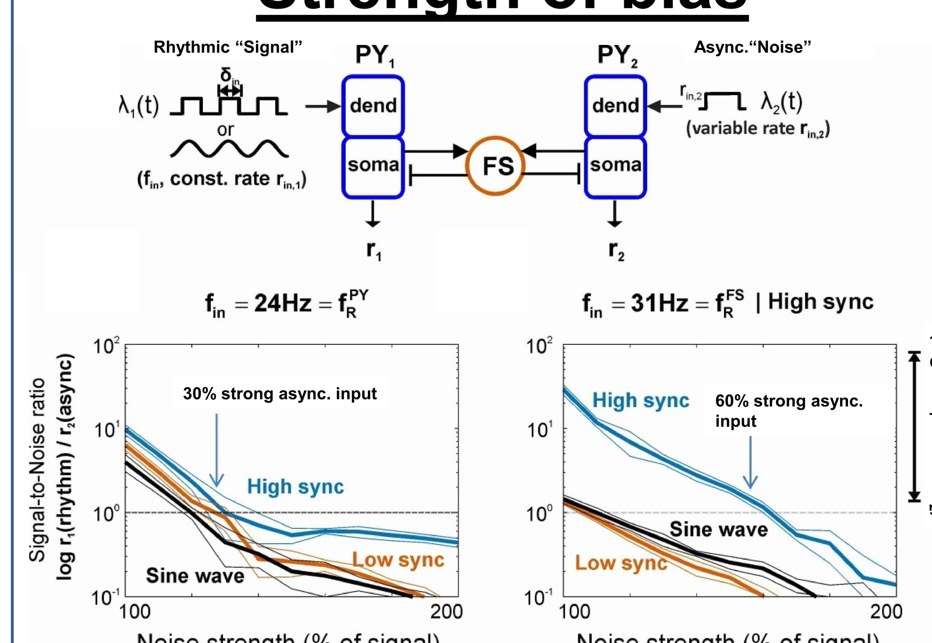
Async.-driven assembly is suppressed by assembly with near-resonant input.

More sync. inputs are more suppressive.

Microcircuit and cognitive operations

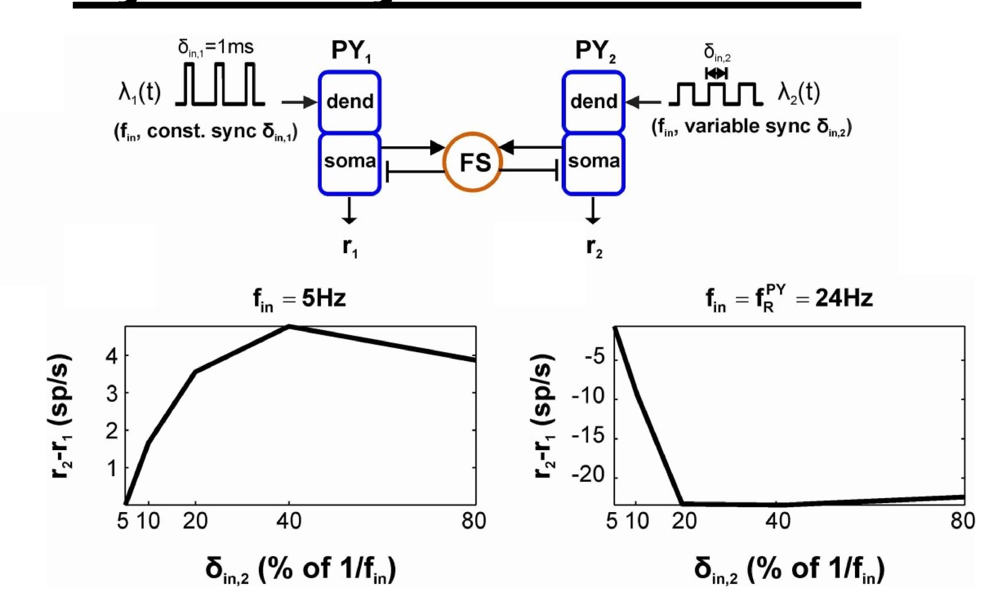


Strength of bias



Sync. rhythmic pathway beats 60% stronger asynchronous pathway.

Synchrony-mediated bias



High spike sync. provides competitive advantage for high freq. inputs only; low sync. is advantageous for low freqs.

Conclusions

- Natural rhythm: PY/FS networks with strong feedback inhibition and feedforward excitation are variable-frequency oscillators controlled by input strength with input synchrony-dependent power.
- There are multiple notions of network resonance; in all cases, resonant properties depend on the statistics (firing rate and synchrony) of source network spiking, in addition to target network properties (inhibition duration and baseline excitation). Thus, a source network can flexibly tune the resonant properties of its target network.
- Network resonance enables rhythm-mediated biased competition to select pathways involved in rule-based action.