Recall of word sequences via short-term plasticity in a temporal context model

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Acknowledgments

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(recall of word lists)

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Tepring Piqado
+ Marissa Stearns

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Martha Erickson + Lauren Maramara

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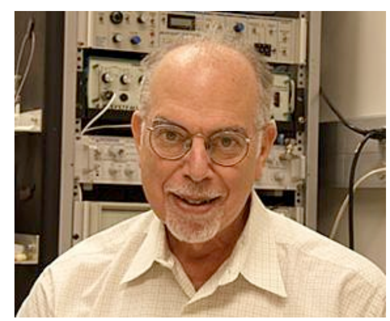
Department of Biology

(synaptic plasticity)



Acknowledgments

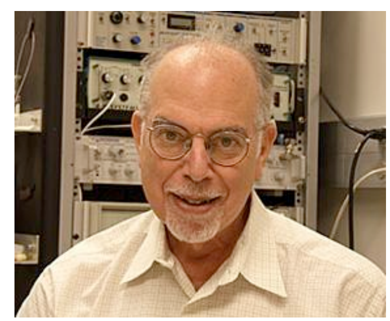
Art Wingfield

Tepring Piqado

… and this little 3-wk old for being more like this:

Martha Erickson

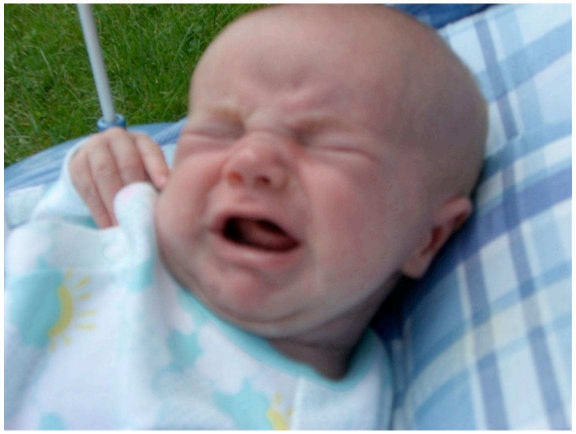
John Lisman



Acknowledgments

Art Wingfield

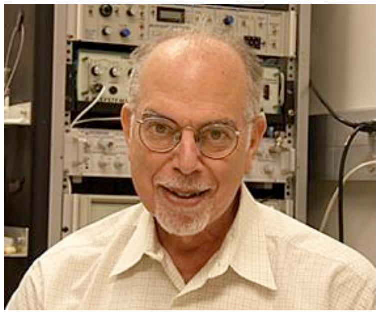
… and less like this.



Tepring Piqado

Martha Erickson

John Lisman



The Question

Why do older adults with poor hearing perform worse at remembering words in a sequence, compared to those with good hearing, **even** when the stimulus is at a sufficient level that they can identify it?

(from McCoy et al Q.J.Exp.Psych. 2005)

Answer 1) Lower stimulus quality means a worse representation is stored.

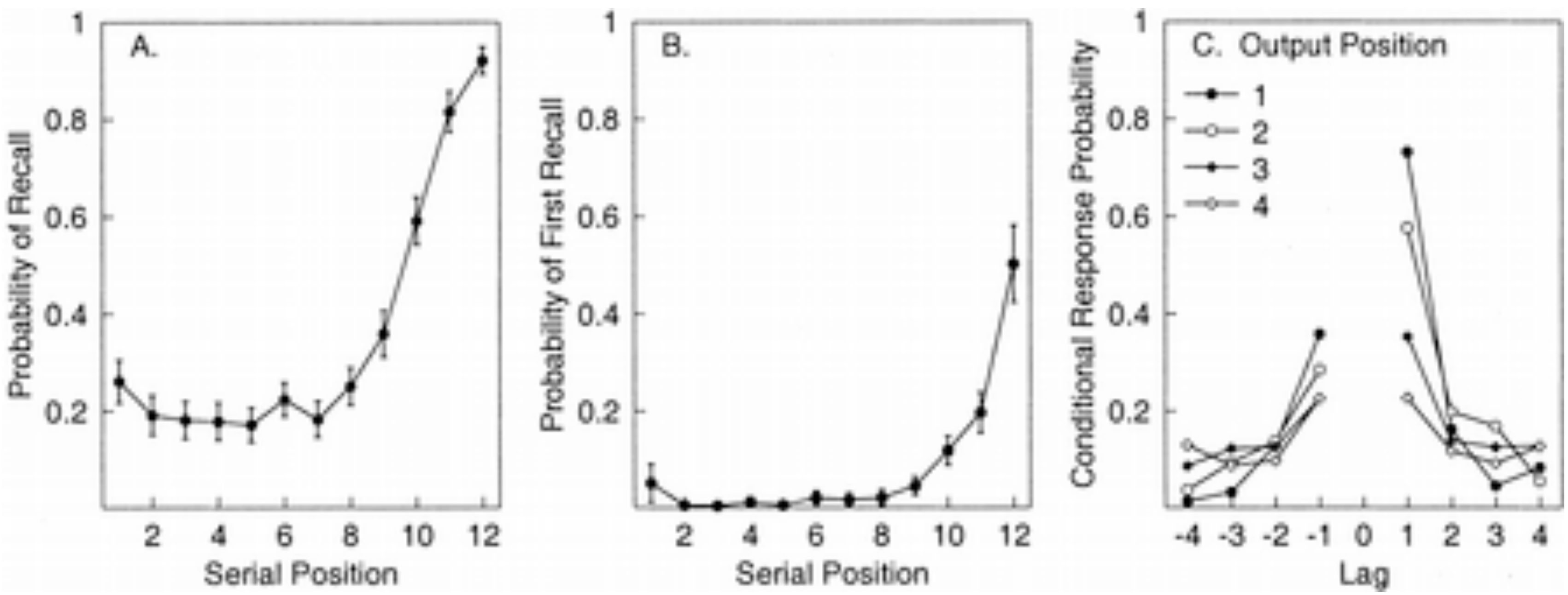
Answer 2) Resources used in the perceptual effort to decode later words compete with resources needed to encode earlier words in memory.

Answer 3) “It is not just where you end up, but how you get there that matters”
To be investigated in this talk.

Classic results for recall of lists of words

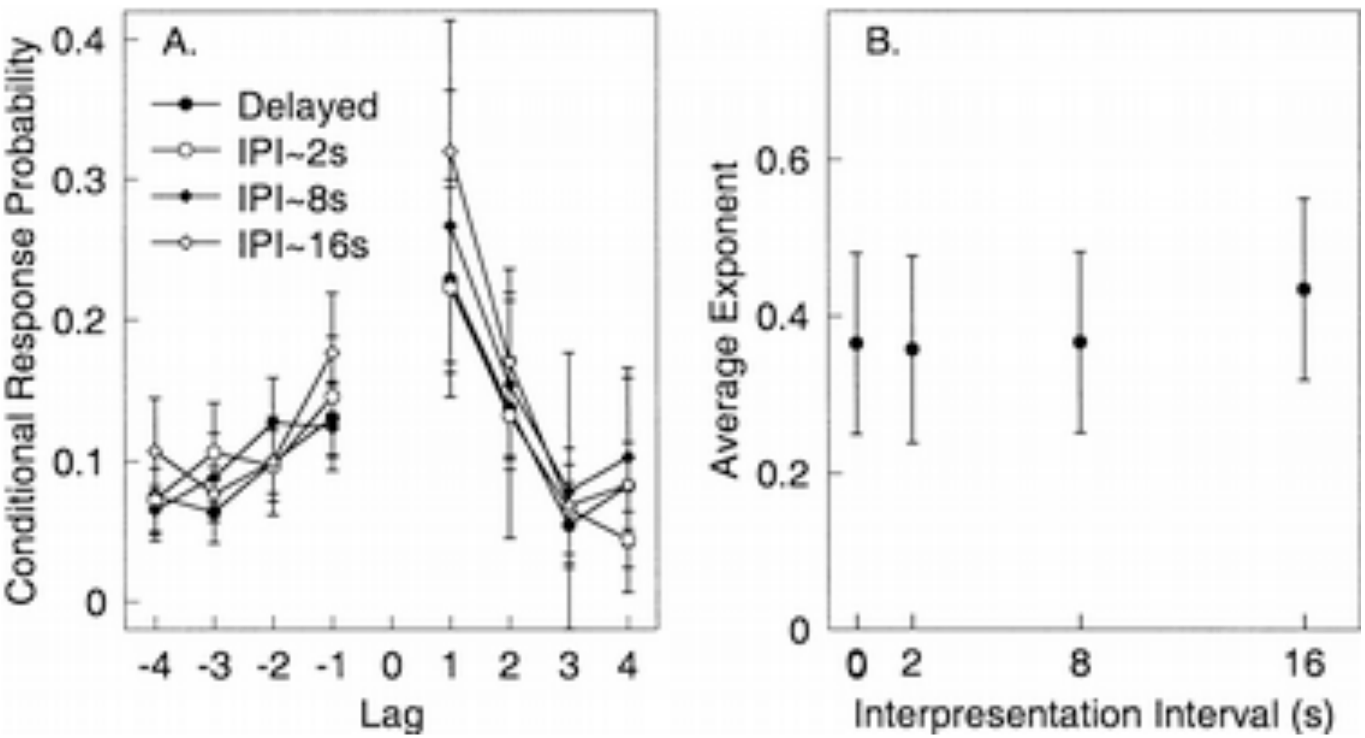
Recency effect

Temporal Association



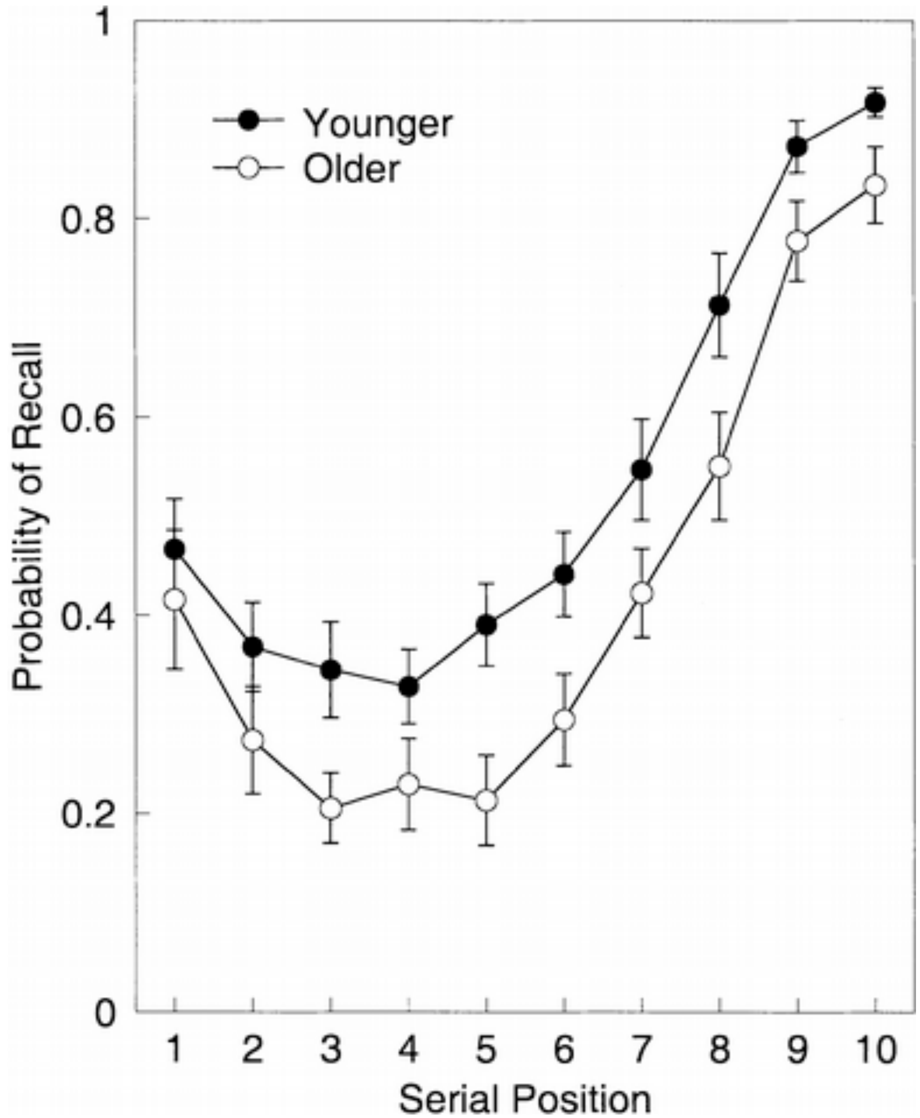
Kahana, Howard, Zaromb, Wingfield, J. Exp. Psych. 2002

Scale invariance of temporal associations

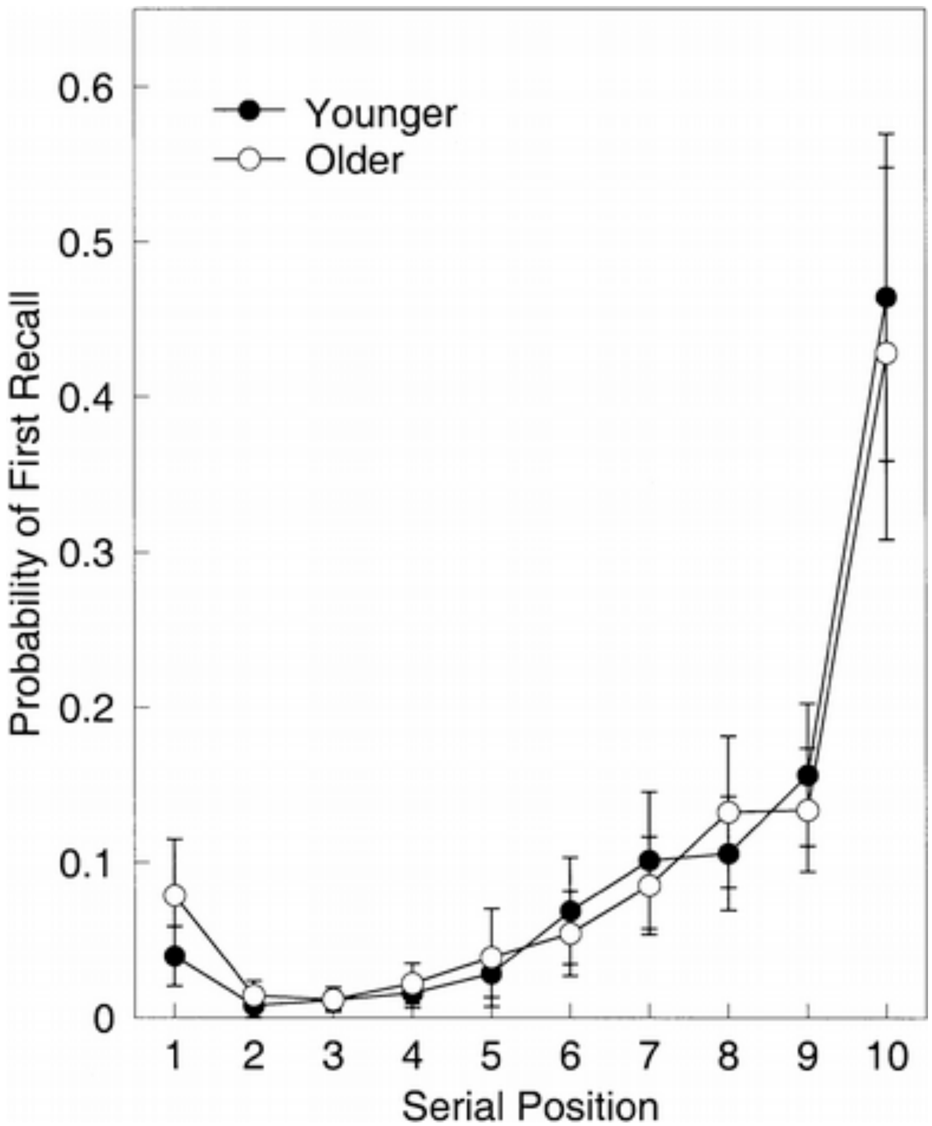


Kahana, Howard, Zaromb, Wingfield, J. Exp. Psych. 2002

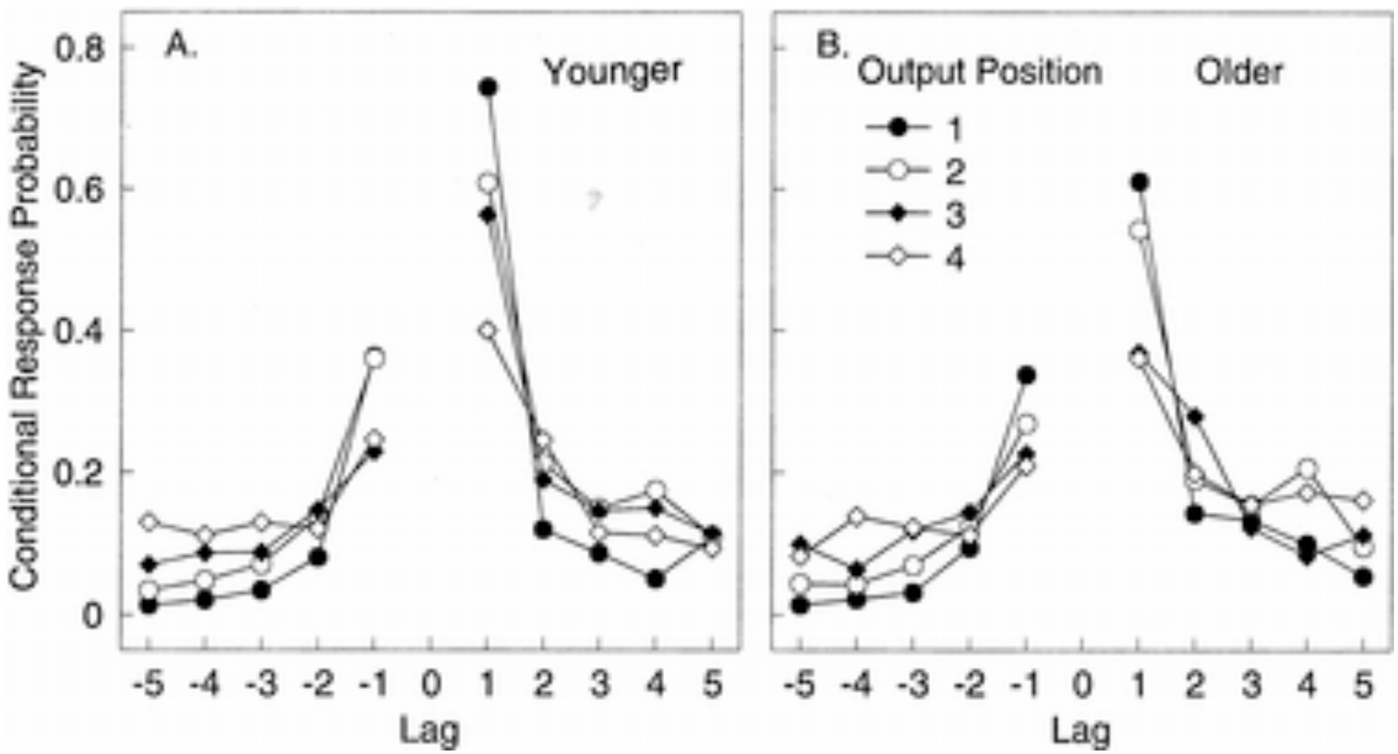
Shape of serial response curve is independent of age,
but overall probability of recall worsens with age.



Probability of first recall is independent of age: recency effect

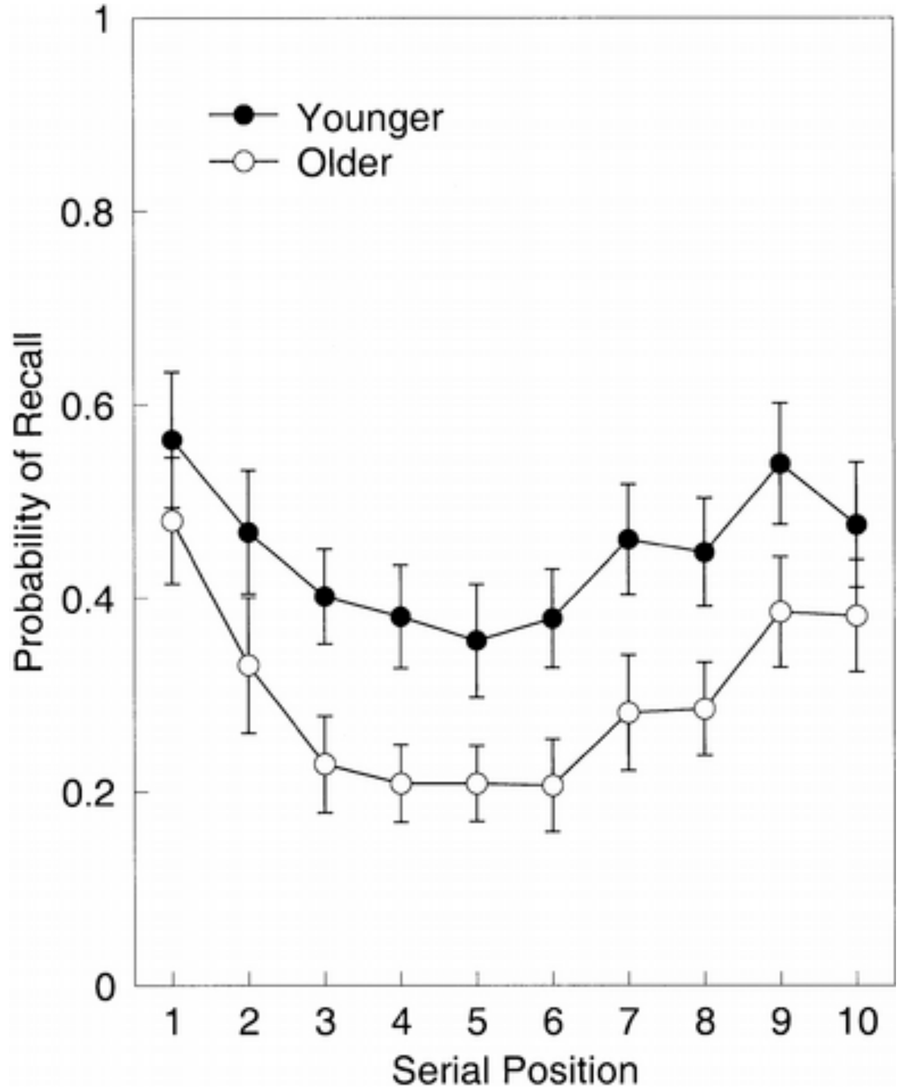


Form of temporal associations is similar across ages

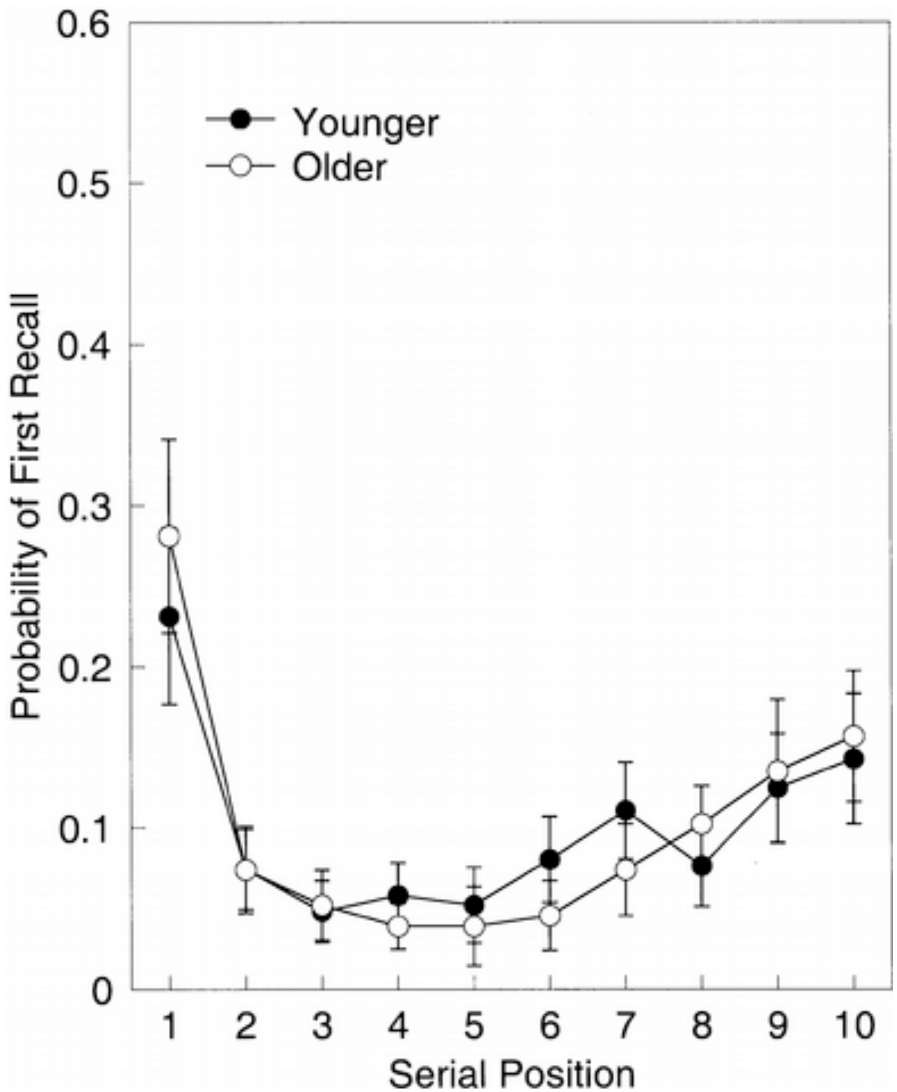


Kahana, Howard, Zaromb, Wingfield, J. Exp. Psych. 2002

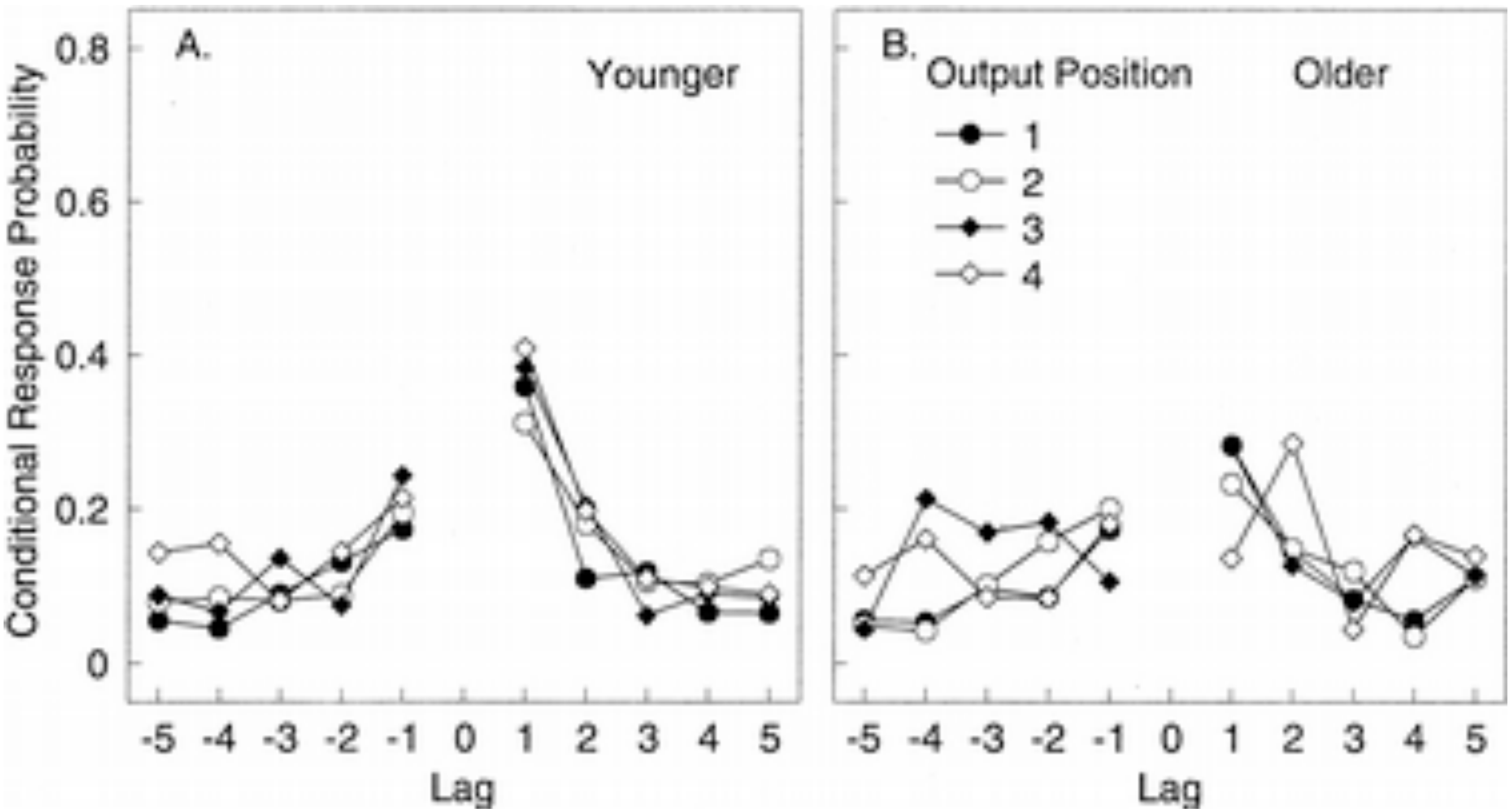
Recency effect disappears with delay following last word (delayed free recall)



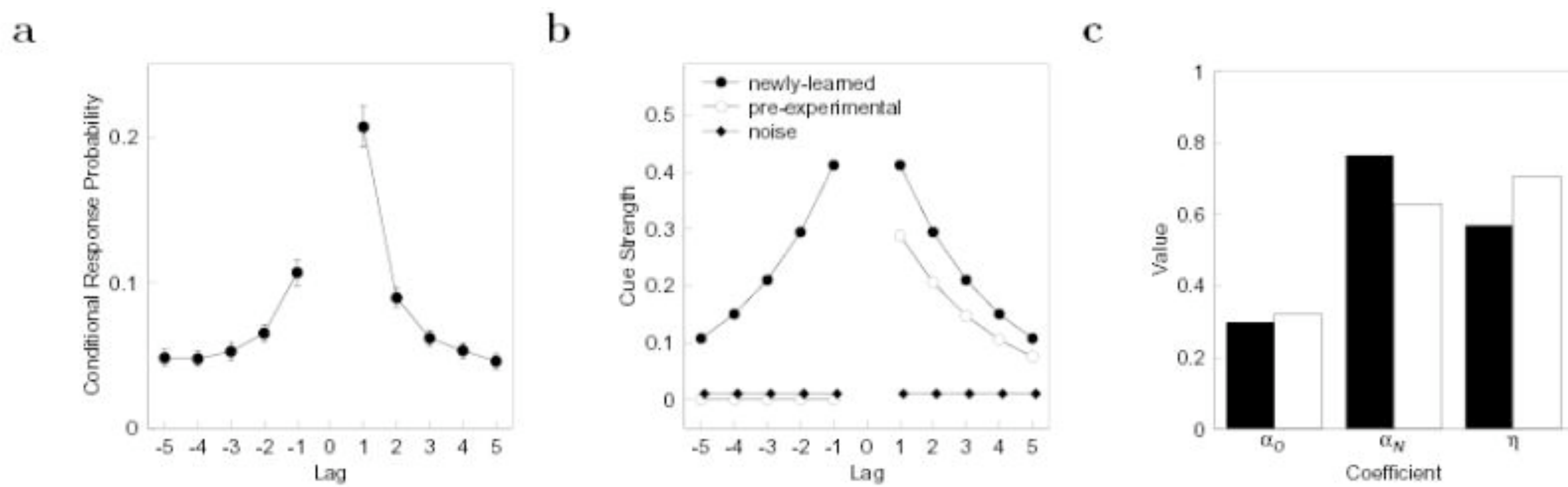
Delayed free recall reveals a primacy effect



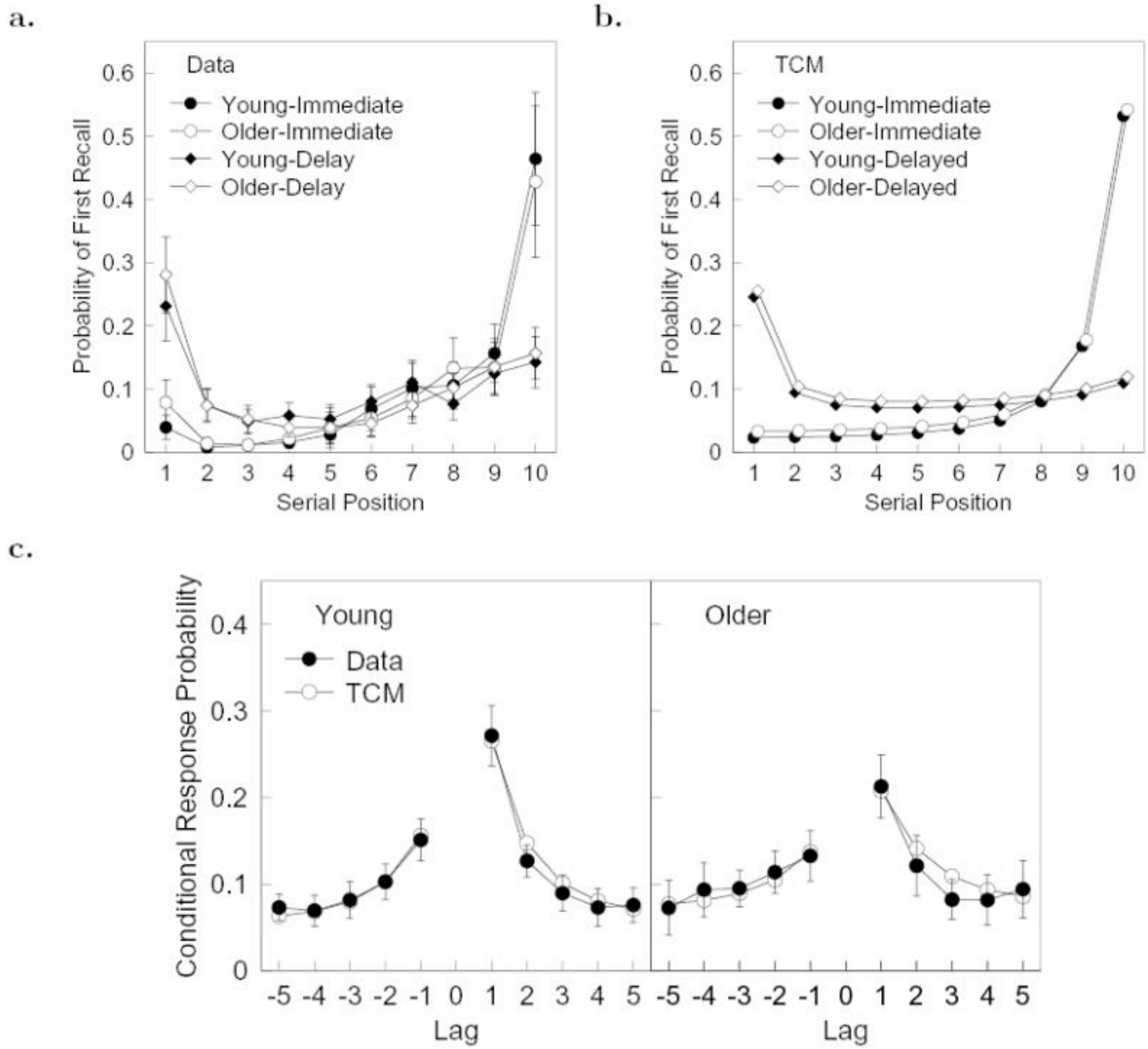
Delayed free recall reveals a deficit in temporal associations for older adults



Kahana, Howard, Zaromb, Wingfield, J. Exp. Psych. 2002

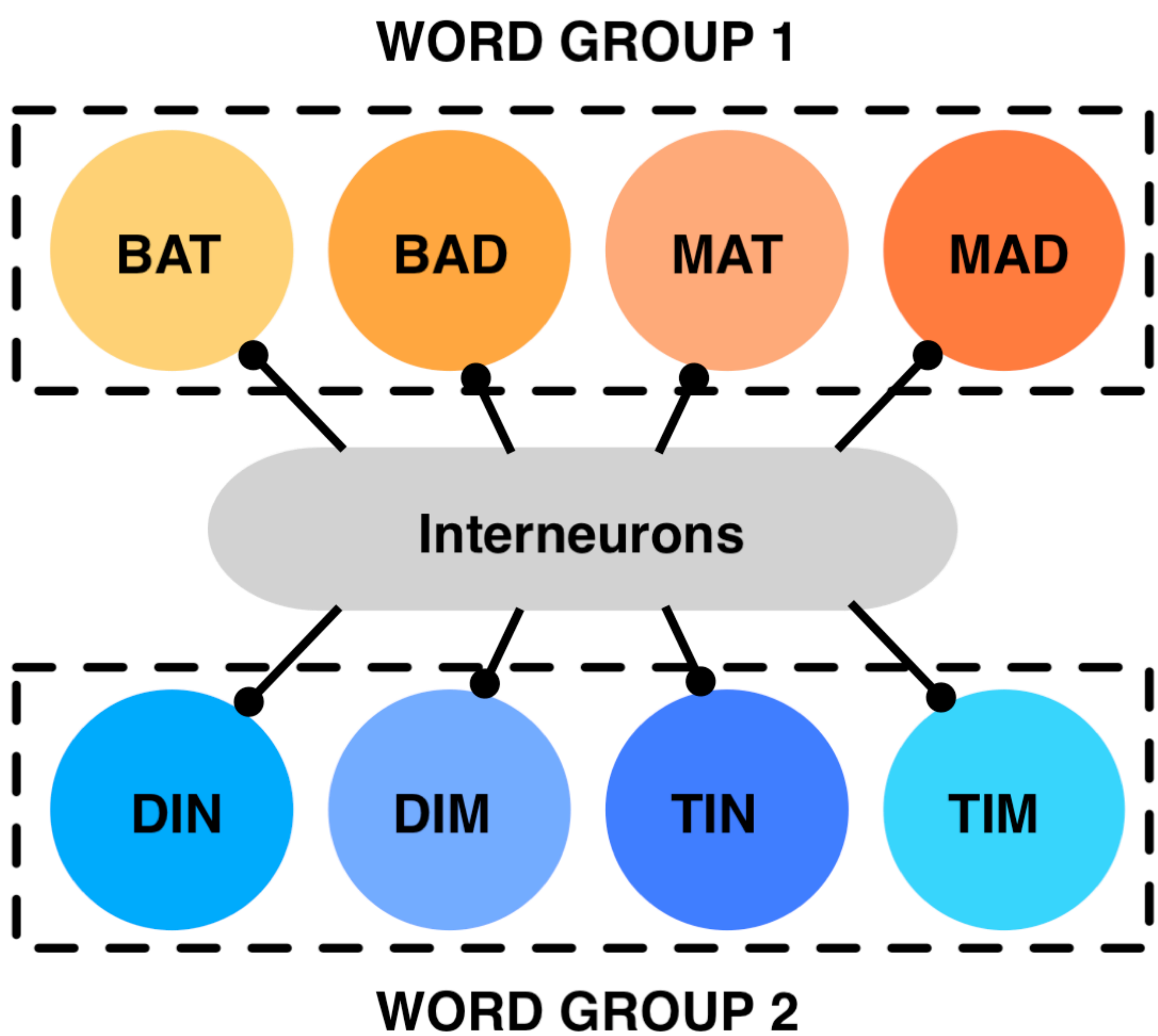


a
Conditional Response Probability
0
0.1
0.2
-5 -4 -3 -2 -1 0 1 2 3 4 5
Lag
b
newly-learned
pre-experimental
noise
Cue Strength
0
0.1
0.2
0.3
0.4
0.5
-5 -4 -3 -2 -1 0 1 2 3 4 5
Lag
c
Value
0
0.2
0.4
0.6
0.8
1
α_O
α_N
η
Coefficient


a.
Data
Young-Immediate
Older-Immediate
Young-Delay
Older-Delay
Probability of First Recall
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10
Serial Position
b.
TCM
Young-Immediate
Older-Immediate
Young-Delayed
Older-Delayed
Probability of First Recall
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10
Serial Position
c.
Young
Older
Data
TCM
Conditional Response Probability
0.4
0.3
0.2
0.1
0
-5 -4 -3 -2 -1 0 1 2 3 4 5 -5 -4 -3 -2 -1 0 1 2 3 4 5
Lag
Lag

Now to think about what could be going on neurally …

Model 1: neurons selective for specific words: winner-takes-all via strong self-excitation, strong cross-inhibition, weak cross-excitation



Winner-takes-all competitive model via cross-inhibition?

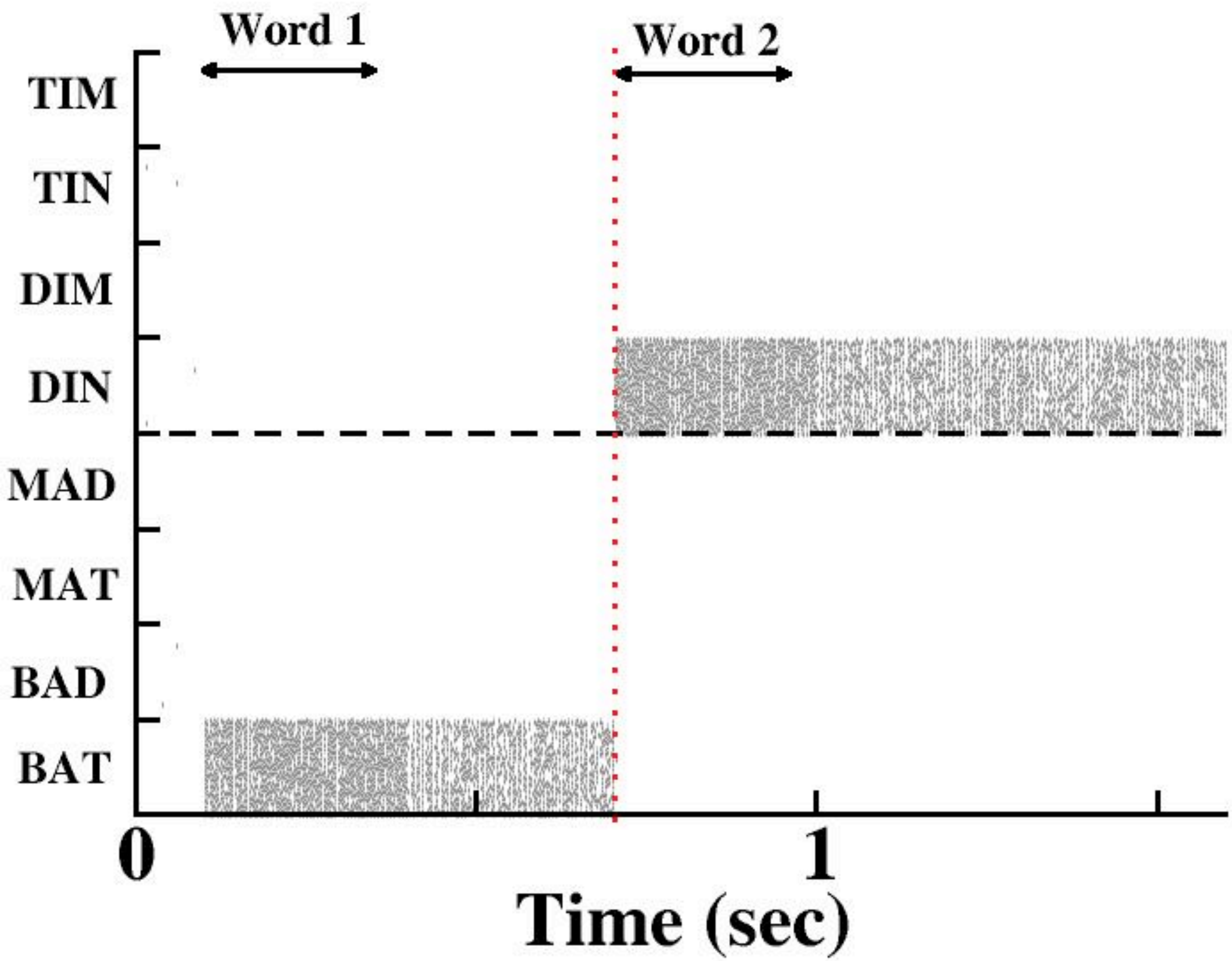
cf Marius Usher and Jay McClelland: “Leaky, competing accumulator model” for word recognition (Psych Rev 2001)

Moreno-Bote, Rubin and Rinzel for perceptual bistability (J Neurophys 2008)

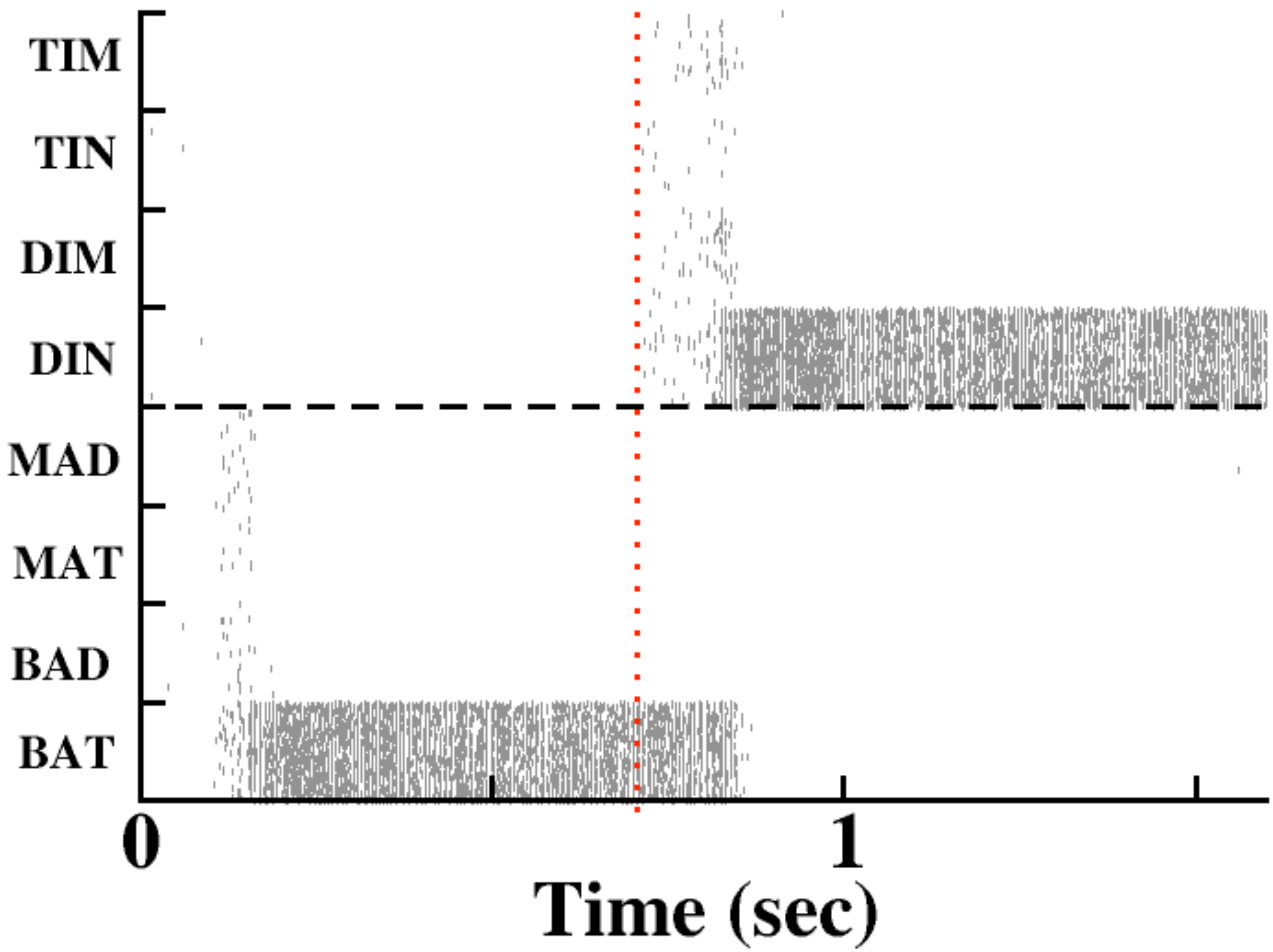
Based on the model of decision-making by Xiao-Jing Wang (Neuron 2002)

Note: in this talk, model has multiple competing items.

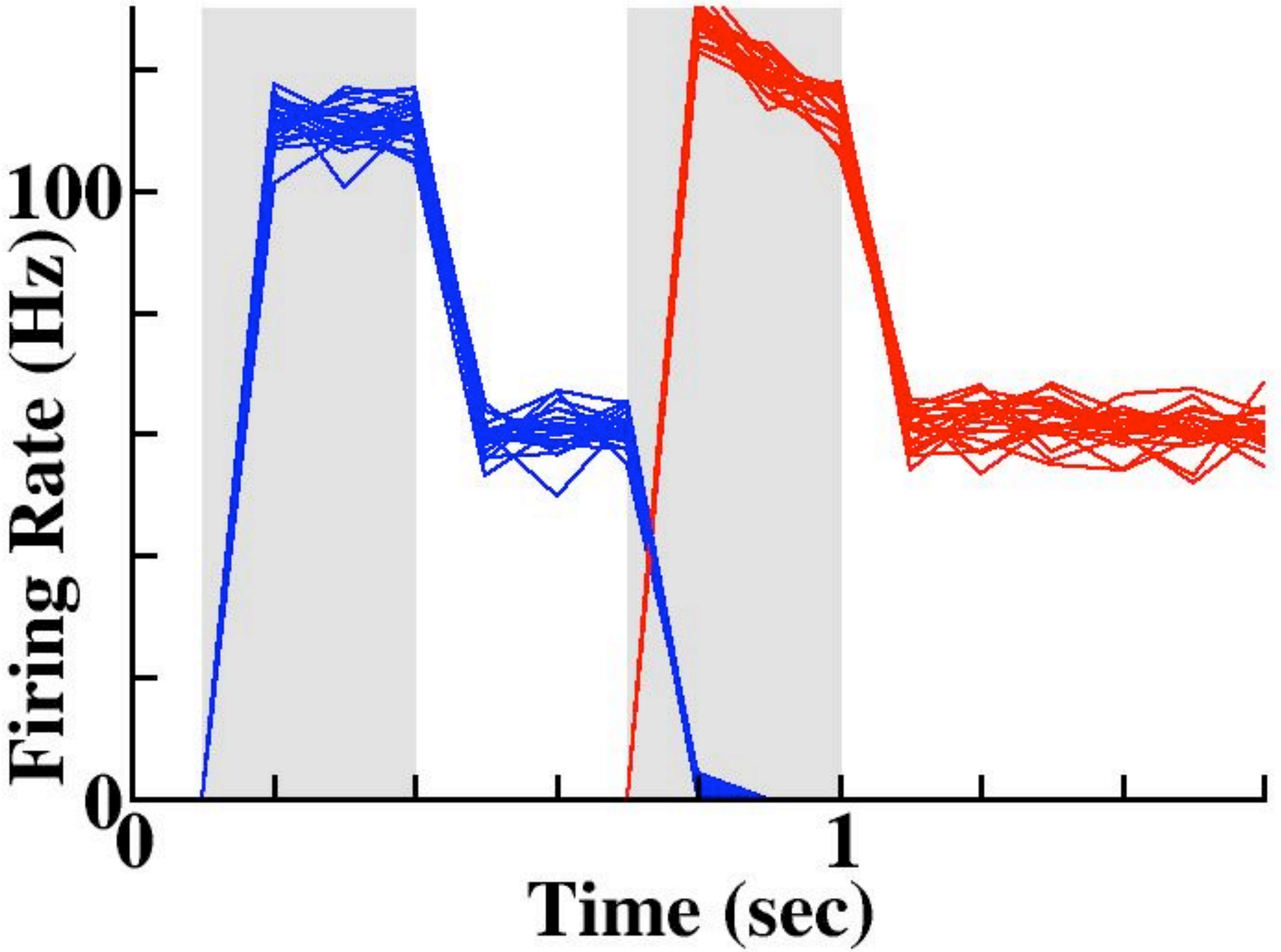
Neural response during stimulus presentation (2 successive strong stimuli)



Neural response during stimulus presentation (2 successive weak stimuli)



Neural response to two successive strong stimuli (20 trials)



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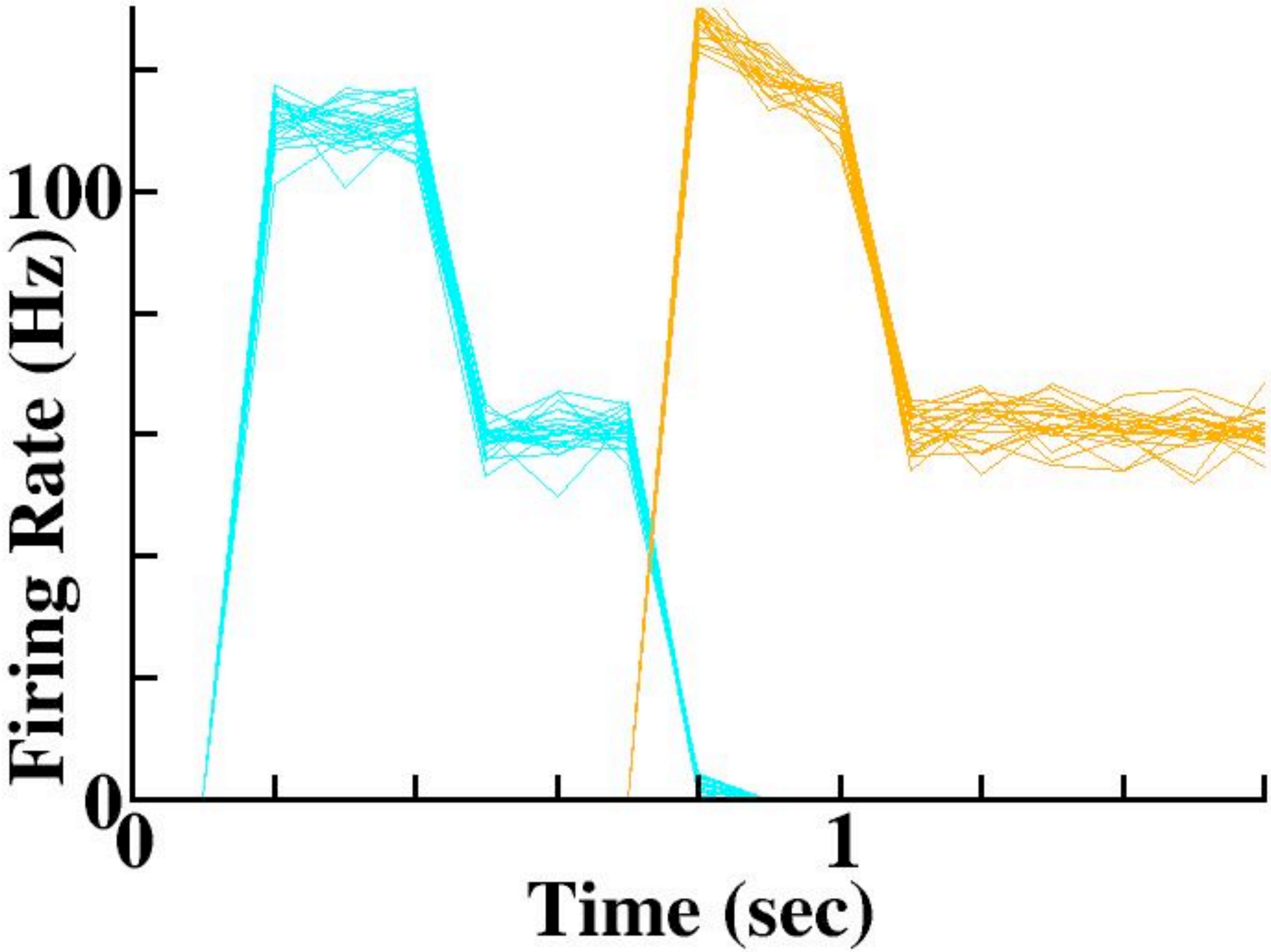
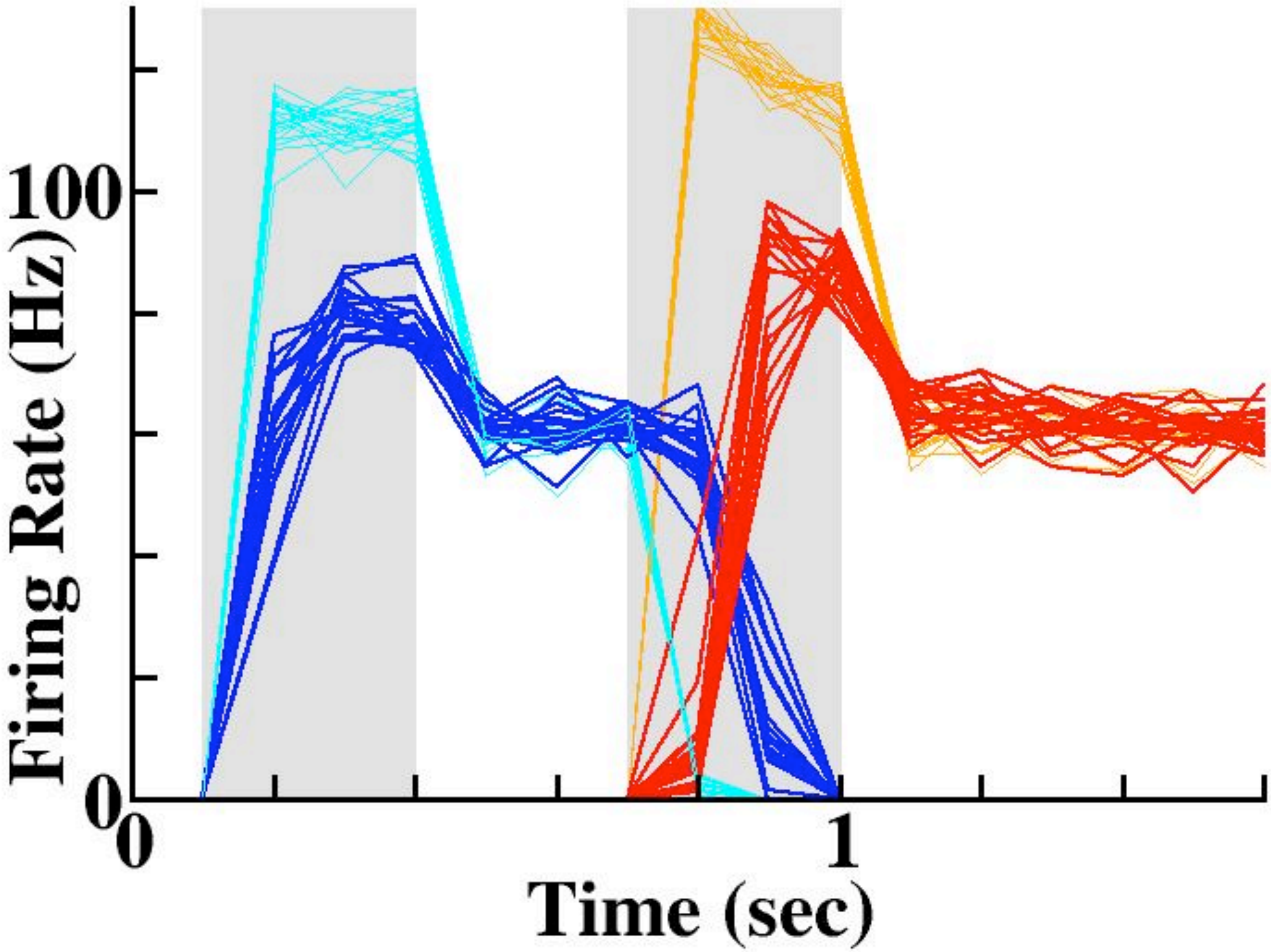
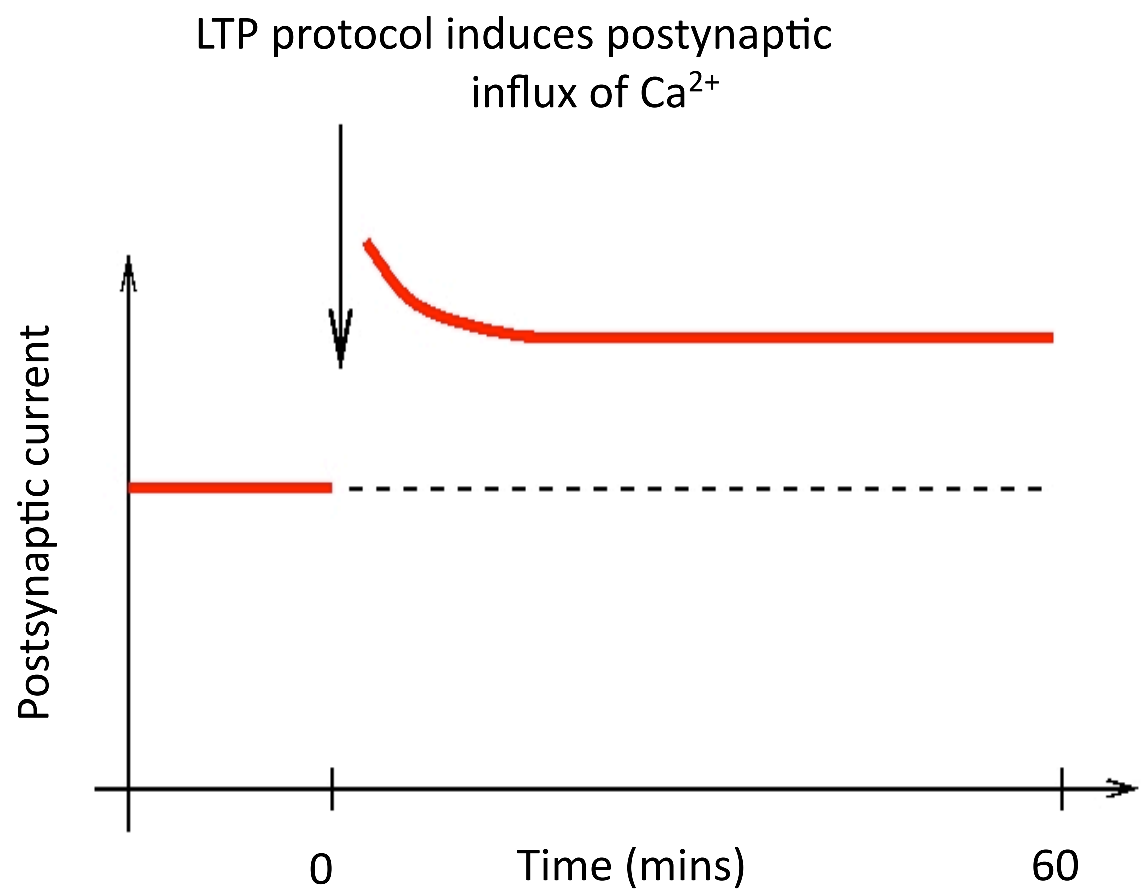


Neural response to two successive weak stimuli (20 trials)



LTP: an increase in synaptic strength

Long-term potentiation (LTP)

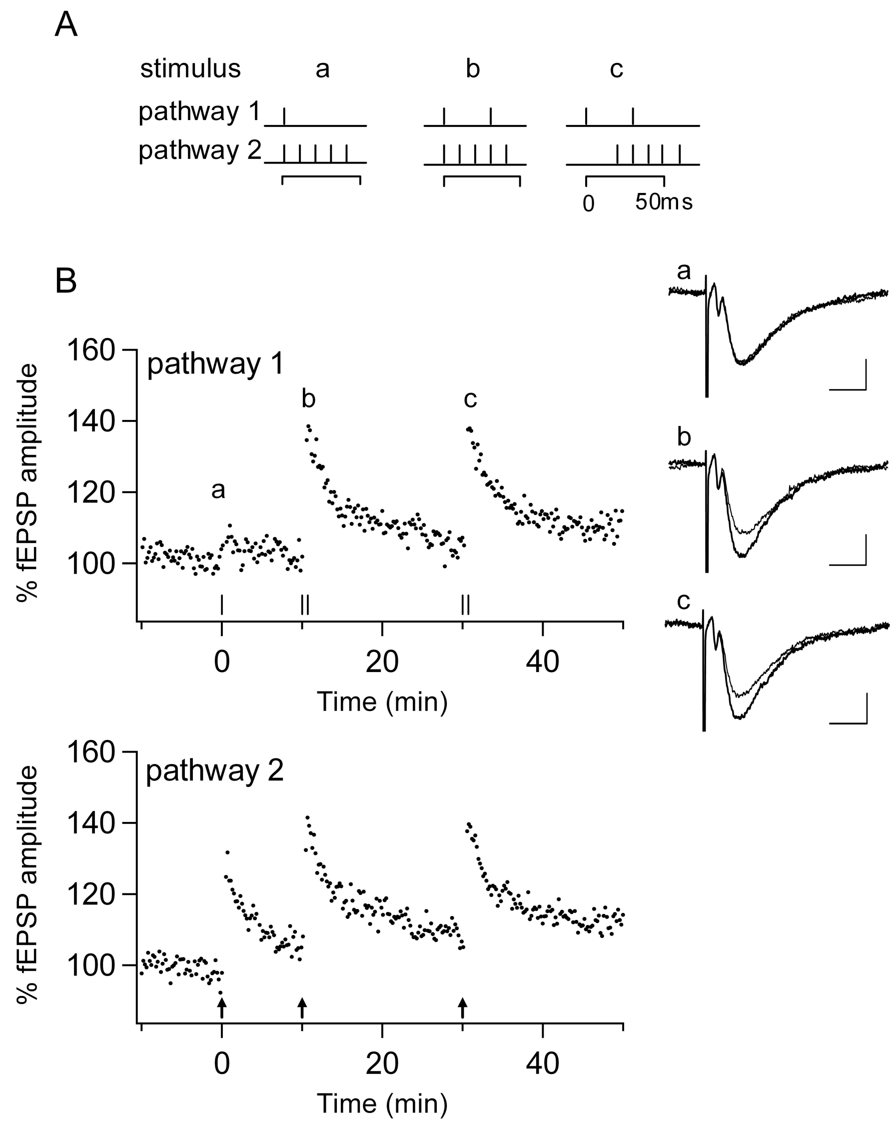


Bliss and Lomo J Physiol, 1973

Associative short-term plasticity

Pairing of two stimuli in pathway 1 with 5 stimuli in pathway 2 produces an increase in EPSP within 12 seconds, that decays over a timescale of minutes.

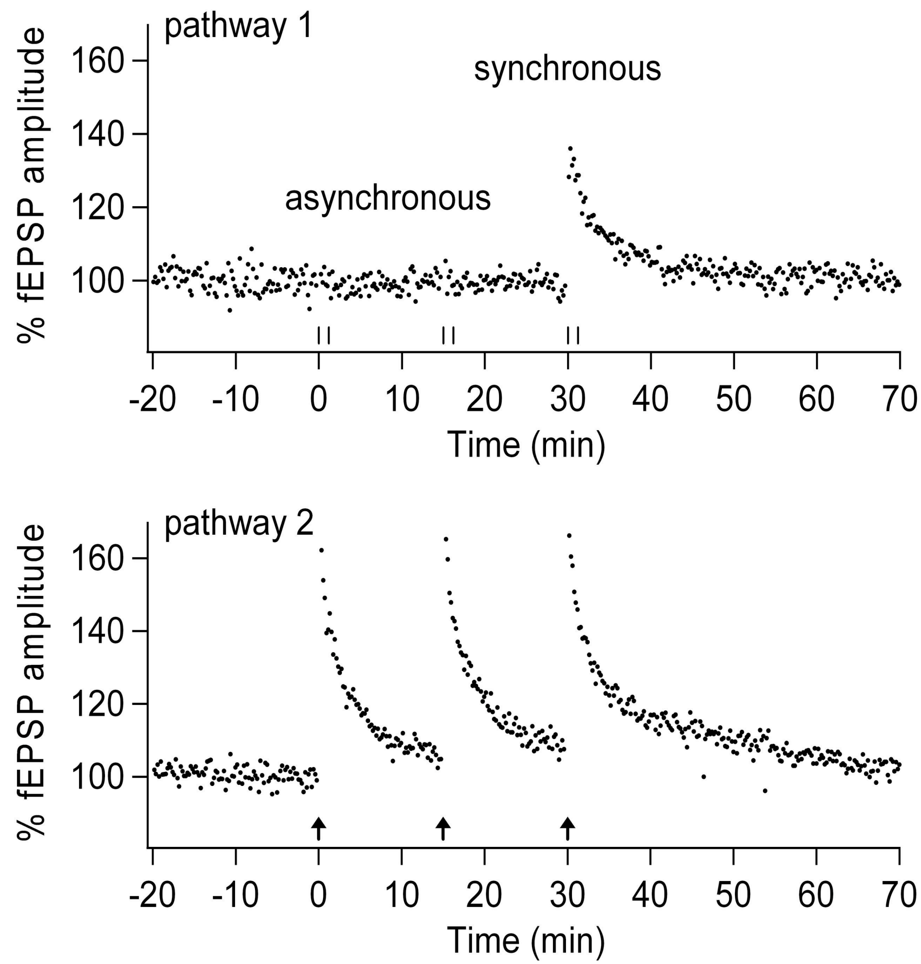
Figure 1



Erickson, Maramara, Lisman 2009 (submitted)

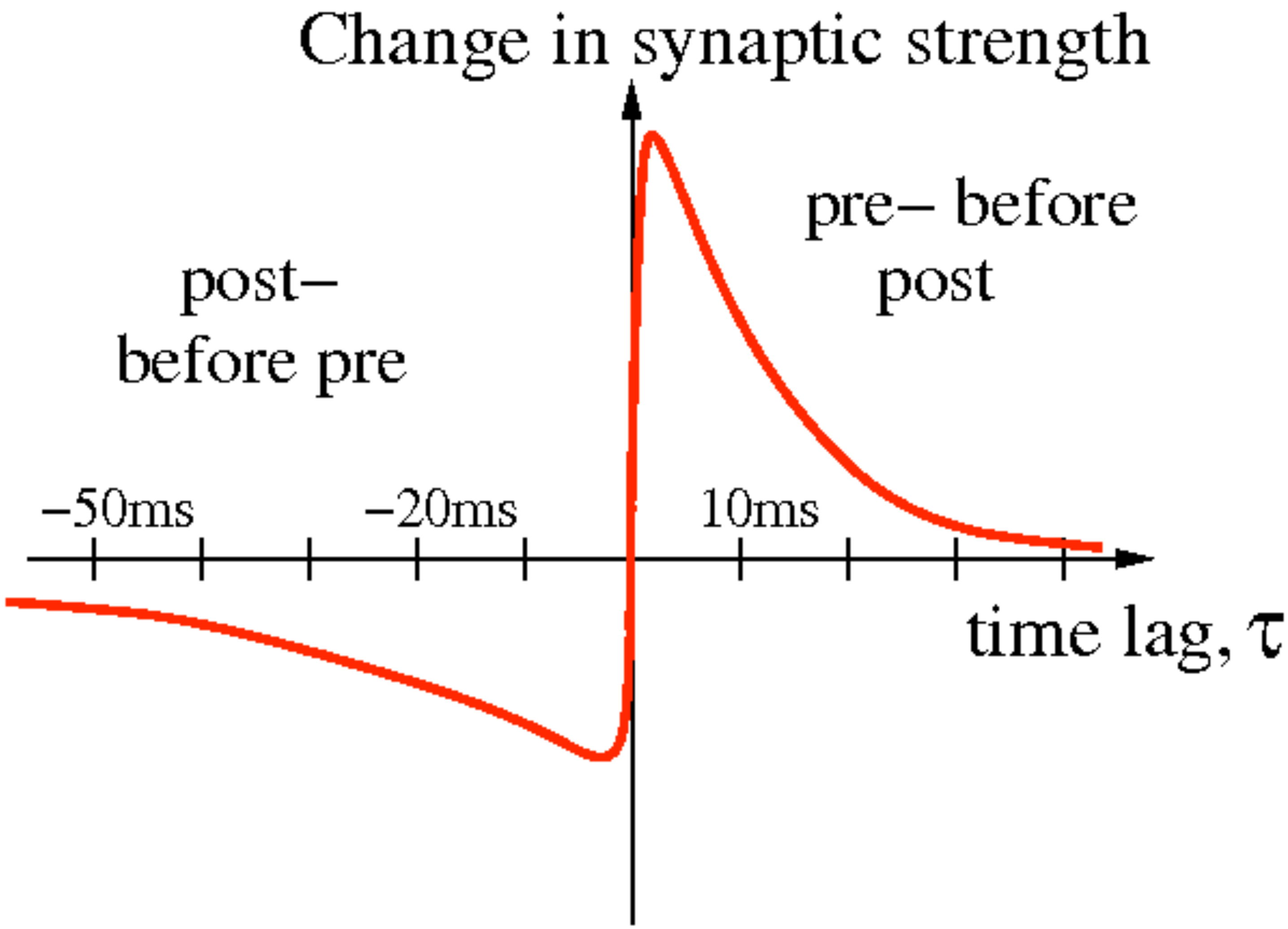
Associative short-term plasticity

Increase in fEPSP of the weakly stimulated pathway 1 only when stimulation is coincident with strong stimulation in Pathway 2.



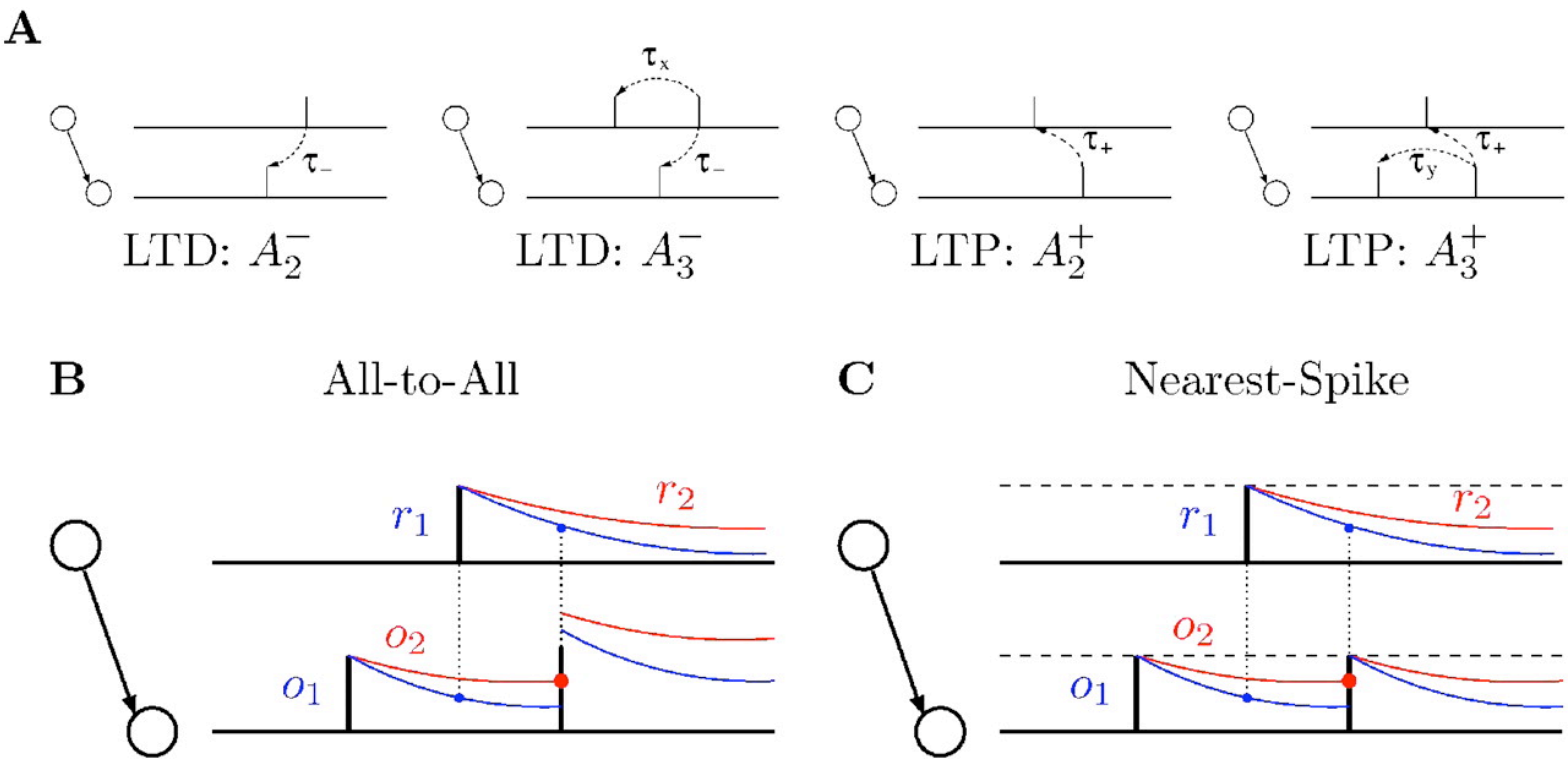
Erickson, Maramara, Lisman 2009 (submitted)

Sign of synaptic plasticity can depend on the relative timing of presynaptic and postsynaptic spikes



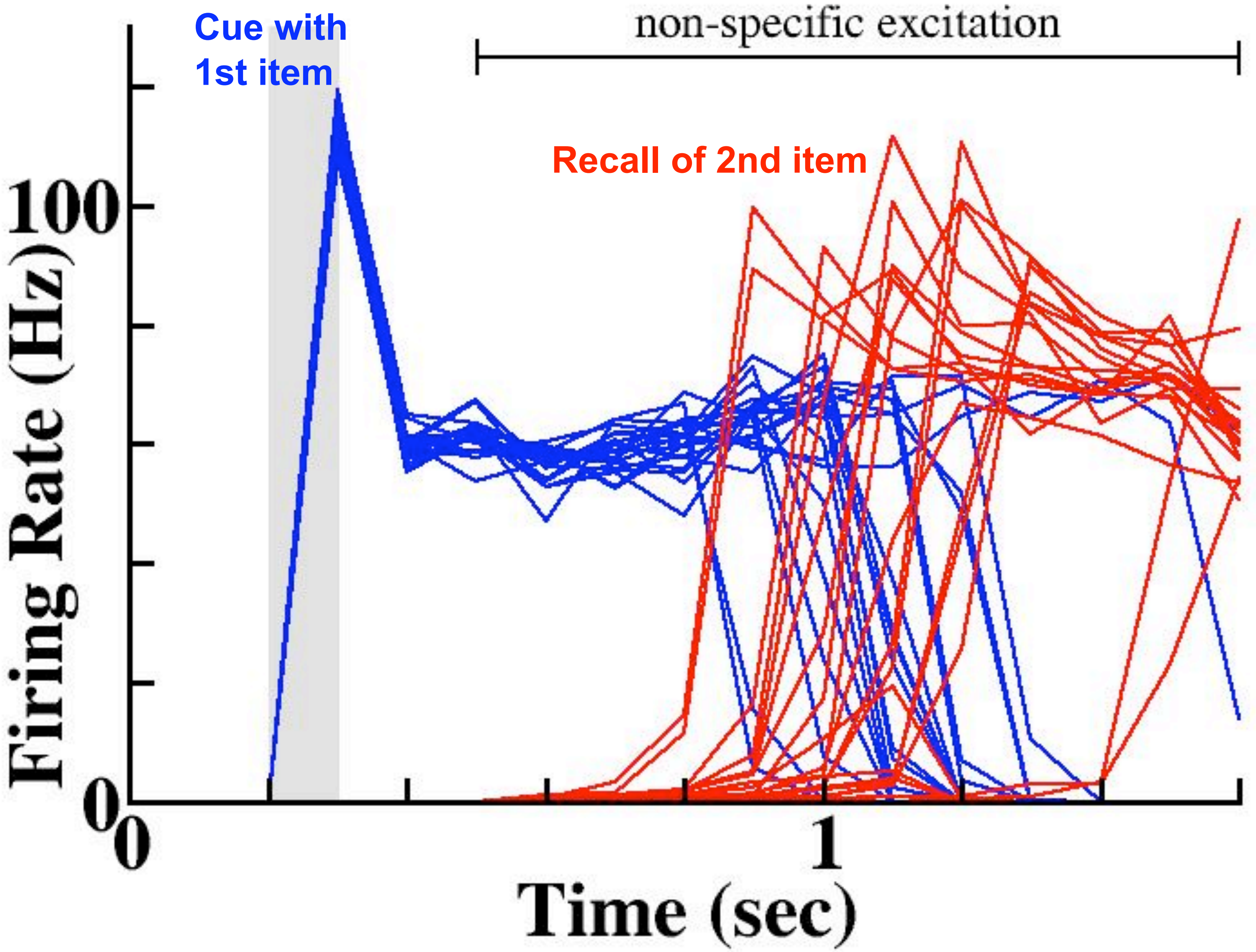
Bi GQ and Poo MM, J Neurosci (1998)

More accurate rules include triplet terms, which reproduce the frequency dependence as well as spike-timing dependence of LTP/LTD

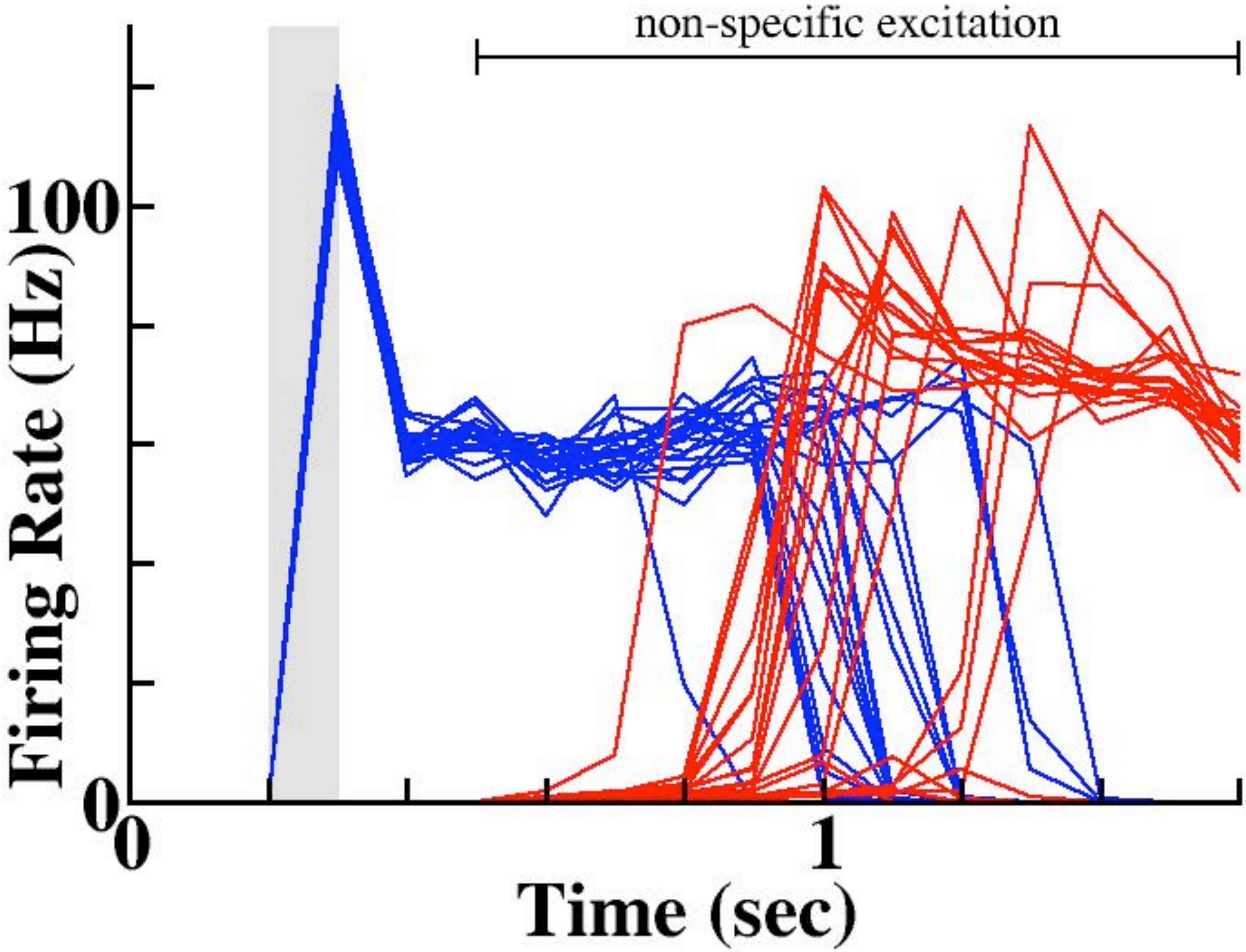


From Pfister J and Gerstner W, J Neurosci (2006)
Based on data from:
Sjöström P, Turrigiano G and Nelson S, Neuron (2001)

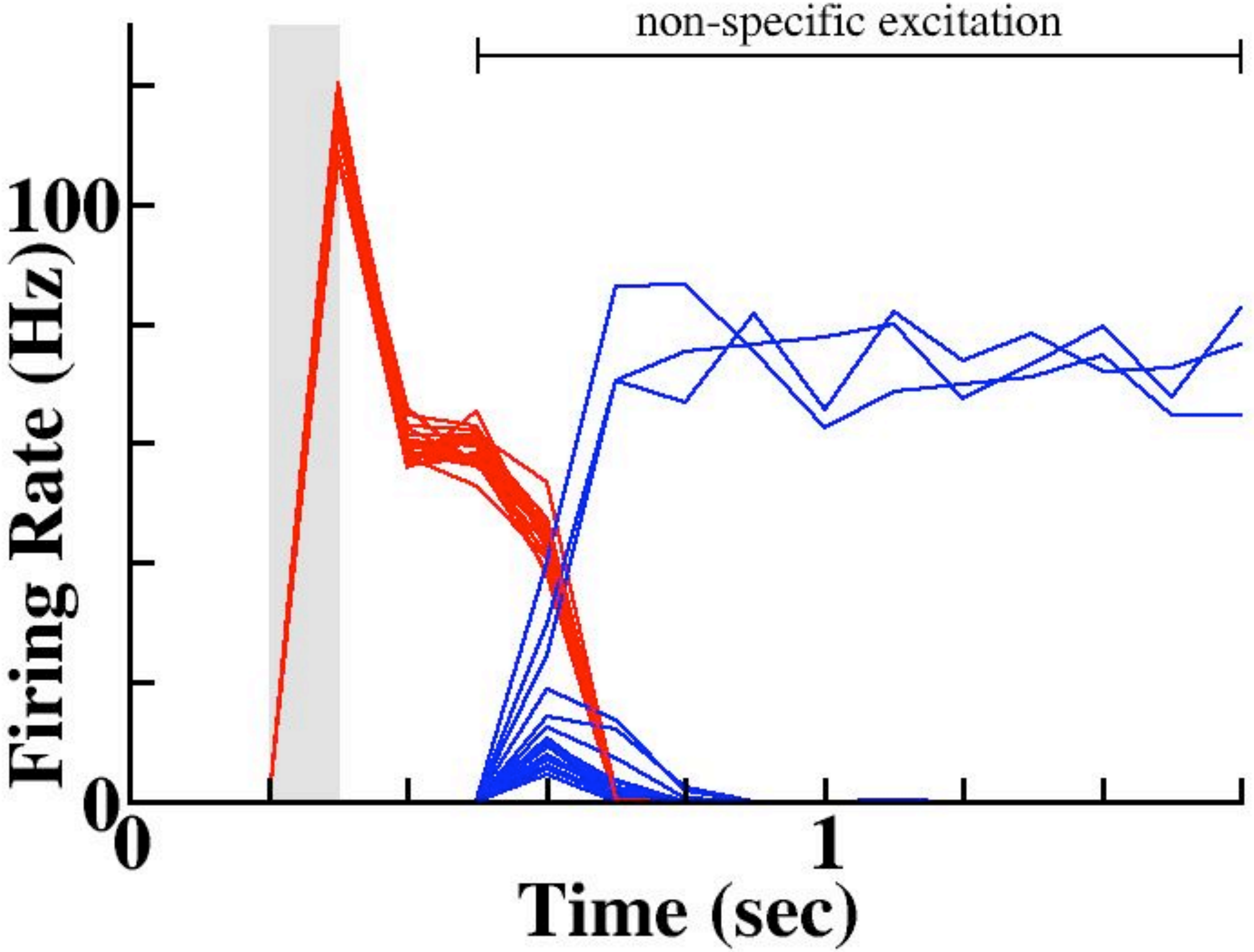
Neural activity in recall of successive strong stimuli (20 trials):
cue blue, 95% recall of red



Neural activity showing worse recall of successive weak stimuli (20 trials):
cue blue, 75% recall of 2nd item

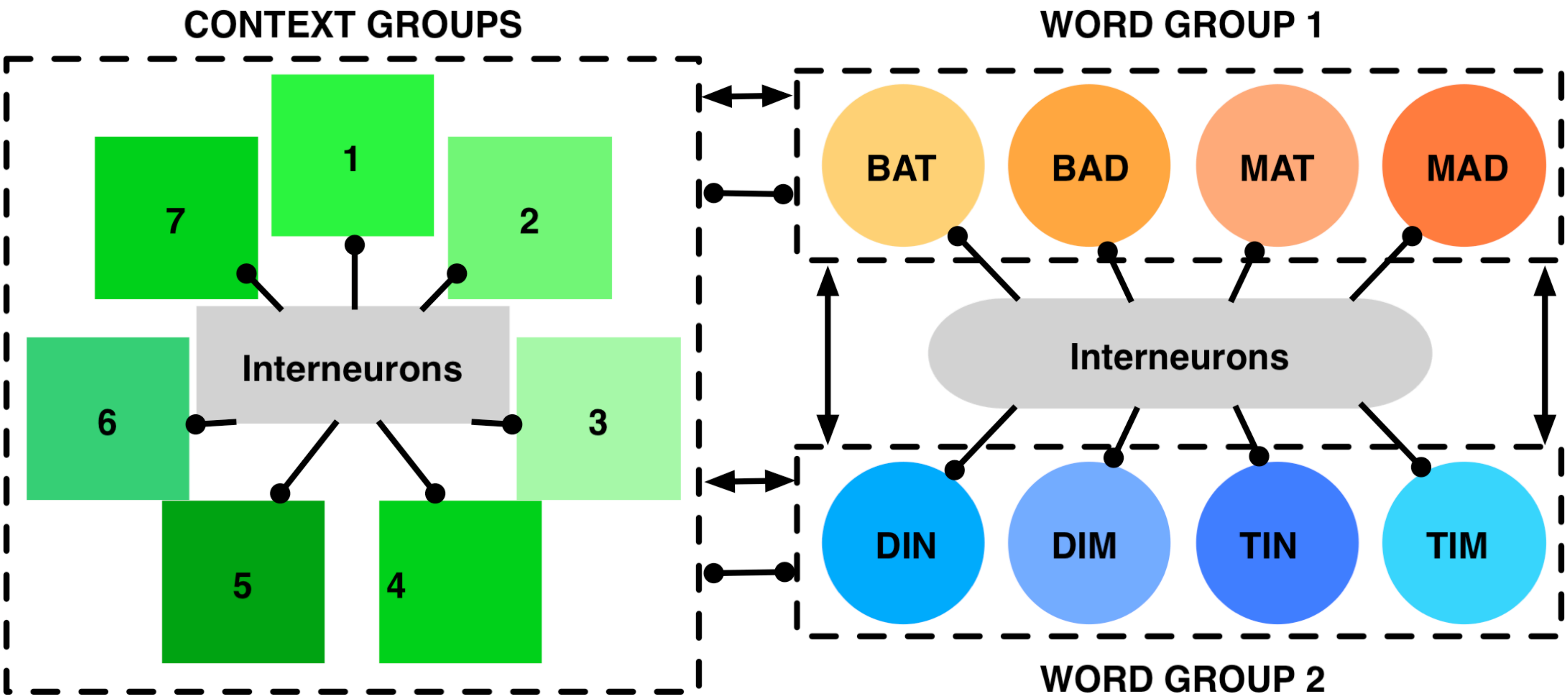


However, reverse recall does not occur, even following strong stimuli
(15% correct = chance)

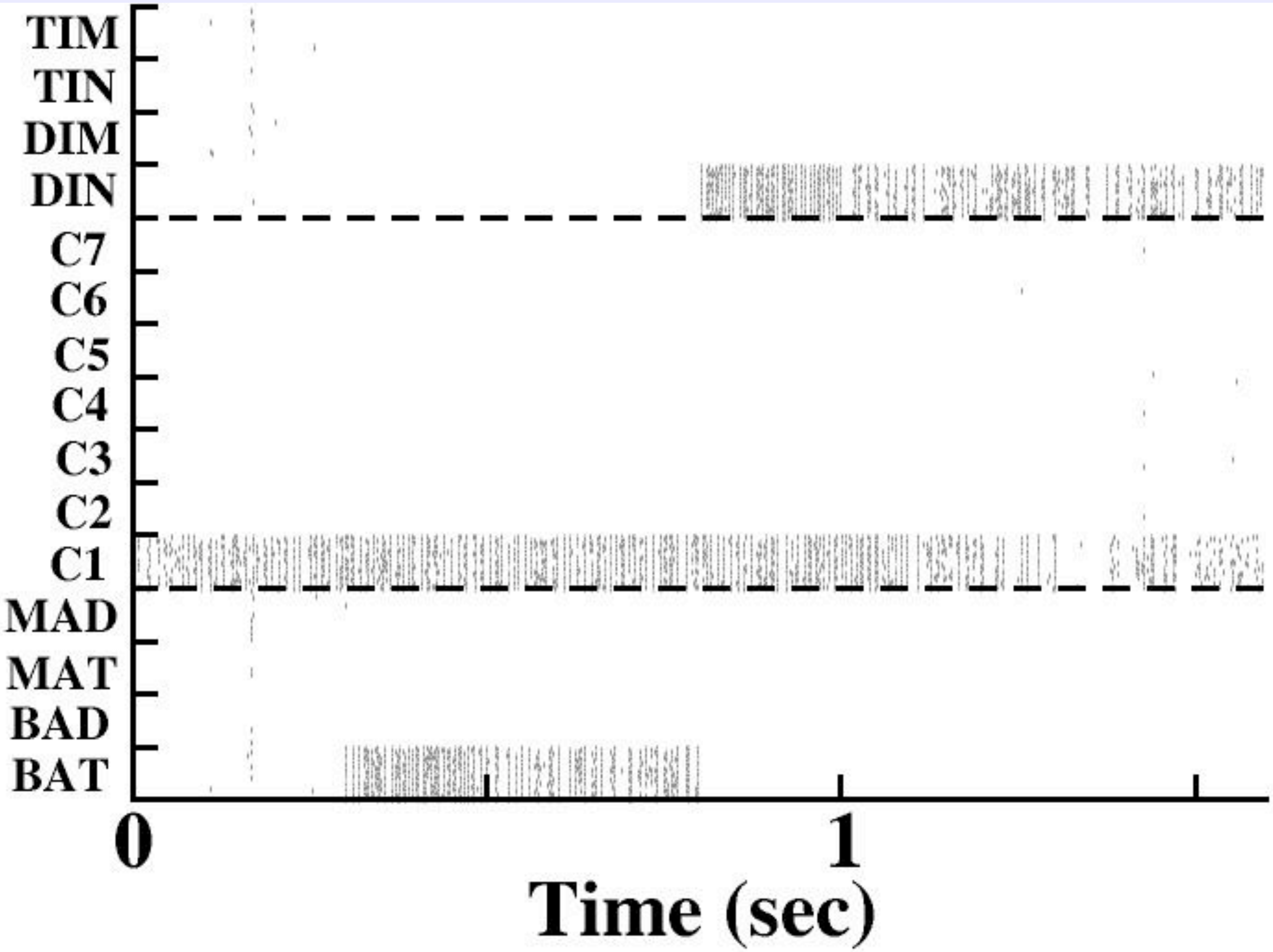


Addition of context groups: the temporal context model

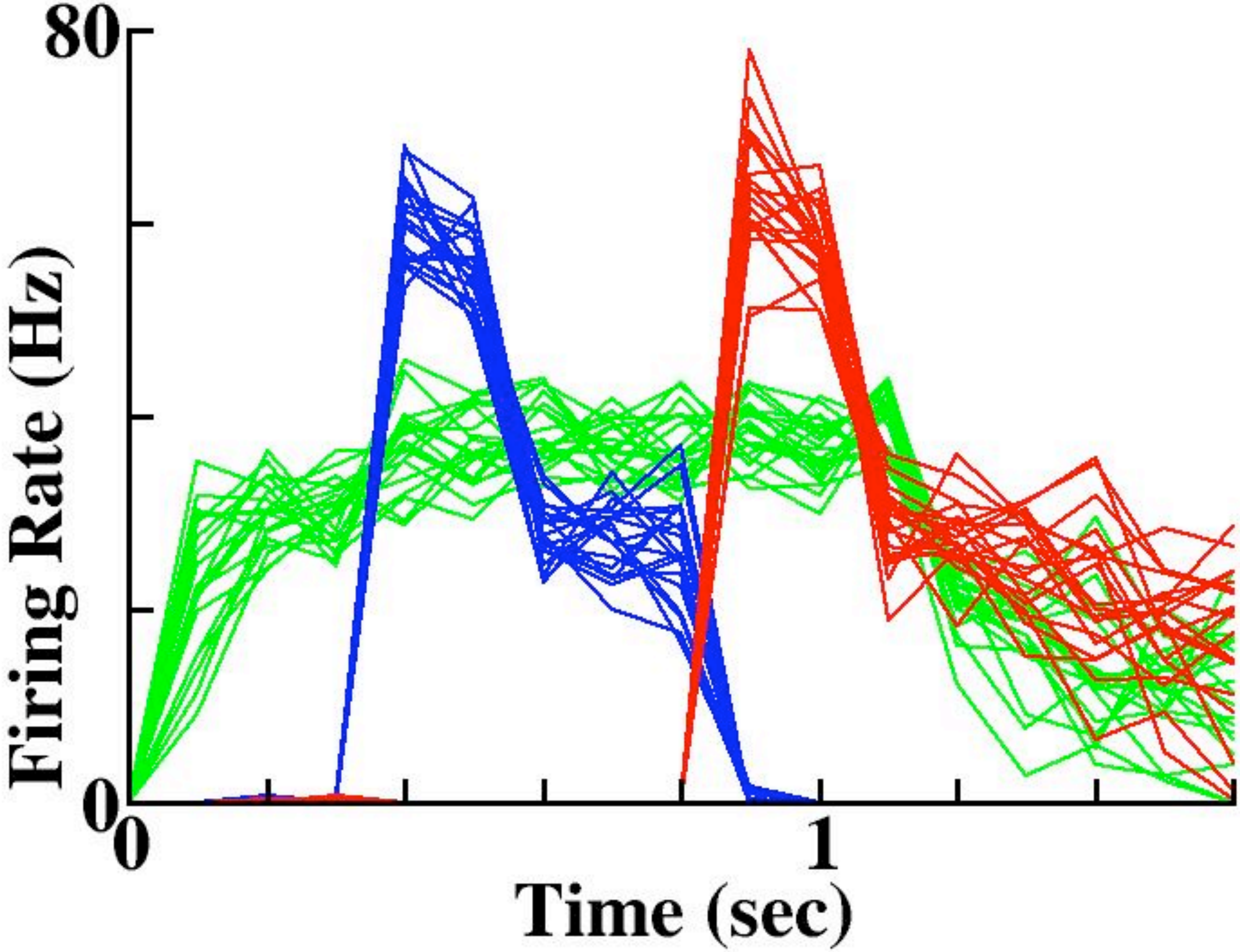
Weaker inhibition between “word” pools and coactive “context” pools

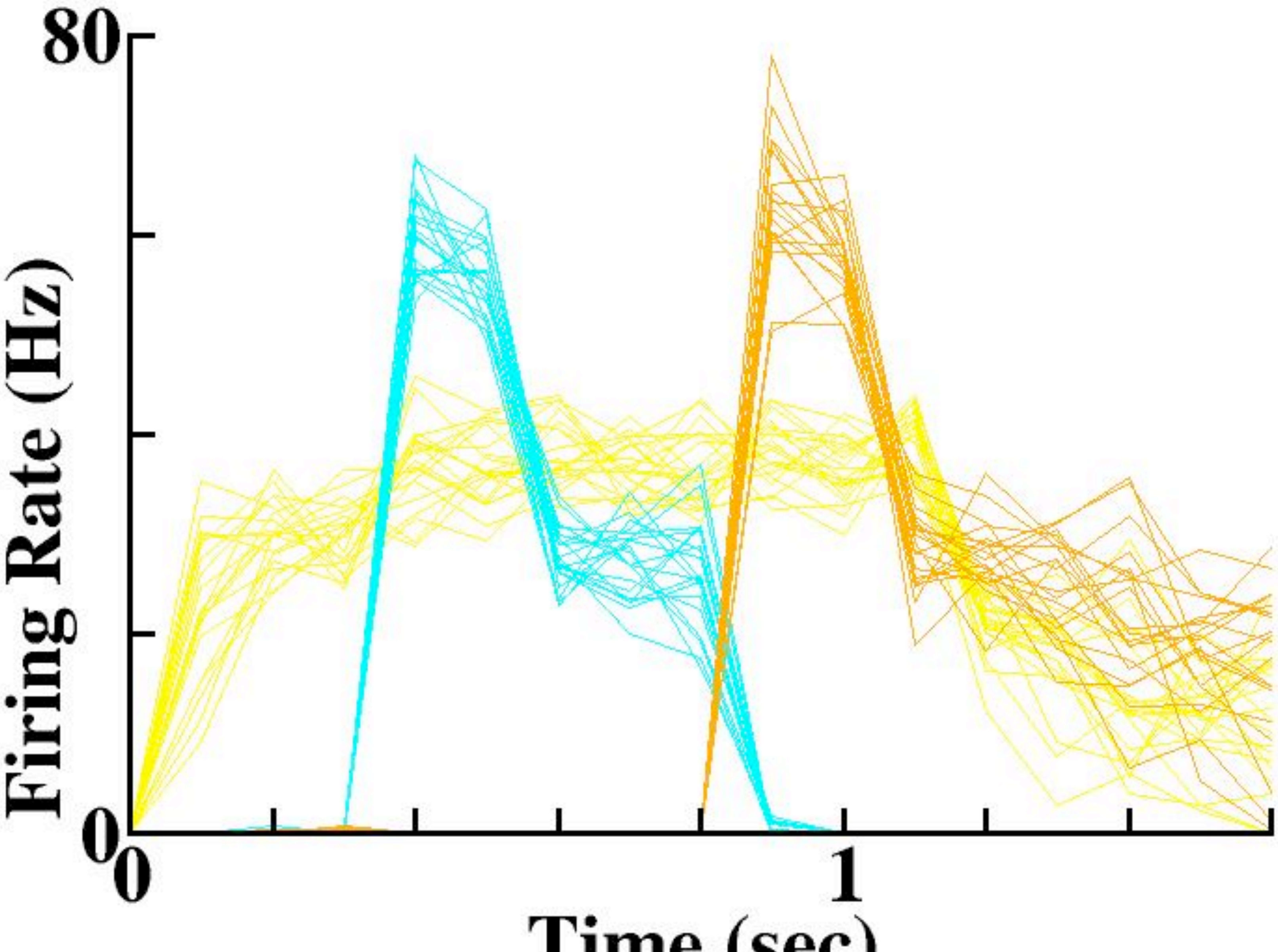


Stimulus presentation: context cells "C1" activated during word presentations



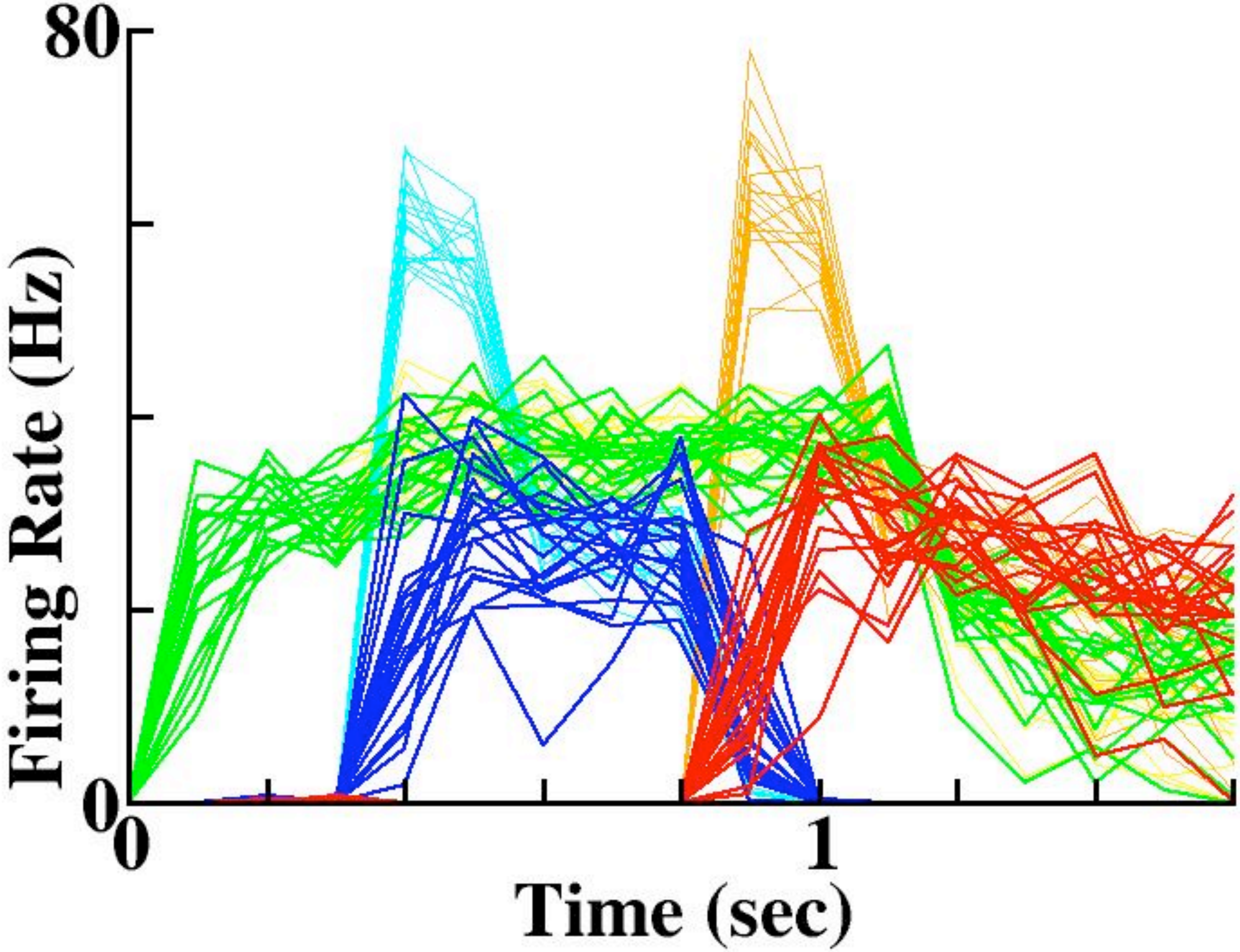
Stimulus presentation: context cells (green) activated during word presentations



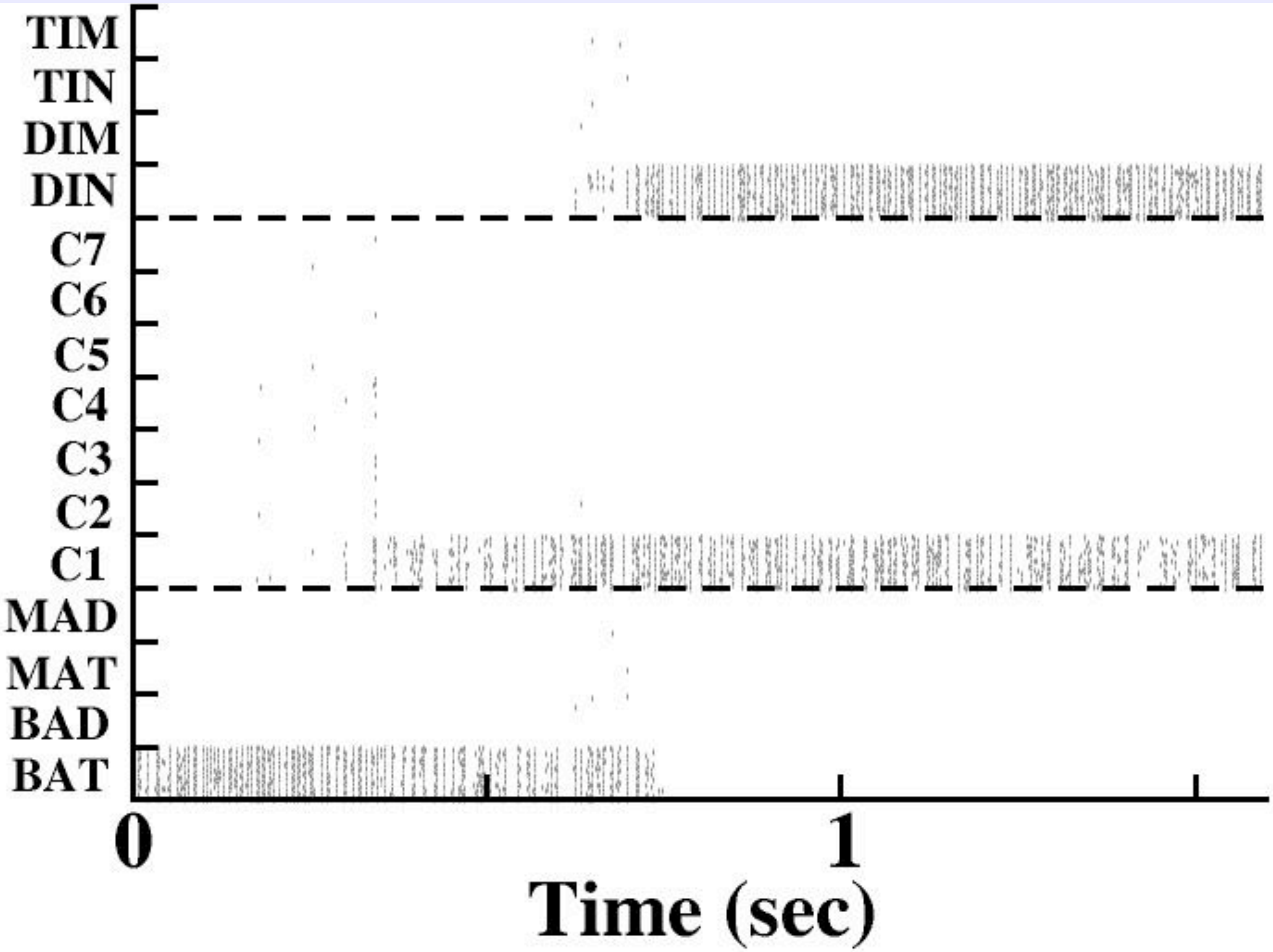


80
Firing Rate (Hz)
0
0
1
Time (sec)

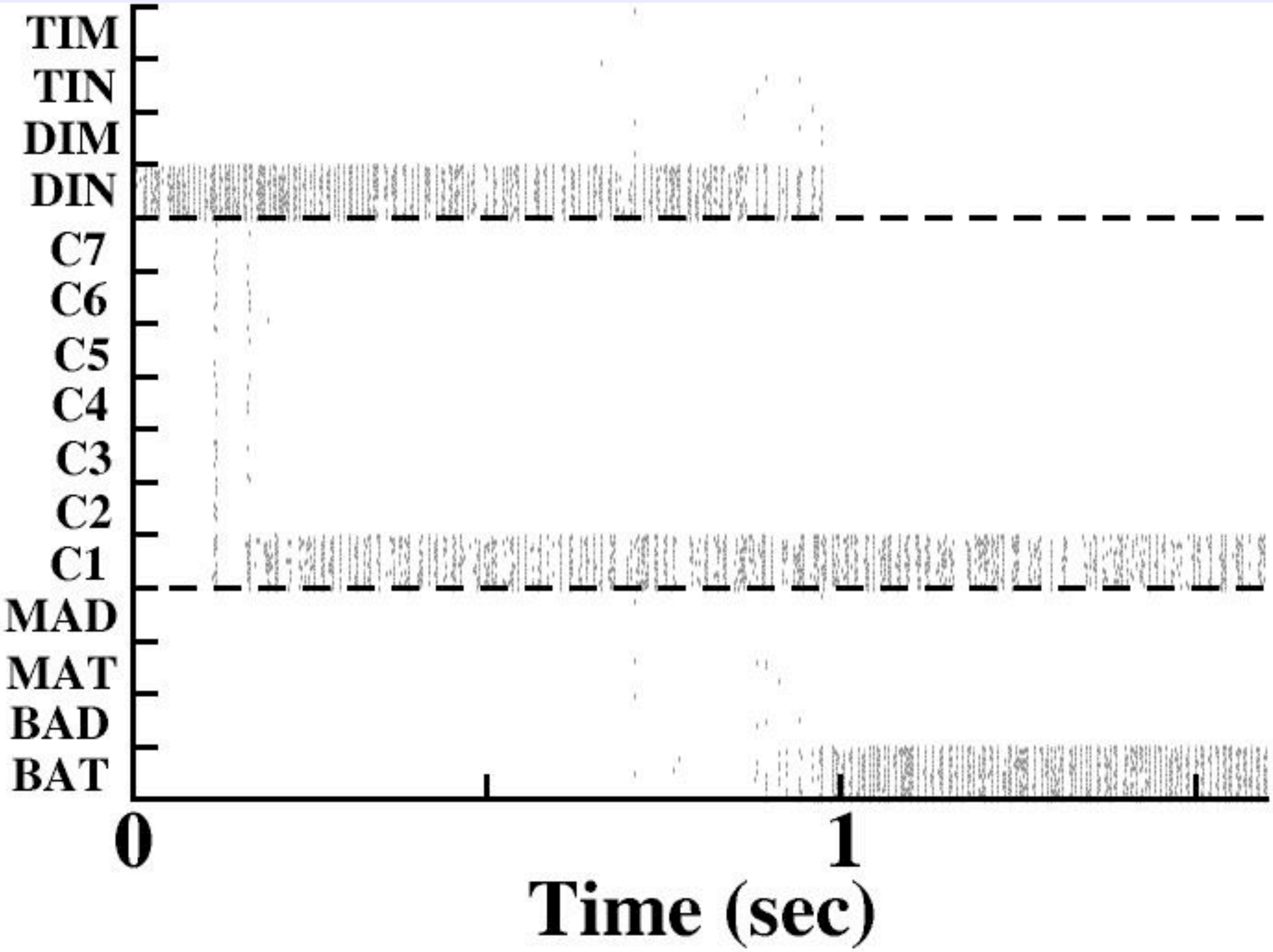
Weak stimulus presentations: context cells (green) activated during word presentations



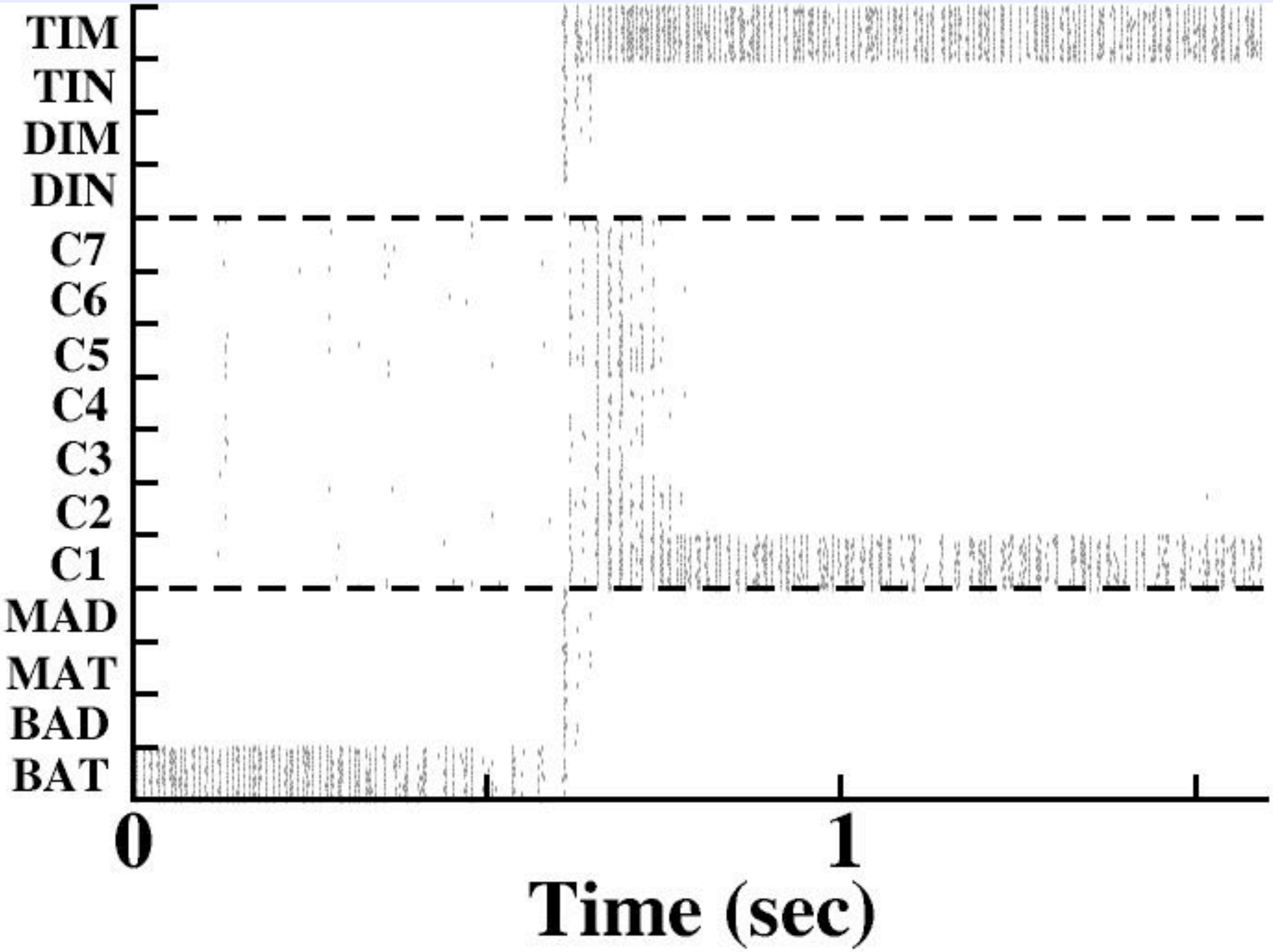
Forward recall: context cells "C1" reactivated by first word, to retrieve second word



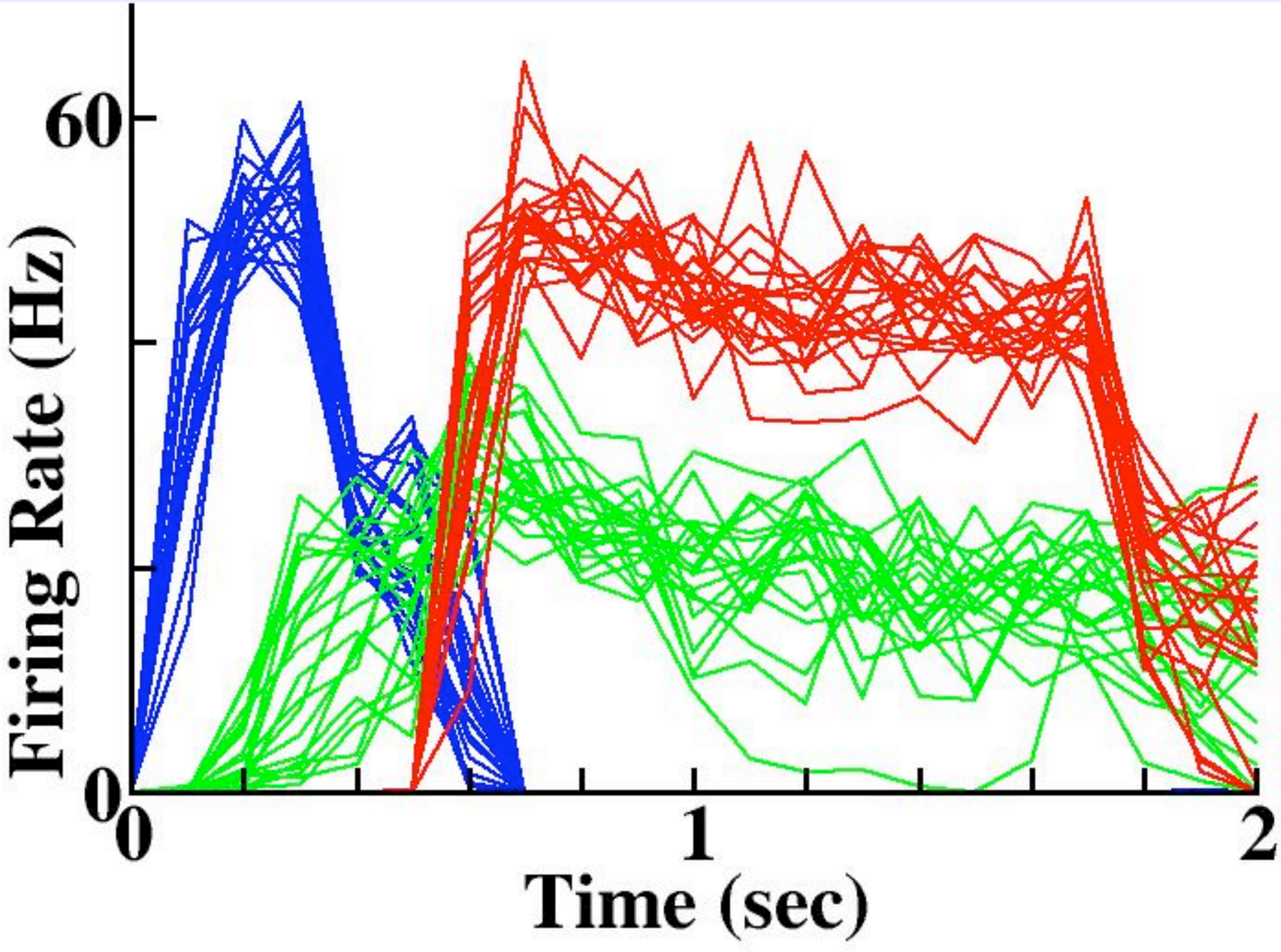
Reverse recall: context cells "C1" reactivated by 2nd word, to retrieve 1st word



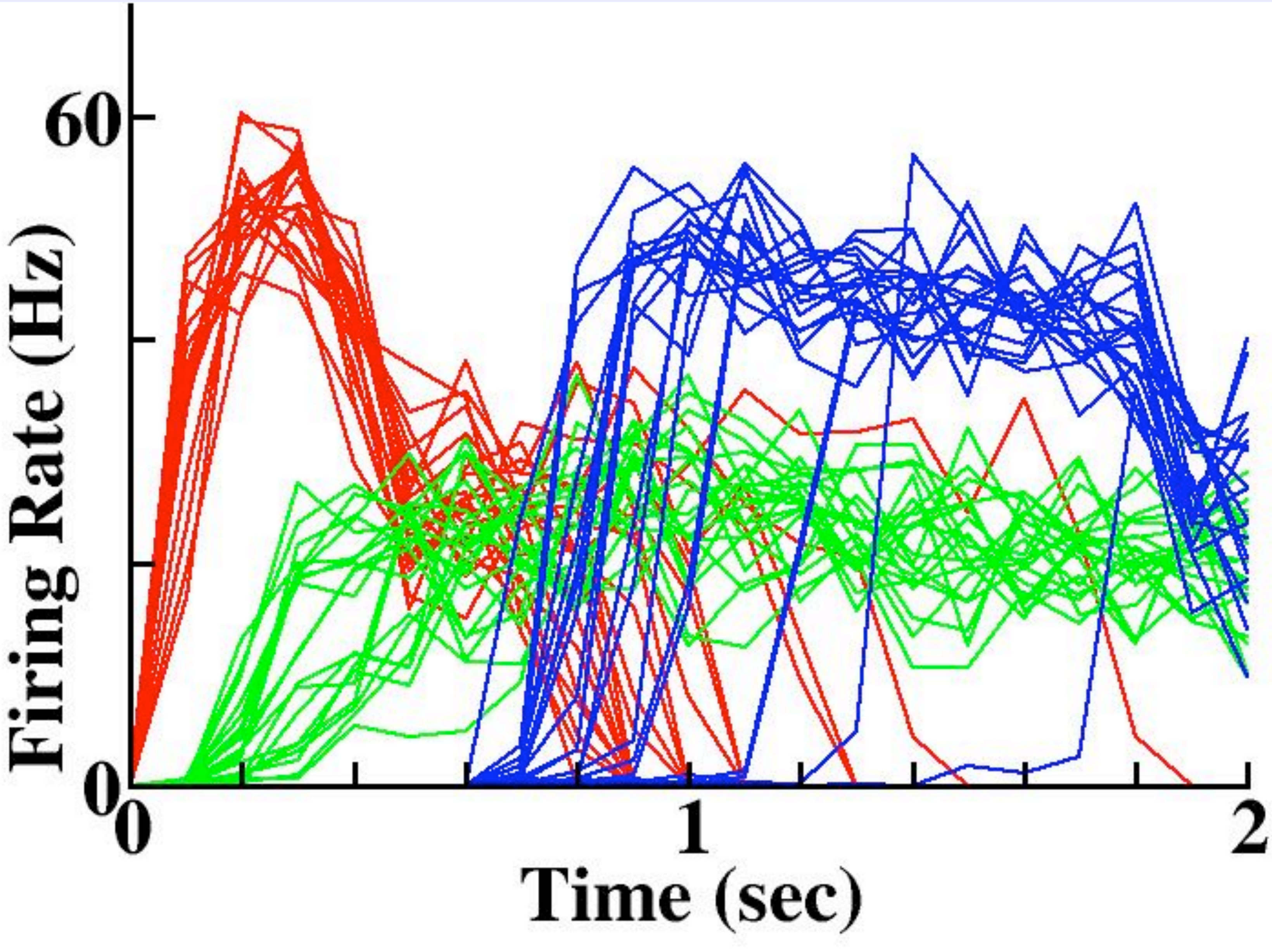
Error trial in forward recall: context cells “C1” not reactivated by first word: Incorrect second word is first retrieved



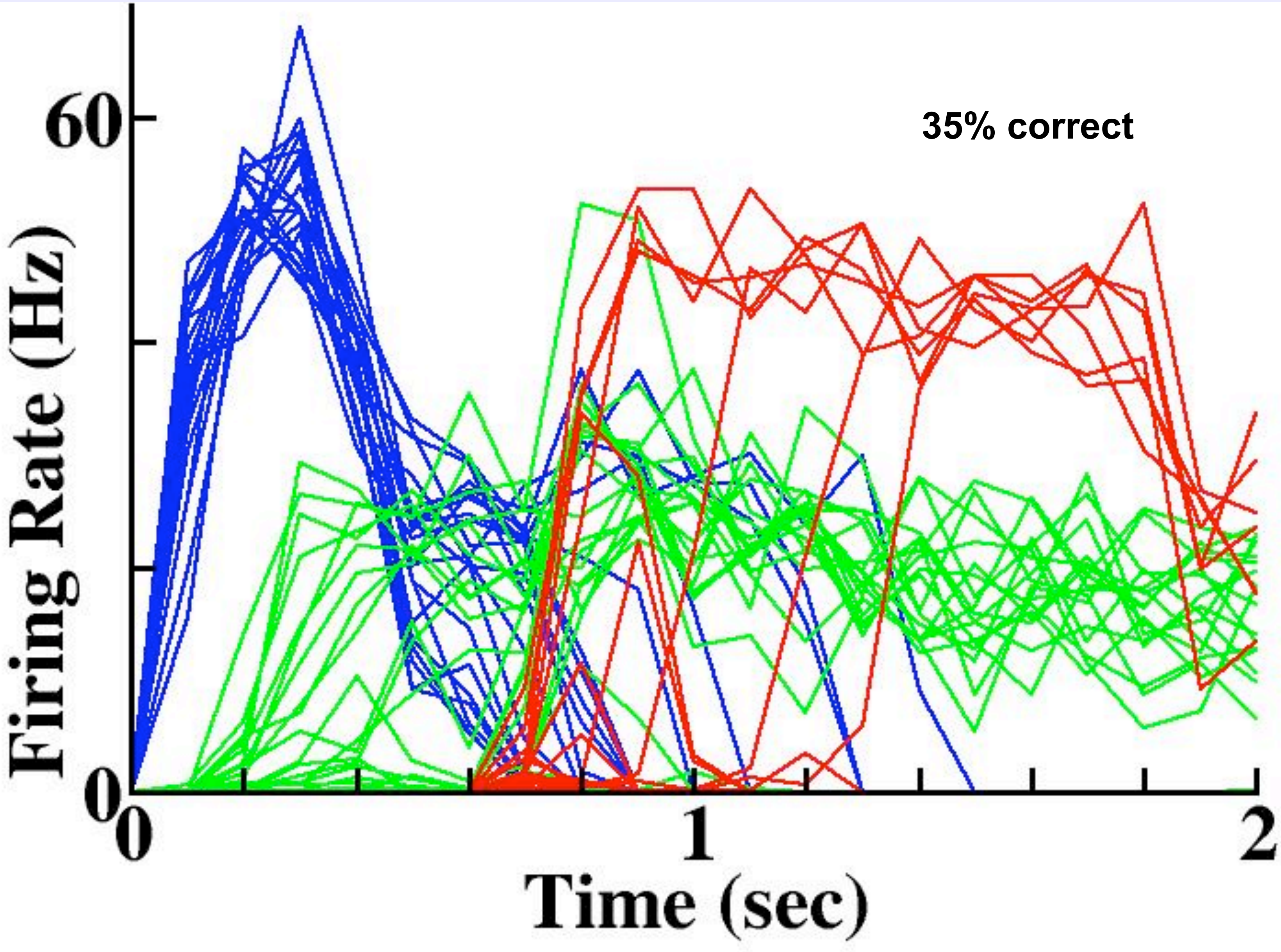
Forward recall when cued with first word (strong stimuli): results of 20 trials



Reverse recall when cued with second word (strong stimuli): results of 20 trials

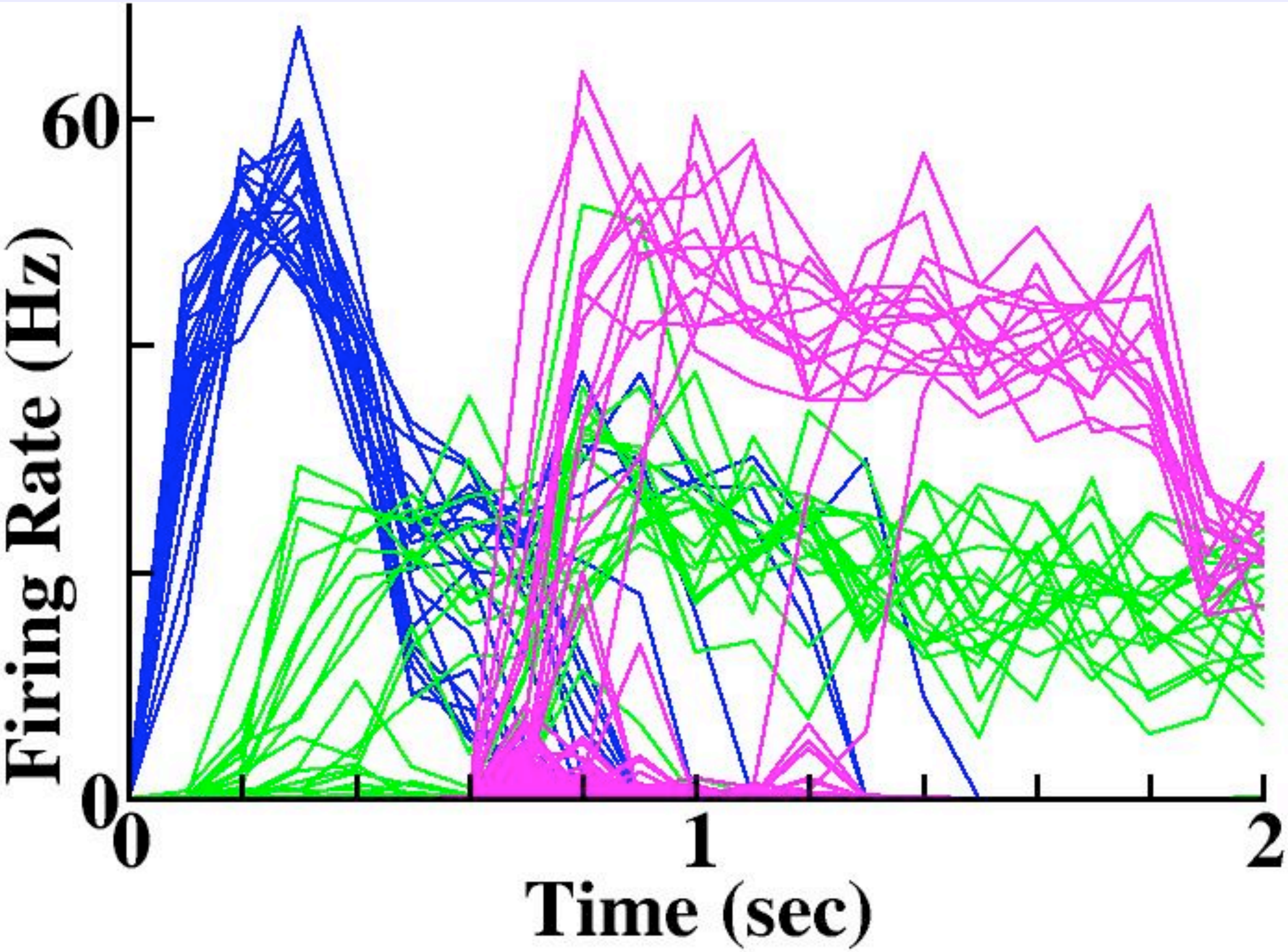


Diminished forward recall when prior stimuli were weak: results of 20 trials

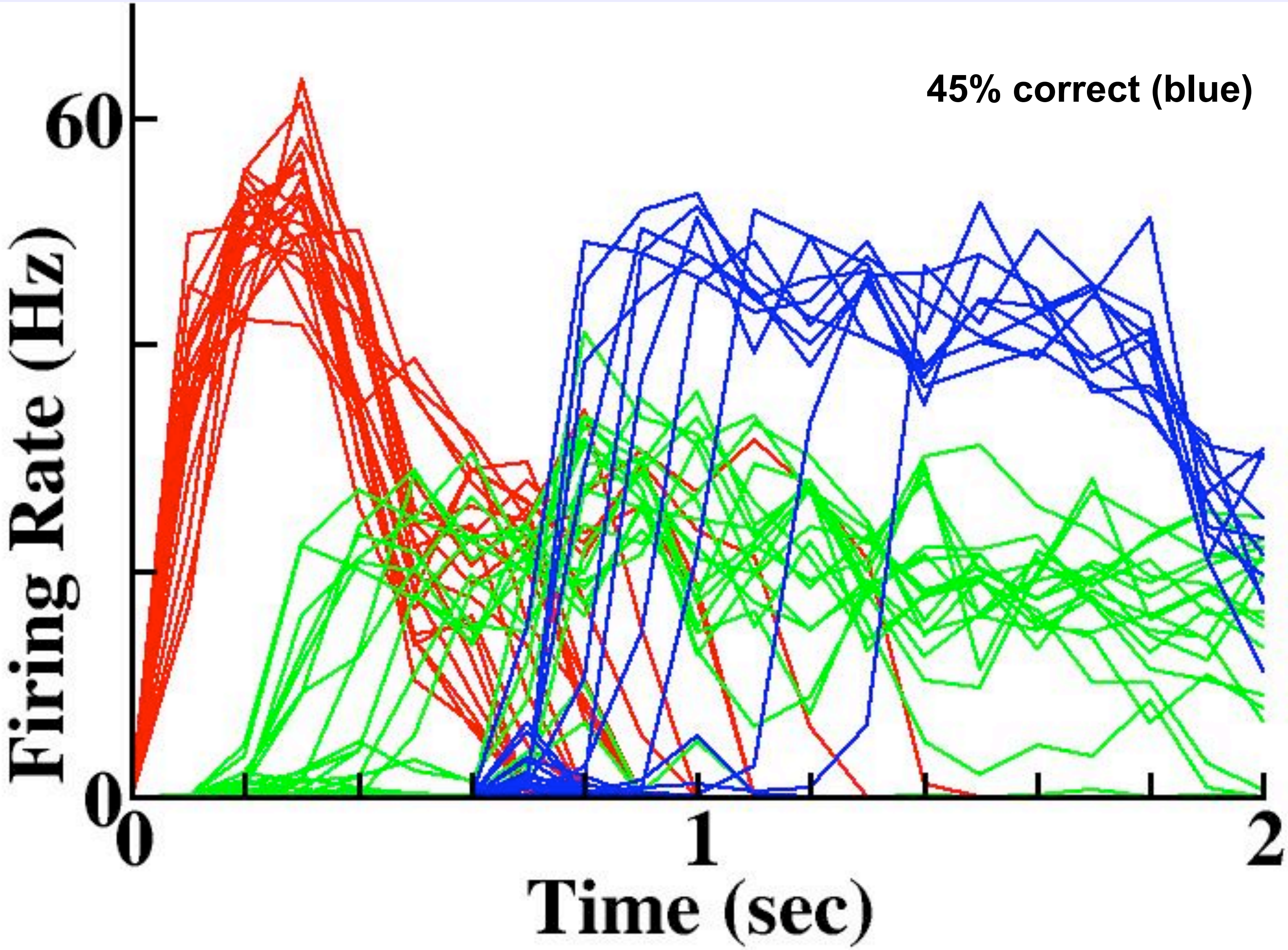


Diminished forward recall when both prior stimuli were weak: results of 20 trials

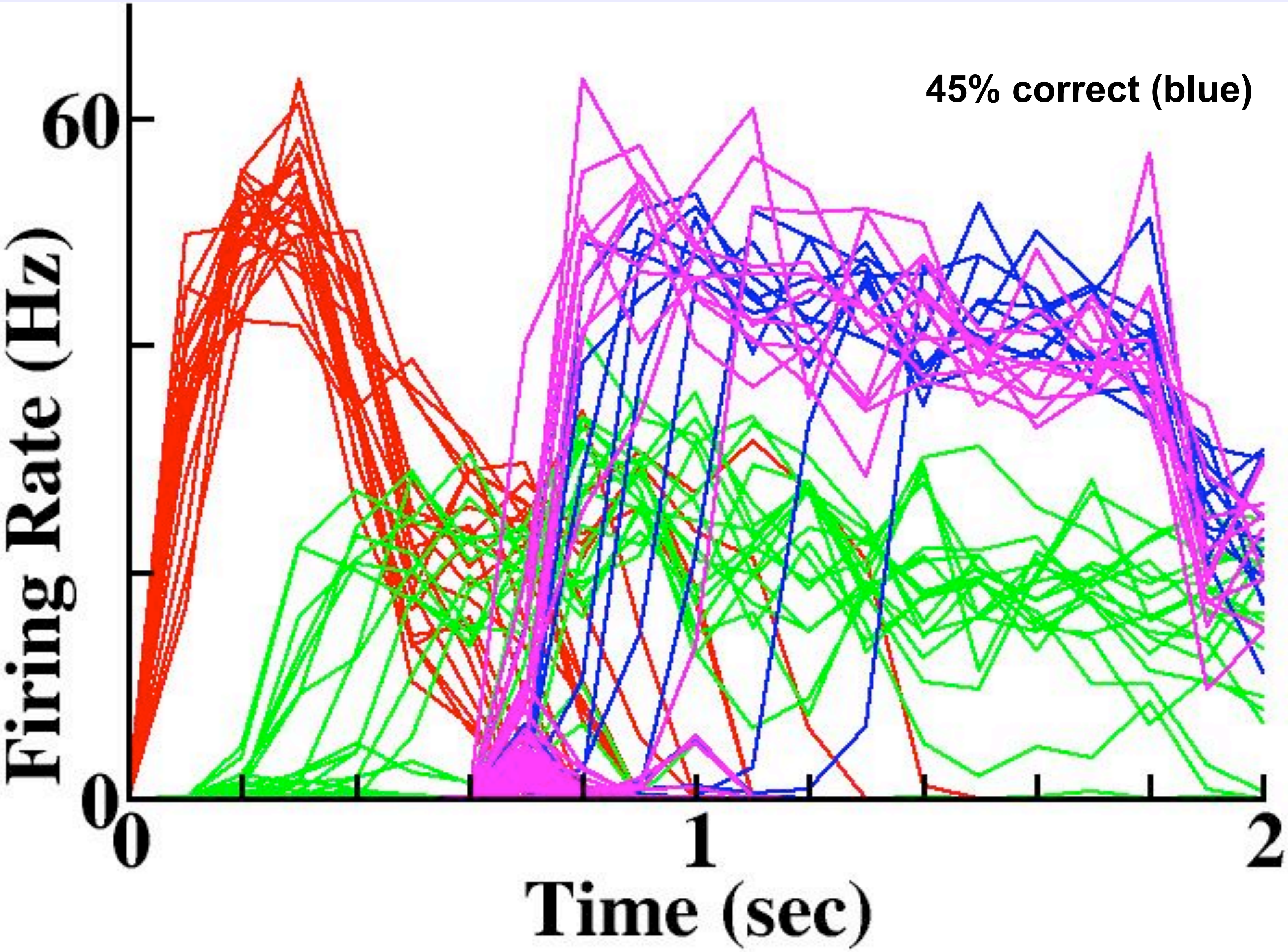
Multiple errors arise (magenta)



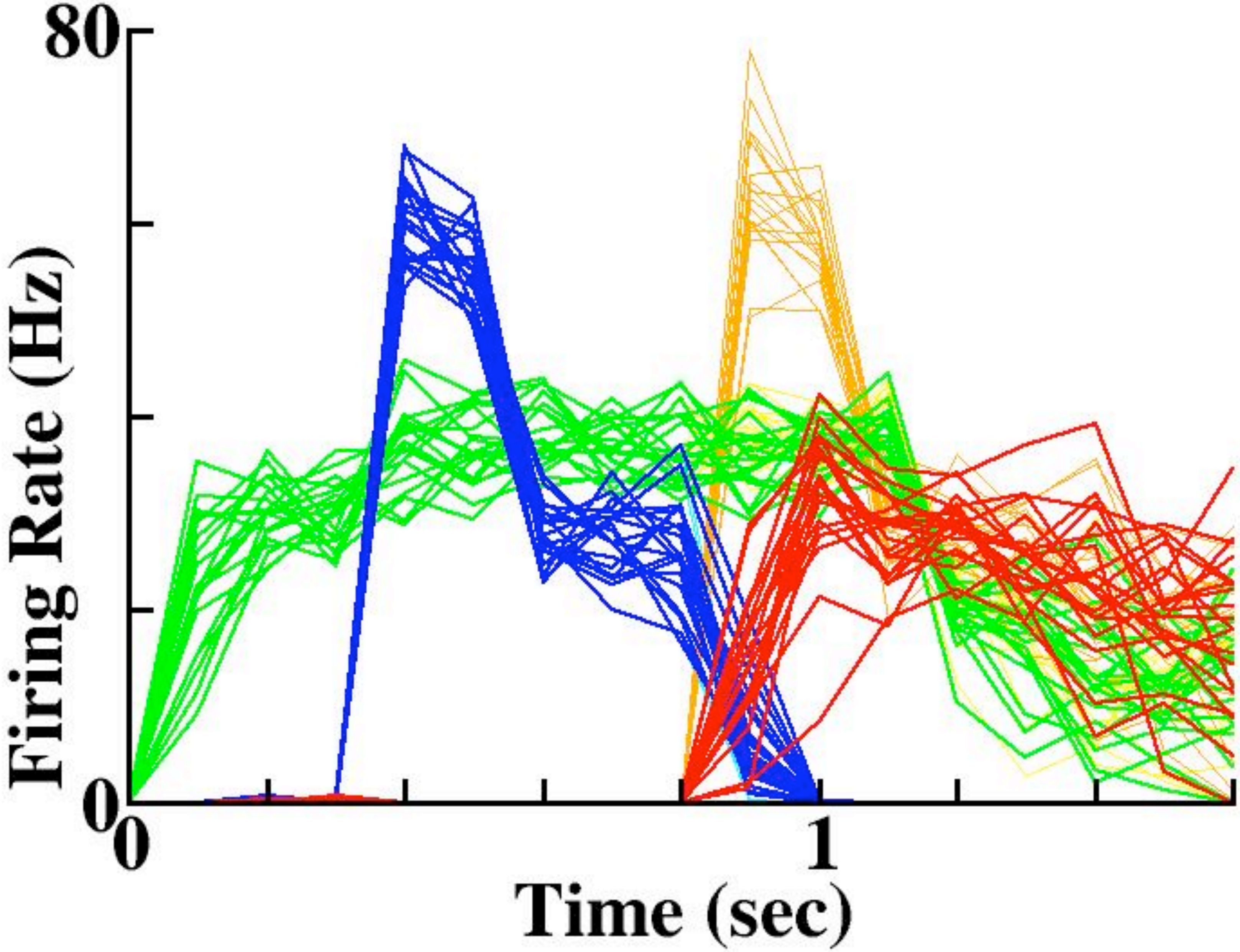
Diminished reverse recall when both prior stimuli were weak: results of 20 trials
Multiple errors arise (magenta)



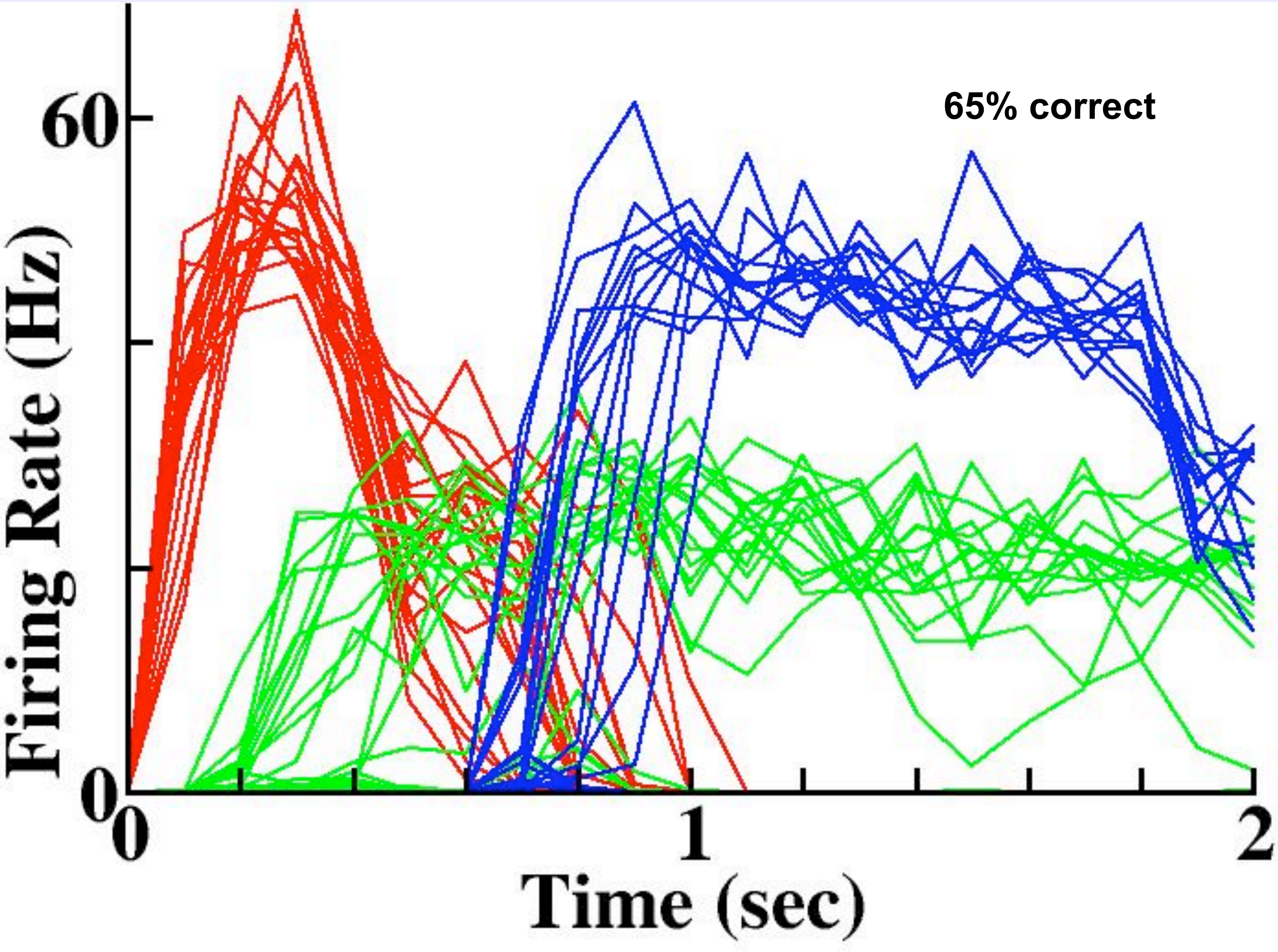
Diminished reverse recall when both prior stimuli were weak: results of 20 trials
Multiple errors arise (magenta)



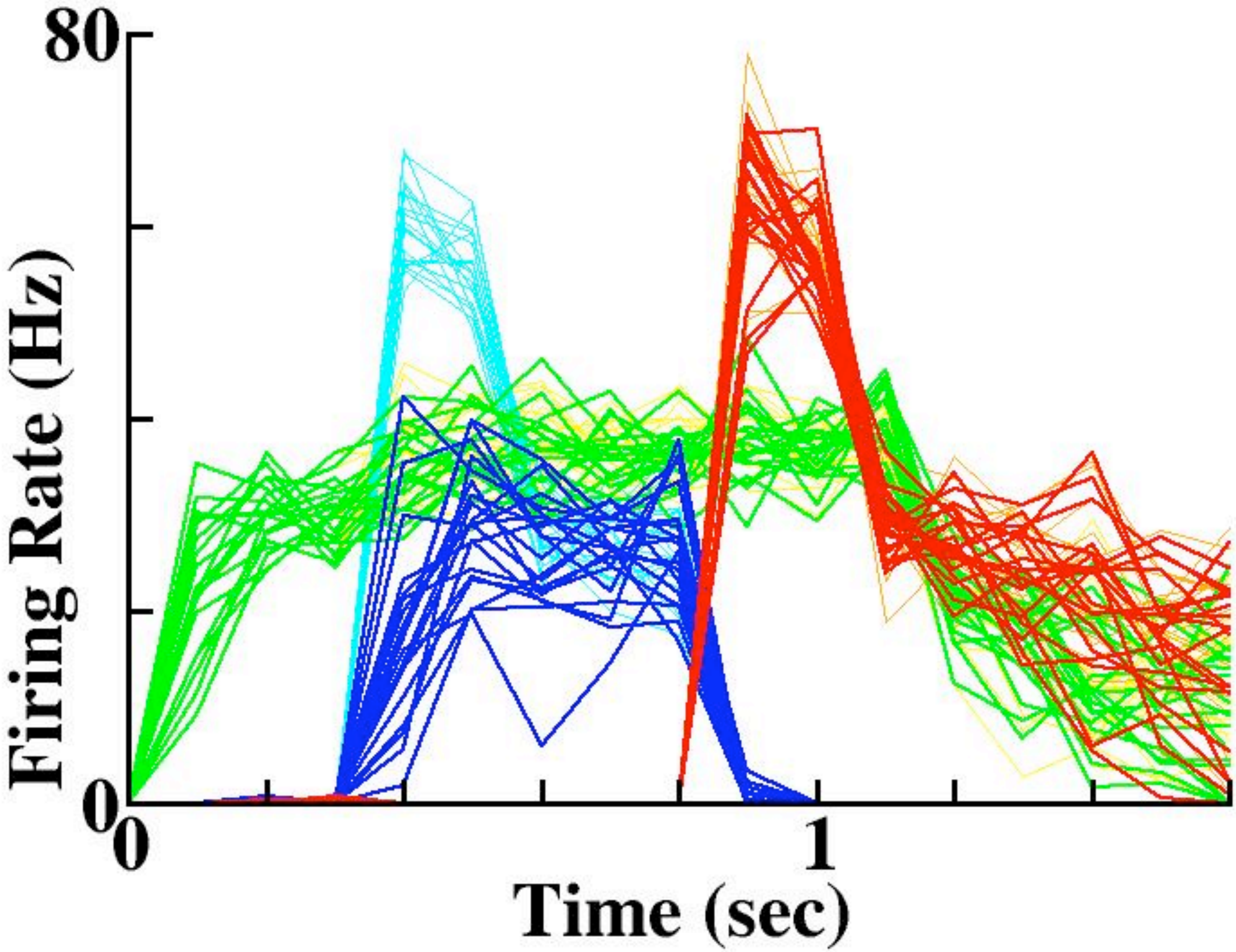
20 stimulus presentations: only 2^{nd} stimulus is weak (red)



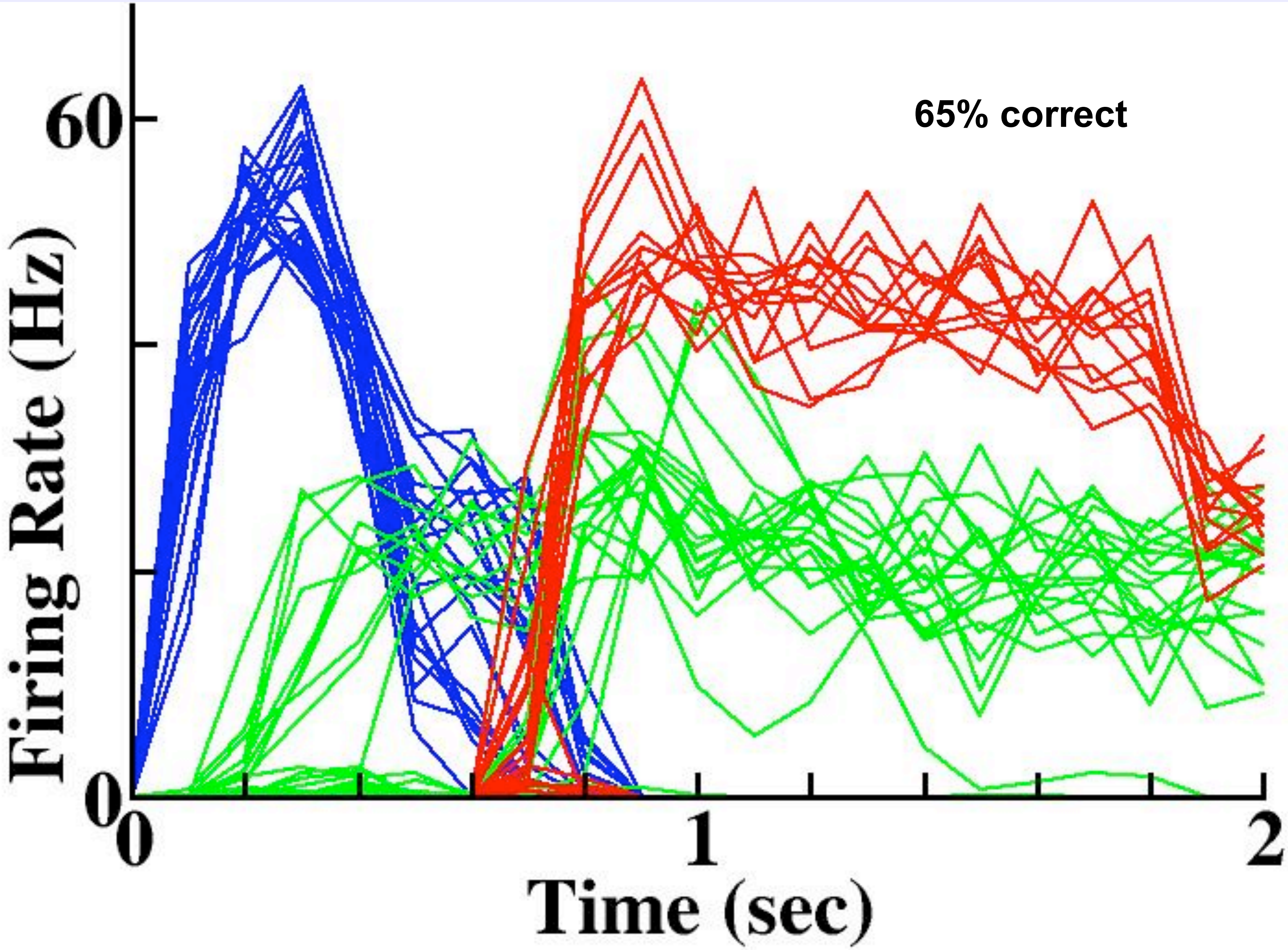
Diminished reverse recall when prior stimuli were strong then weak: results of 20 trials



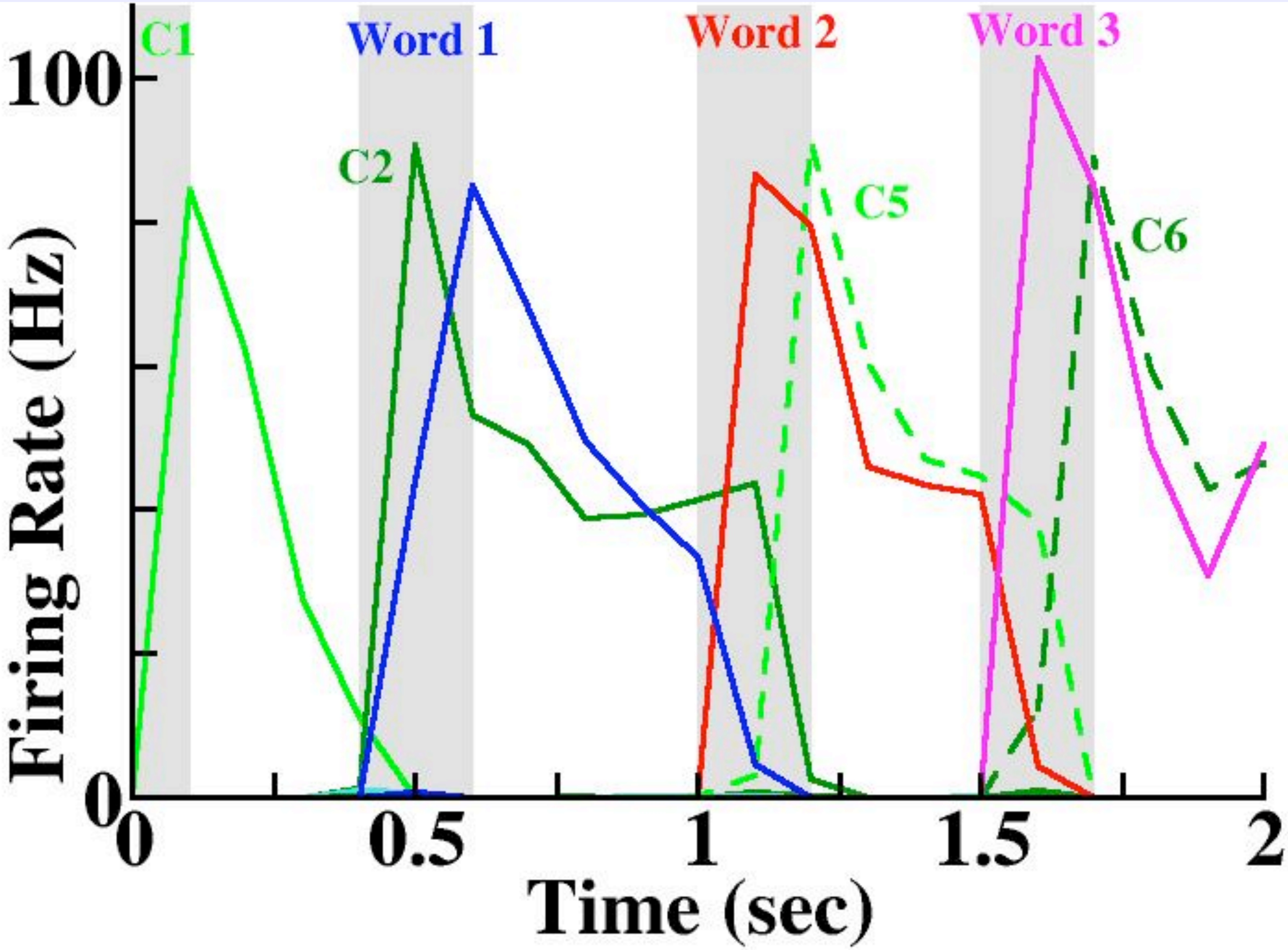
20 stimulus presentations: only 1st stimulus is weak (dark blue)



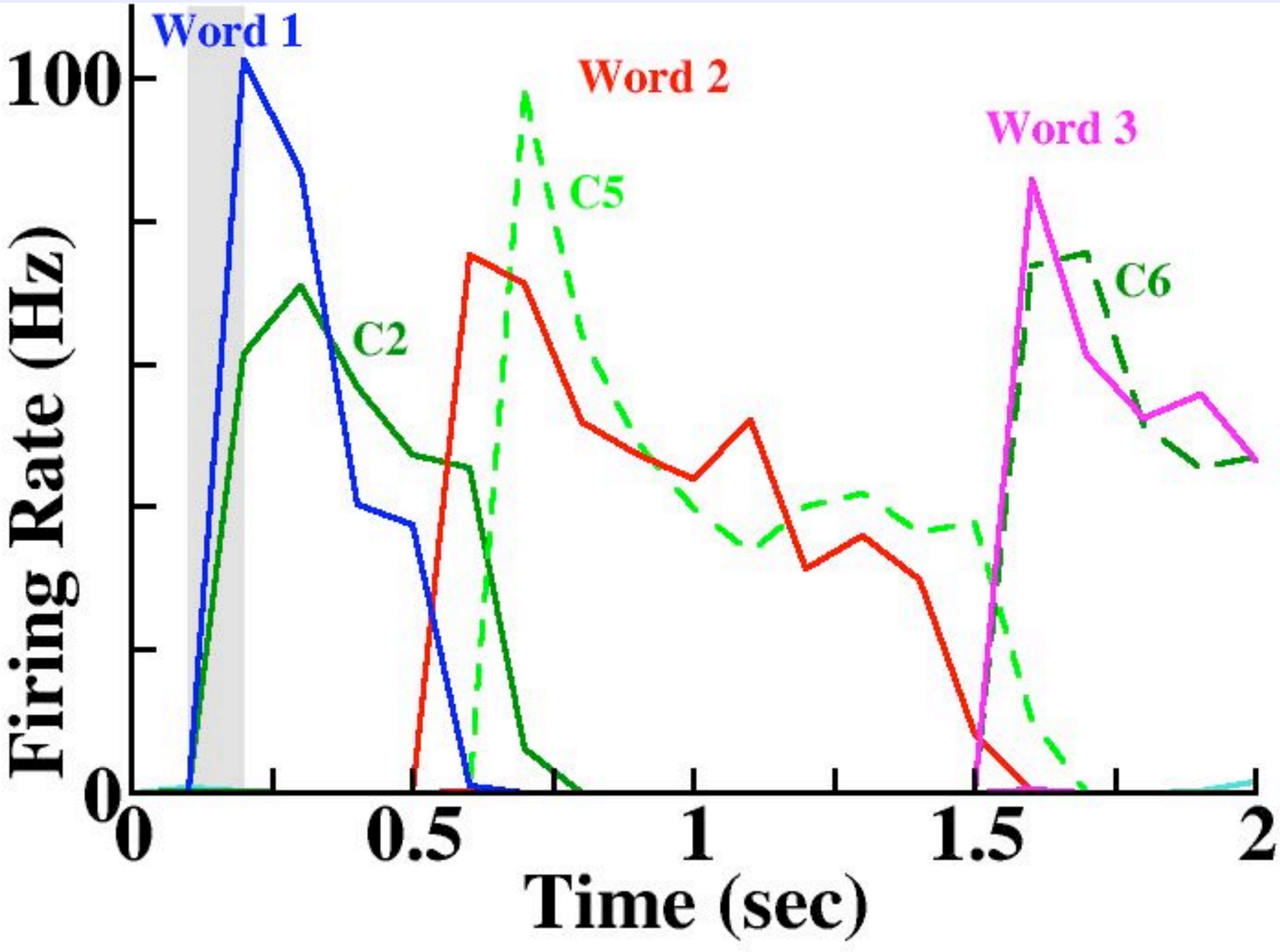
Diminished forward recall when prior stimuli were weak then strong: results of 20 trials



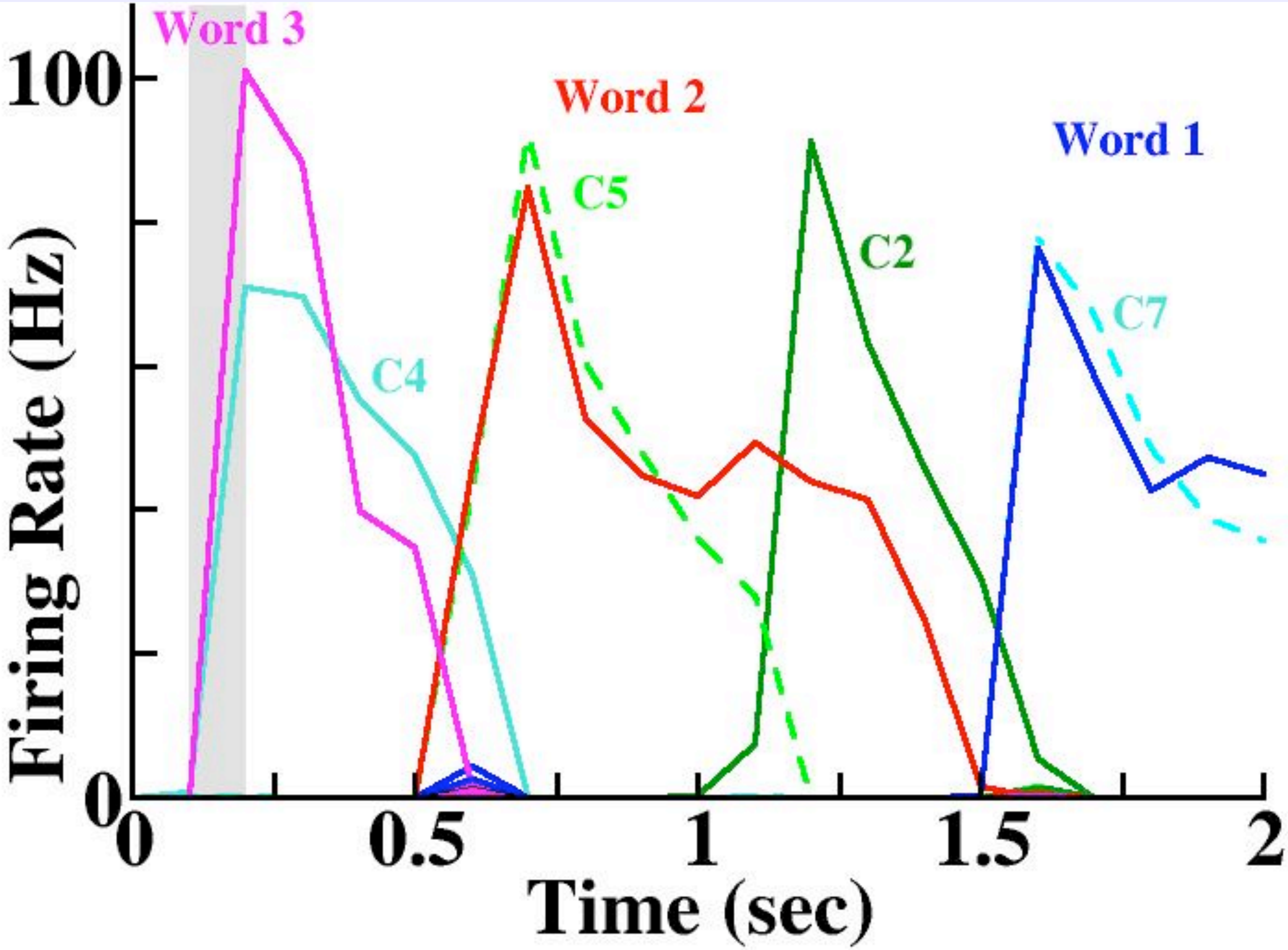
Allowing context to switch randomly between states (3-word presentation)



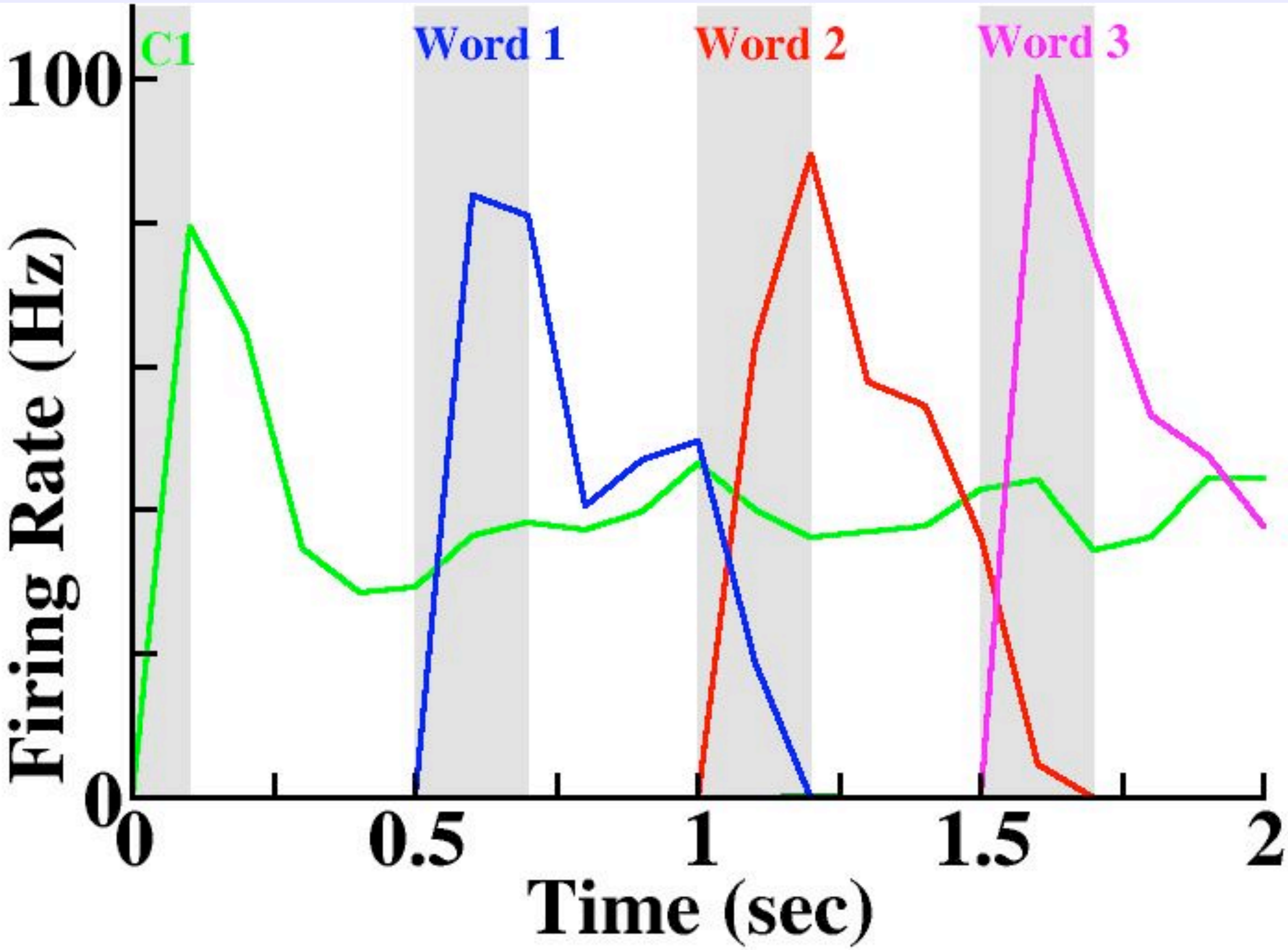
Forward recall of 3-word sequence with random prior contexts



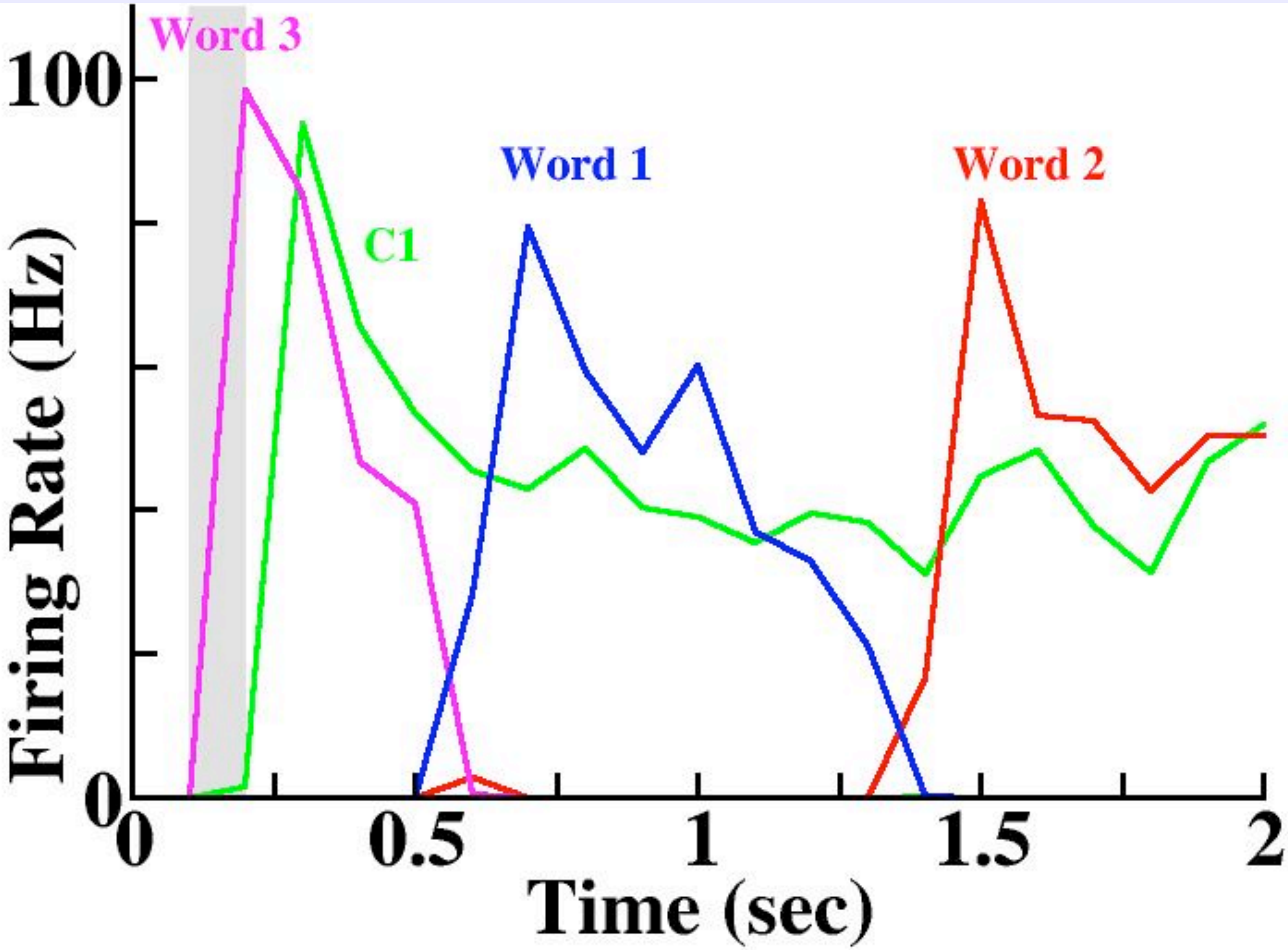
Reverse recall of 3-word sequence with random intermediate contexts



3-word sequence in a trial when by chance, context does not switch



3-word sequence recall with swapping of order and single context



Expectations based on Simulations

1) Poor quality stimulus is least likely to be recalled
   (broken “link” in both forward and reverse direction)

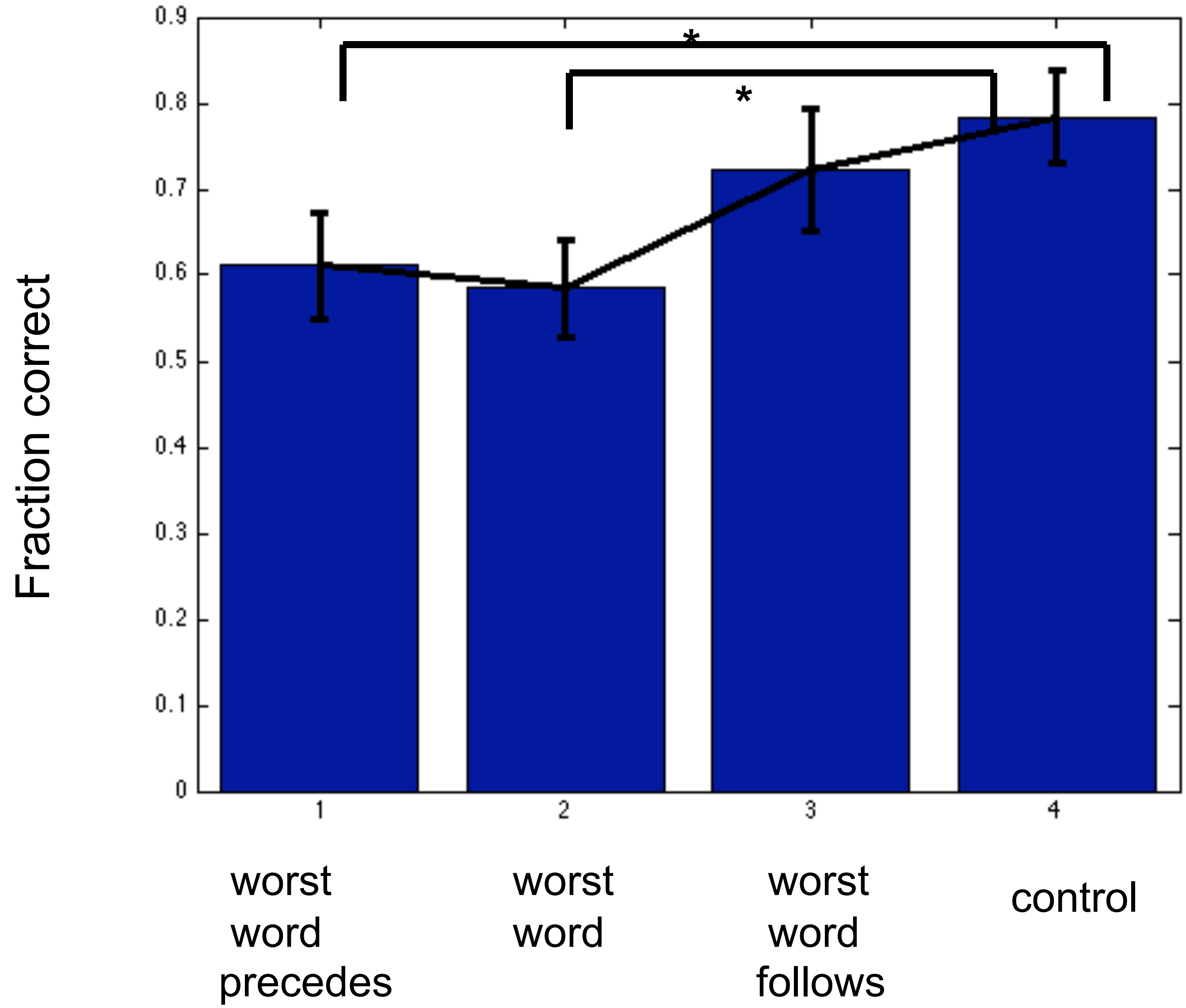
2) Neighboring stimuli are less likely than average to be recalled
   (broken “link” to and from the poor quality stimulus)

Six-word lists containing one low-quality stimulus

horror	widow	climate	diamond	sugar	planet

sorrow	orange	funeral	error	captive	elder
rival	voyage	despair	mistress	habit	passion
prairie	lecture	acid	mirror	wrinkle	eagle
velvet	cellar	lion	turkey	flavor	angel

Probability of recall depends on relative location of worst word



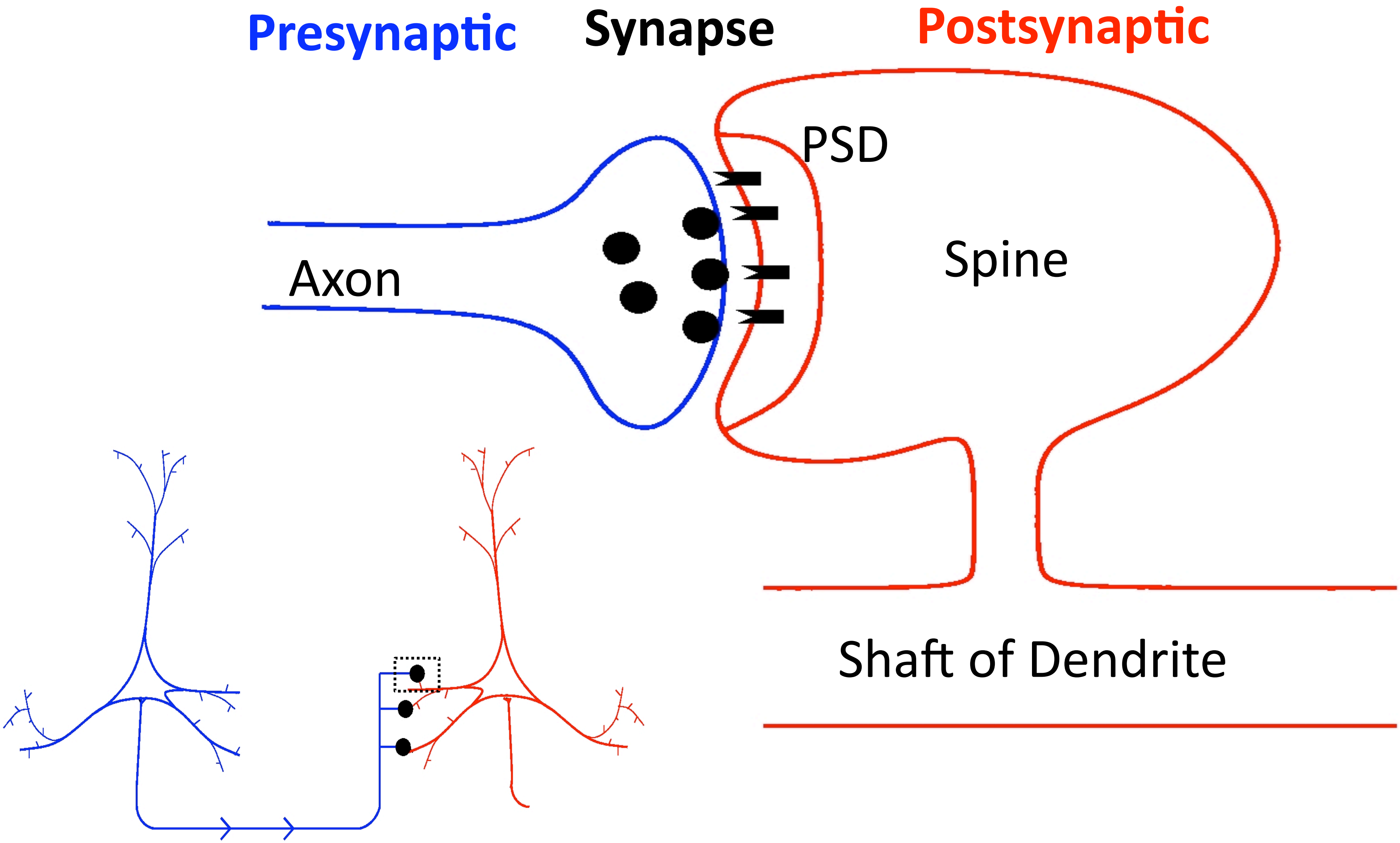
Summary

1) Forward and reverse recall is possible via a contextual pool that is able to be coactive with stimulus representation. (Support for the temporal context model).

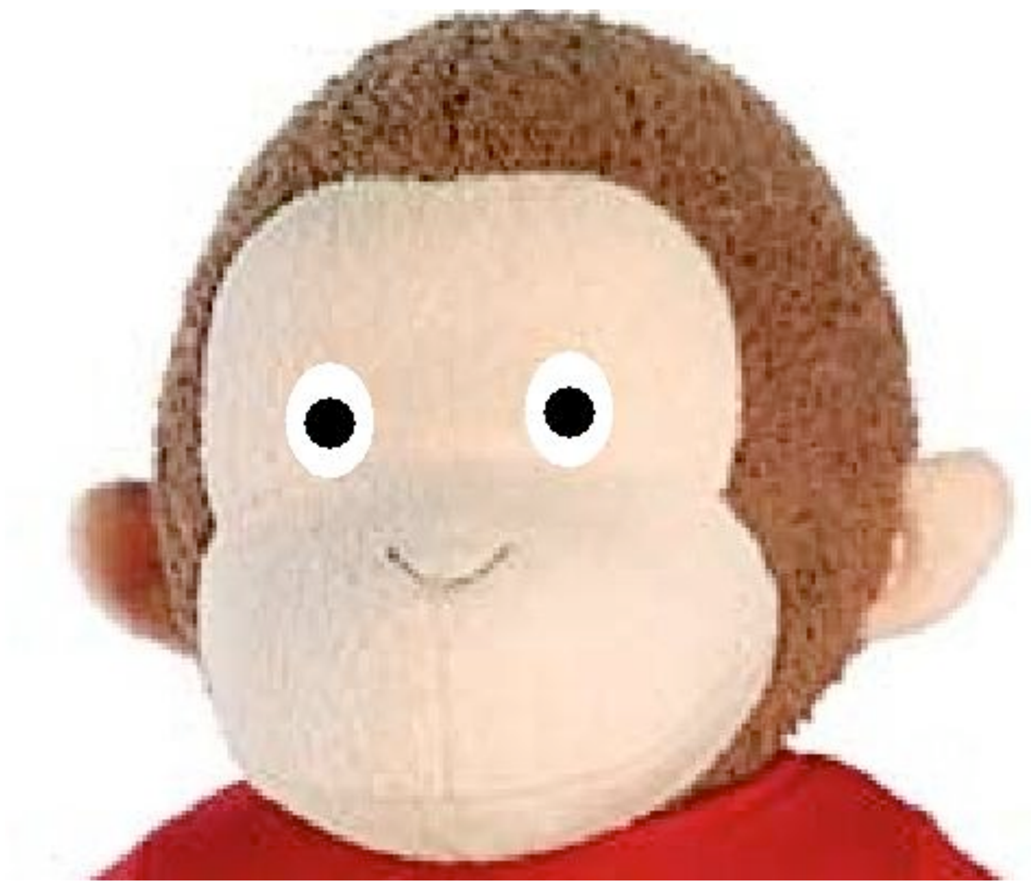
2) The means through which a representation is reached affects recall of that representation. (Transient amplitude seems more important than speed of response).

3) Experimentally, a poor stimulus can affect recall of neighboring, clear stimuli, even later, clear stimuli. (As suggested by simulation results, but other “higher level” reasons are possible and these data are preliminary).

Thank you for your attention!

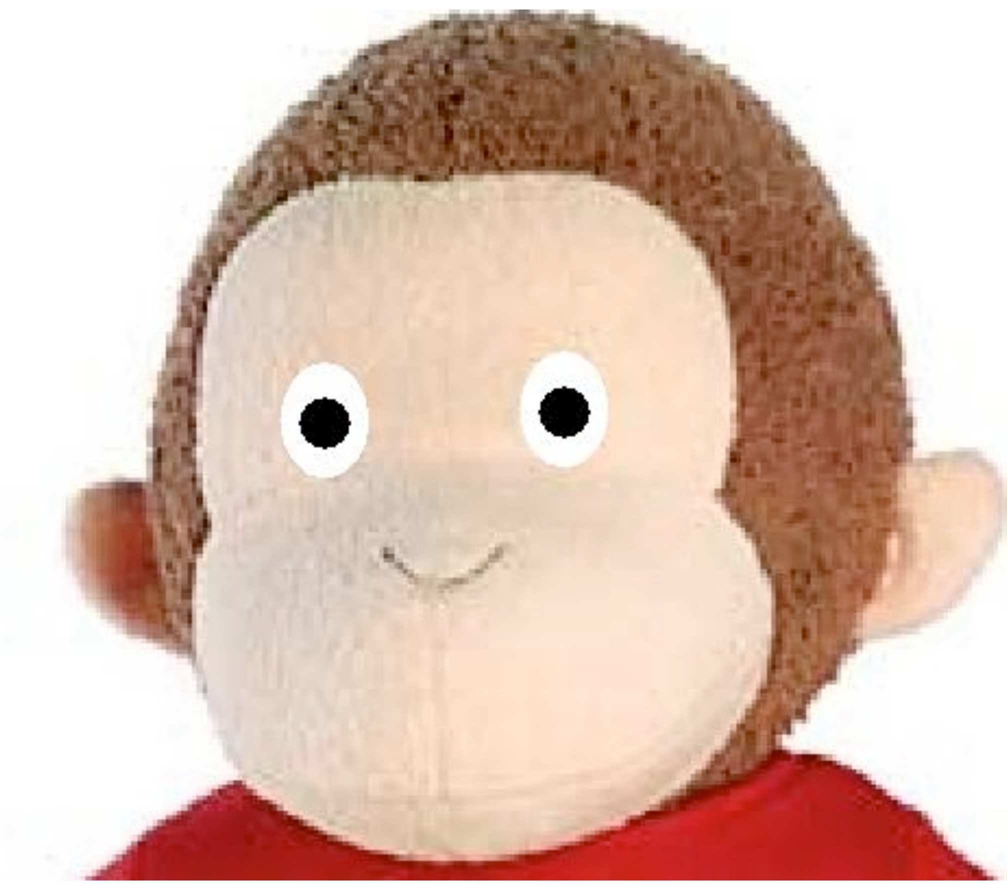

Presynaptic
Synapse
Postsynaptic
PSD
Axon
Spine
Shaft of Dendrite

Discrete working memory

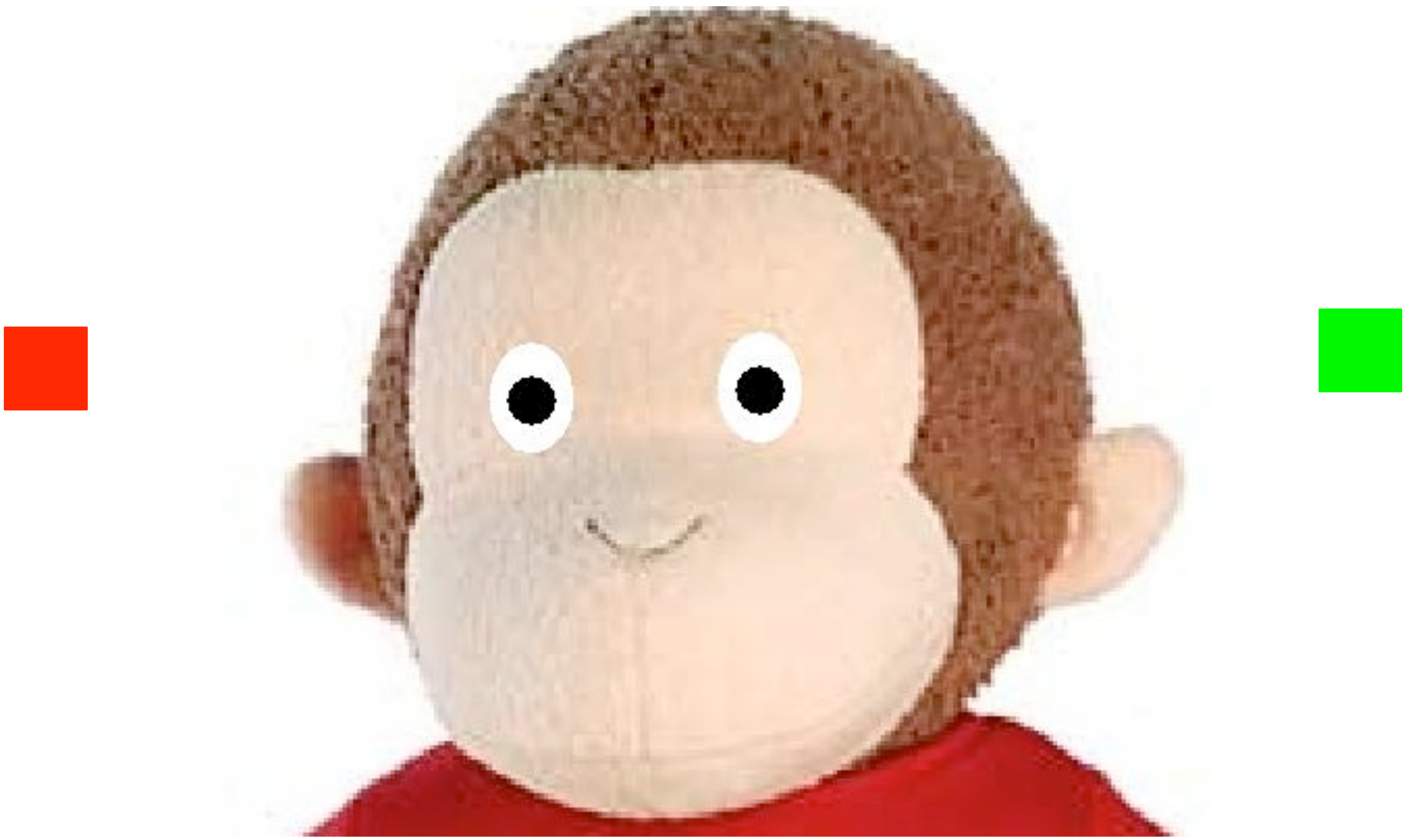


Discrete working memory

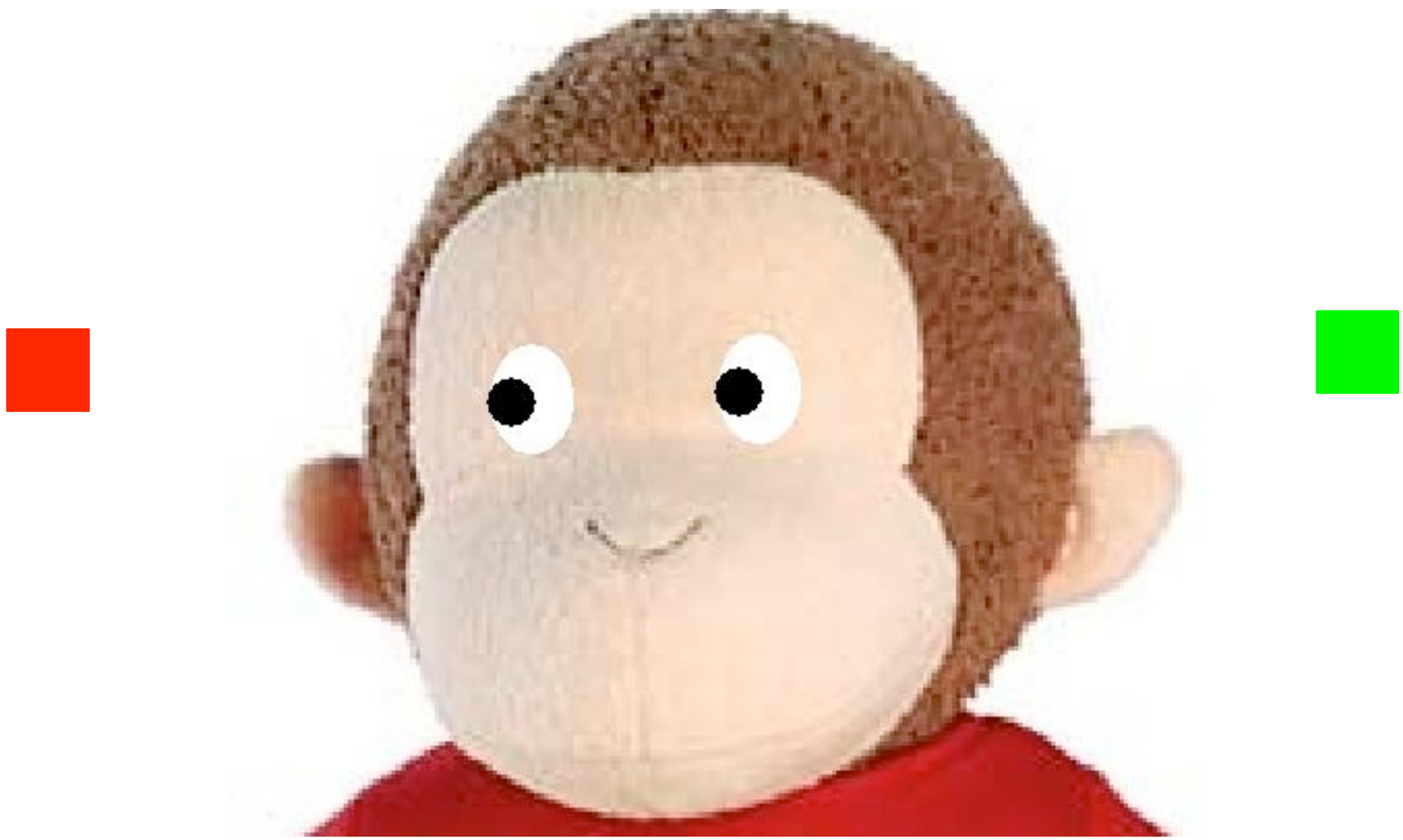
Delay



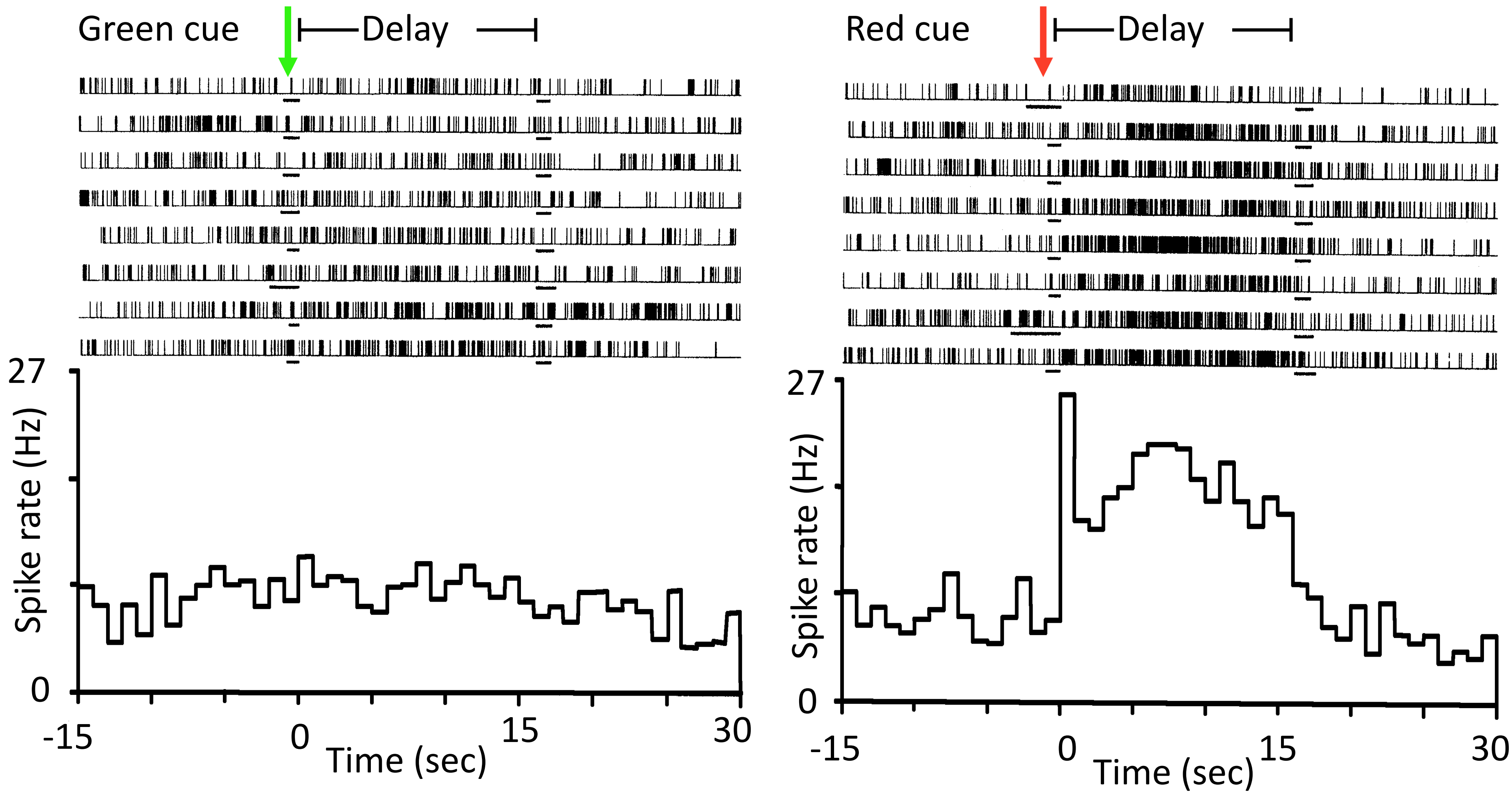
Discrete working memory



Discrete working memory

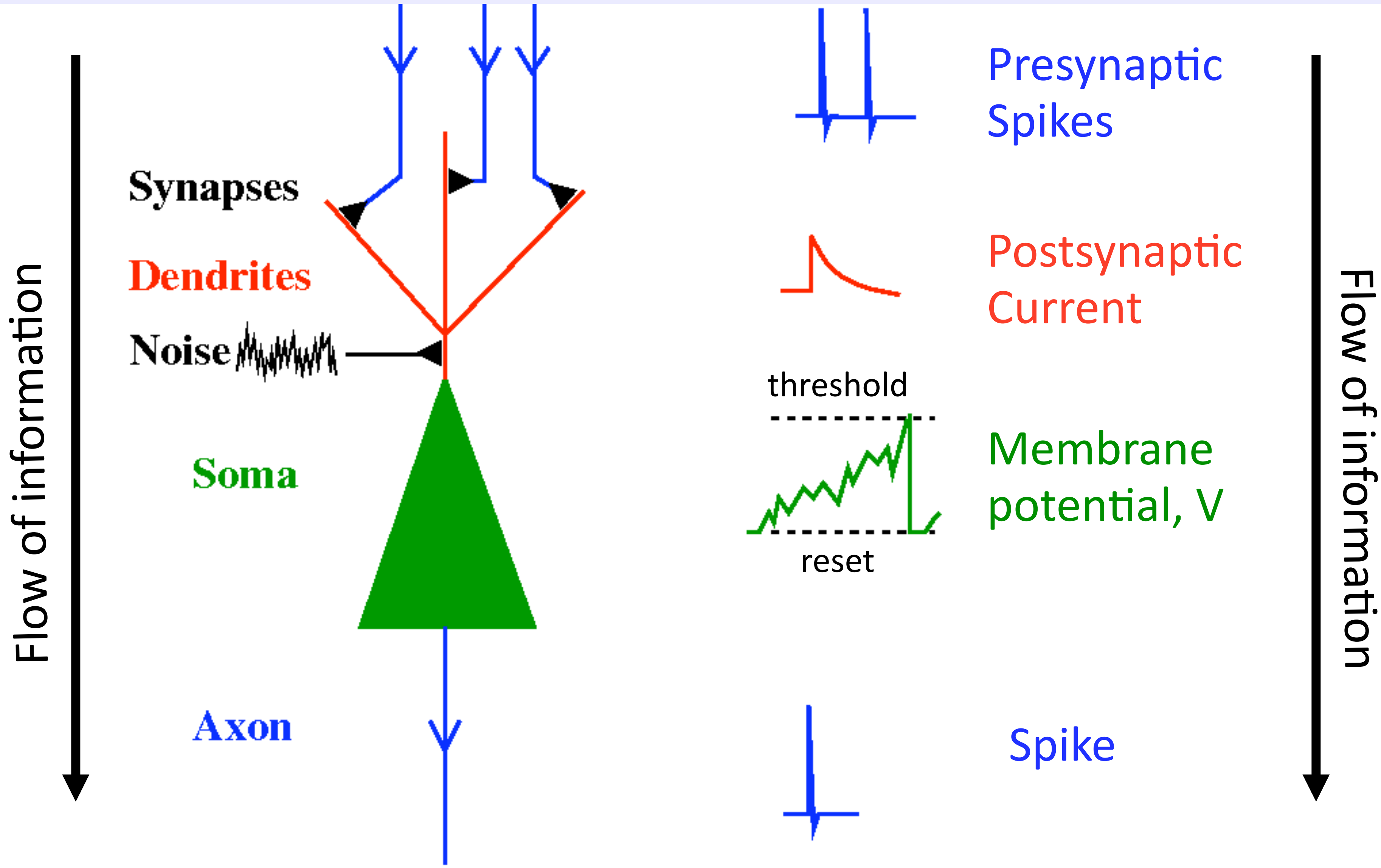


Discrete working memory

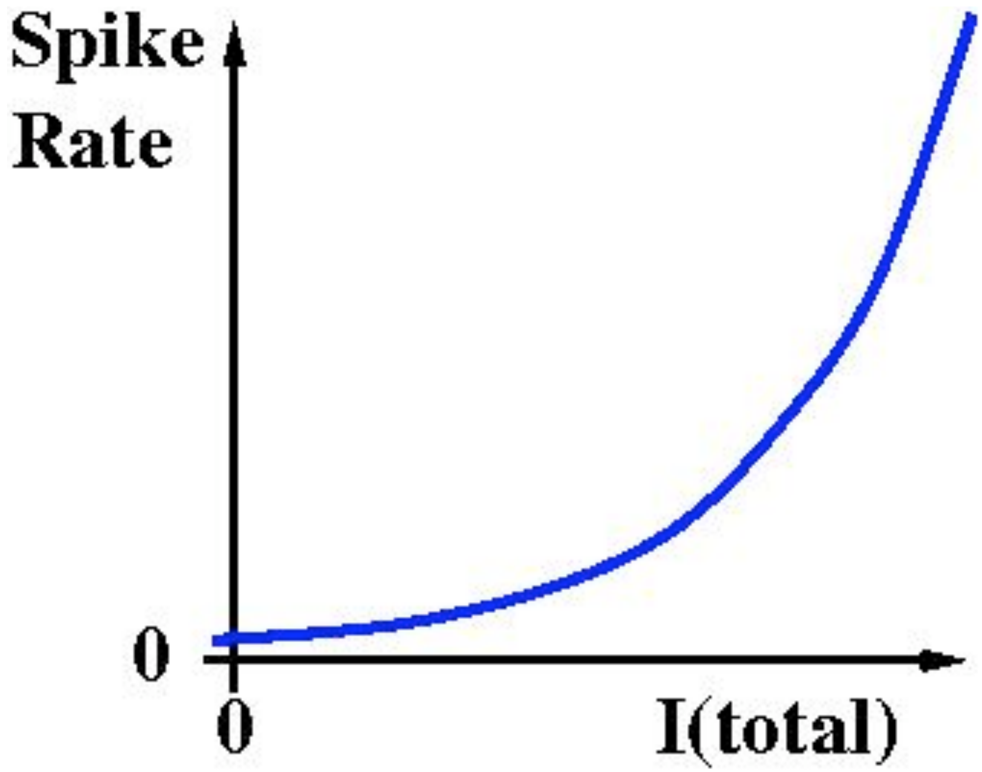


Data from inferotemporal cortex
Fuster and Jervey, Science (1981)

Network model: using leaky integrate-and-fire neurons

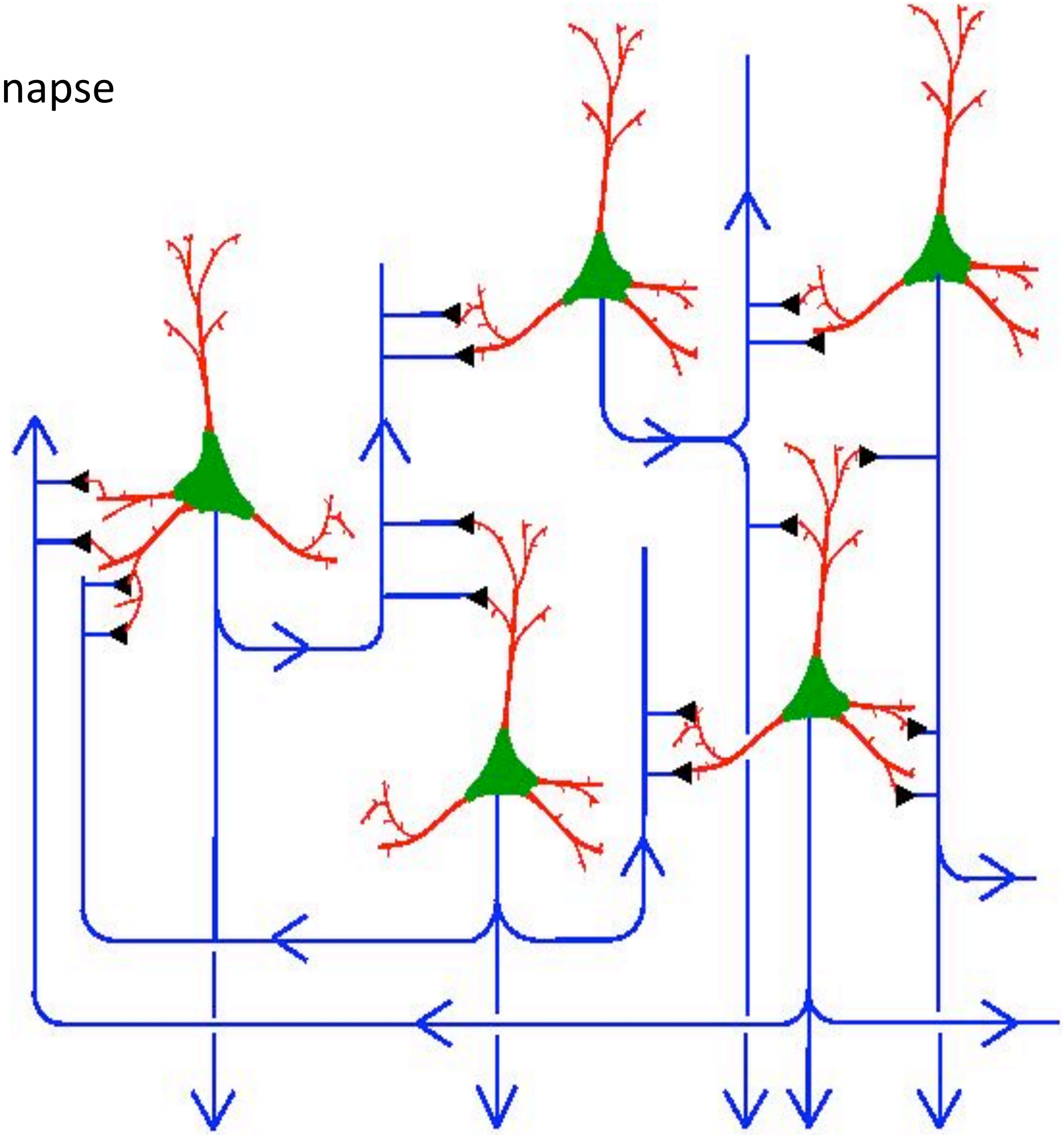


Network model: firing rate curve

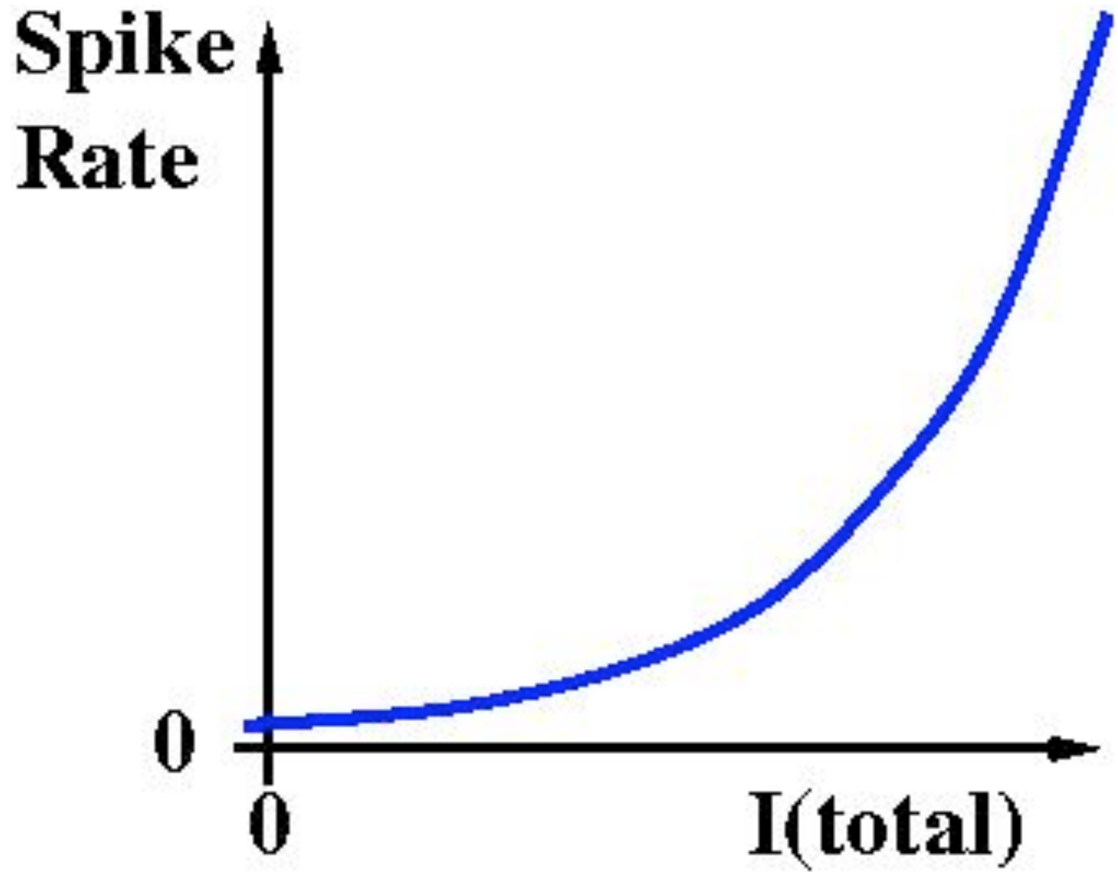


Network model: recurrent excitation

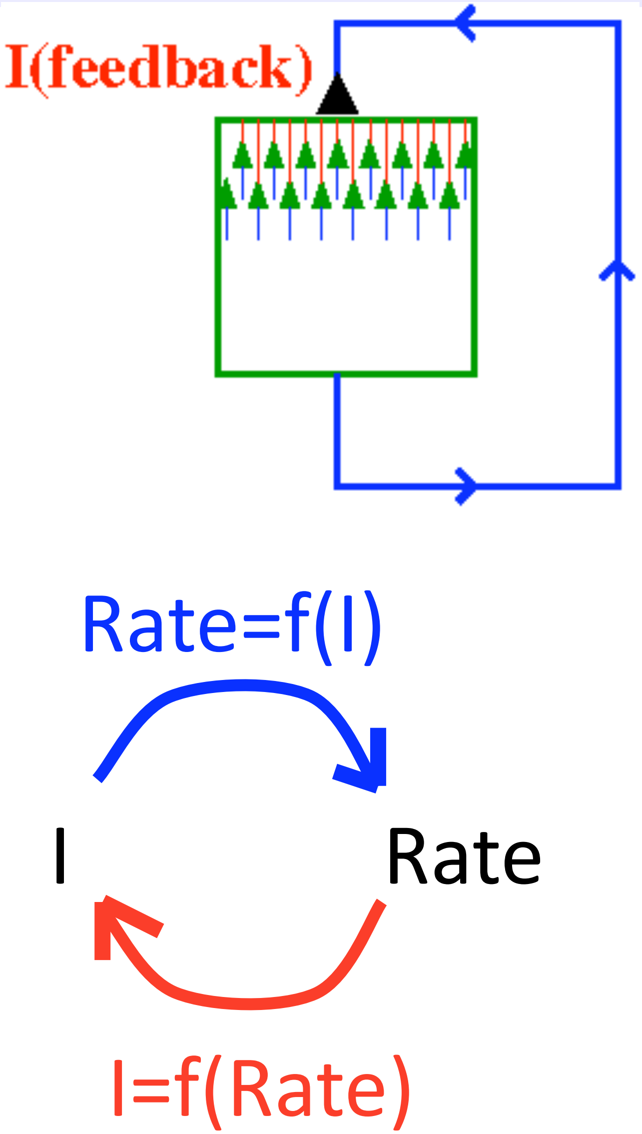
◀ = excitatory synapse

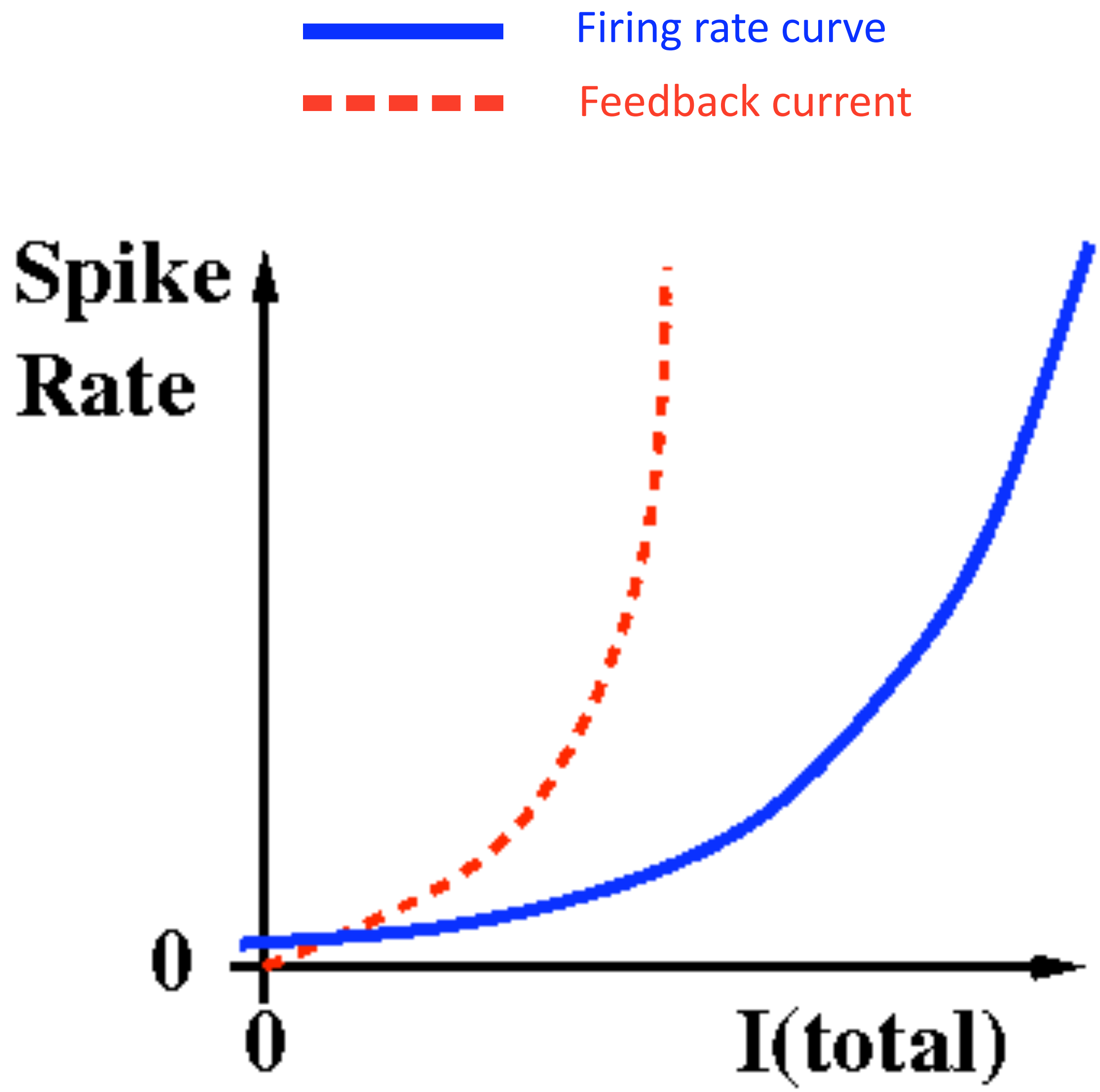


Network model: firing rate curve (mean-field theory)

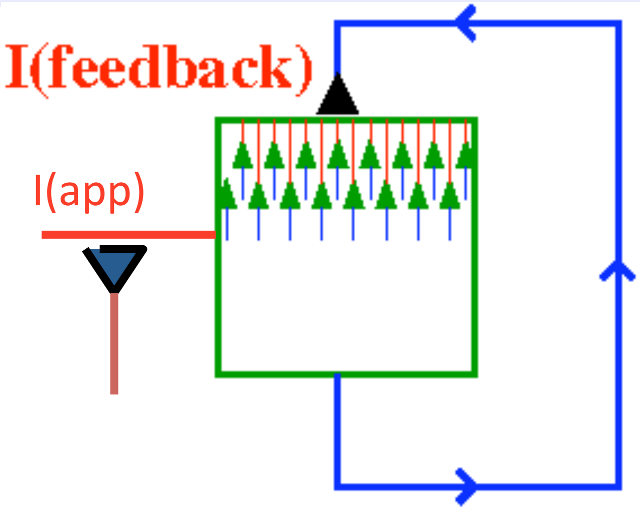


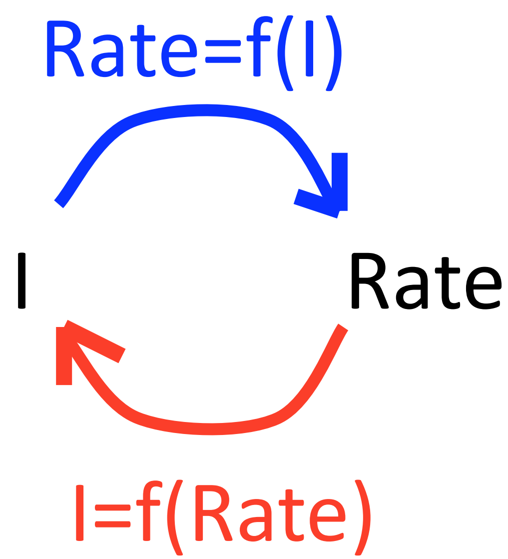
Network model: firing rates with weak feedback

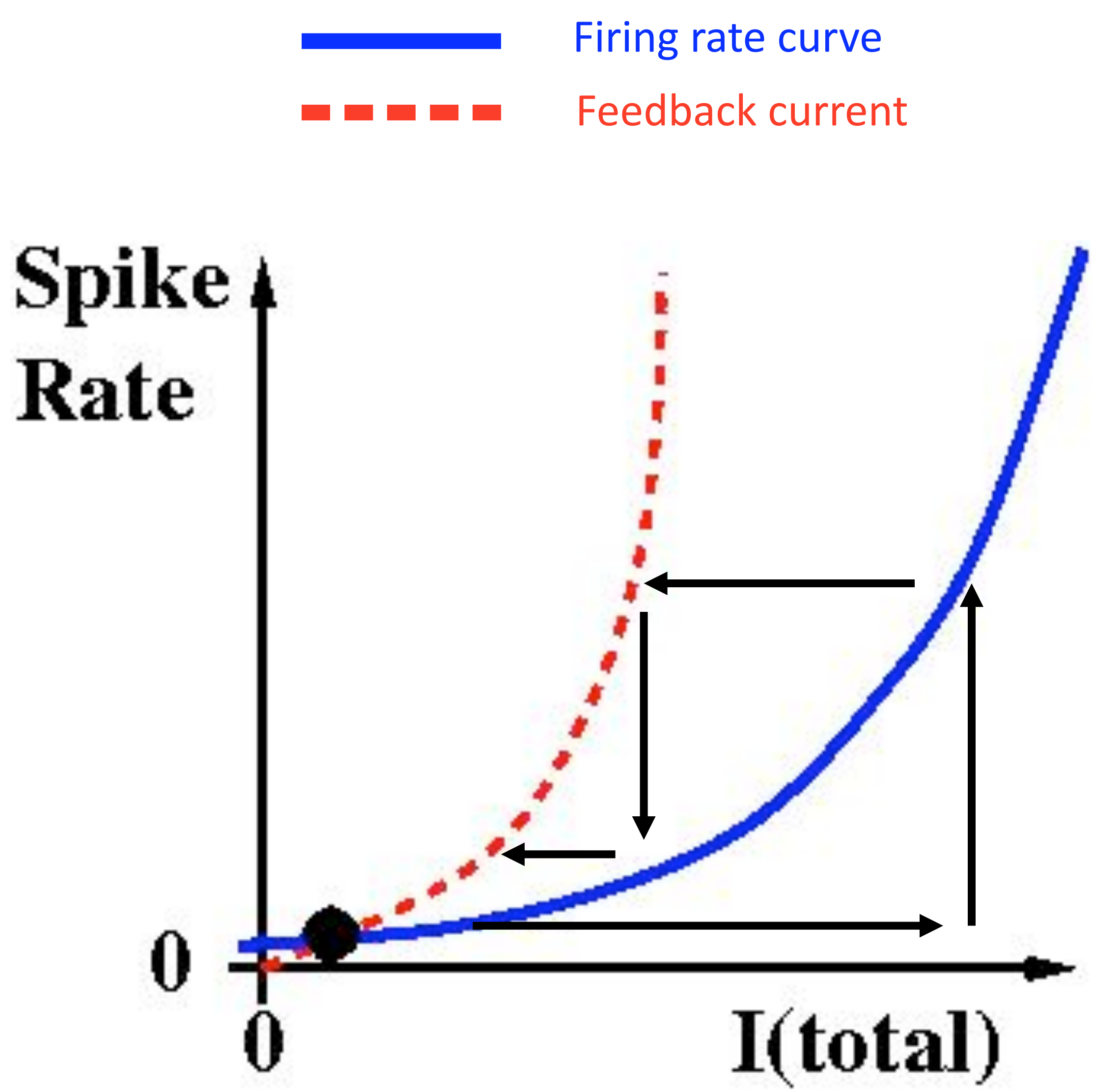




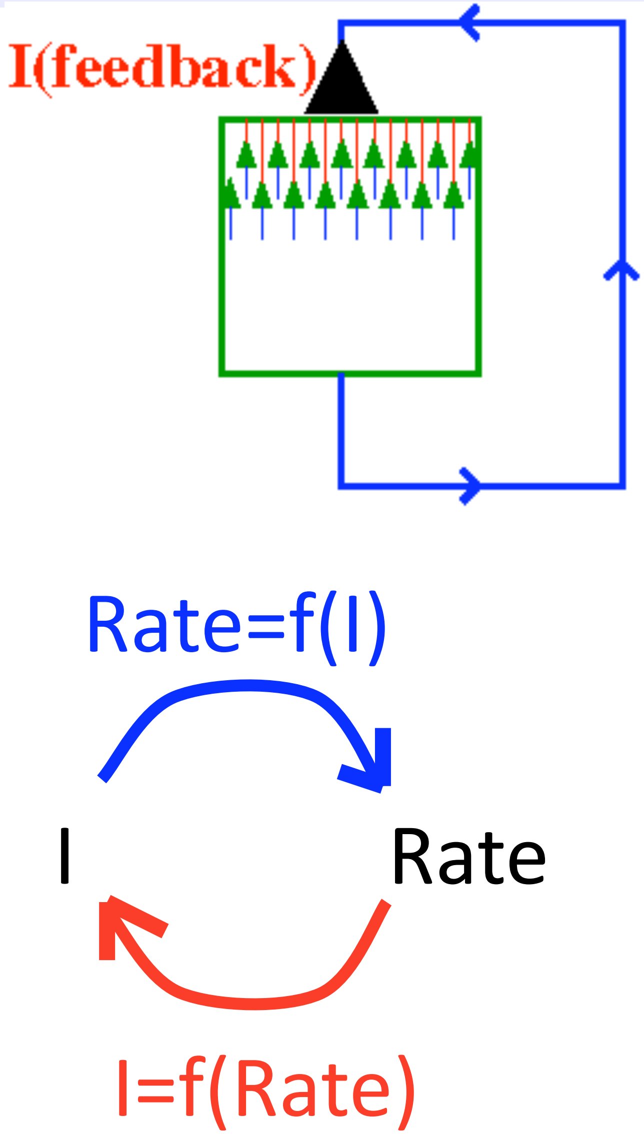
Network model: firing rates with weak feedback

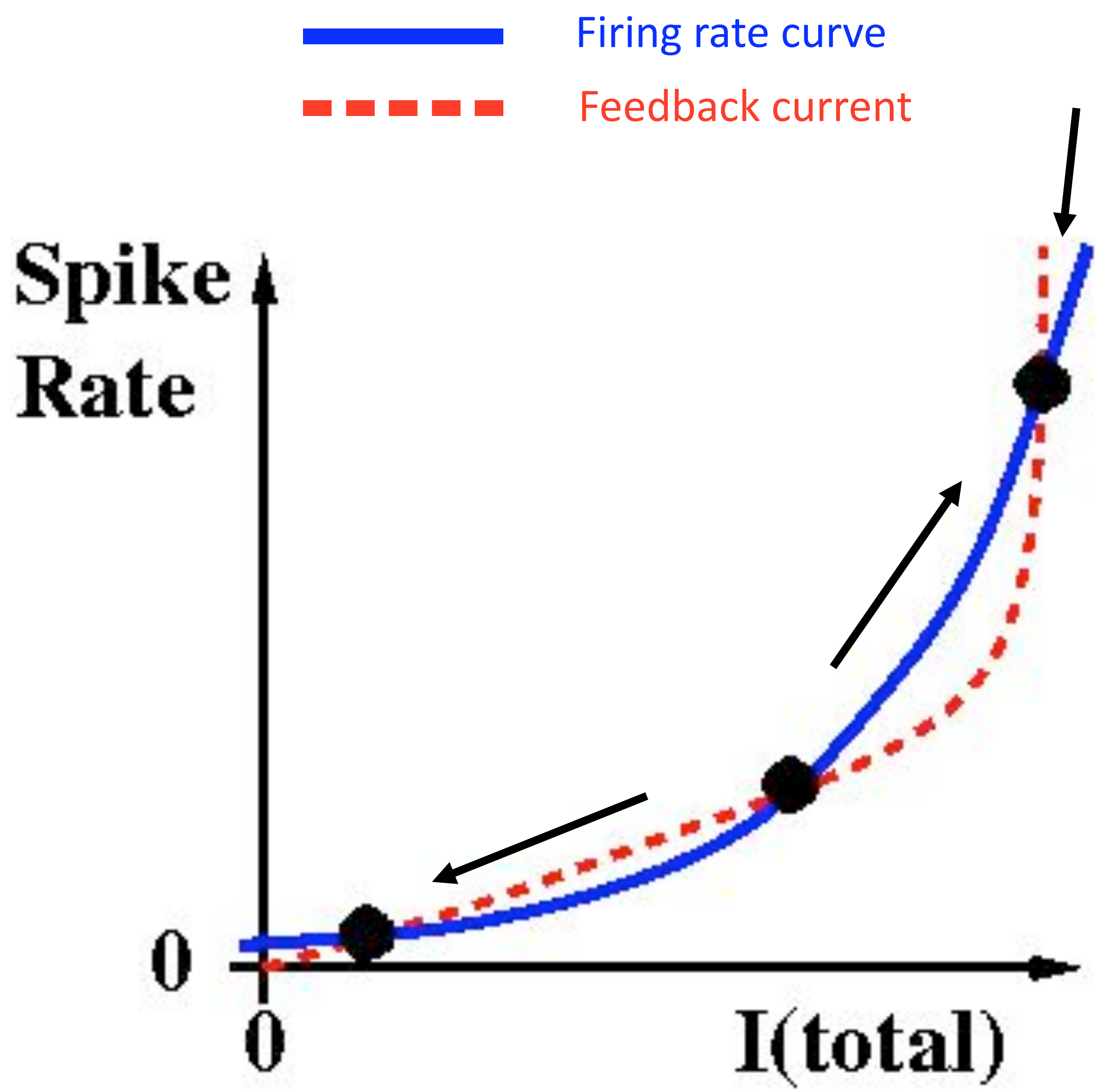




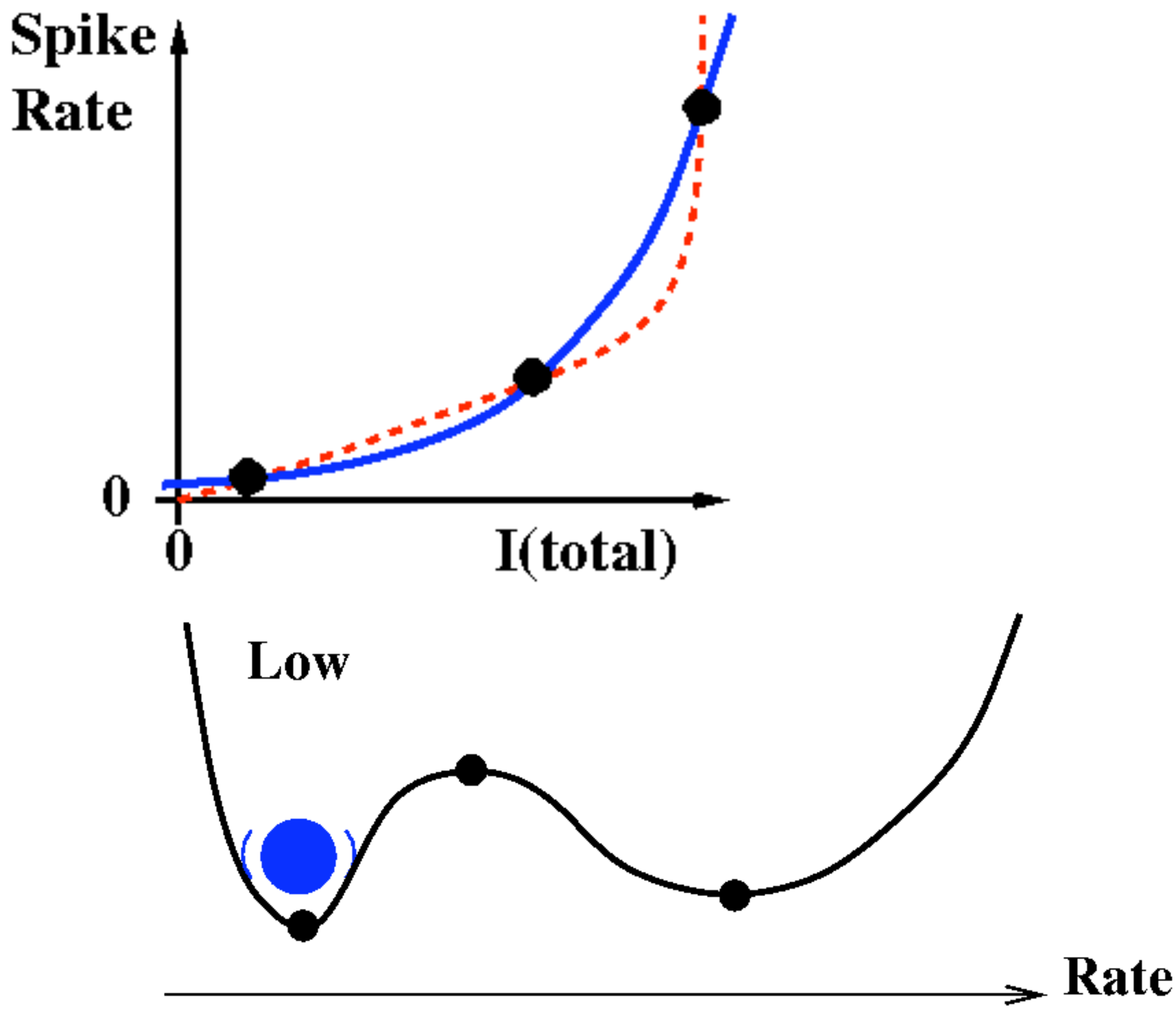


Network model: firing rates with strong feedback

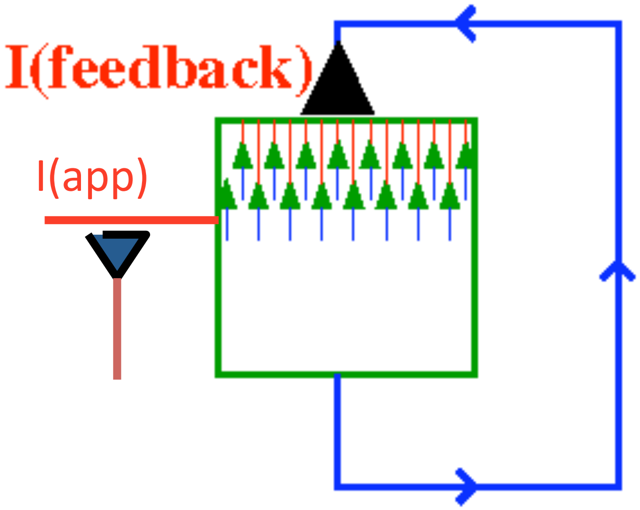


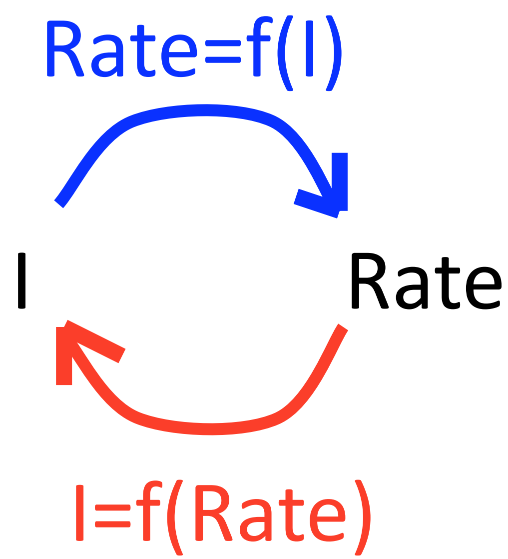


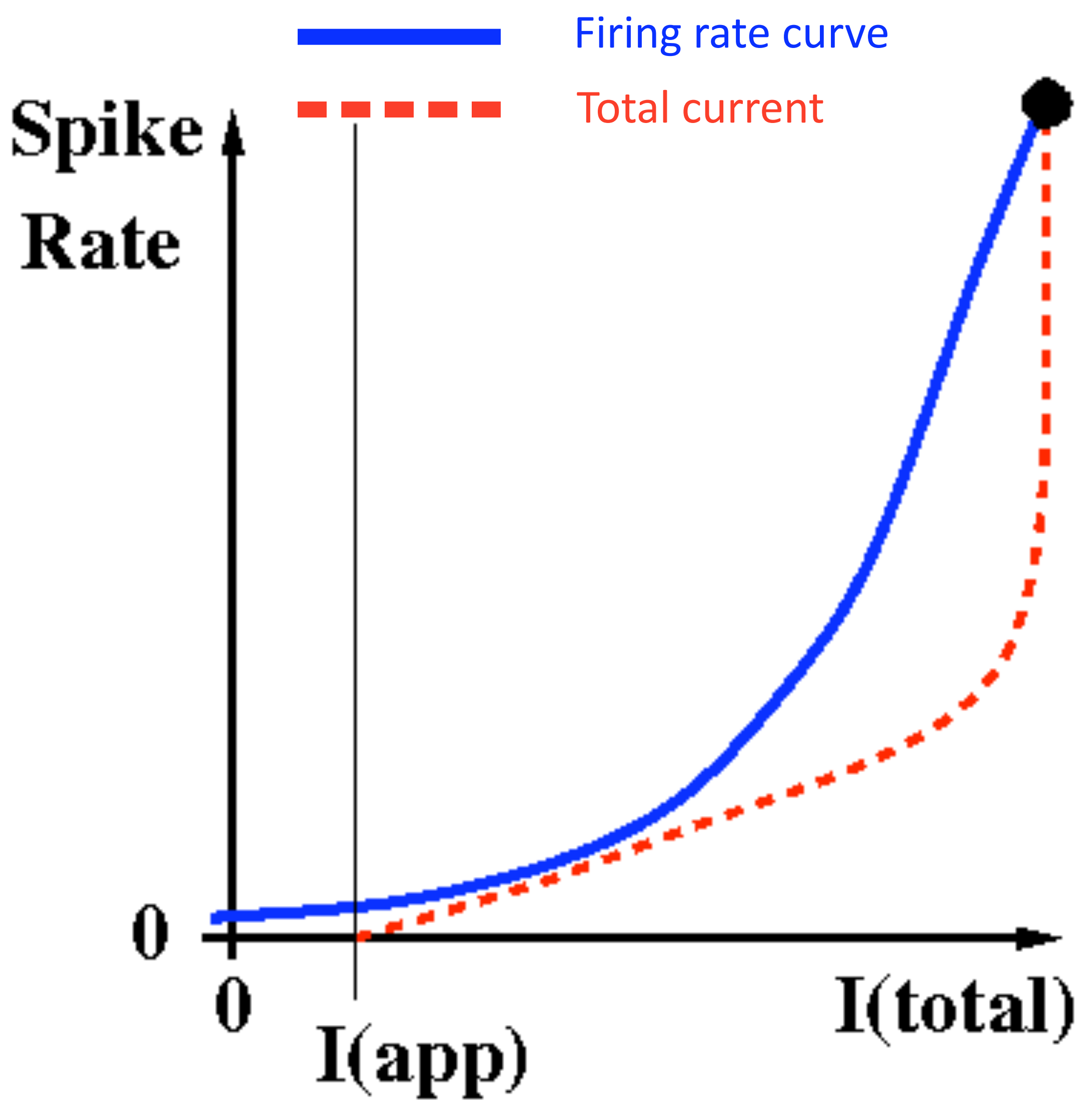
Network model: Bistability from strong feedback



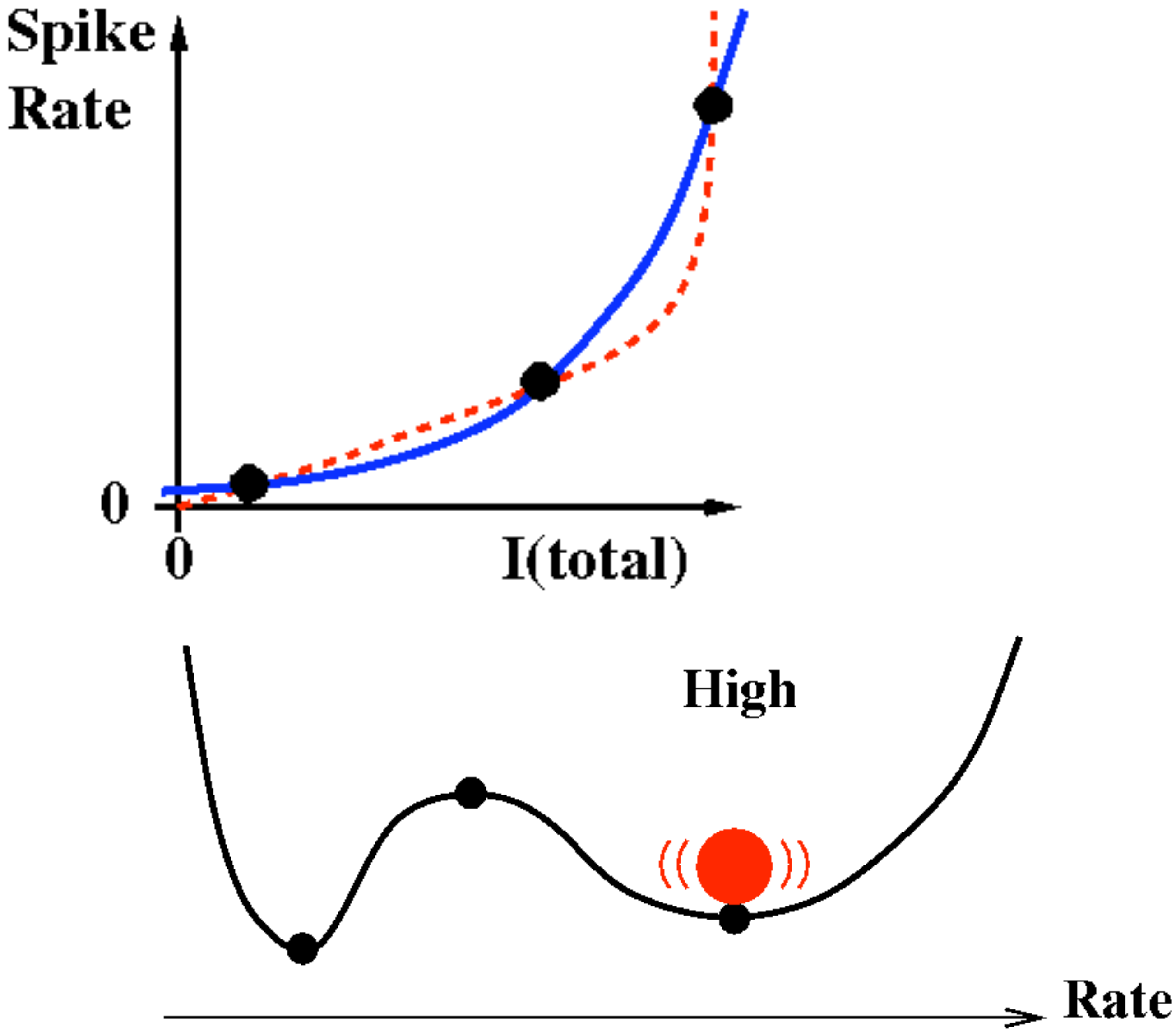
Network model: firing rates with strong feedback



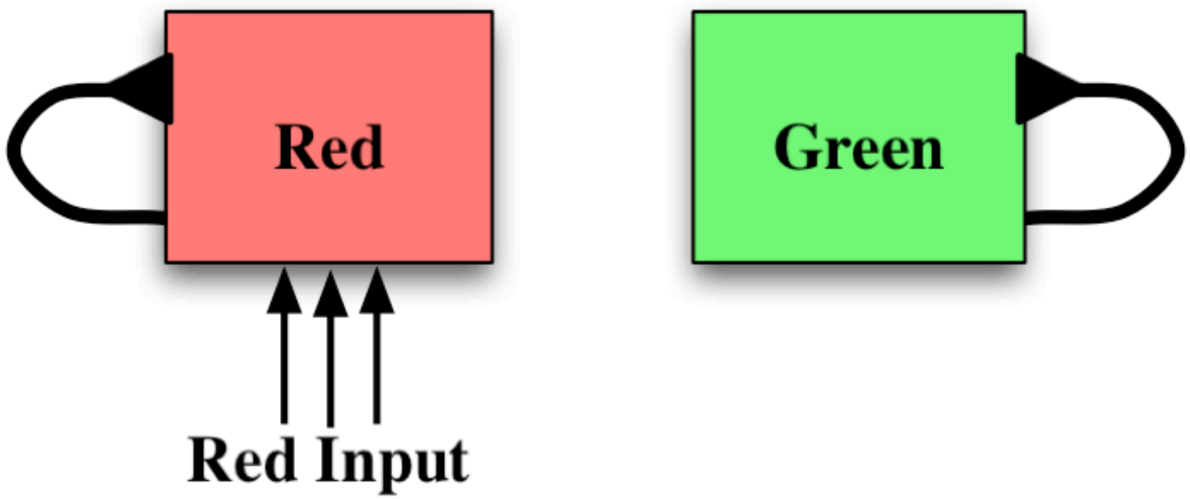


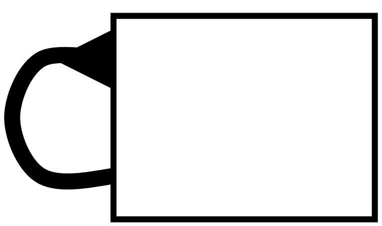


Network model: Bistability from strong feedback



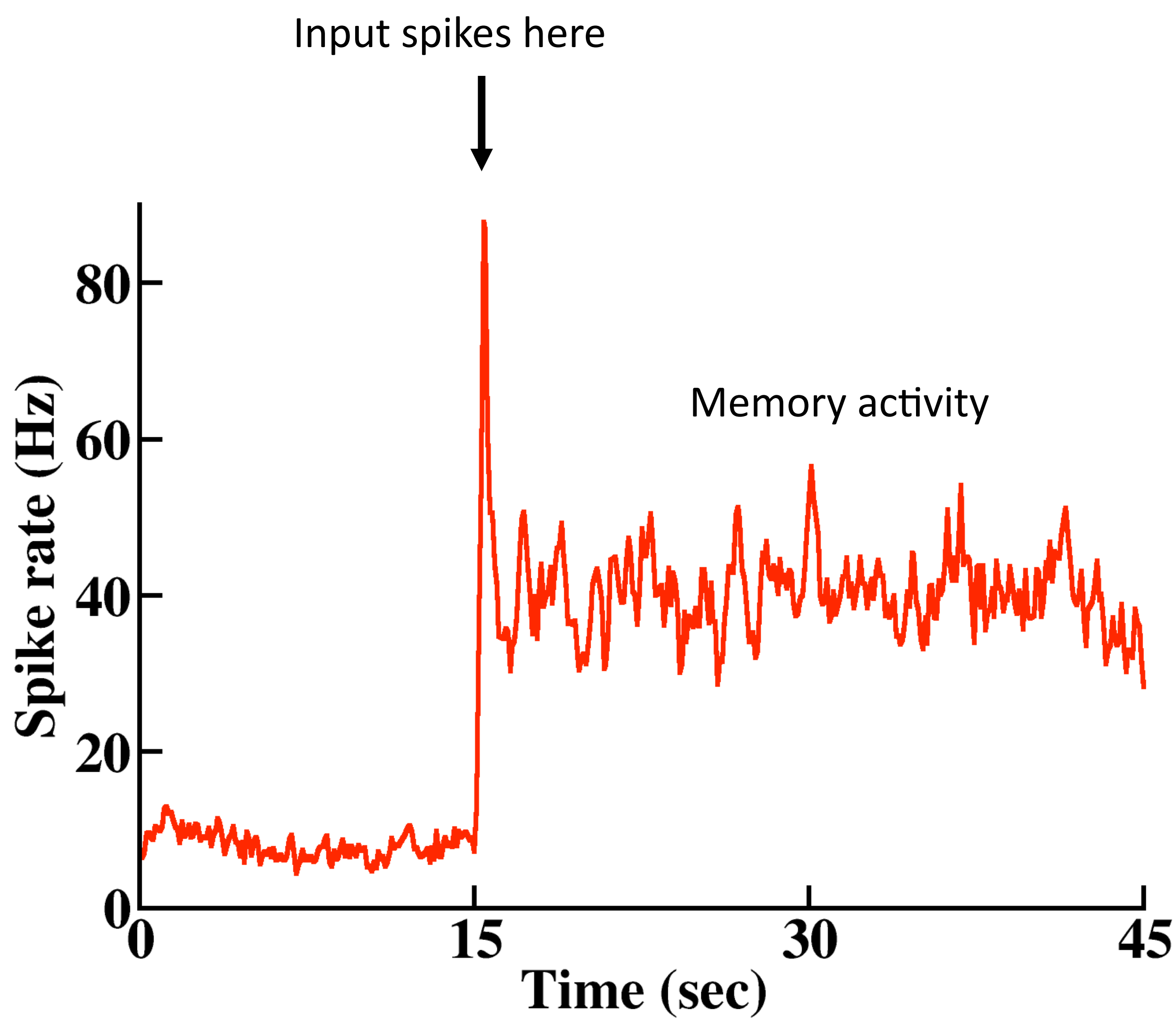
Network model: recurrent excitation



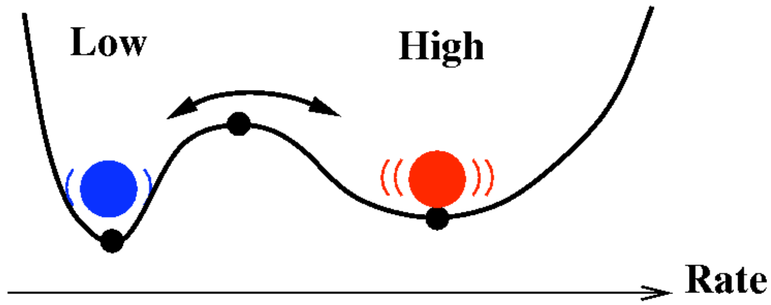


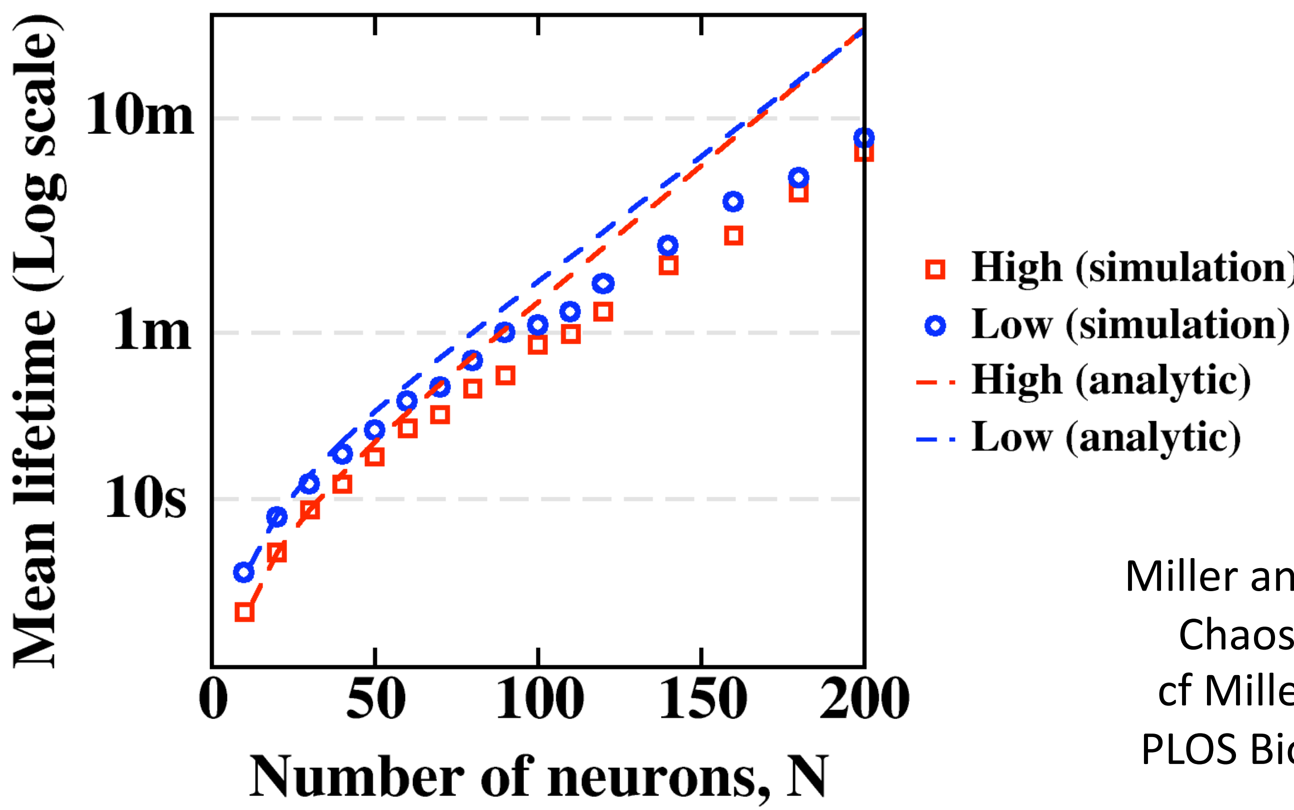
= pool of tens to hundreds of self-exciting neurons

Network model: bistability from recurrent excitation



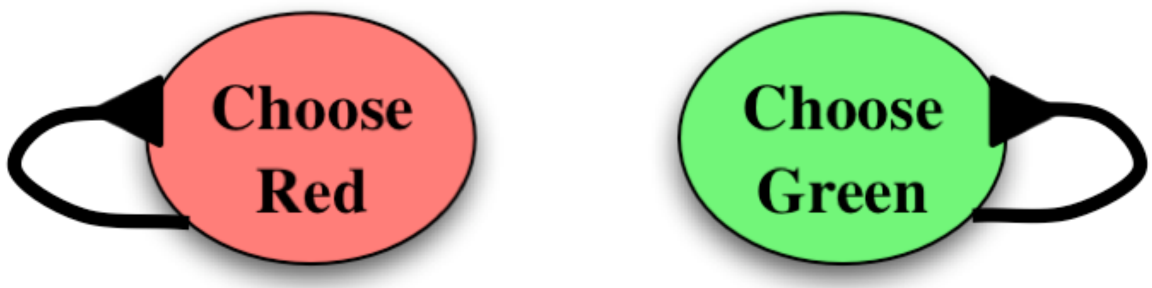
Stability increases exponentially with number of neurons in pool



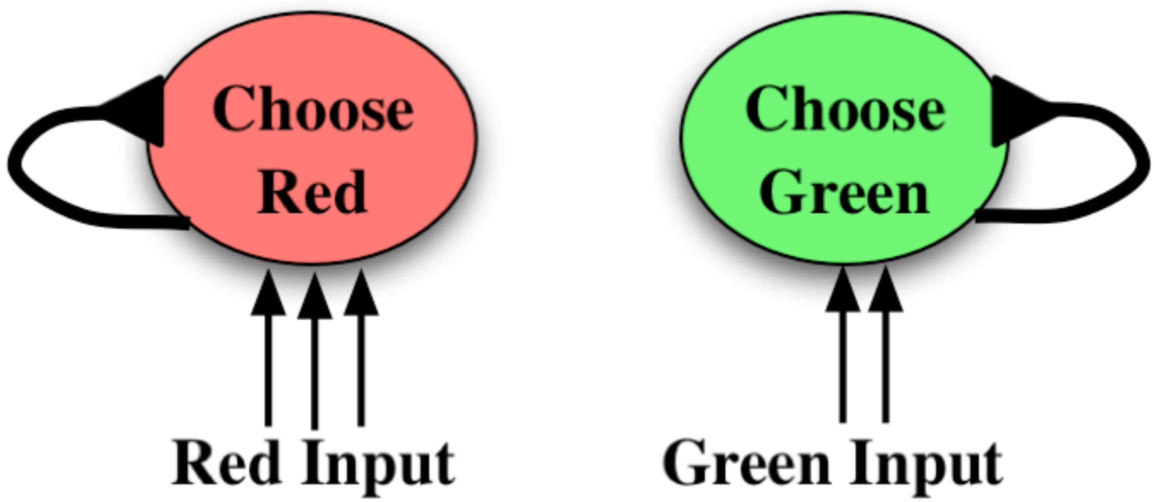


Miller and Wang, Chaos 2006
cf Miller et al, PLOS Biol. 2005

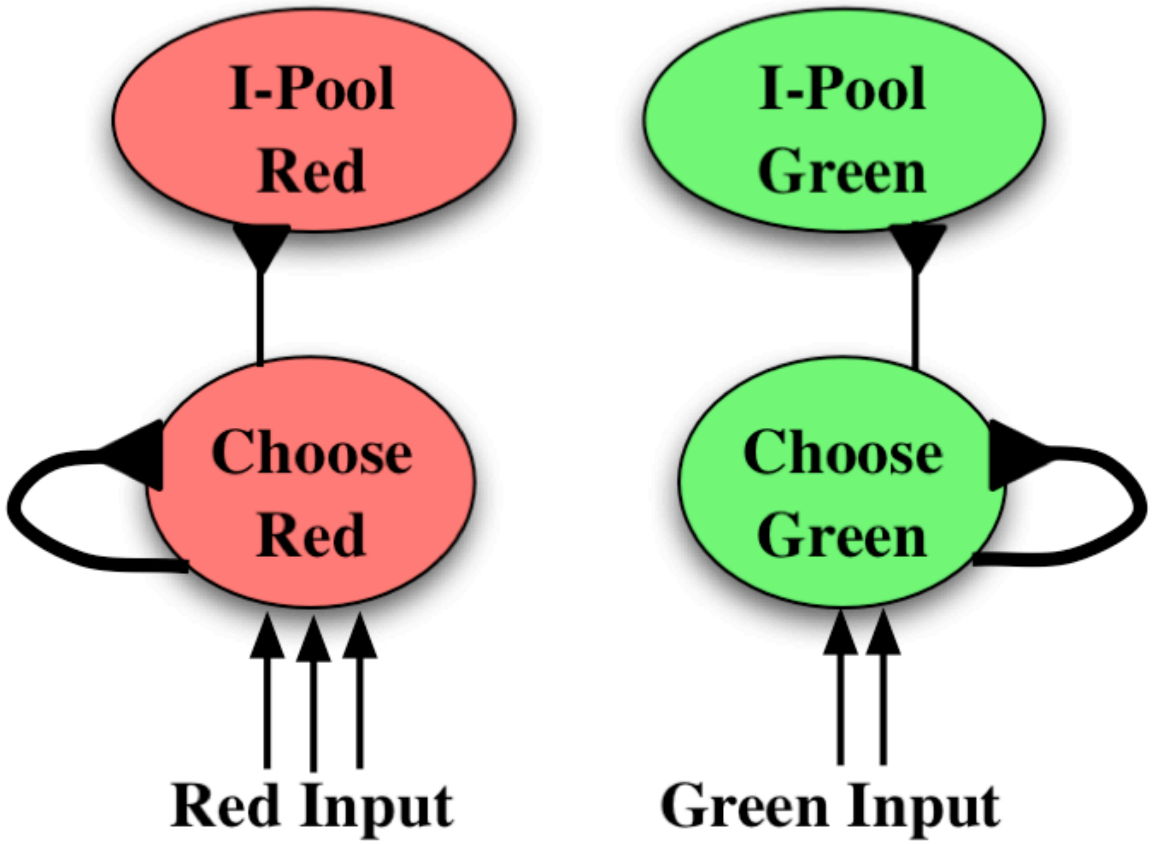
Perceptual Decision as a competition between pools



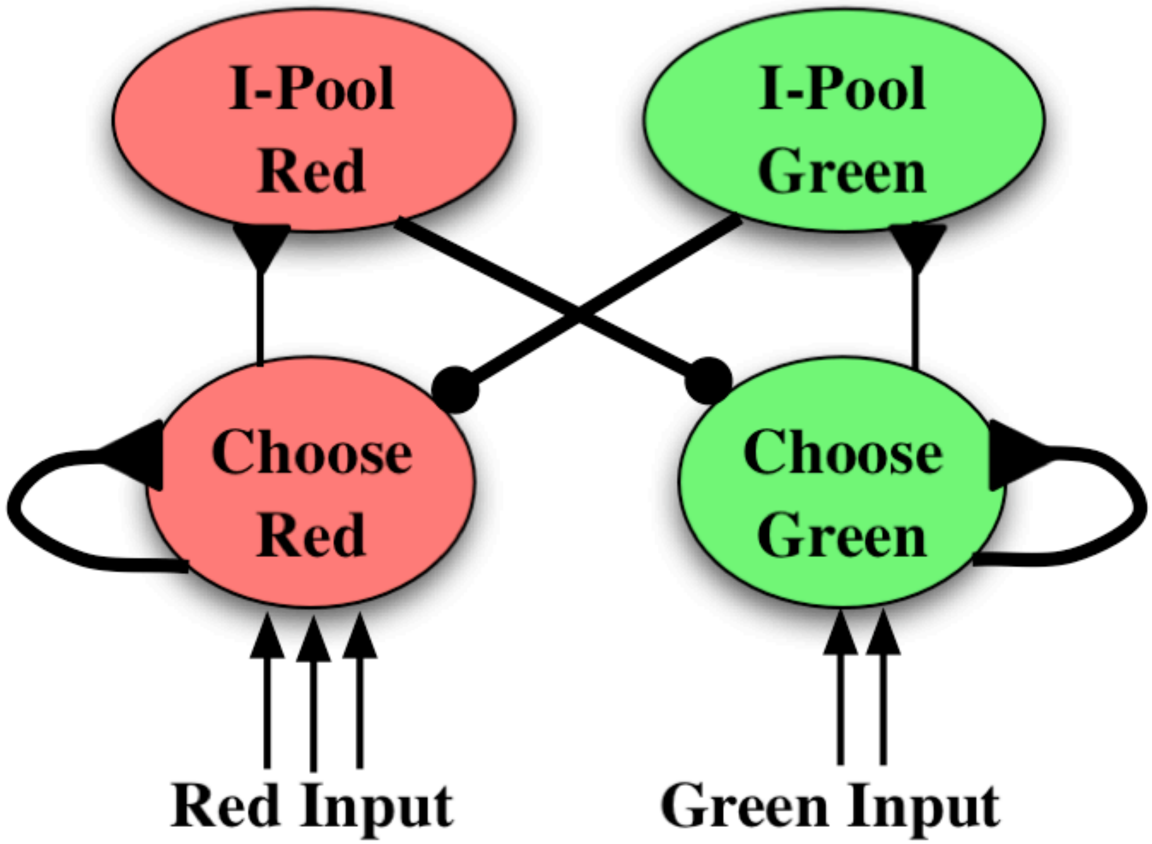
Perceptual Decision as a competition between pools



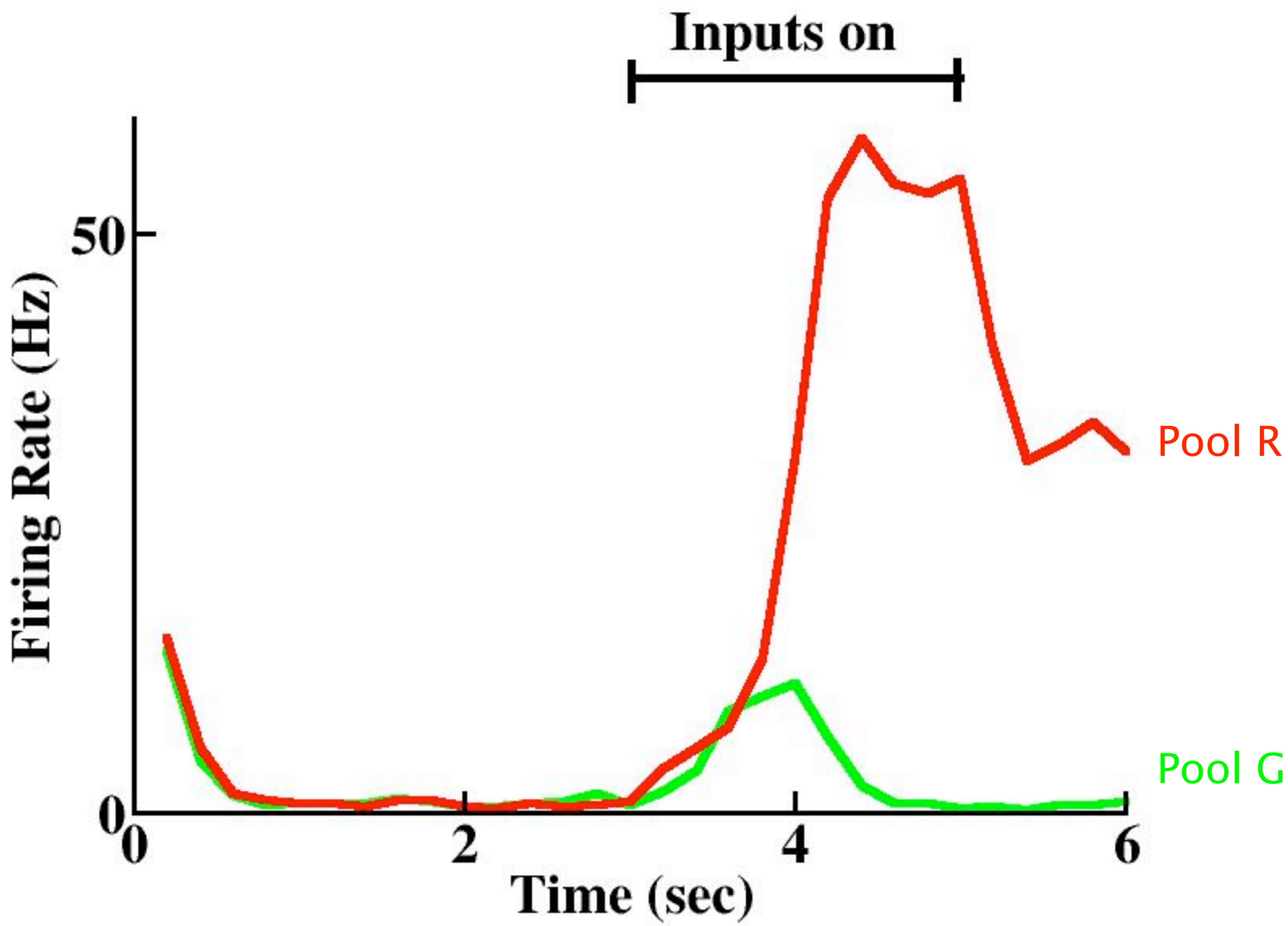
Perceptual Decision as a competition between pools



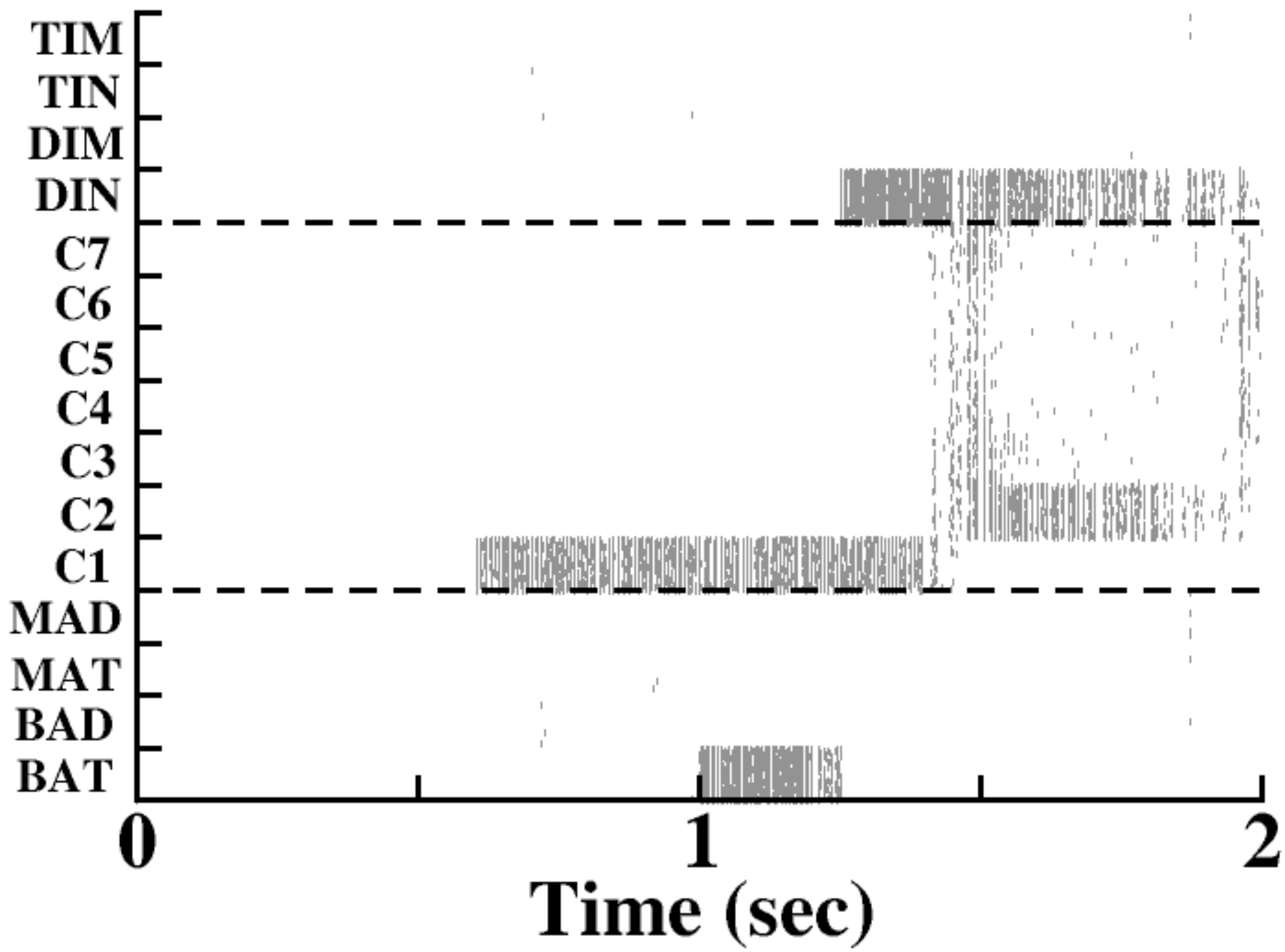
Perceptual Decision as a competition between pools



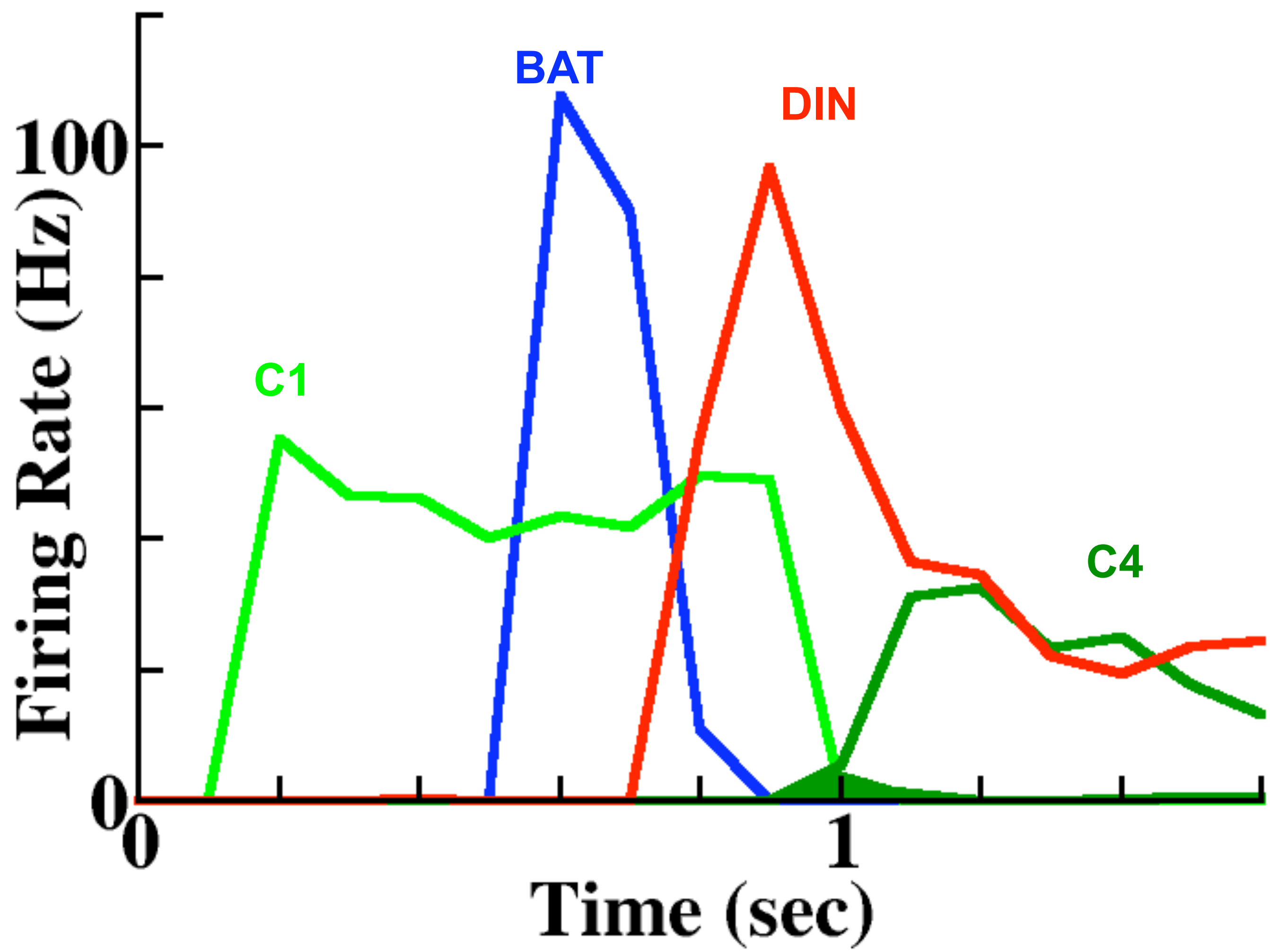
Perceptual Decision as a competition between pools



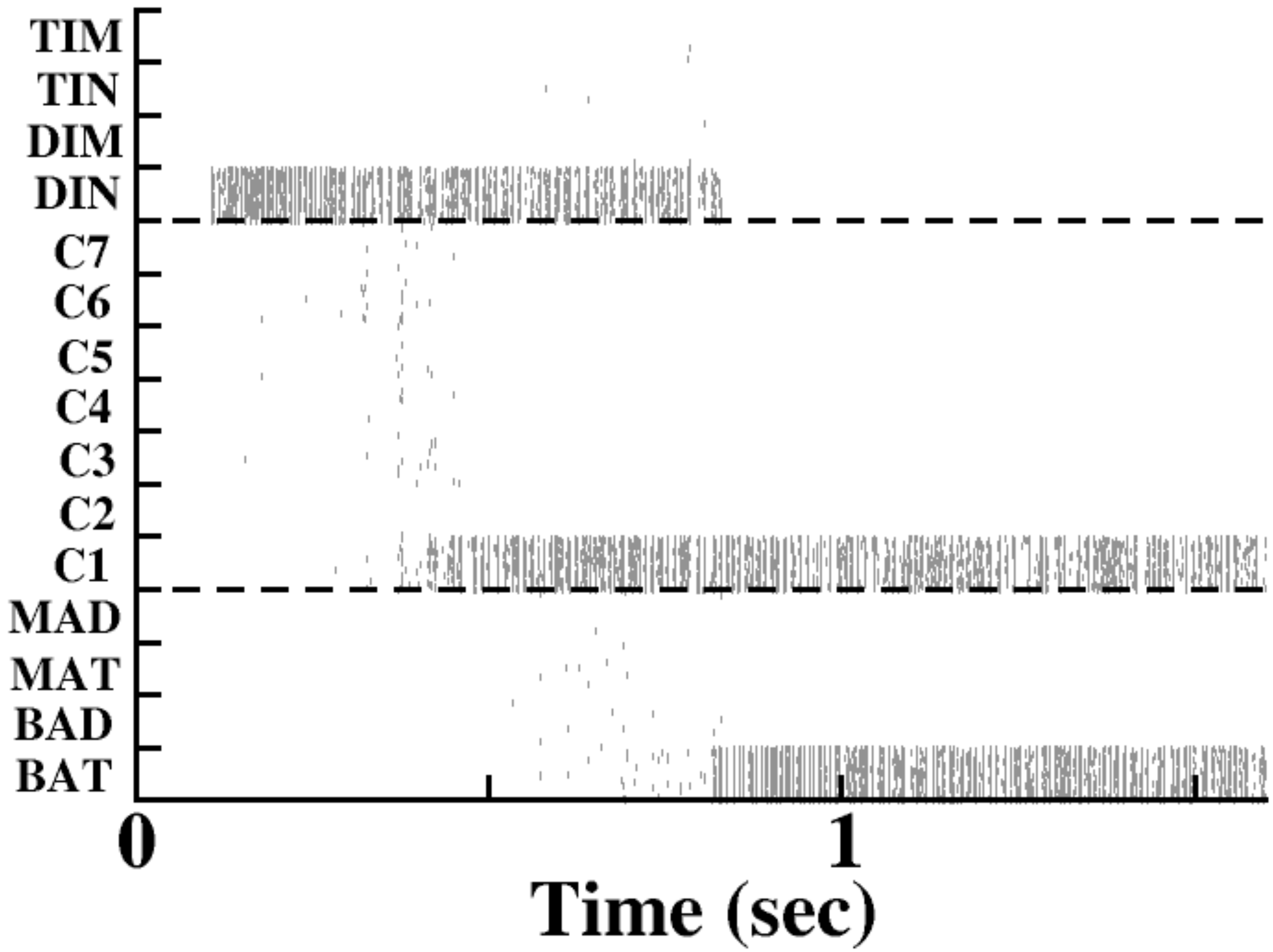
Spike trains during stimulus presentation



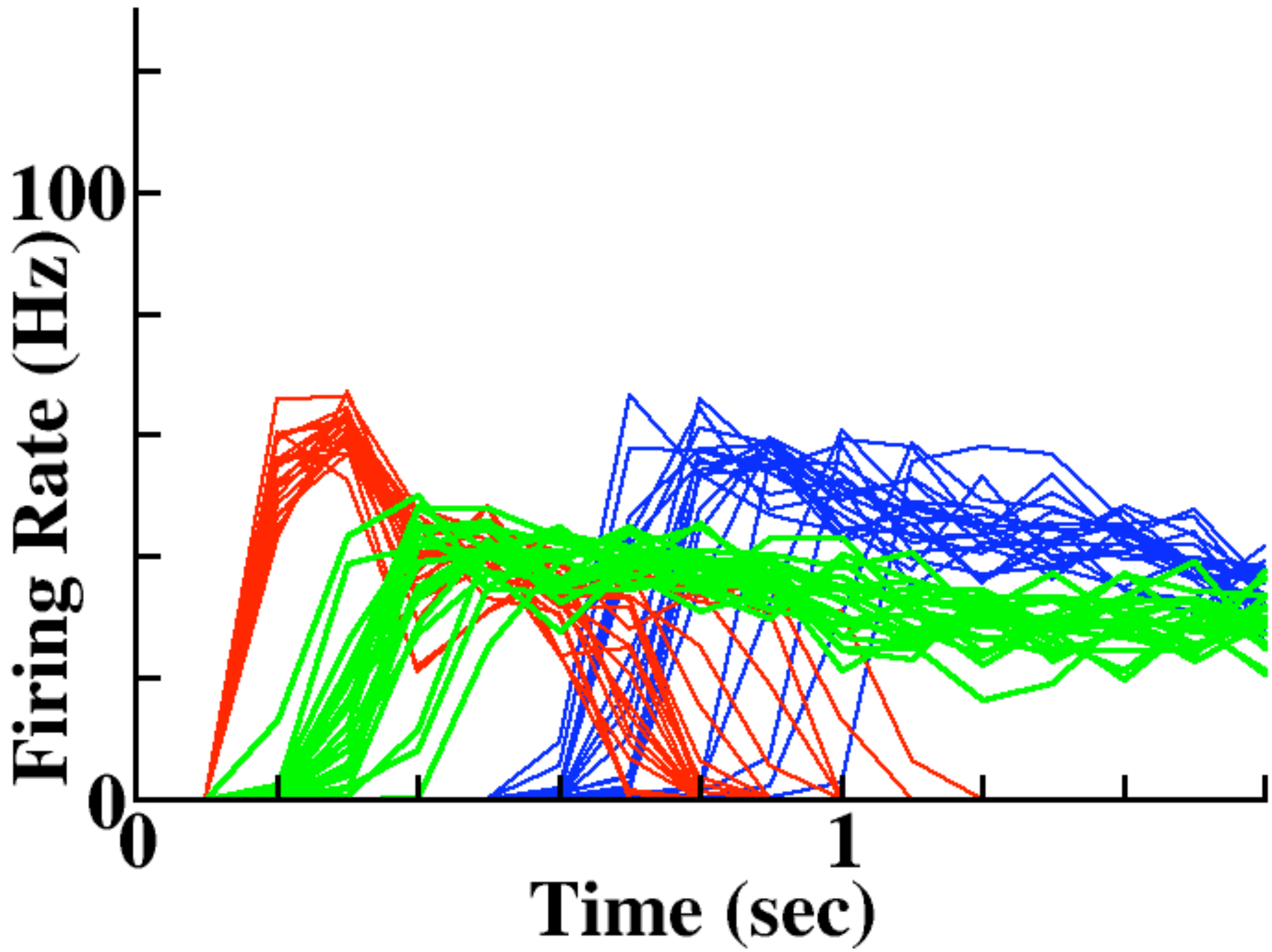
Firing rates during stimulus presentation (strong stimuli)



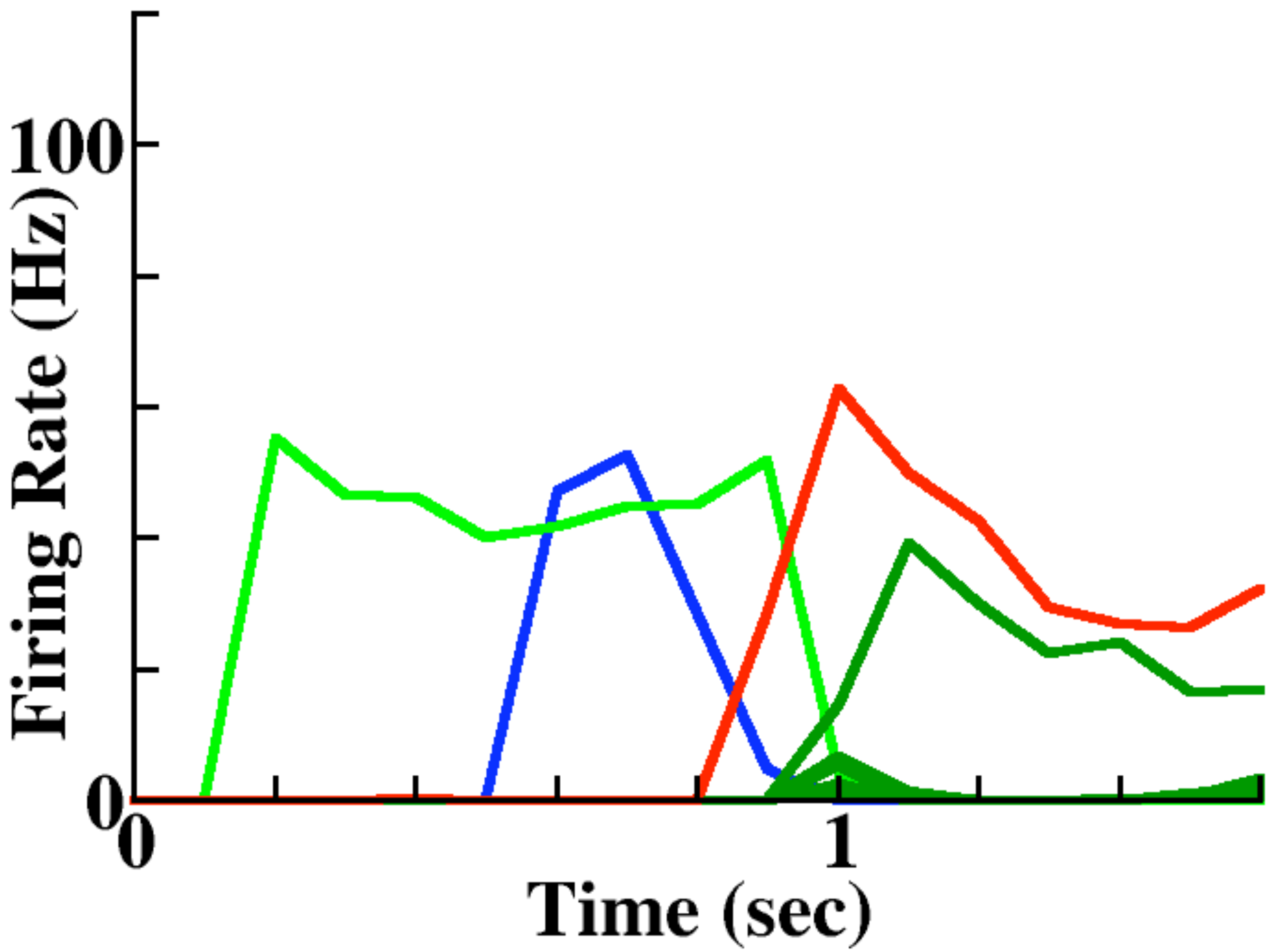
Reverse recall now possible (following strong stimuli)



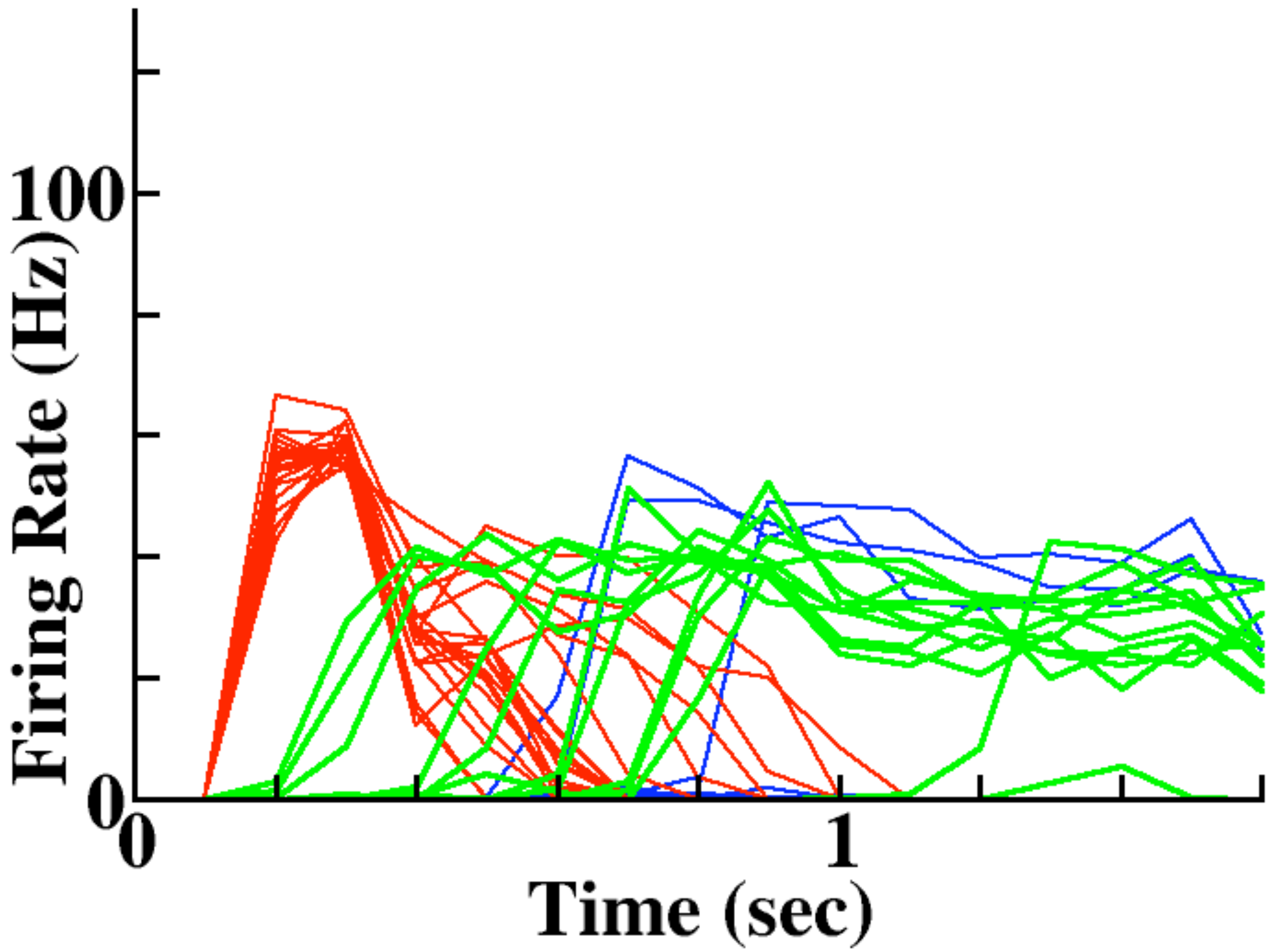
Reverse recall now possible (following strong stimuli)



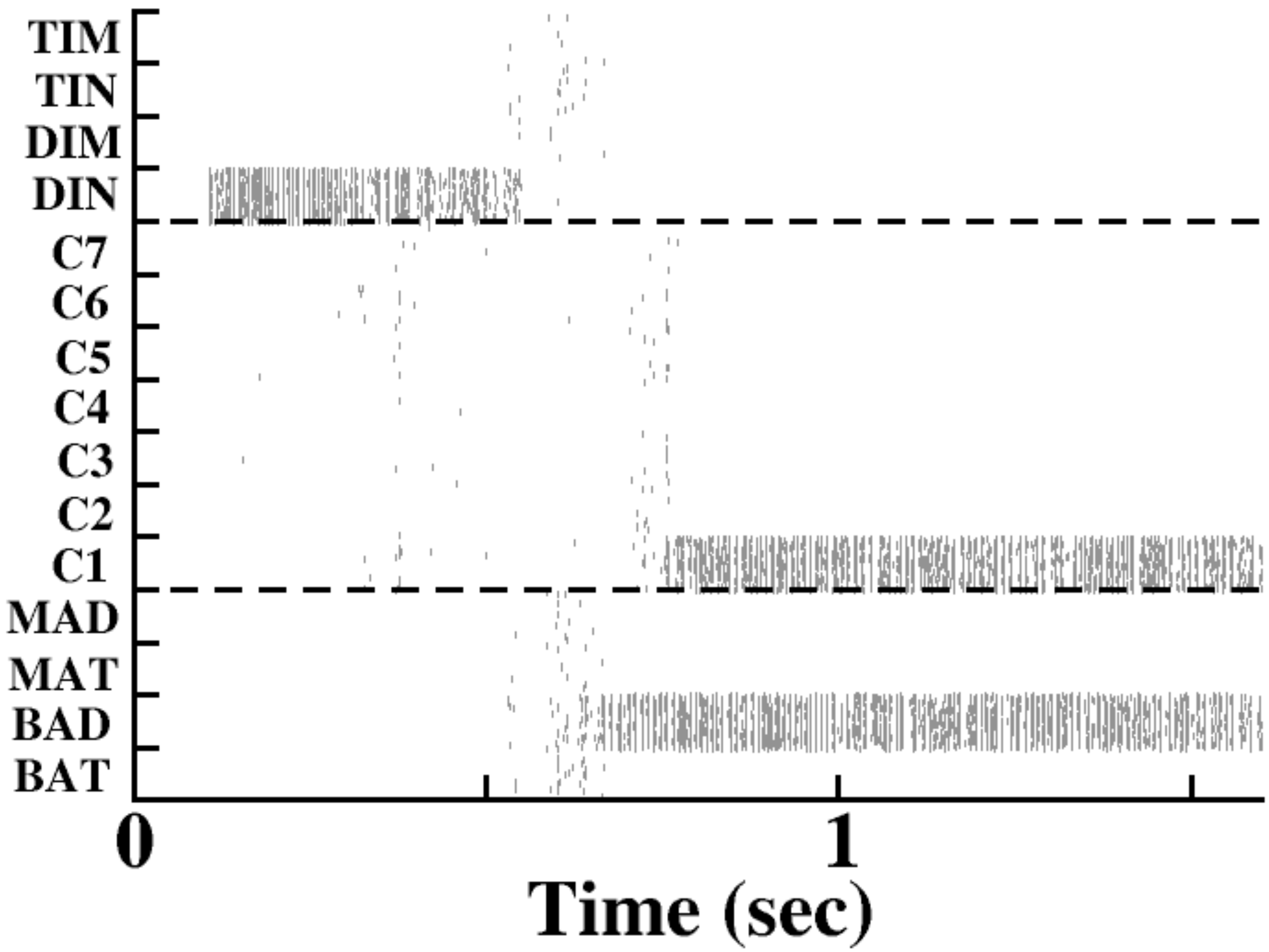
Firing rates during stimulus presentation (weaker stimuli)



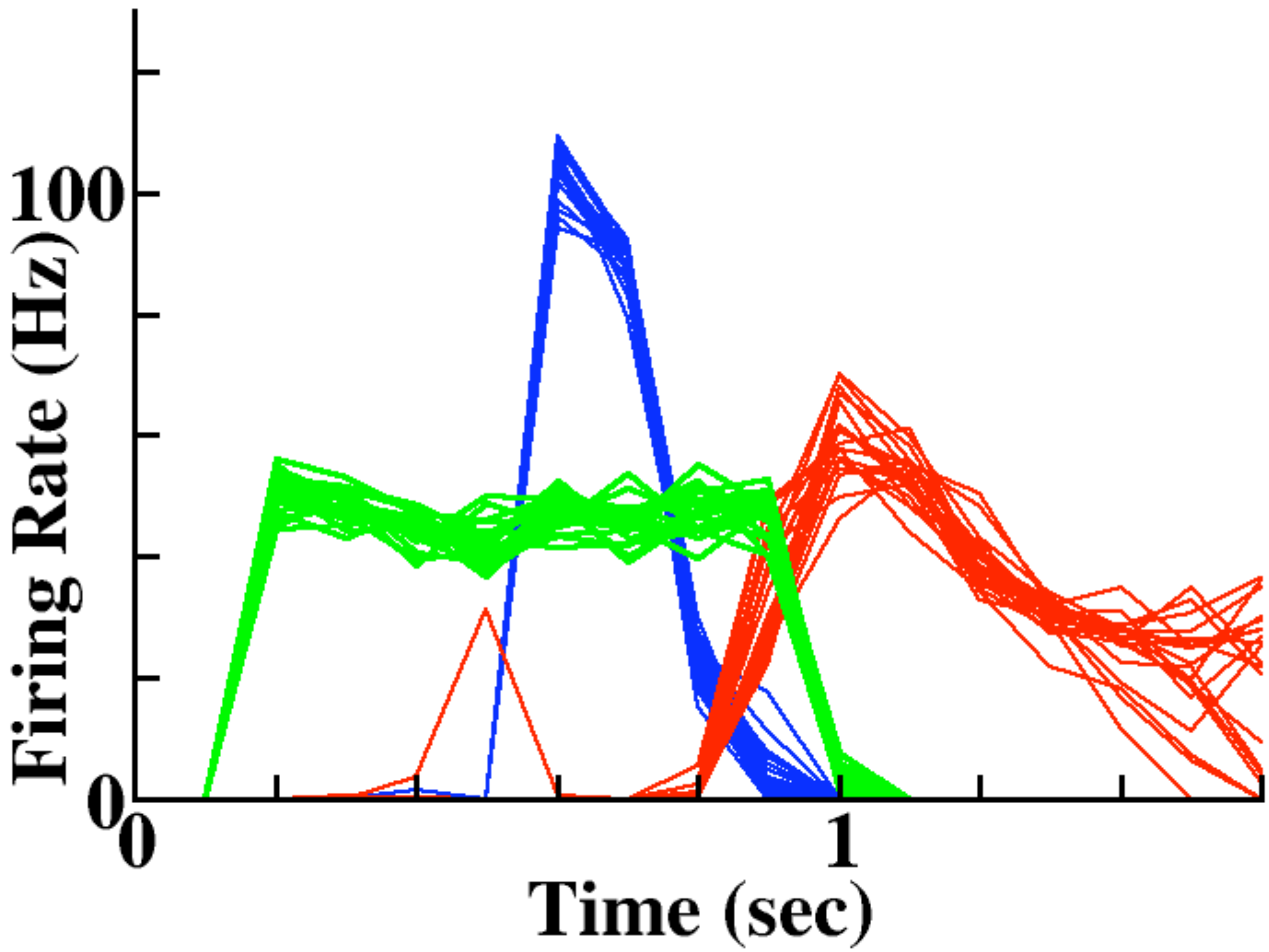
Reverse recall less often following weak stimuli
(15% correct)



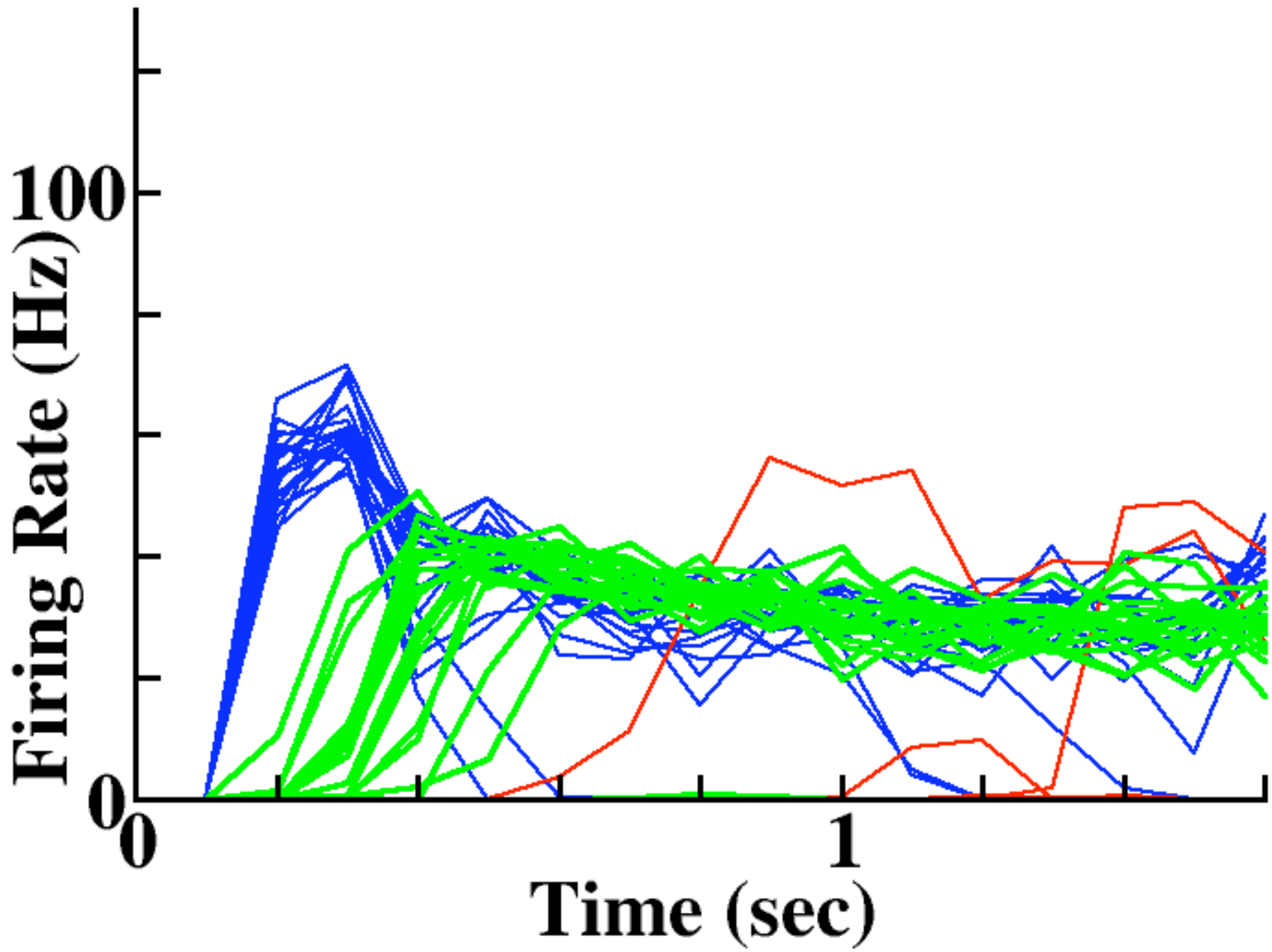
Example of error following weak stimuli during reverse recall



How about a strong-then-weak stimulus pair?
Activity during presentation:



Forward recall deteriorates (strong-then-weak stimulus pair)
10% correct



Reverse recall also deteriorates (strong-then-weak stimulus pair)
35% correct