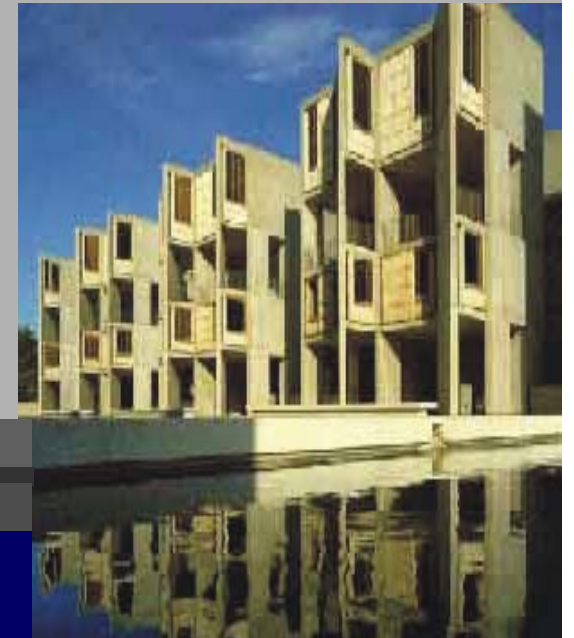


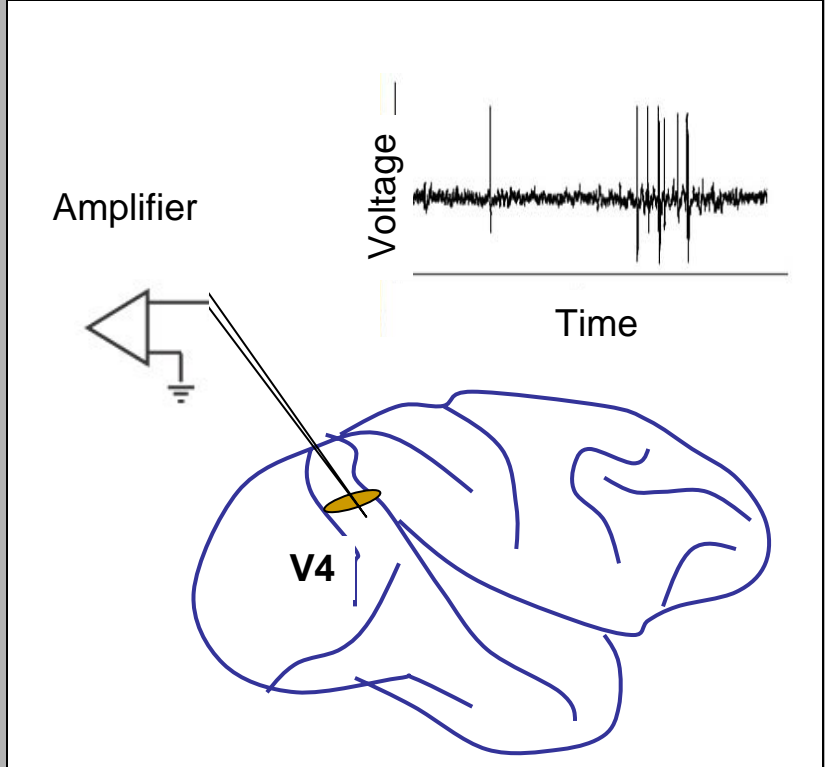
Attention reduces low frequency correlated noise in macaque V4

Jude F. Mitchell
Kristy A. Sundberg
John H. Reynolds



SALK INSTITUTE
FOR BIOLOGICAL STUDIES

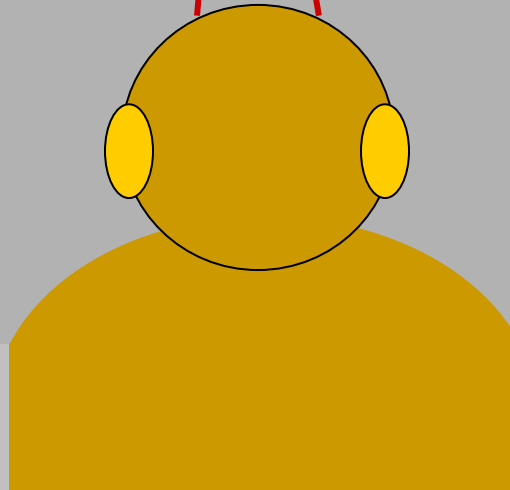
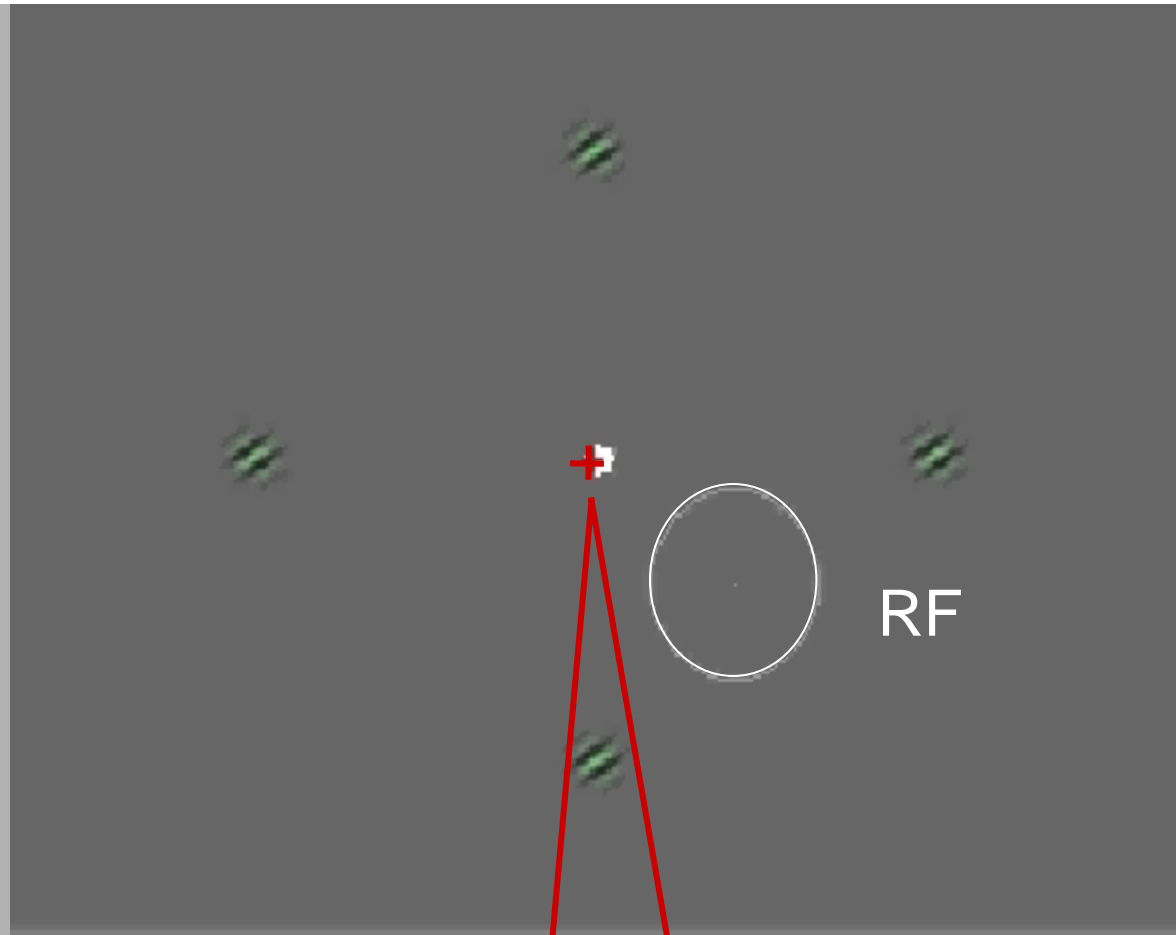




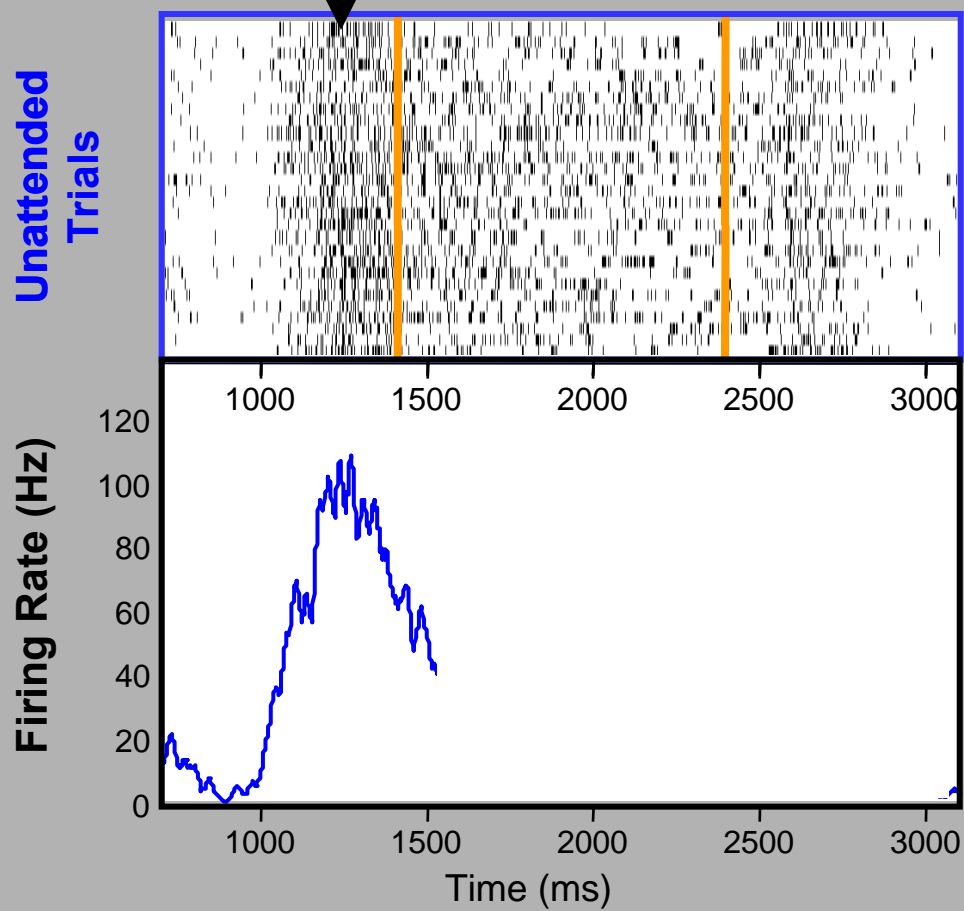
Multiple-object tracking

(Pylyshyn & Storm, 1988)

(Mitchell et al, 2007)



Stimulus
enters
RF



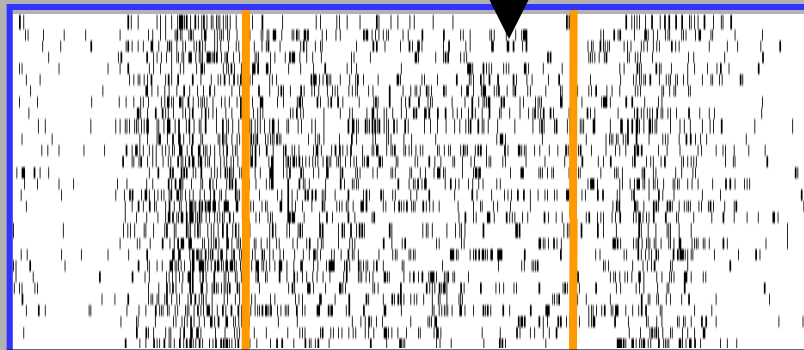
Attend
away
from
stimulus
in RF

Stimulus
enters
RF

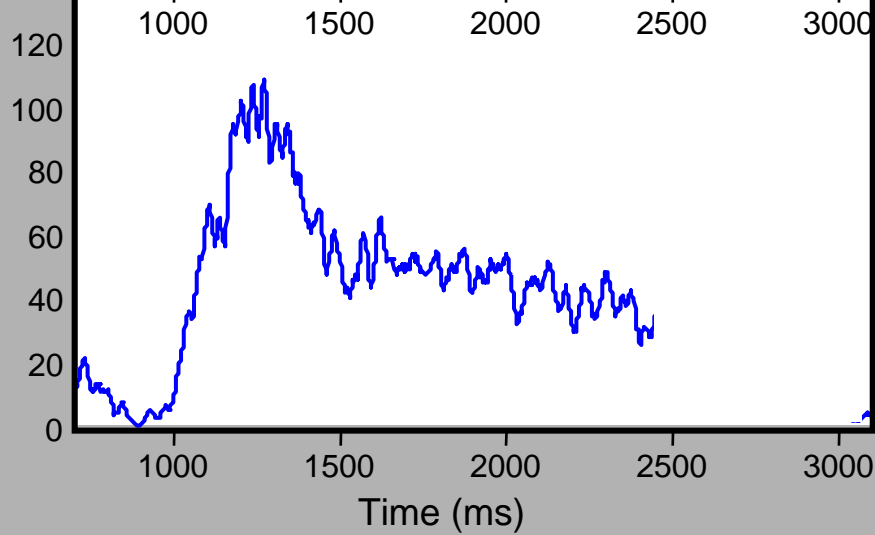
**Stimulus
sustained
in RF**



Unattended
Trials



Firing Rate (Hz)



Attend
away
from
stimulus
in RF

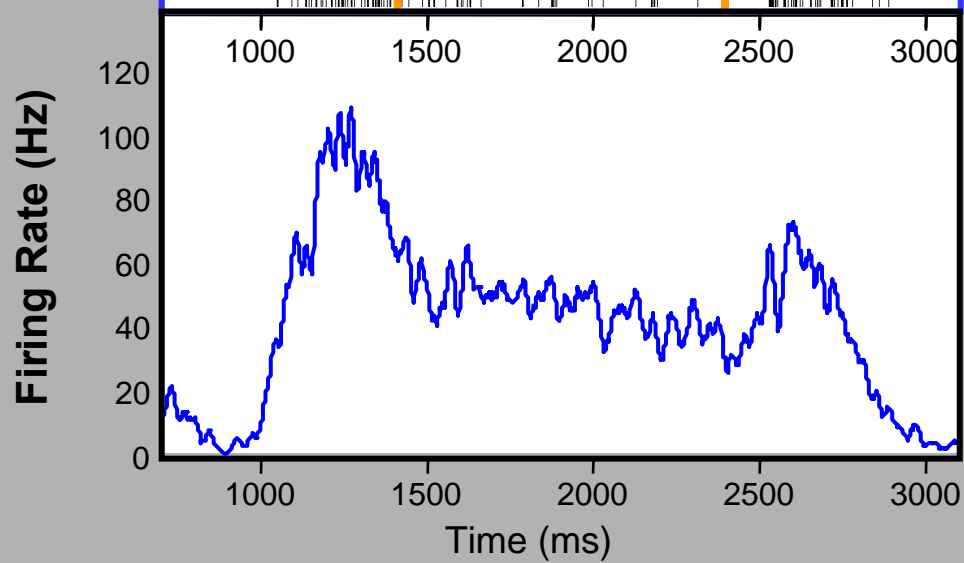
Stimulus
enters
RF

Stimulus
sustained
in RF

**Stimulus
leaves
RF**



Unattended
Trials

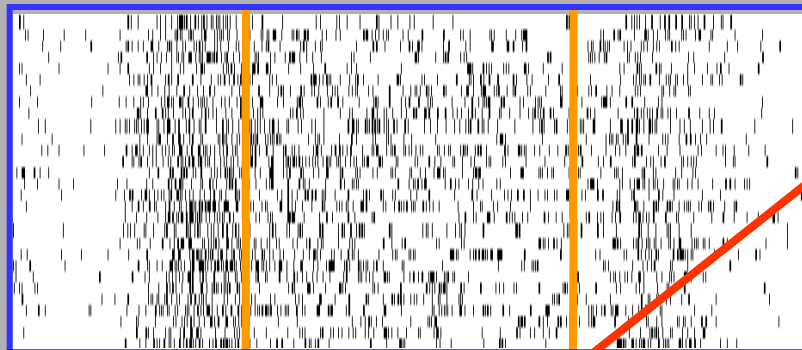


Attend
away
from
stimulus
in RF

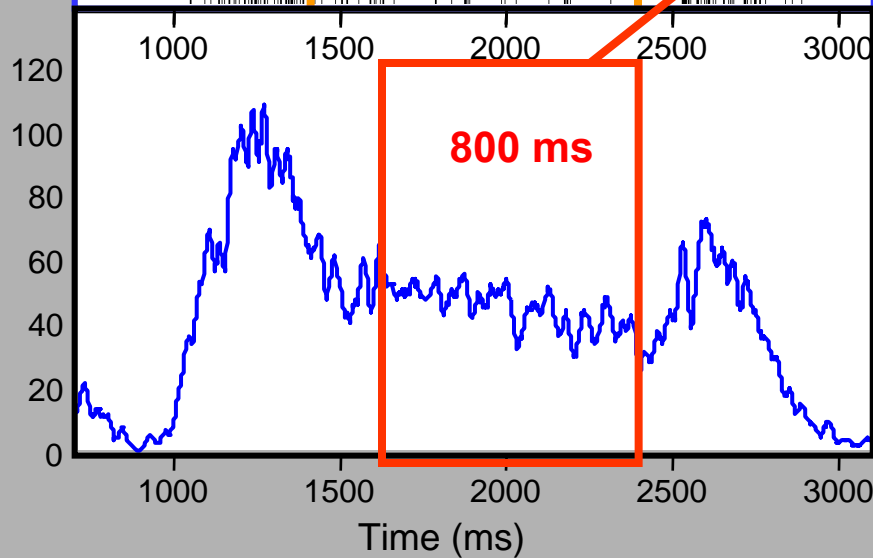
Stimulus enters RF Stimulus sustained in RF Stimulus leaves RF

Sustained response interval

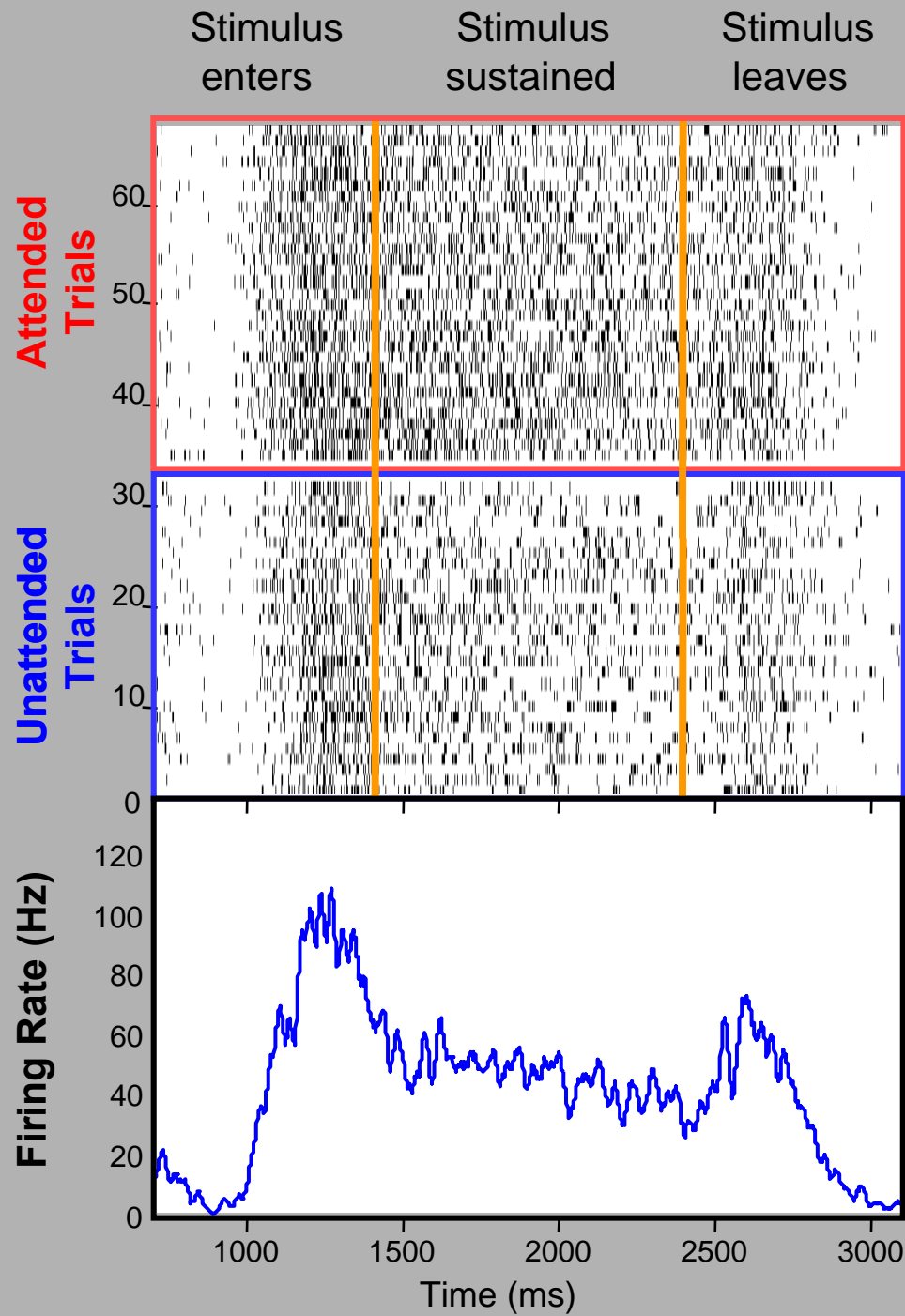
Unattended Trials



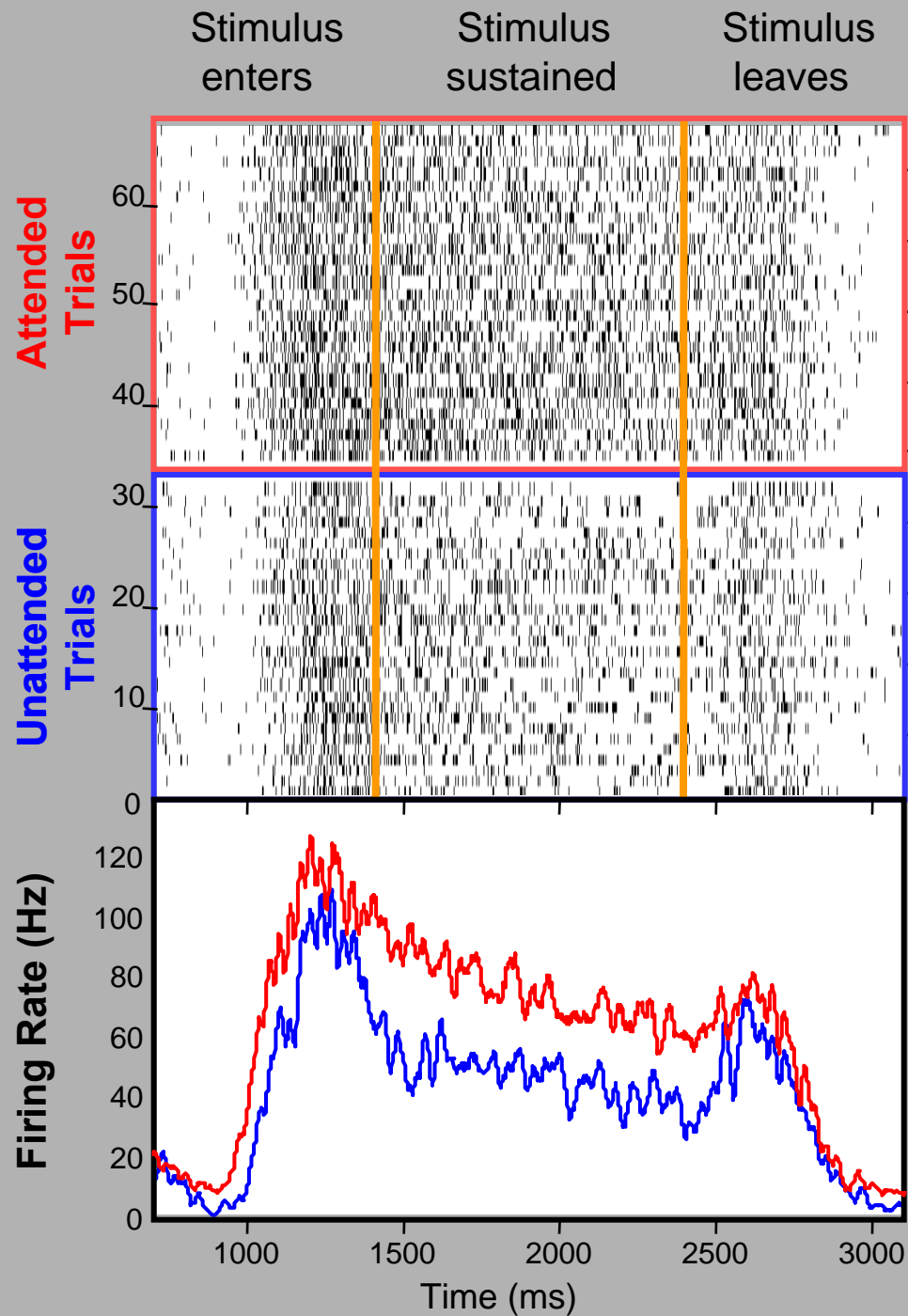
Firing Rate (Hz)



Attend away from stimulus in RF



Attend towards stimulus in RF

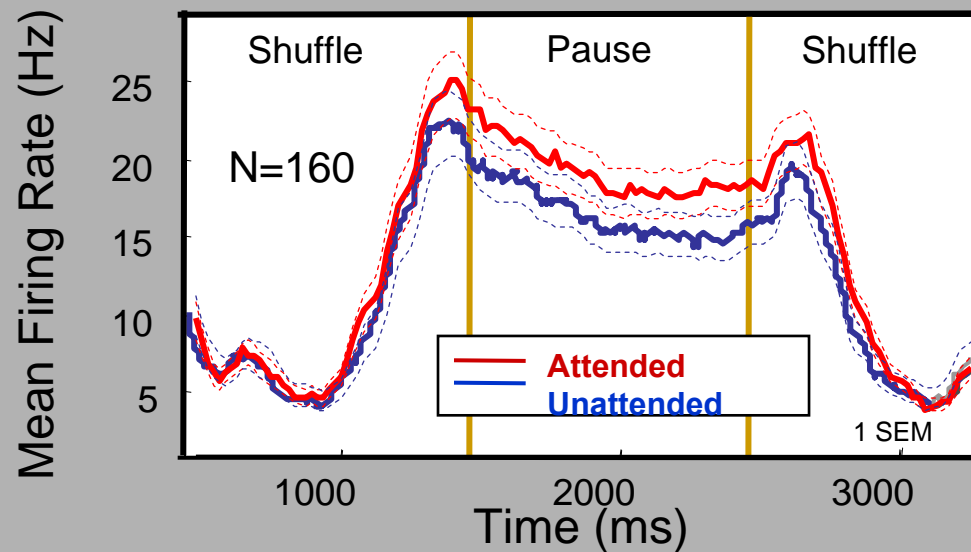


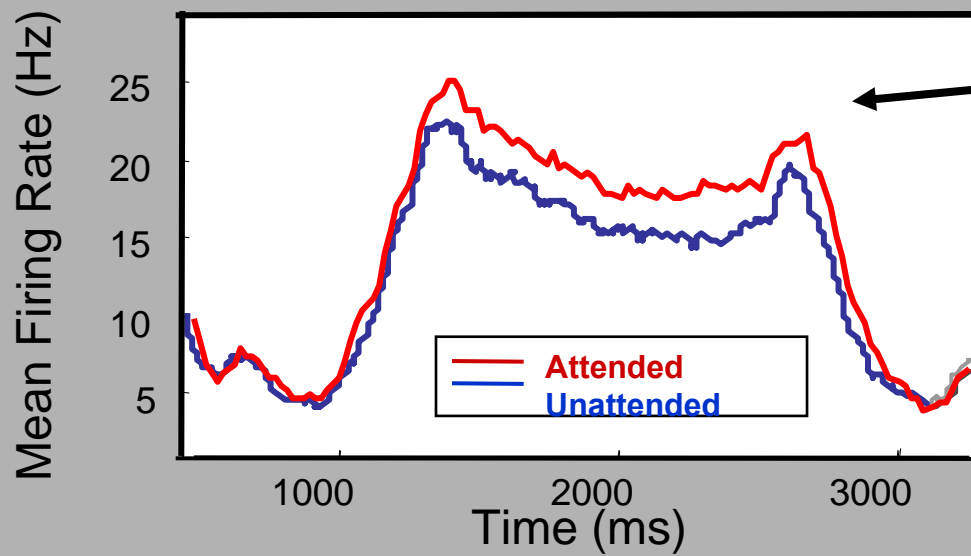
**Mean firing rate
increases
for attended items**

**Mean firing rate
increases
for attended items**

20 % median
increase

Population Average Firing Rate

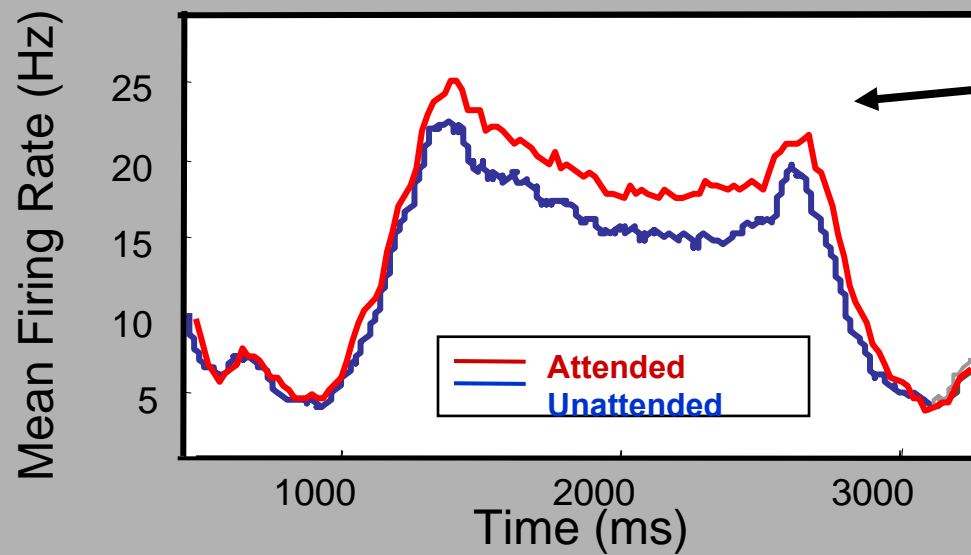




Signal increase
with attention



Signal to noise ratio?



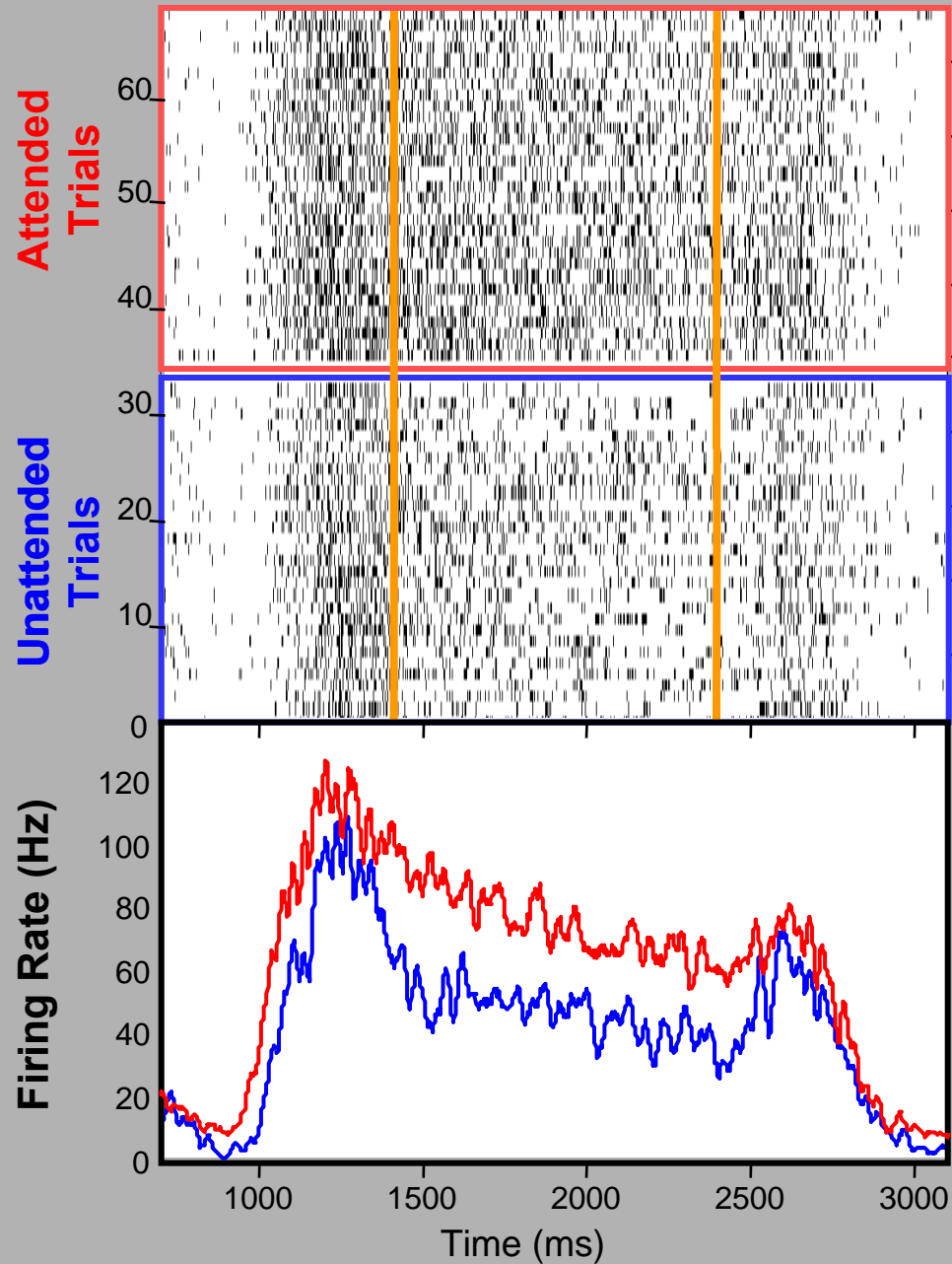
Signal increase
with attention

Attention-dependent modulation of response variability?

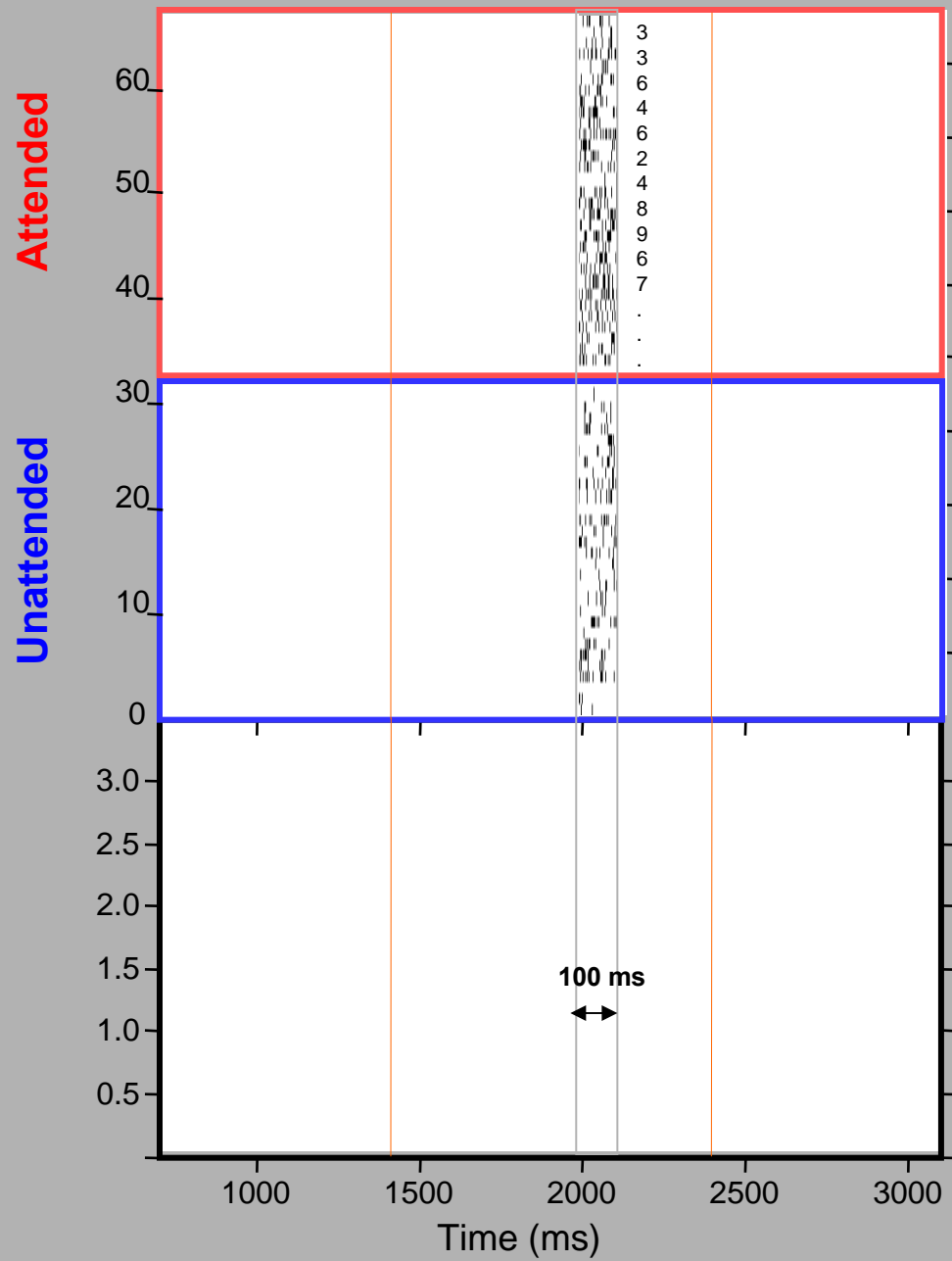
(Mitchell et al,
Neuron, 2007)

Attention-dependent modulation of response variability?

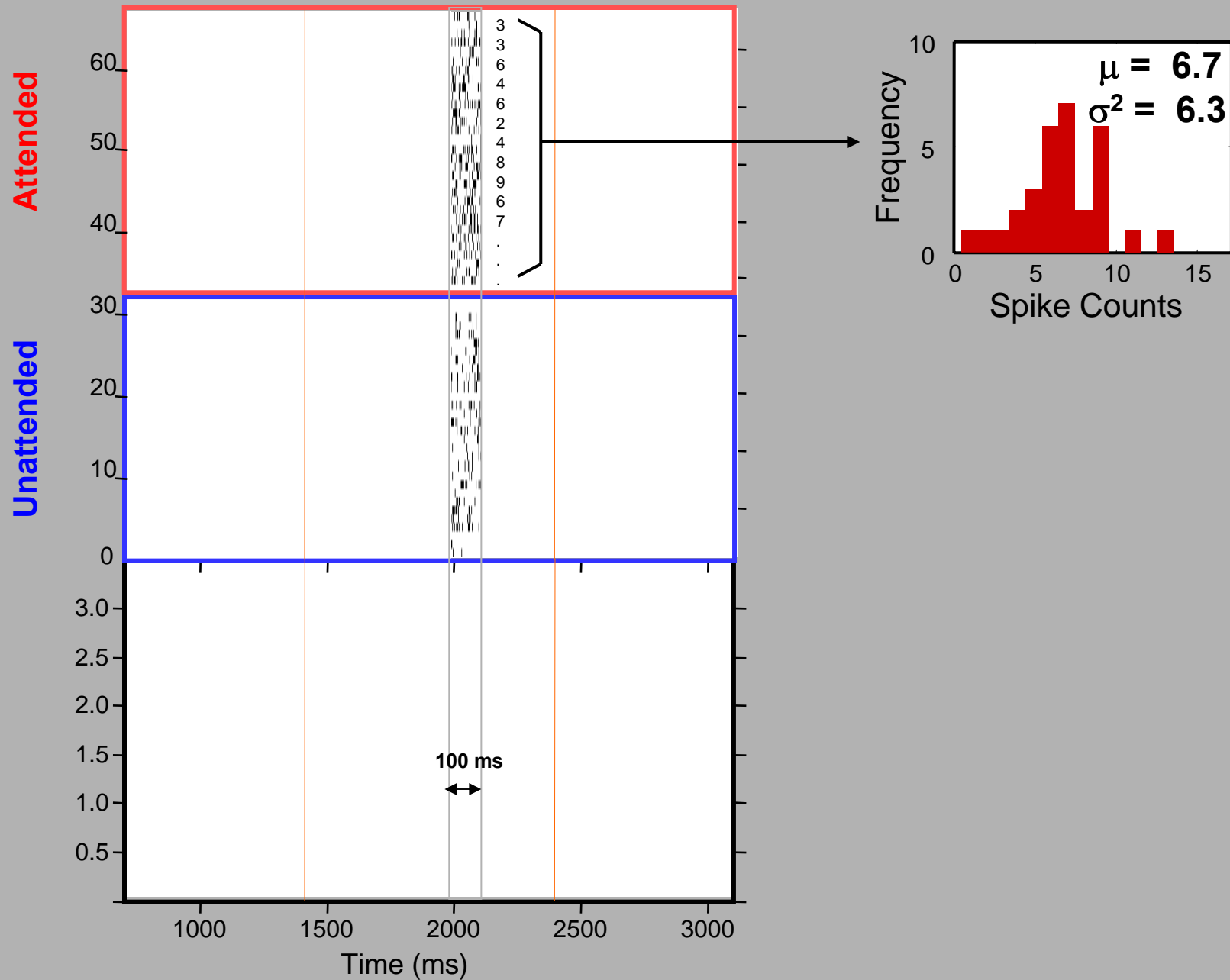
(Mitchell et al,
Neuron, 2007)



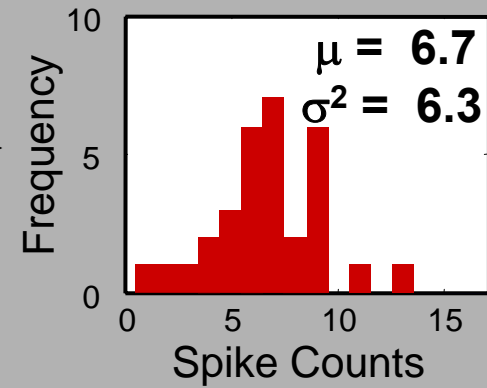
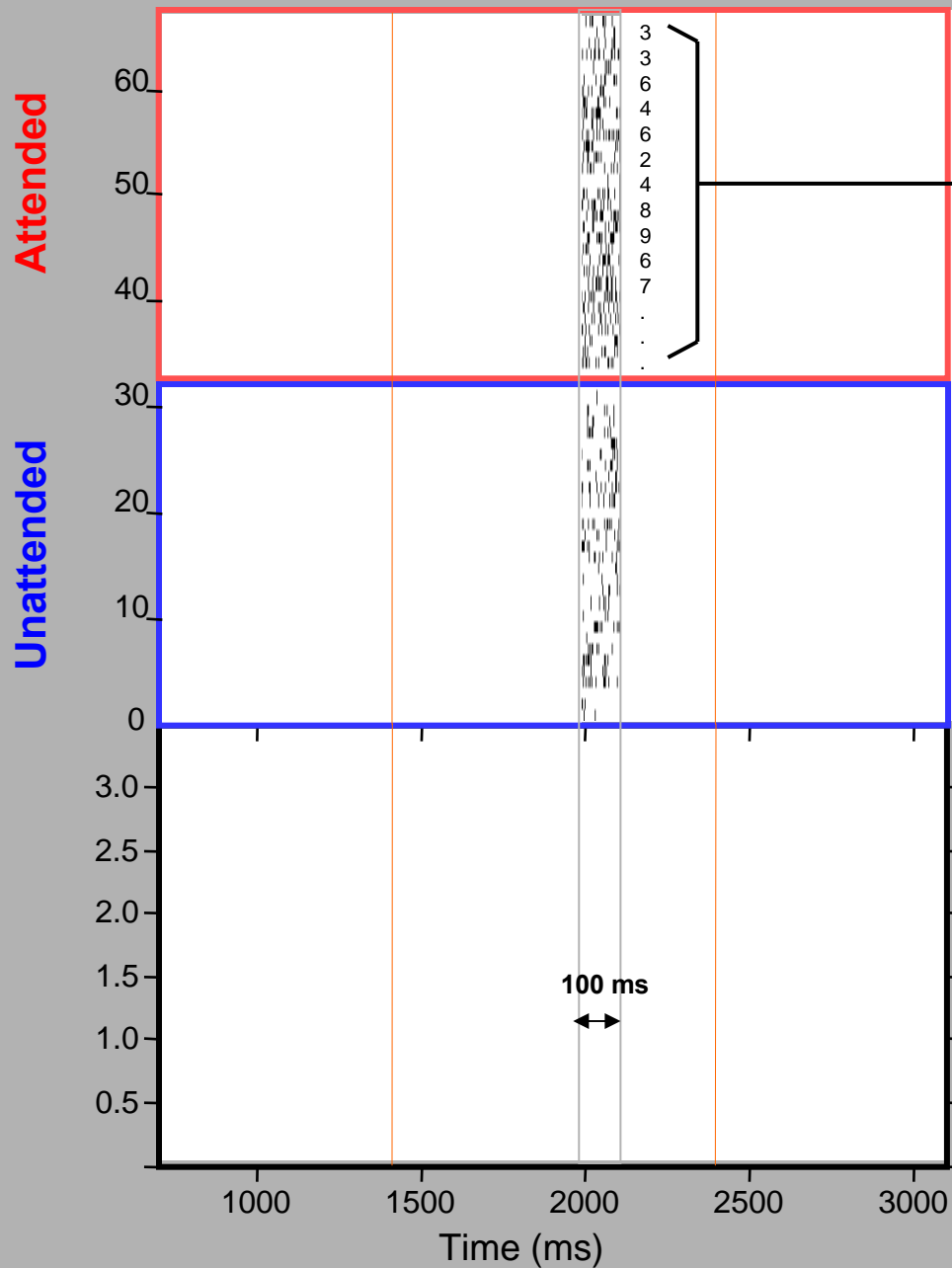
Attention-dependent modulation of response variability?



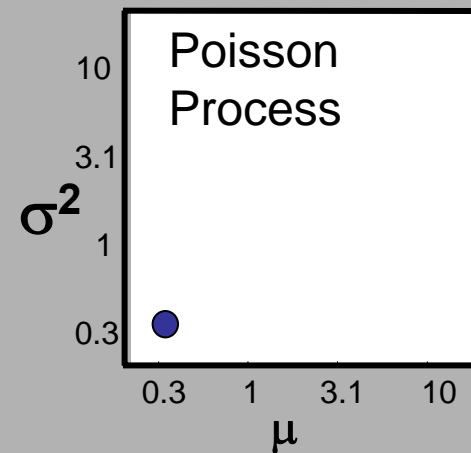
Attention-dependent modulation of response variability?



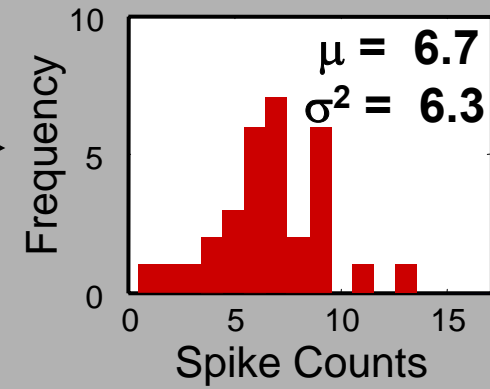
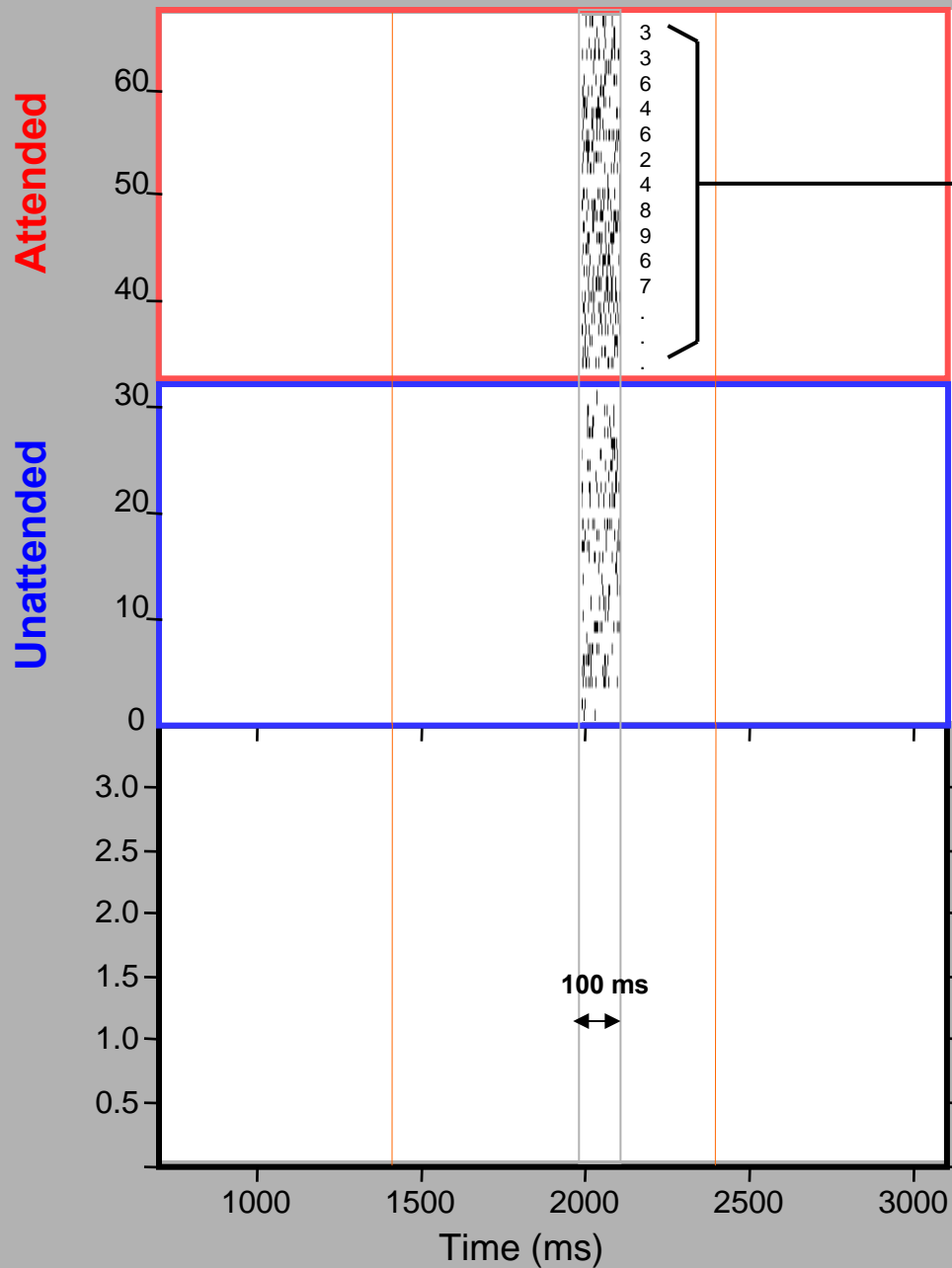
Attention-dependent modulation of response variability?



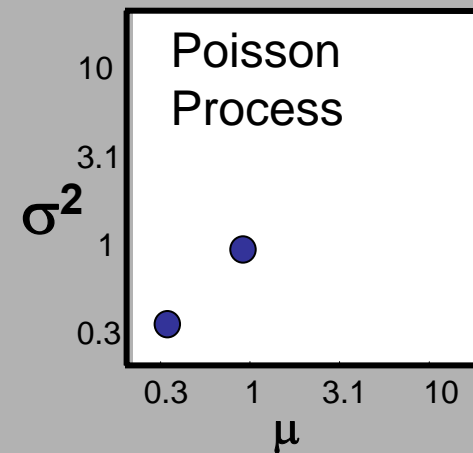
Variance grows with rate



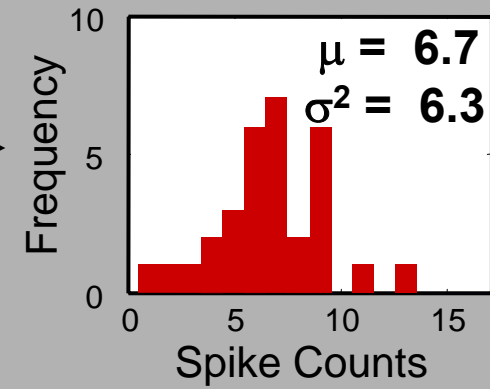
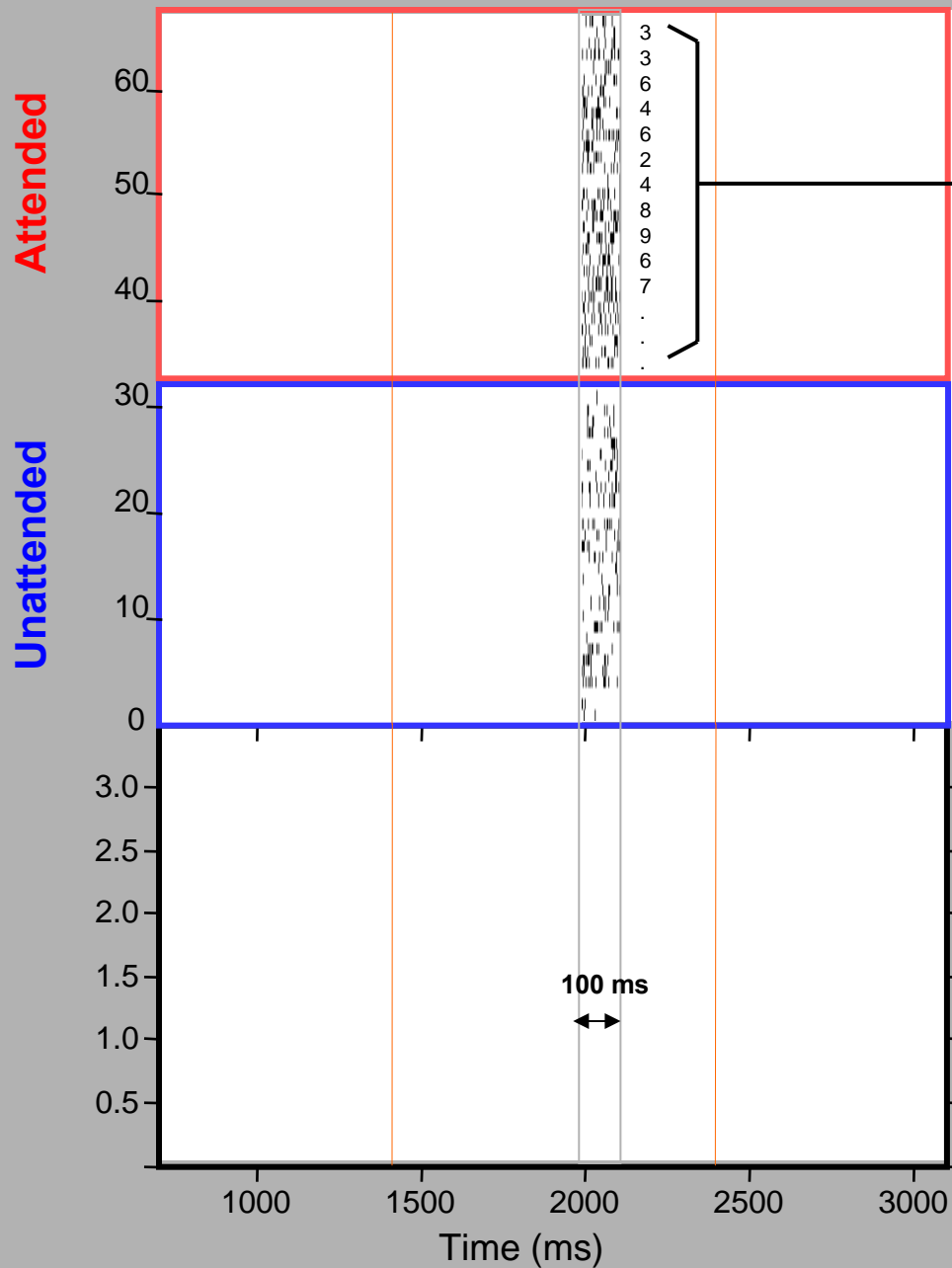
Attention-dependent modulation of response variability?



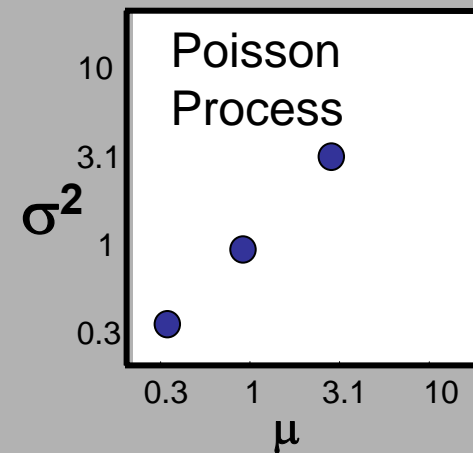
Variance grows with rate



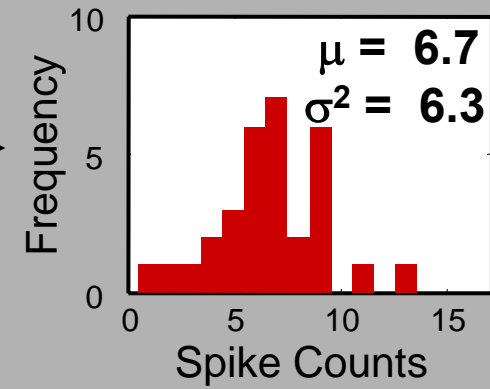
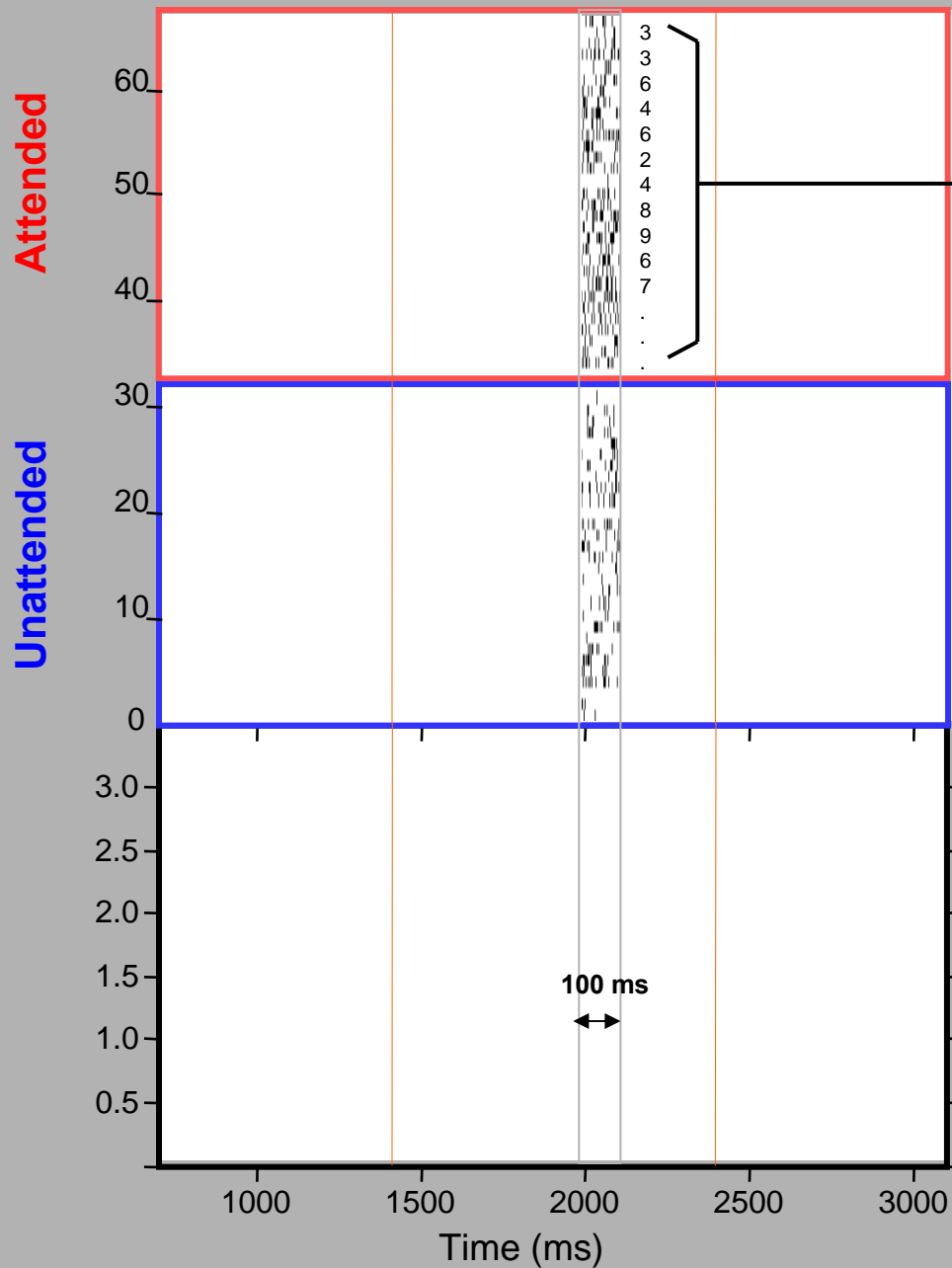
Attention-dependent modulation of response variability?



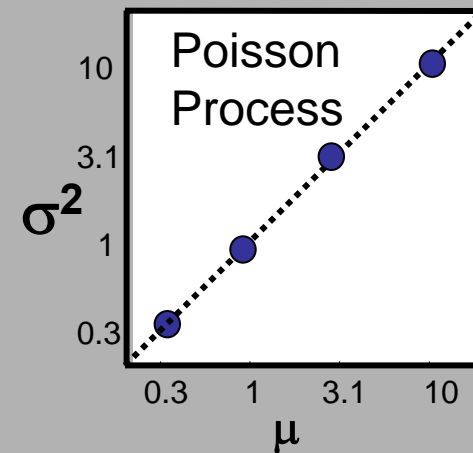
Variance grows with rate



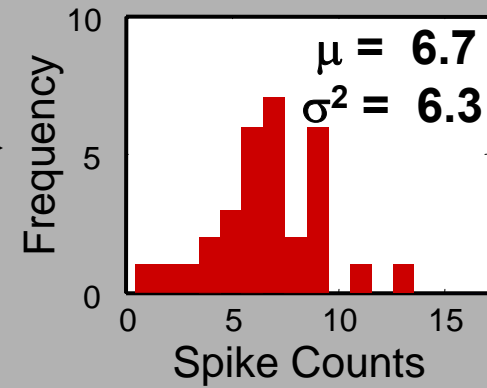
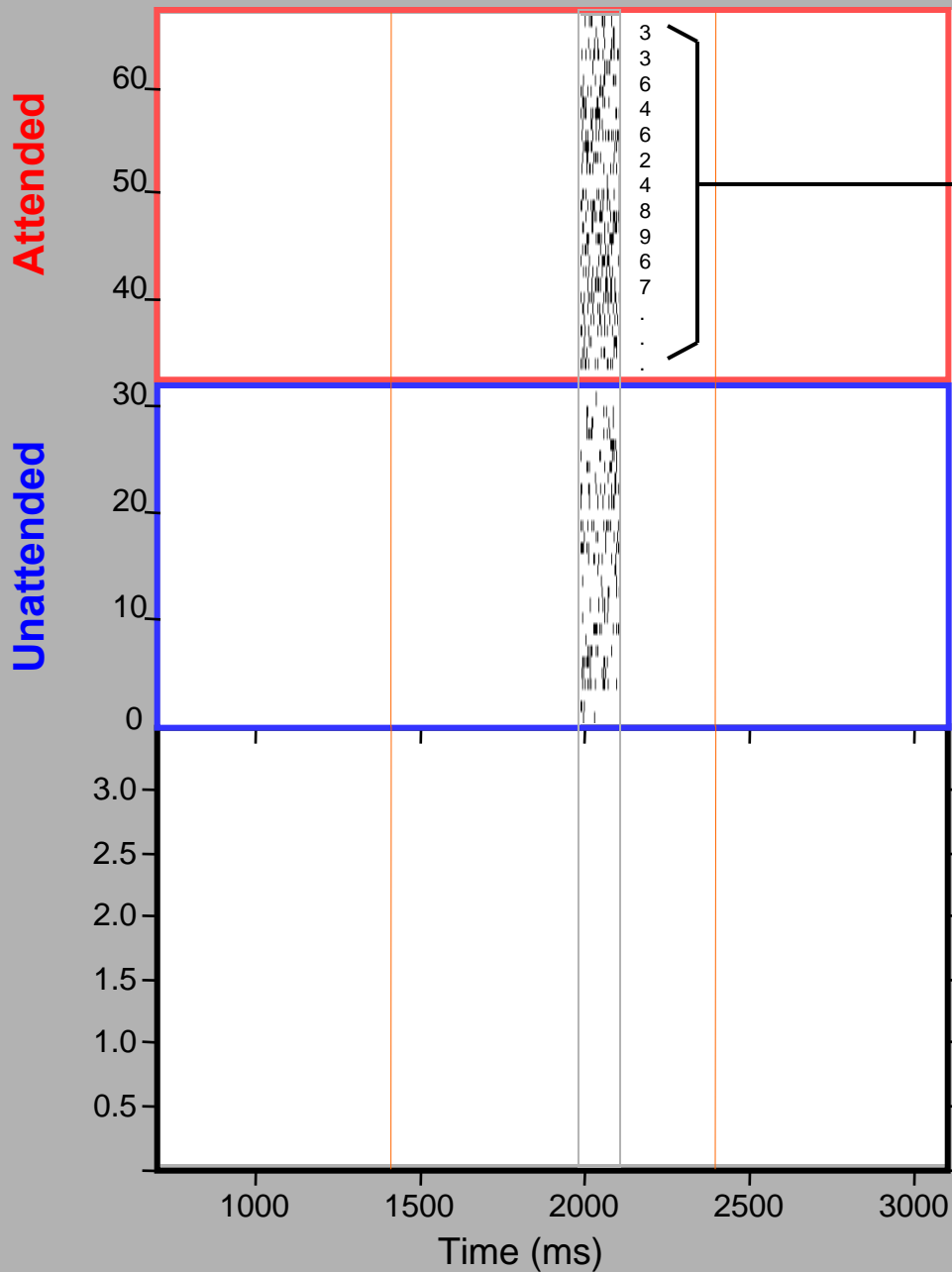
Attention-dependent modulation of response variability?



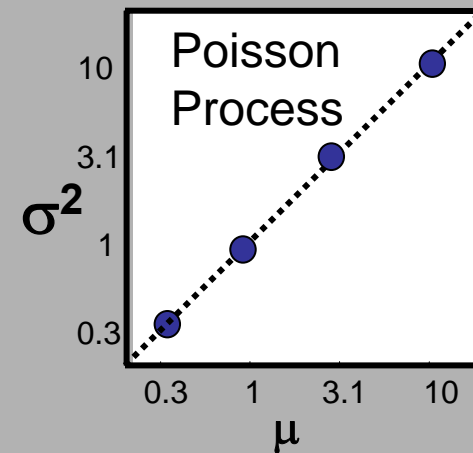
Variance grows with rate



Attention-dependent modulation of response variability?

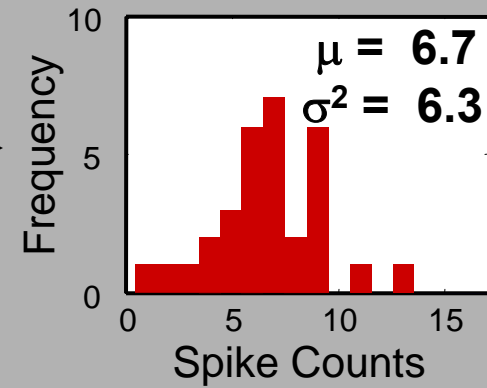
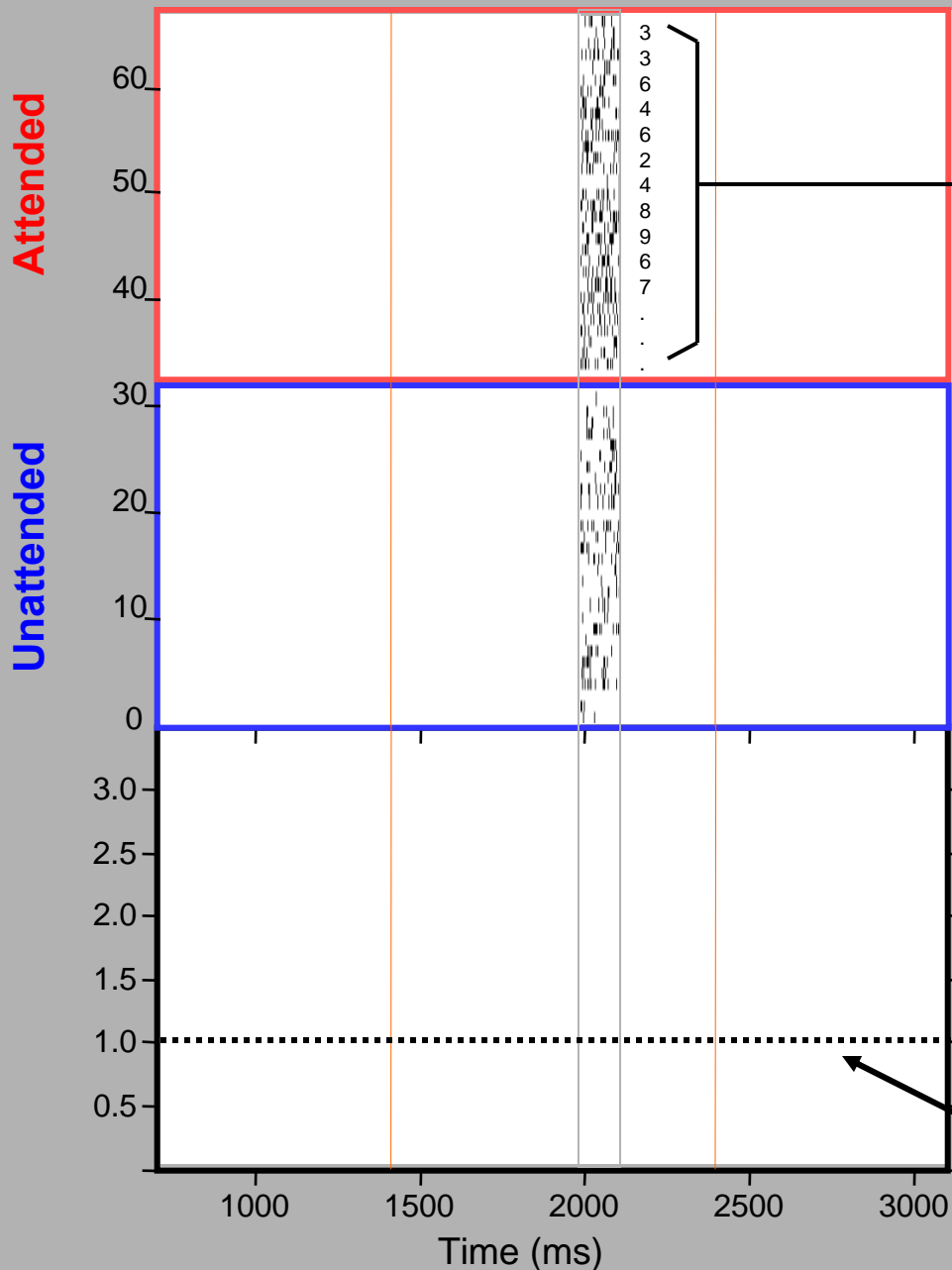


Variance grows with rate

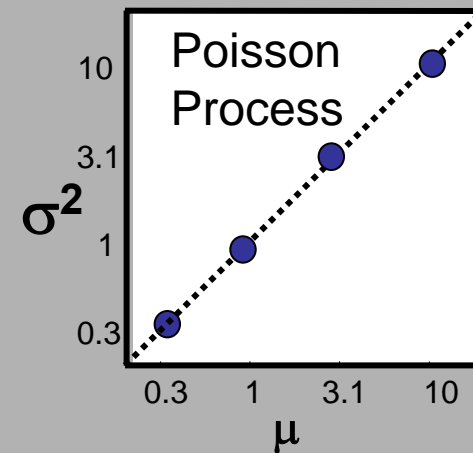


$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Attention-dependent modulation of response variability?



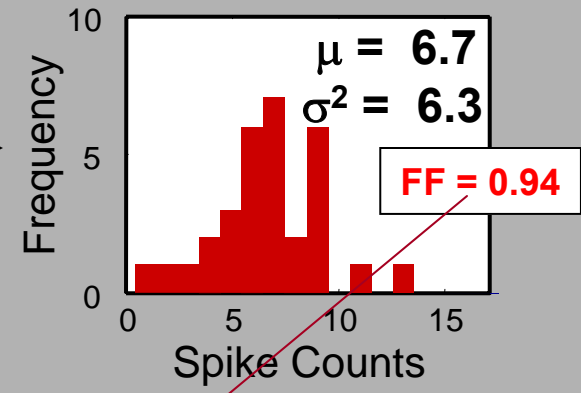
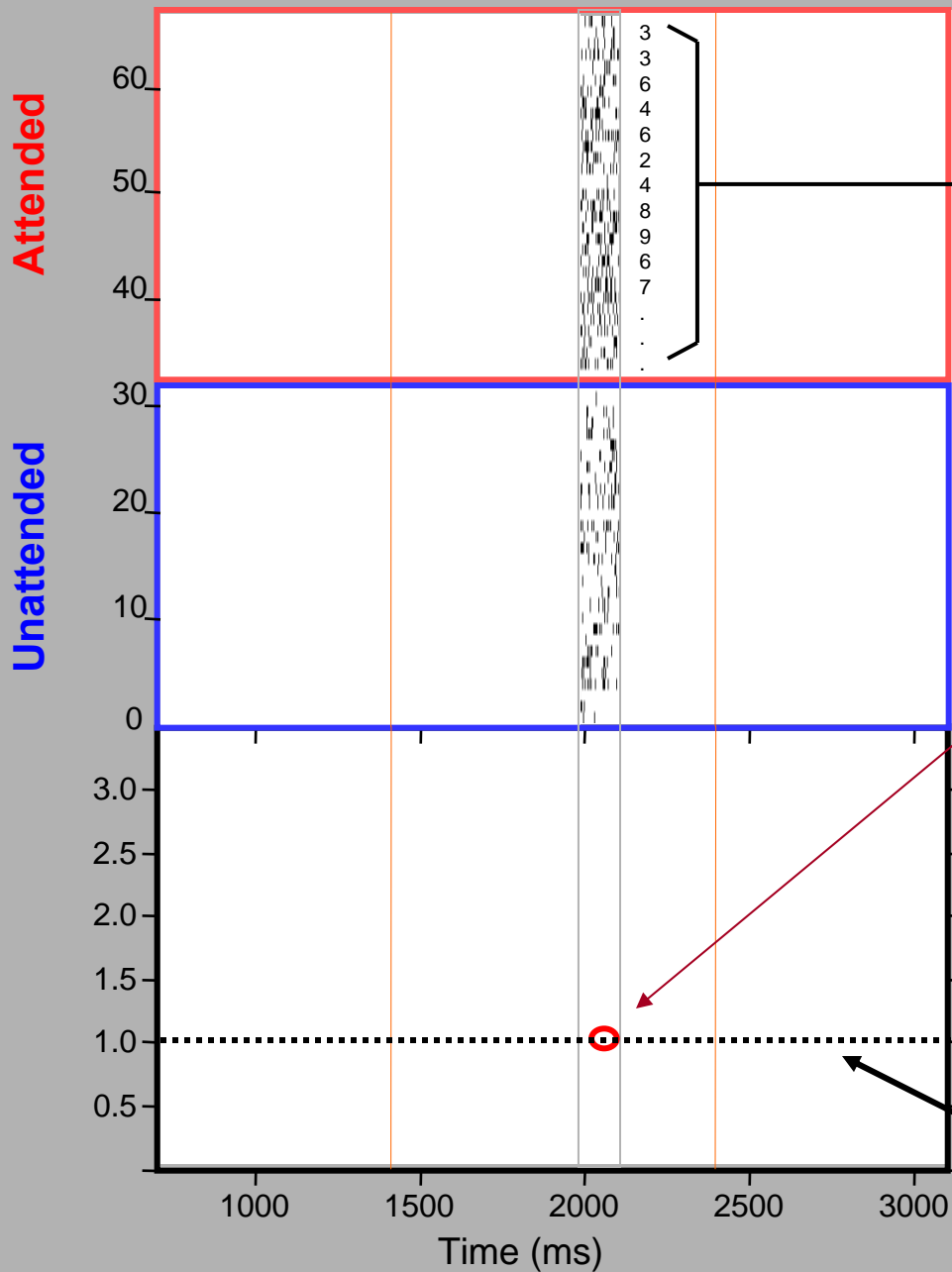
Variance grows with rate



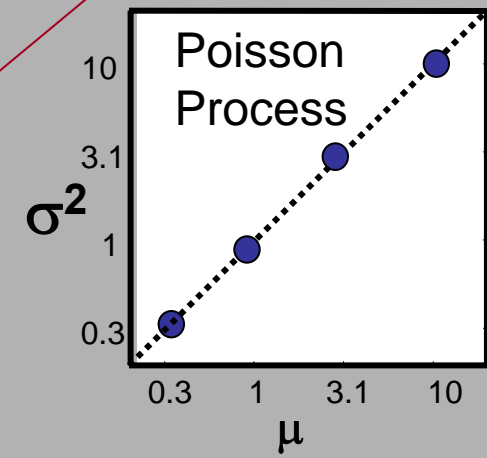
$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Poisson: FF = 1

Attention-dependent modulation of response variability?



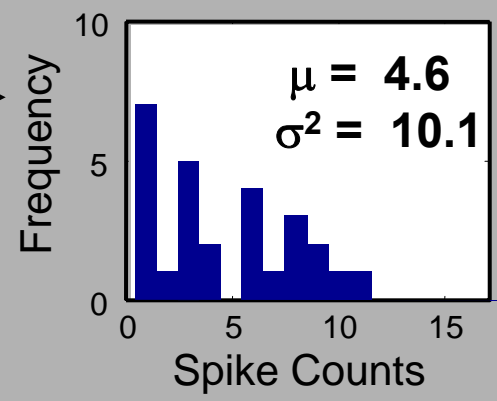
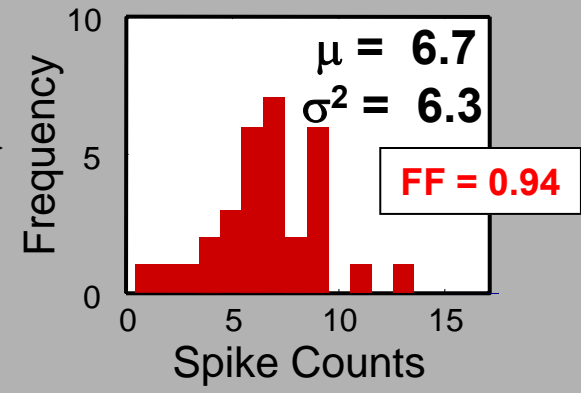
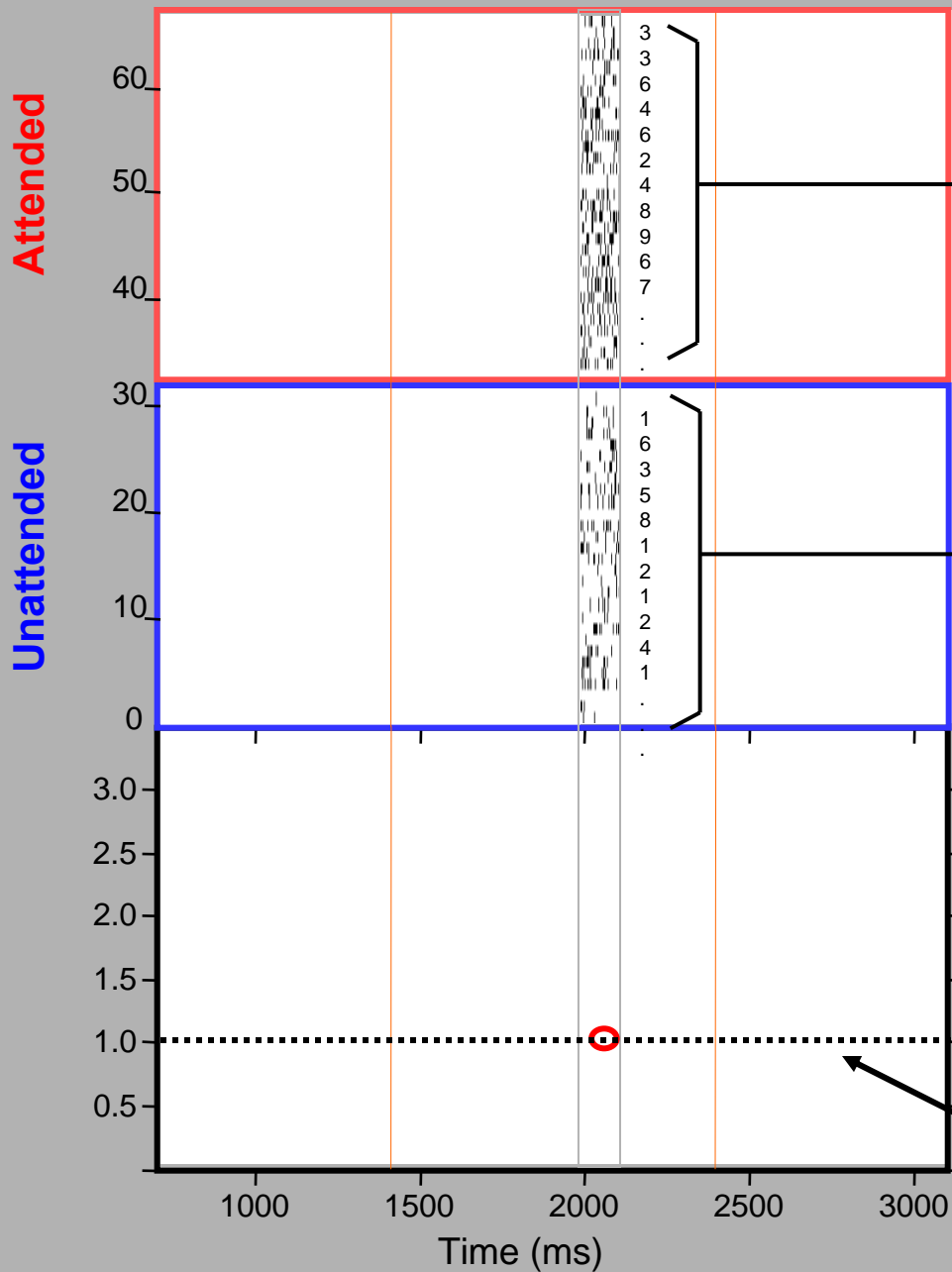
Variance grows with rate



$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Poisson: FF = 1

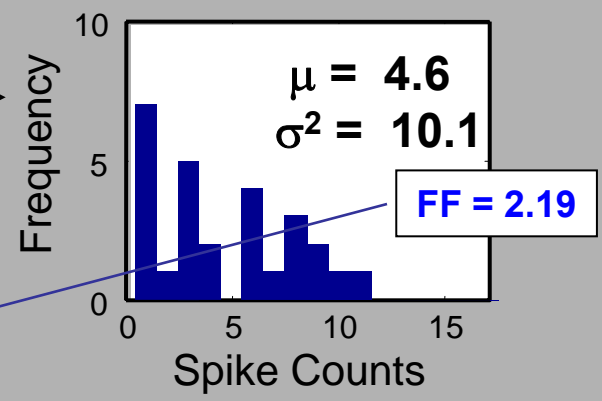
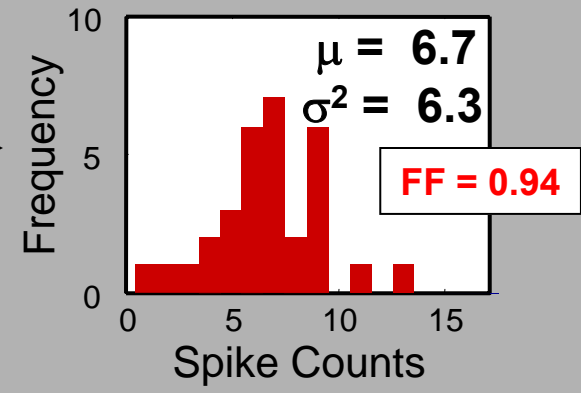
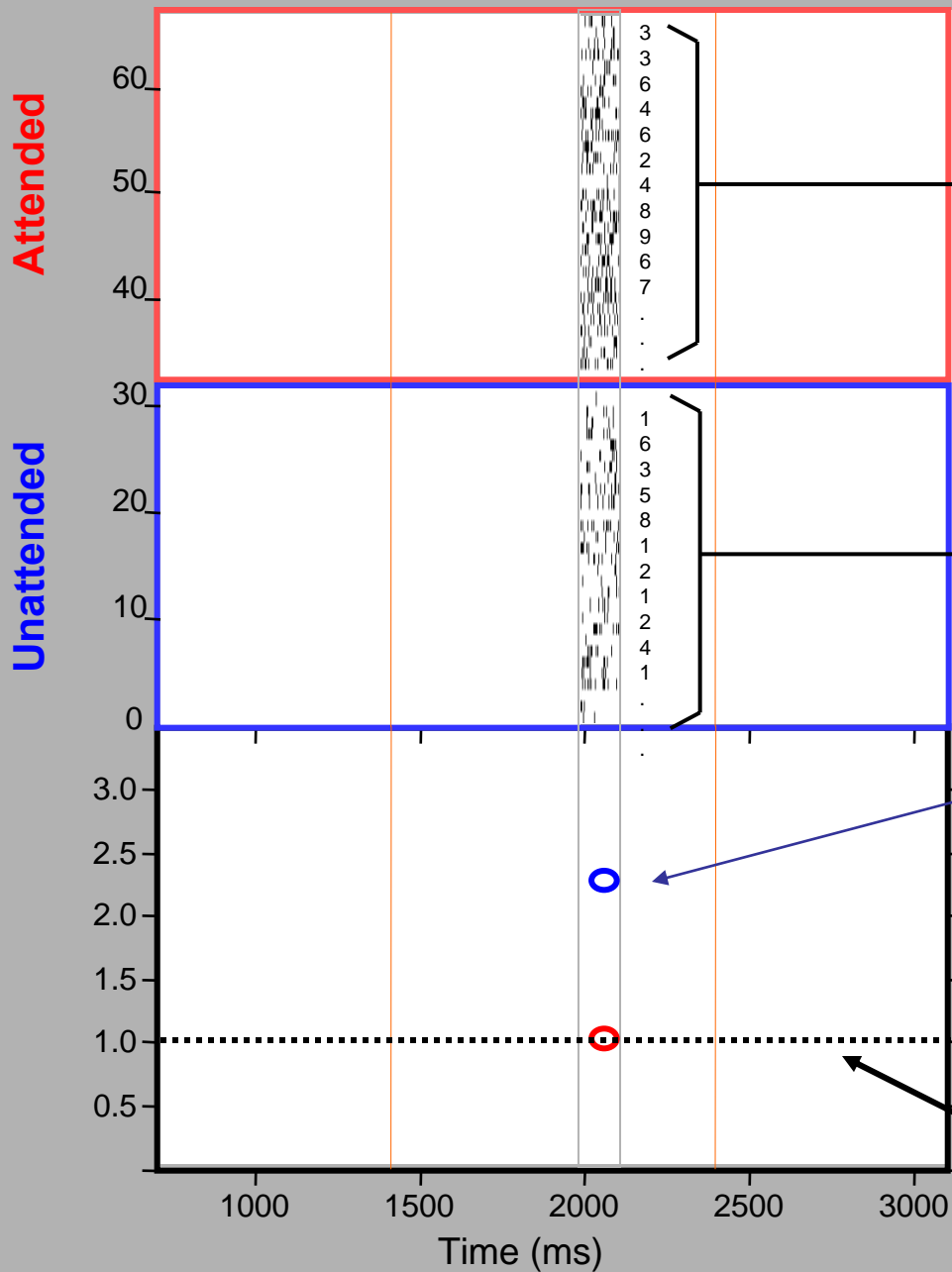
Attention-dependent modulation of response variability?



$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Poisson: FF = 1

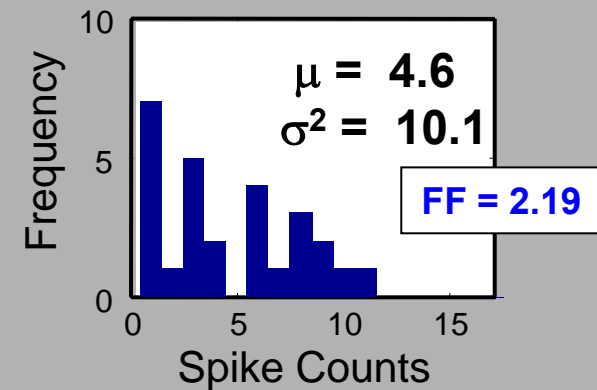
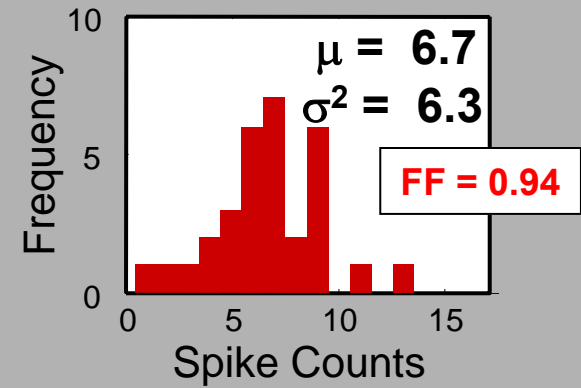
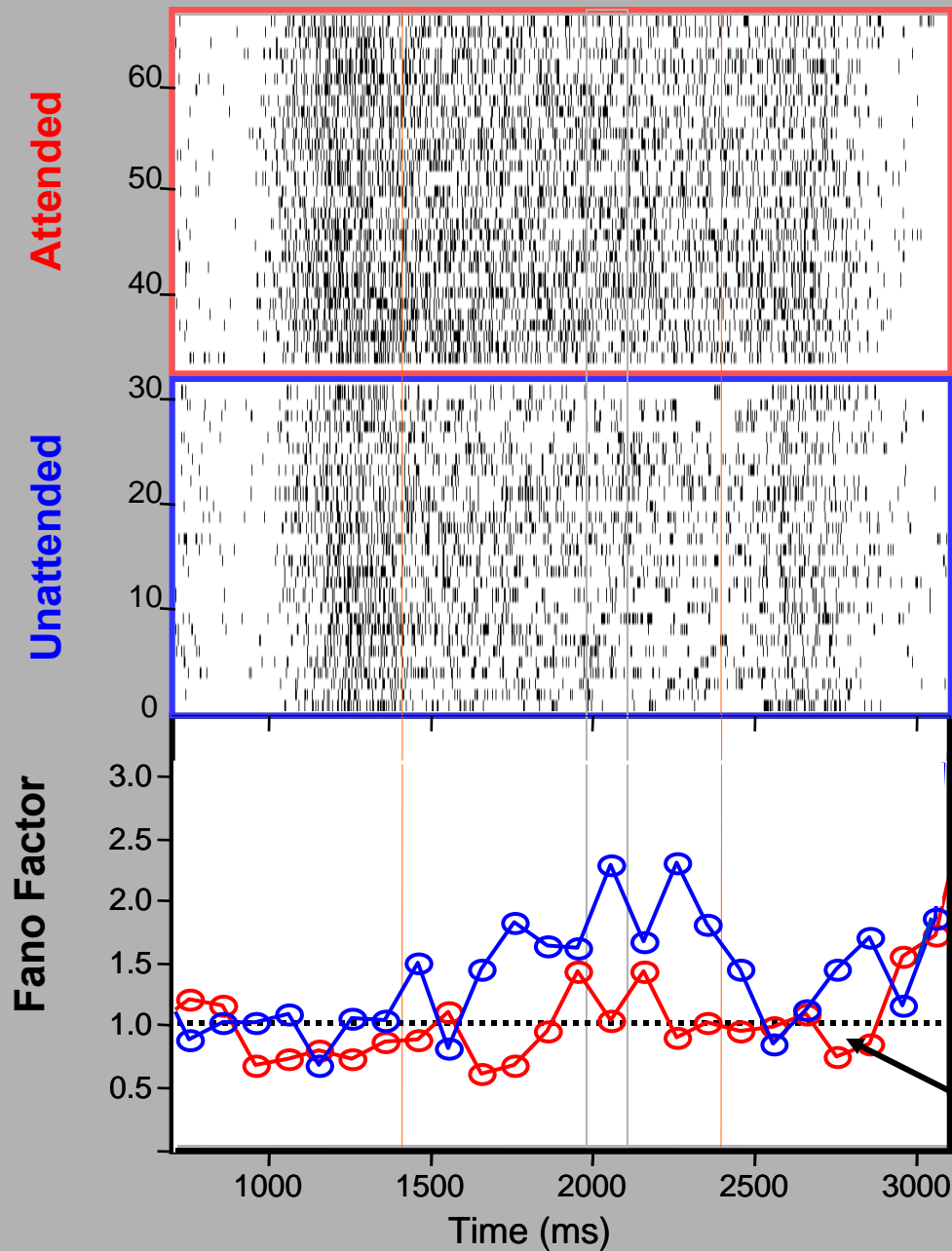
Attention-dependent modulation of response variability?



$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Poisson: FF = 1

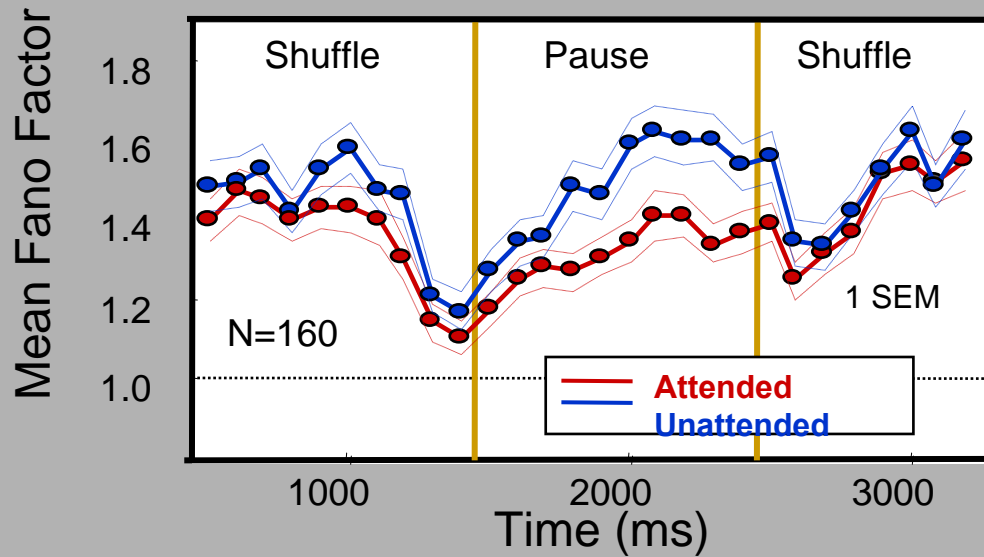
Attention-dependent modulation of response variability?



$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

Poisson: FF = 1

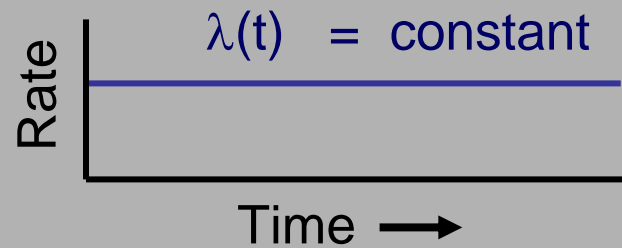
Population Average Fano Factor



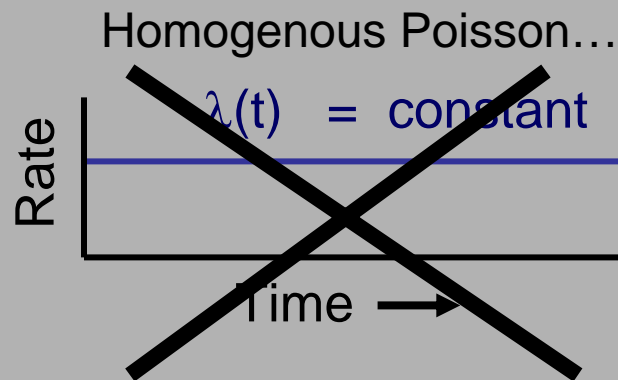
Origins of variability?

Origins of variability?

Homogenous Poisson...

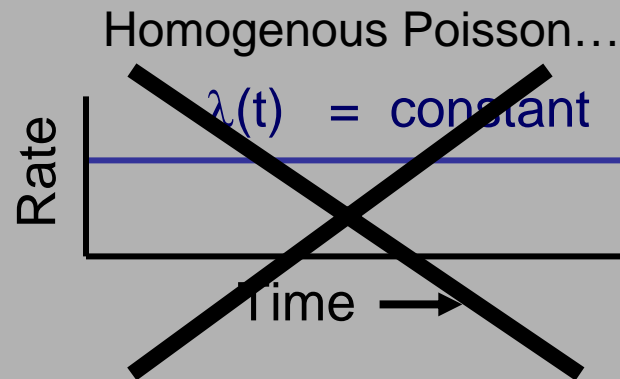


Origins of variability?



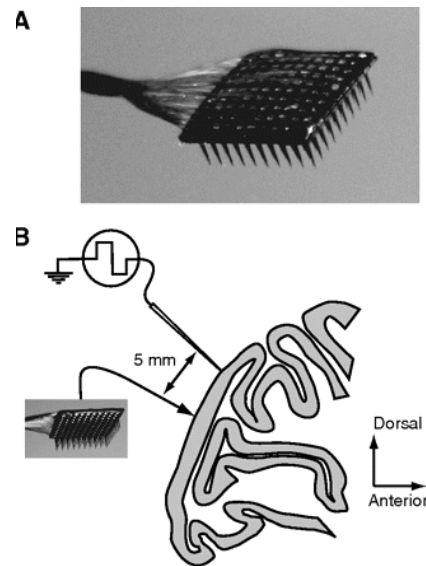
More than Poisson variability....
What mechanisms underlie noise?

Origins of variability?



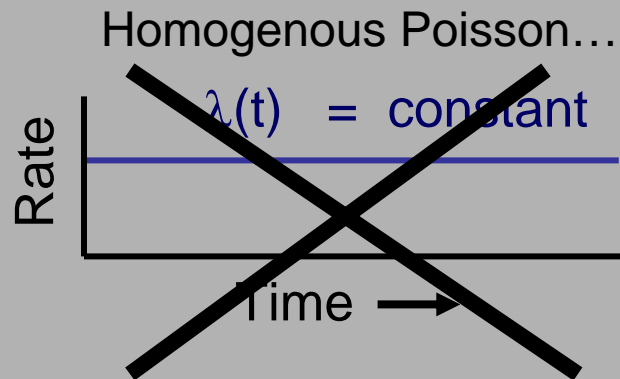
More than Poisson variability....
What mechanisms underlie noise?

Ongoing
cortical
activity?



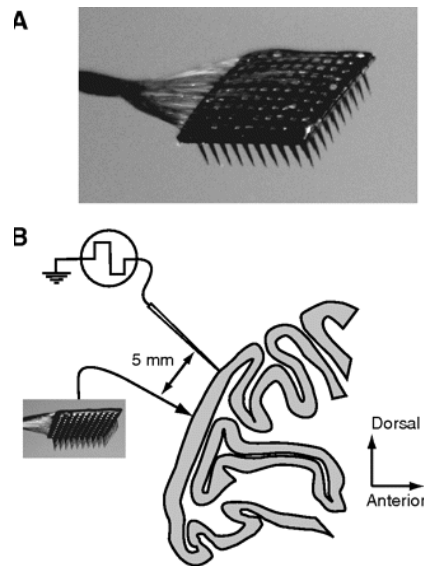
(from Smith and Kohn, 2008)

Origins of variability?



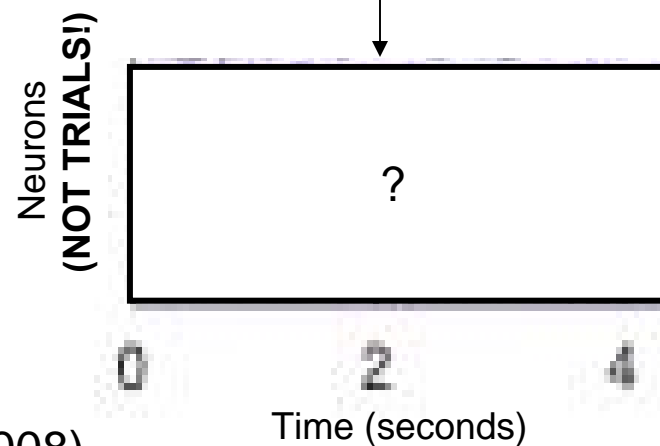
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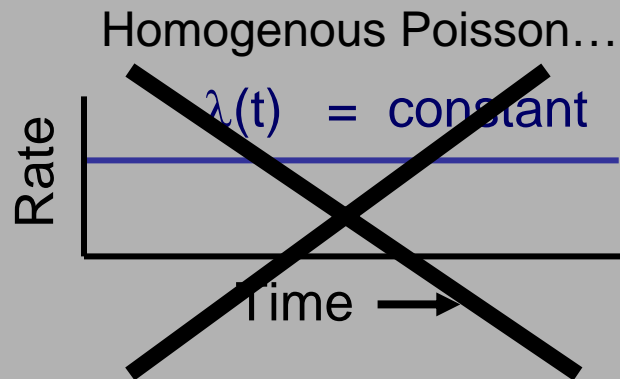


(from Smith and Kohn, 2008)

Population of 100 Neurons
Spontaneous Activity over
a Single Trial

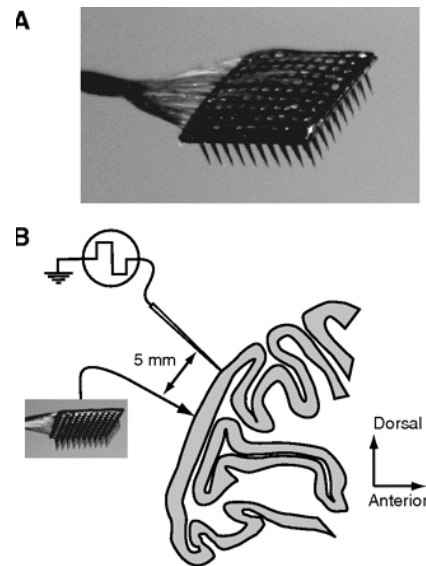


Origins of variability?



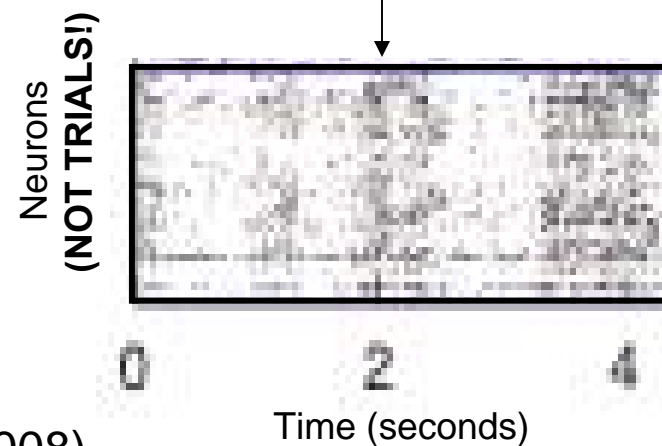
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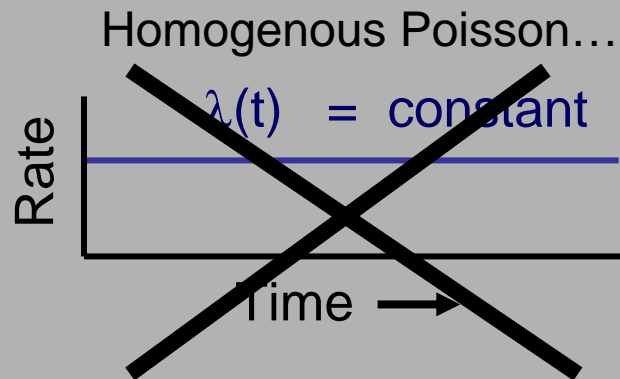


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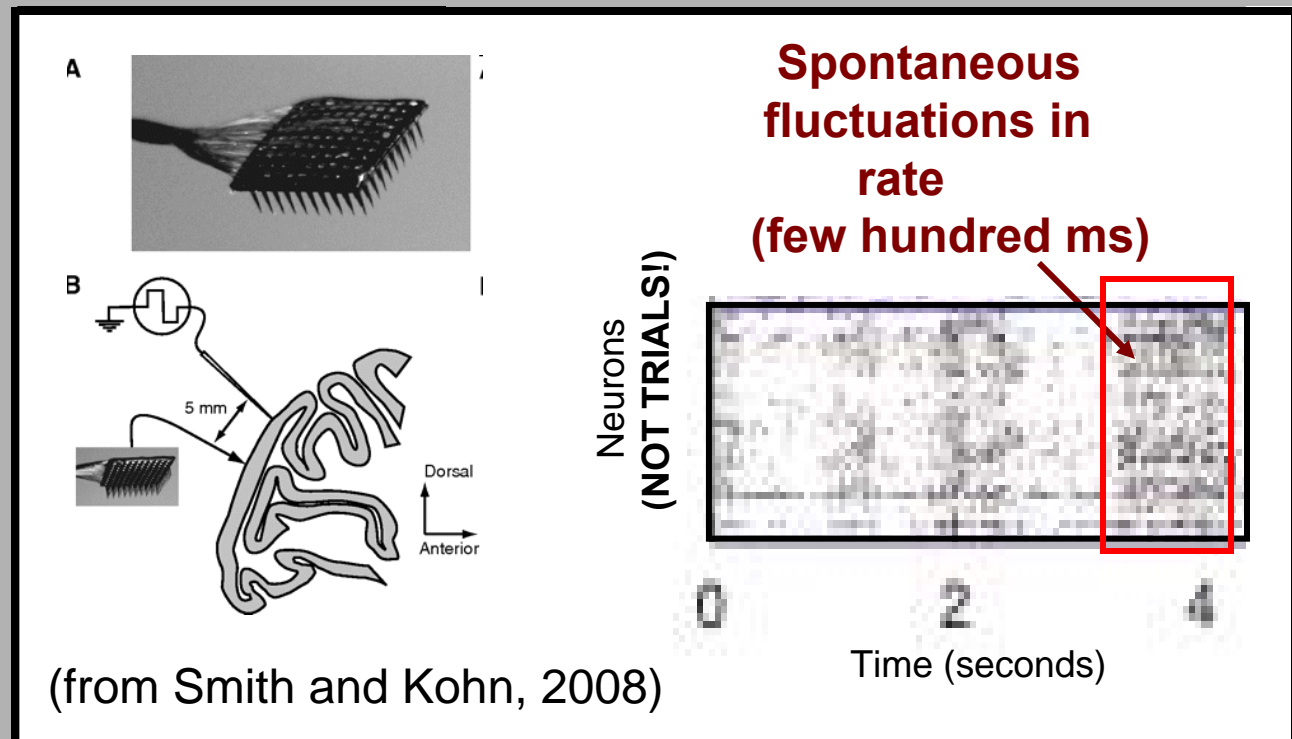


Origins of variability?

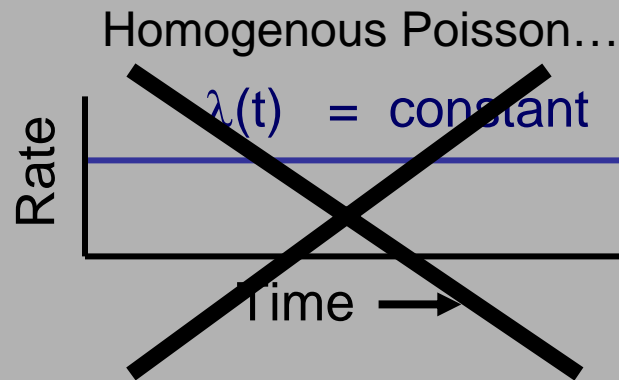


More than Poisson variability....
What mechanisms underlie noise?

Ongoing cortical activity?

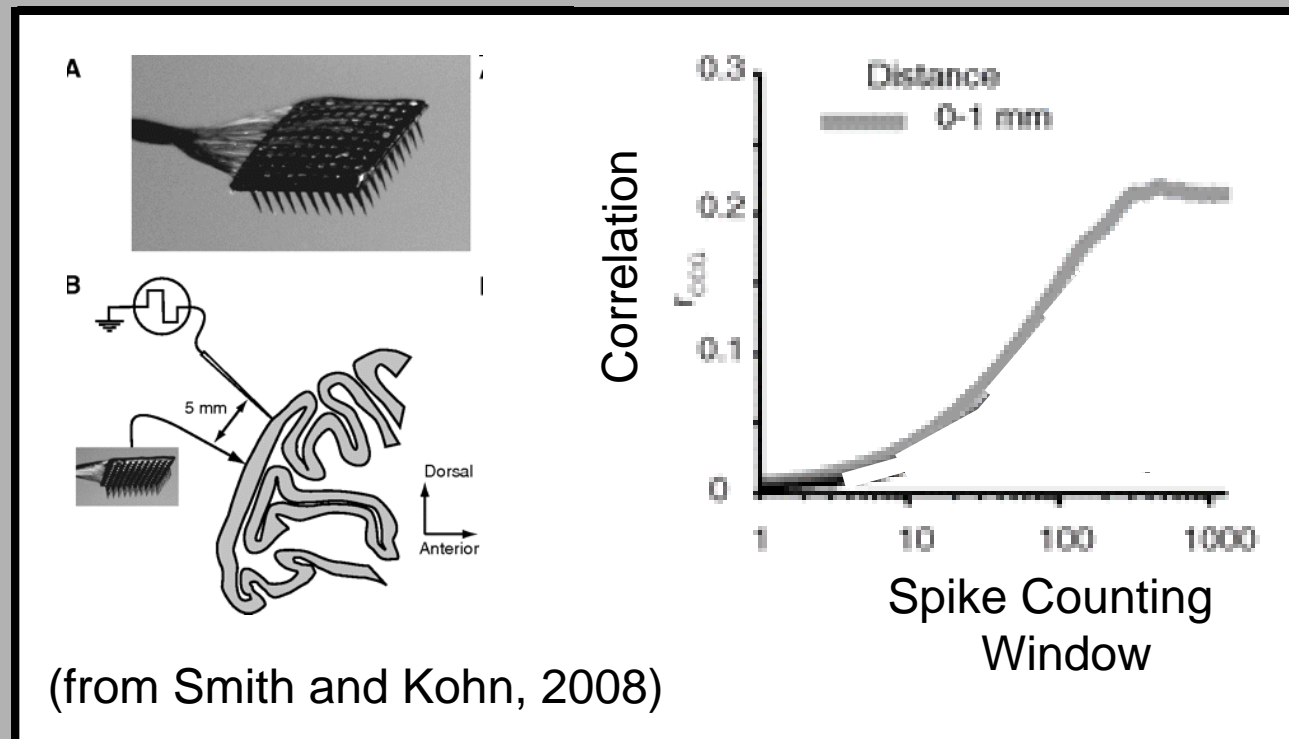


Origins of variability?

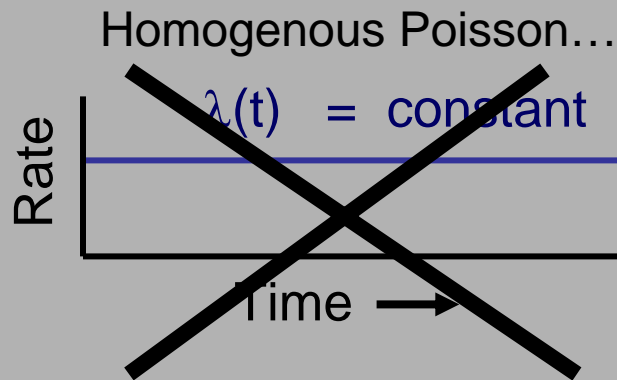


More than Poisson variability....
What mechanisms underlie noise?

Ongoing cortical activity?

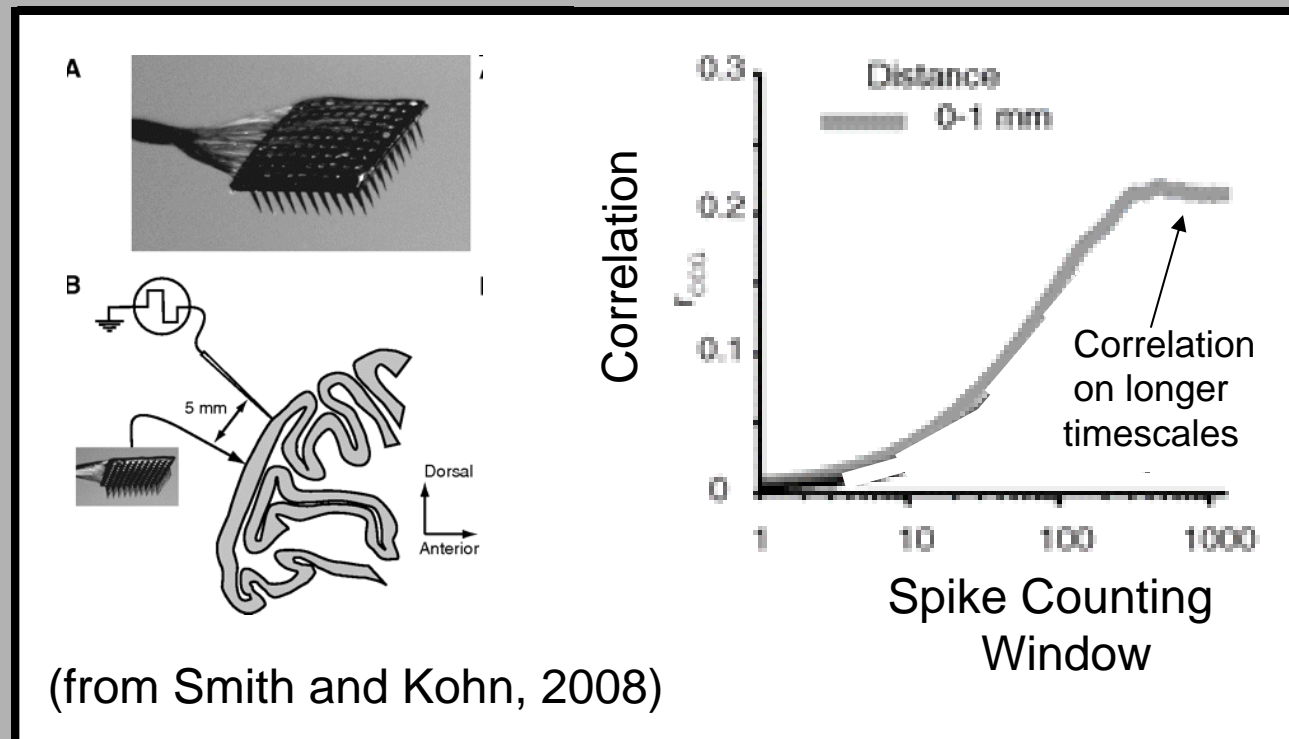


Origins of variability?

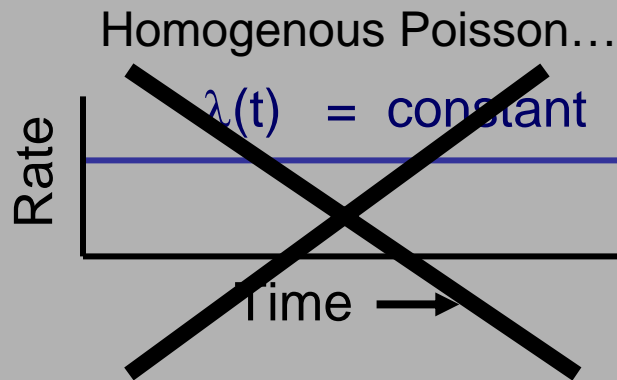


More than Poisson variability....
What mechanisms underlie noise?

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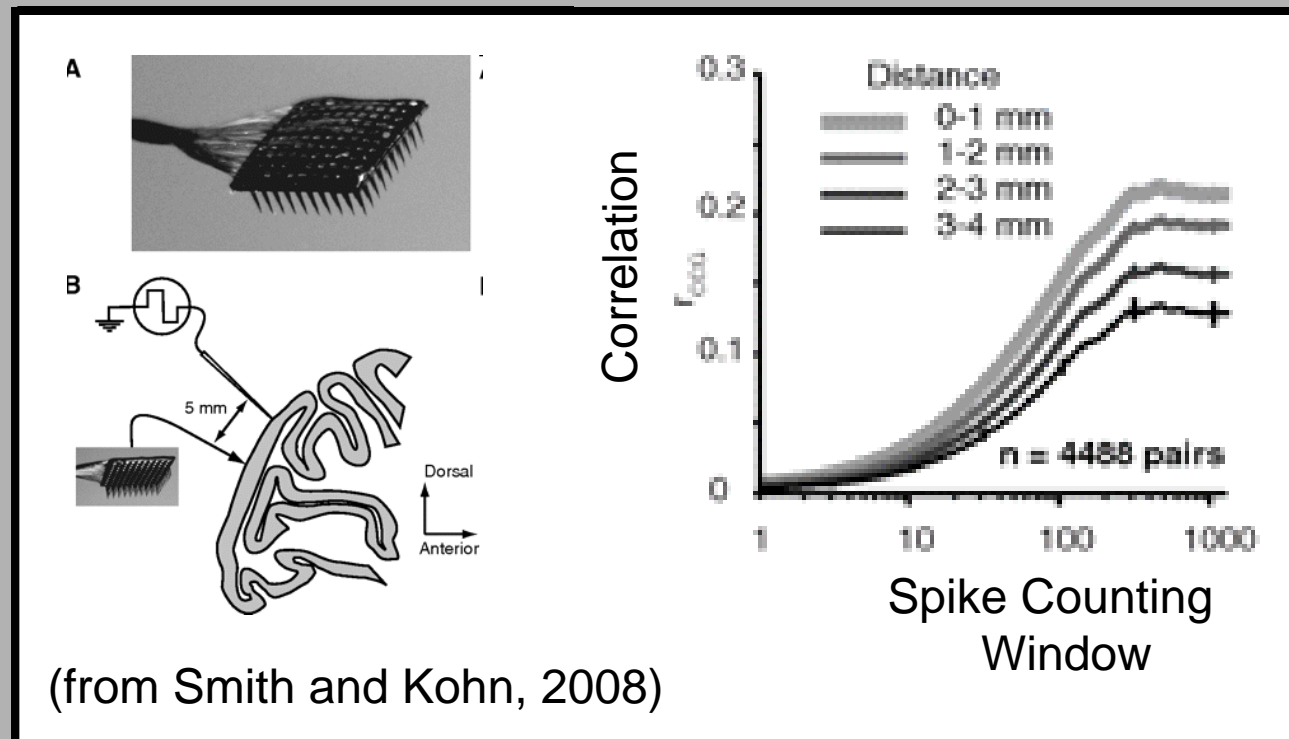


Origins of variability?

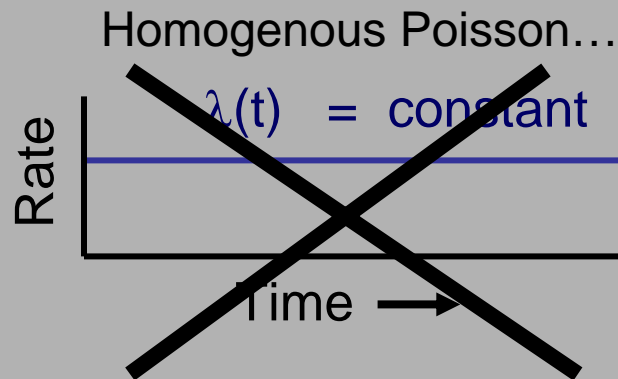


More than Poisson variability....
What mechanisms underlie noise?

Ongoing cortical activity?

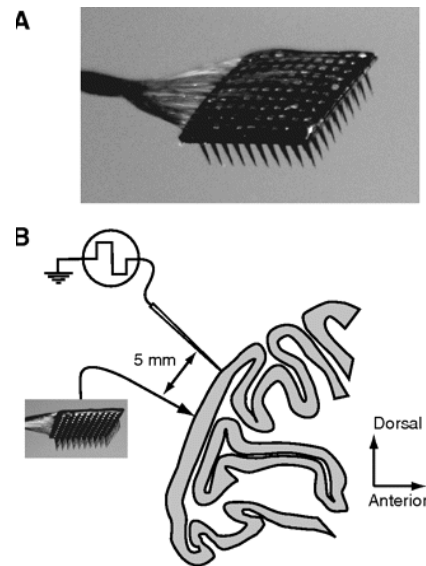


Origins of variability?



More than Poisson variability....
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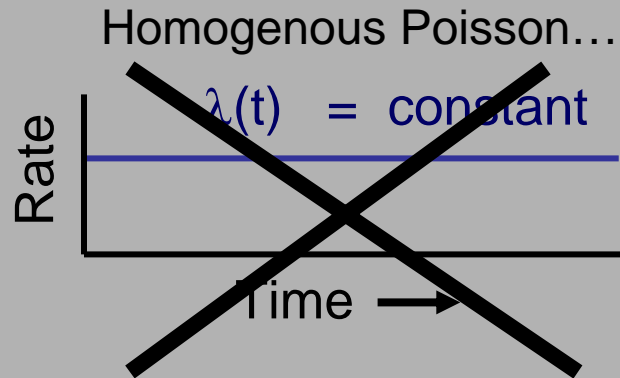
(from Smith and Kohn, 2008)

Neurons
(NOT TRIALS!)



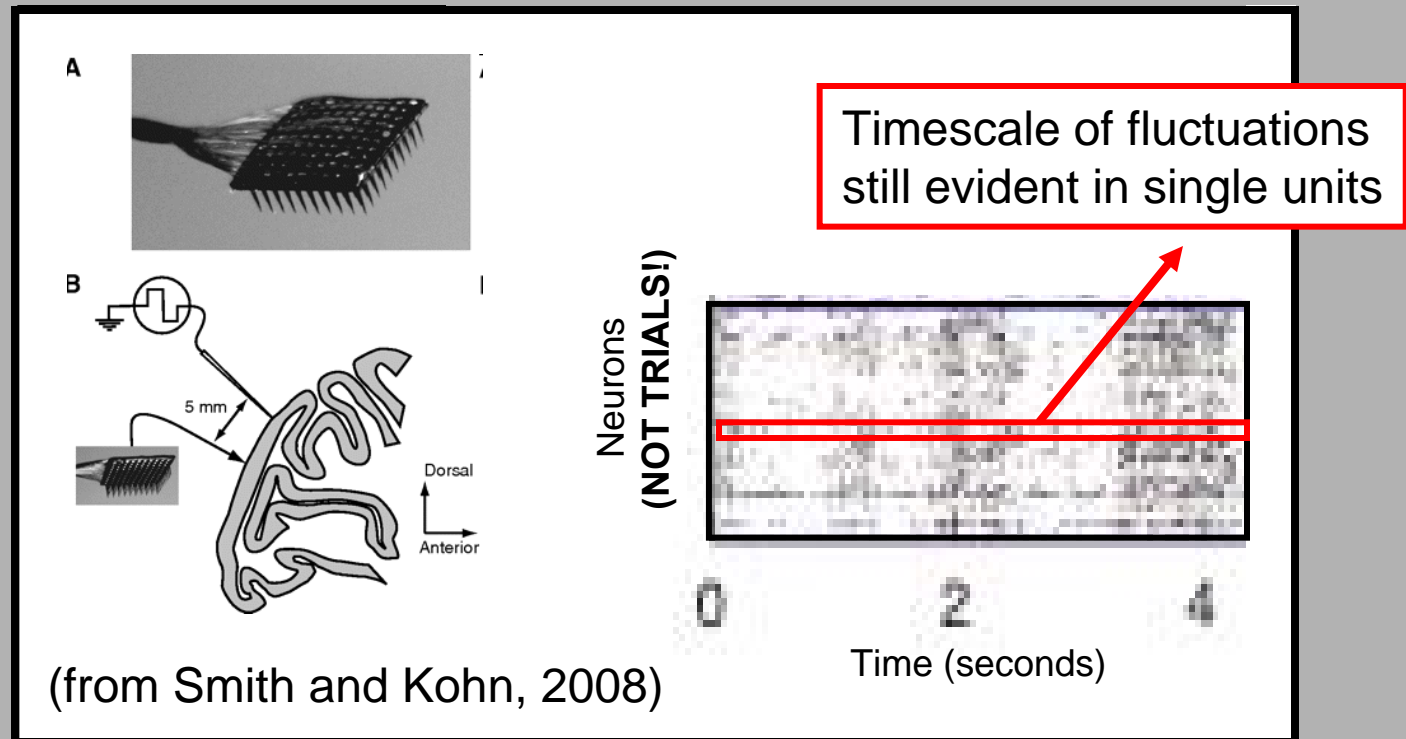
Time (seconds)

Origins of variability?

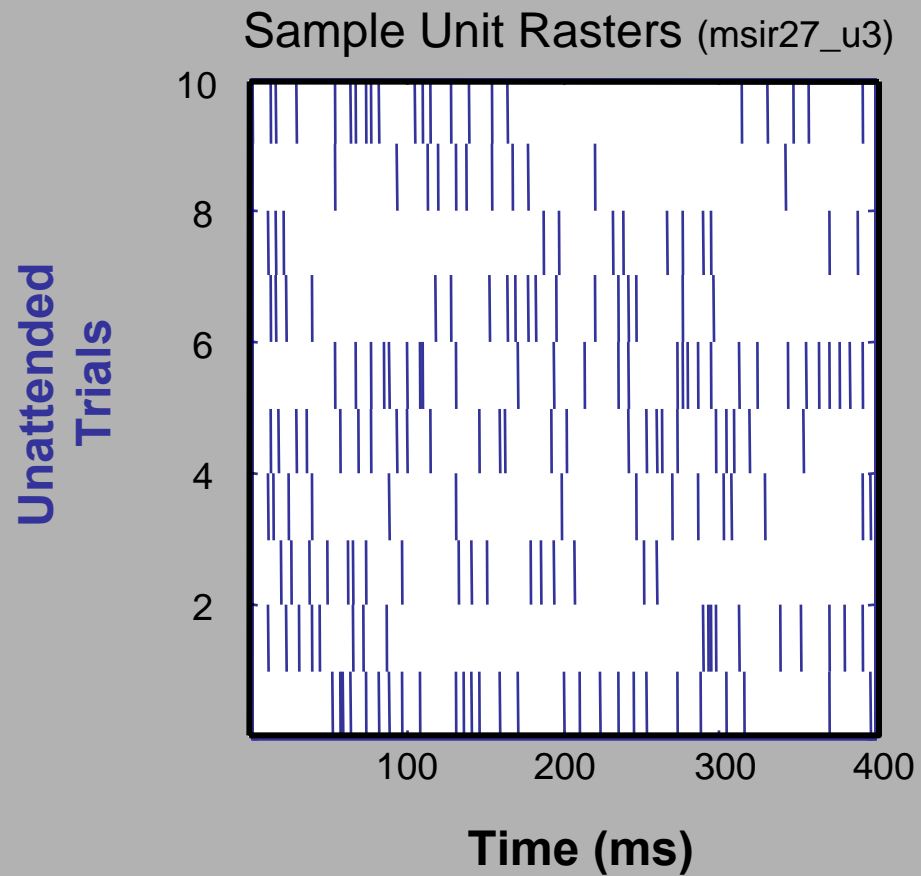


More than Poisson variability....
What mechanisms underlie noise?

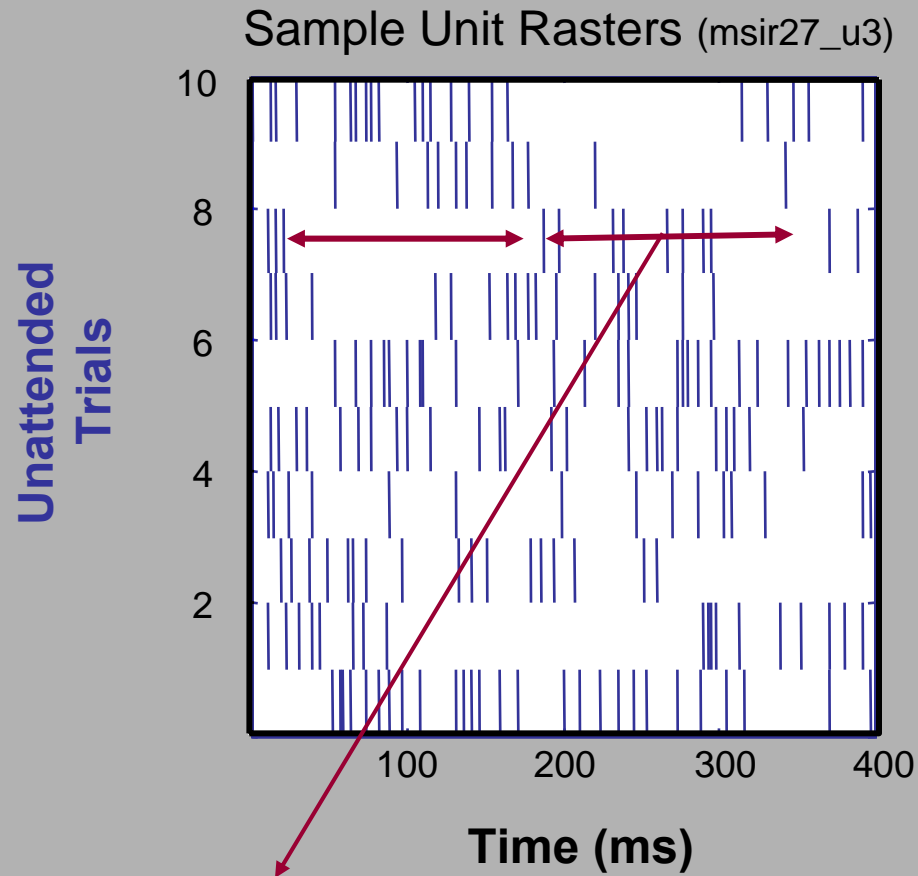
Ongoing cortical activity?



Timescales of the spiking variability

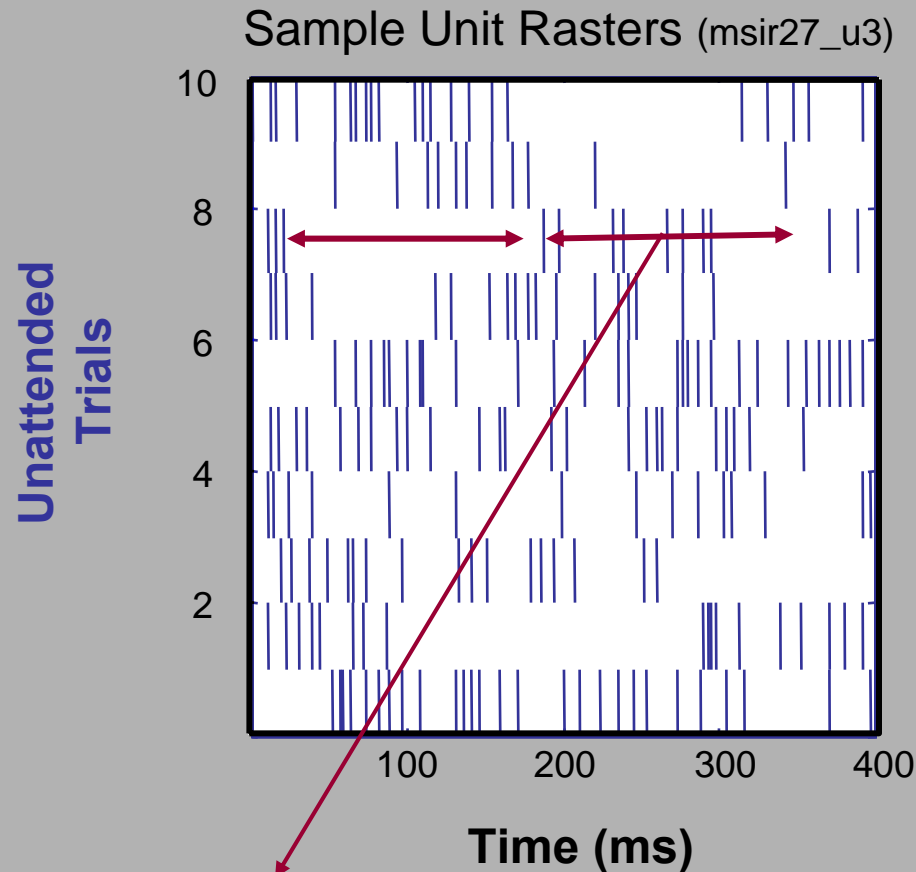


Timescales of the spiking variability

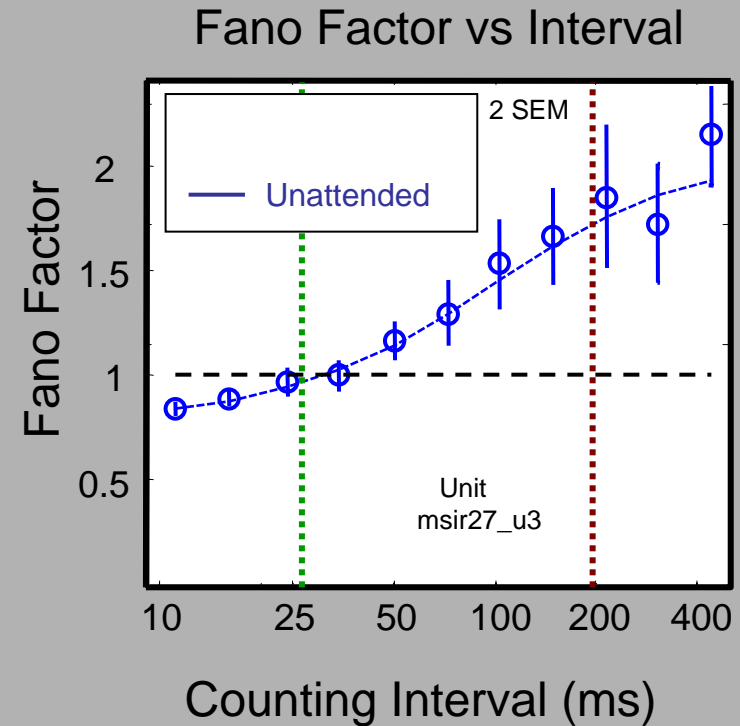


Fluctuations
at 100 ms
or longer
counting intervals

Timescales of the spiking variability

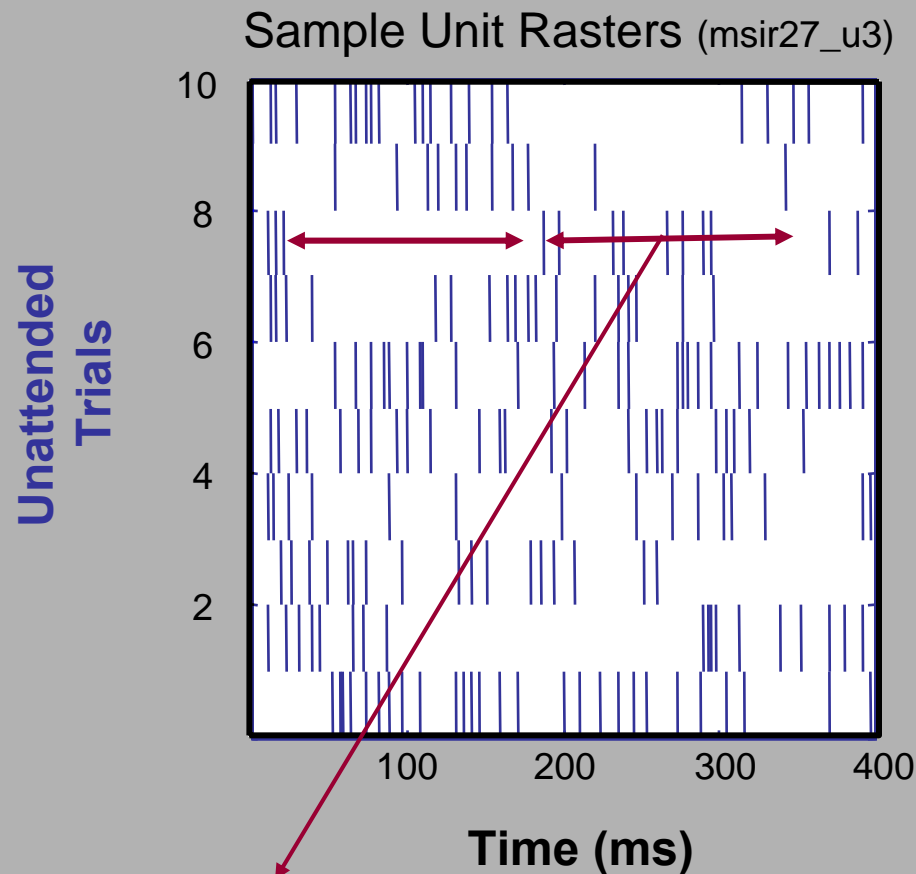


Fluctuations
at 100 ms
or longer
counting intervals

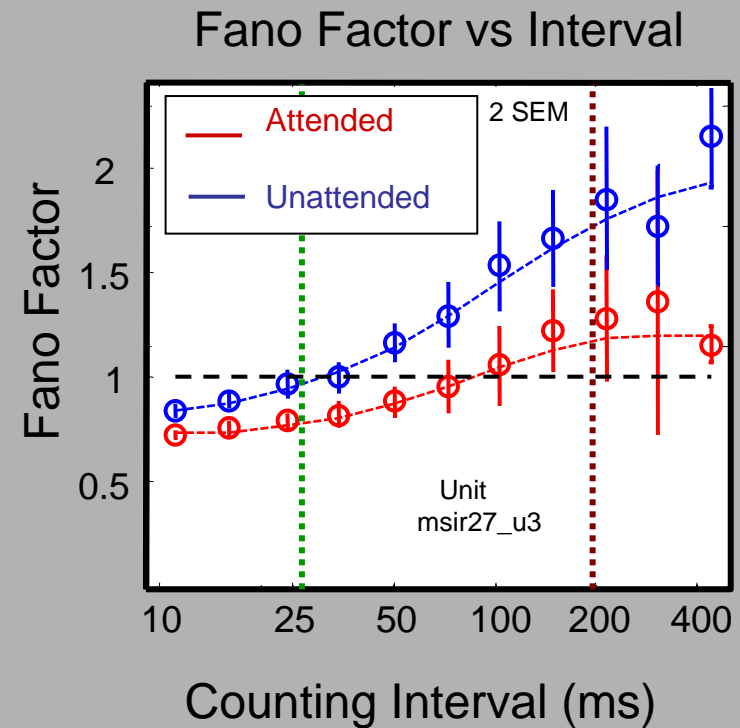


(Lowden and
Teich, 1995)

Timescales of the spiking variability



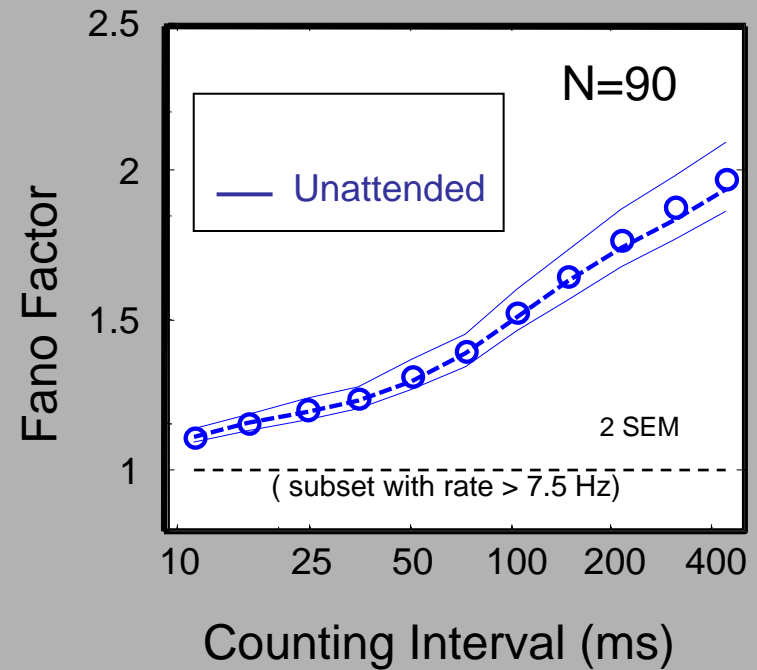
Fluctuations
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or longer
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(Lowden and
Teich, 1995)

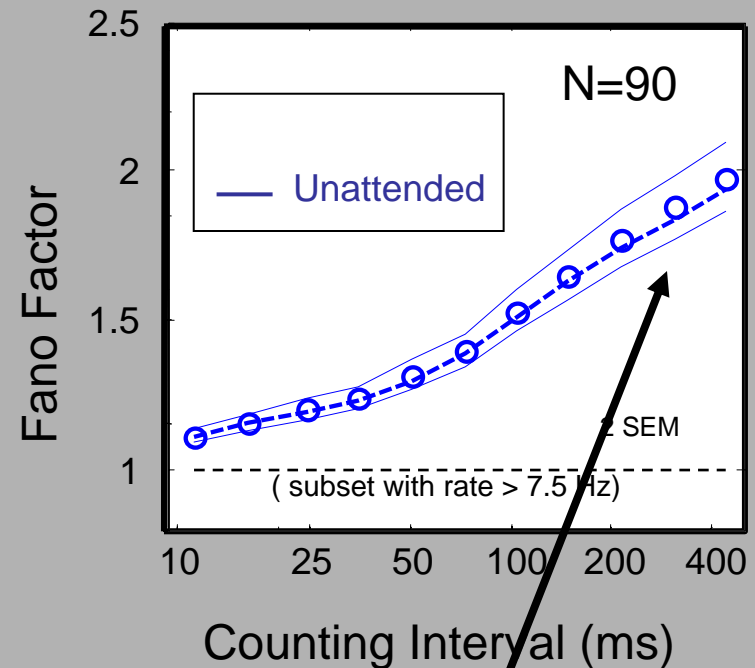
Timescales of the spiking variability

Population
Fano Factor



Timescales of the spiking variability

Population
Fano Factor

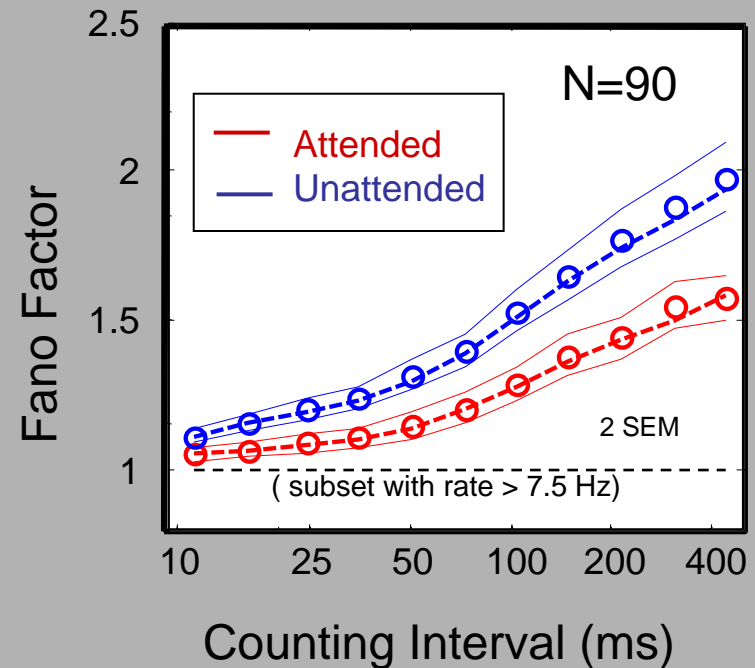


Consistent with
long timescales

(see also Lowen and Teich, 1996)

Timescales of the spiking variability

Population
Fano Factor

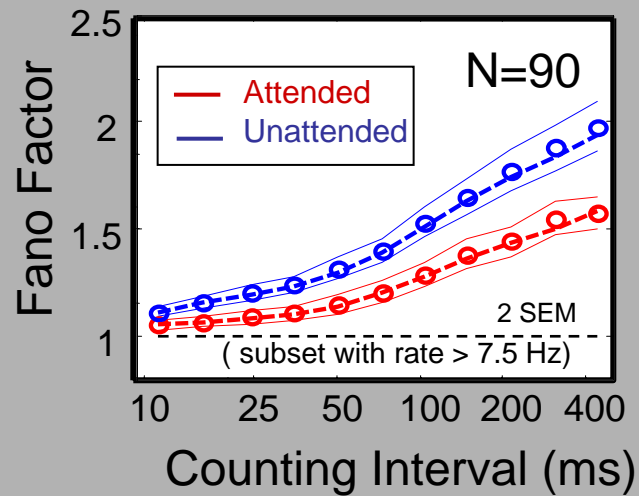


Consistent with
long timescales

(see also Lowen and Teich, 1996)

(Two Monkeys)

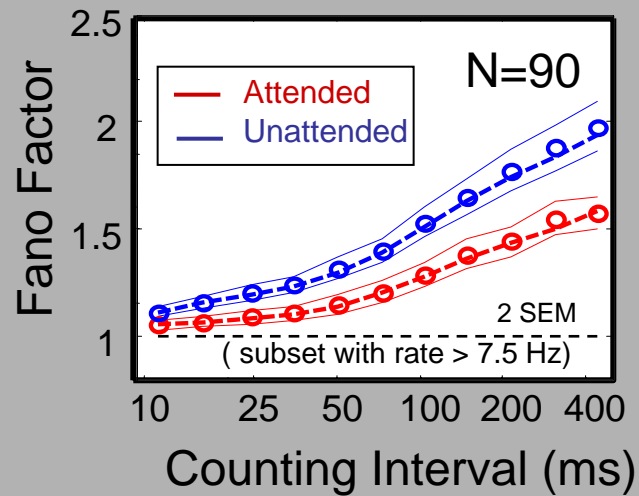
Population Fano Factor



Consistent with
long timescales

(Two Monkeys)

Population Fano Factor



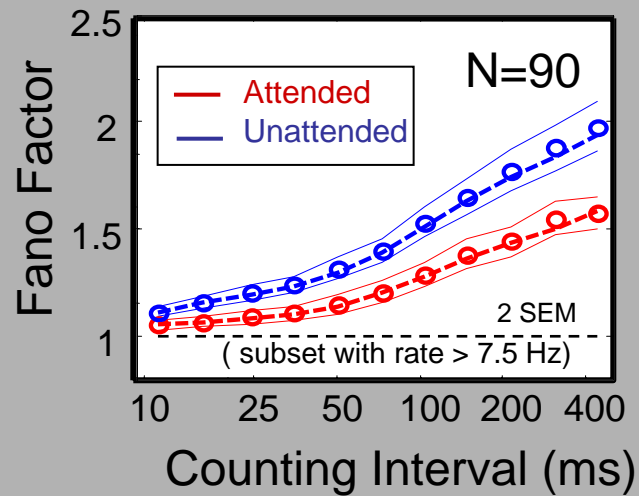
Are fluctuations correlated over wide populations?

Consistent with long timescales

(Two Monkeys)

(In a single monkey
with pairs
1-3 mm apart)

Population Fano Factor

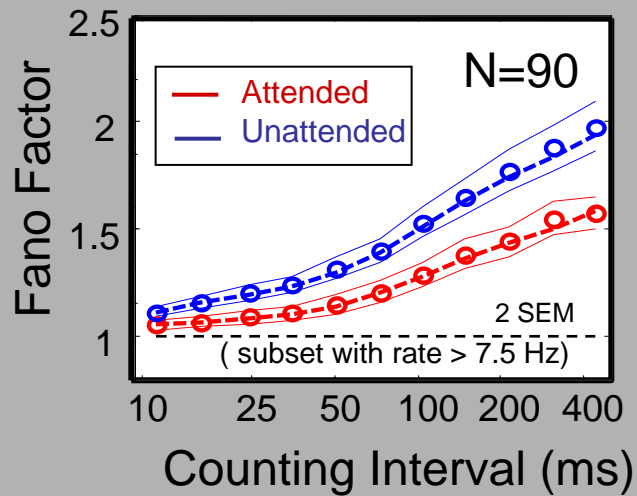


Are fluctuations
correlated over
wide populations?

Consistent with
long timescales

(Two Monkeys)

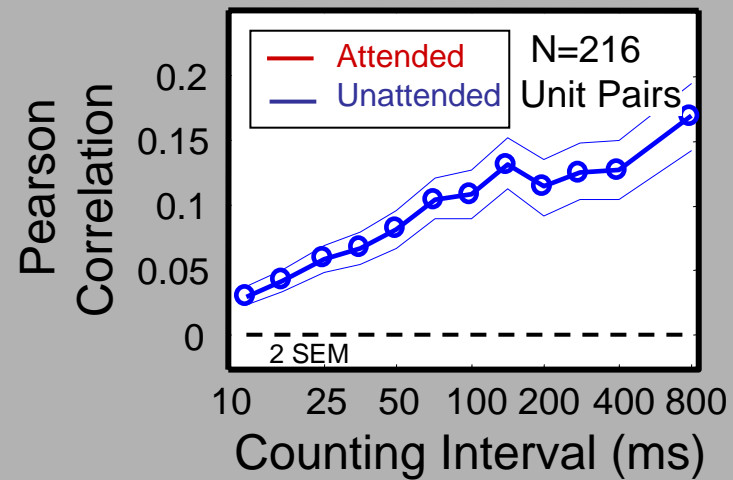
Population Fano Factor



Consistent with
long timescales

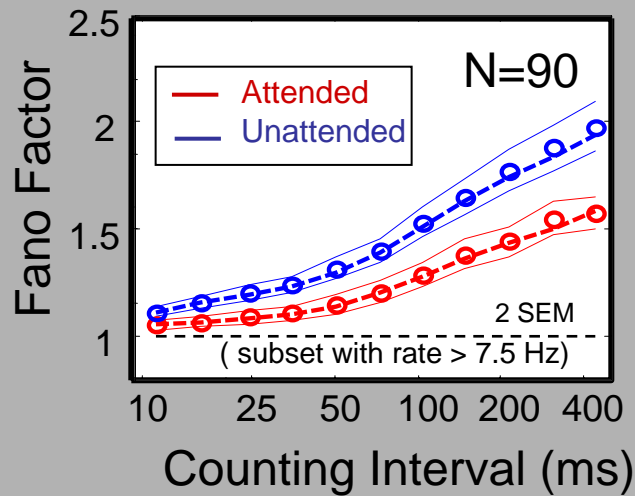
(In a single monkey
with pairs
1-3 mm apart)

Population Correlation



(Two Monkeys)

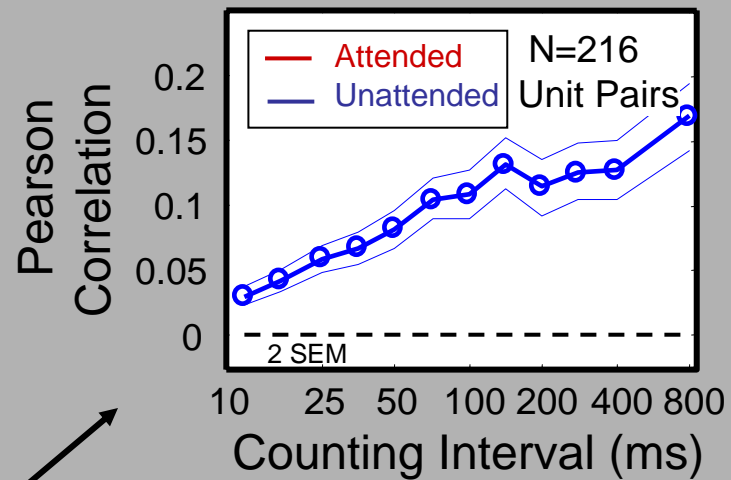
Population Fano Factor



Consistent with long timescales

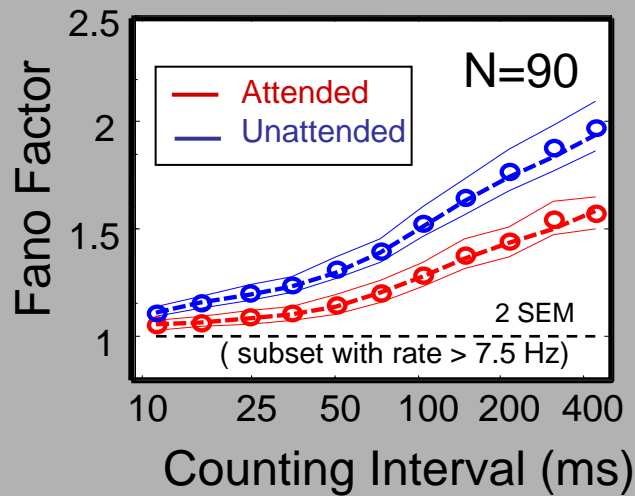
(In a single monkey with pairs 1-3 mm apart)

Population Correlation



(Two Monkeys)

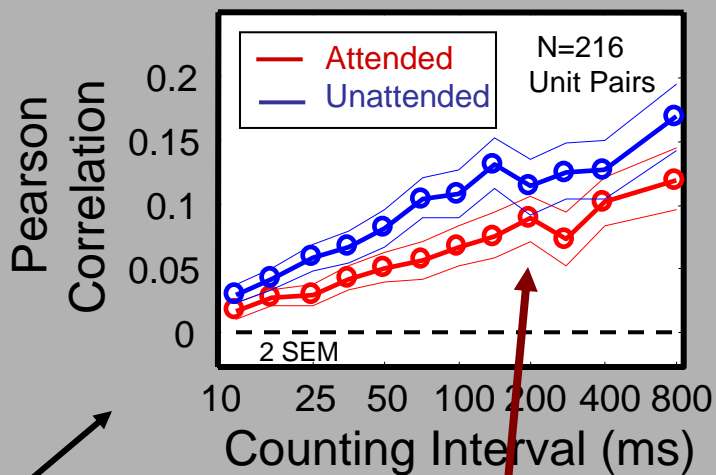
Population Fano Factor



Consistent with long timescales

(In a single monkey with pairs 1-3 mm apart)

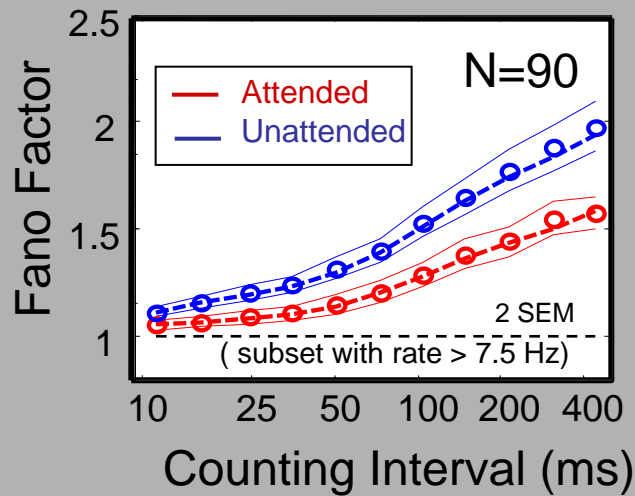
Population Correlation



Attention reduces correlations in firing

(Two Monkeys)

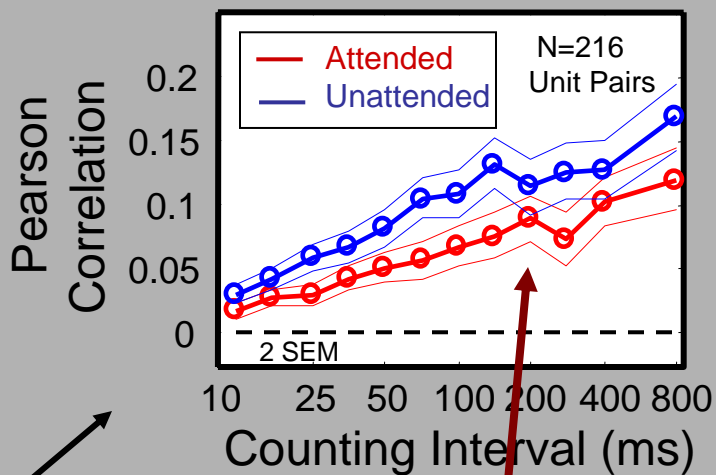
Population Fano Factor



Consistent with long timescales

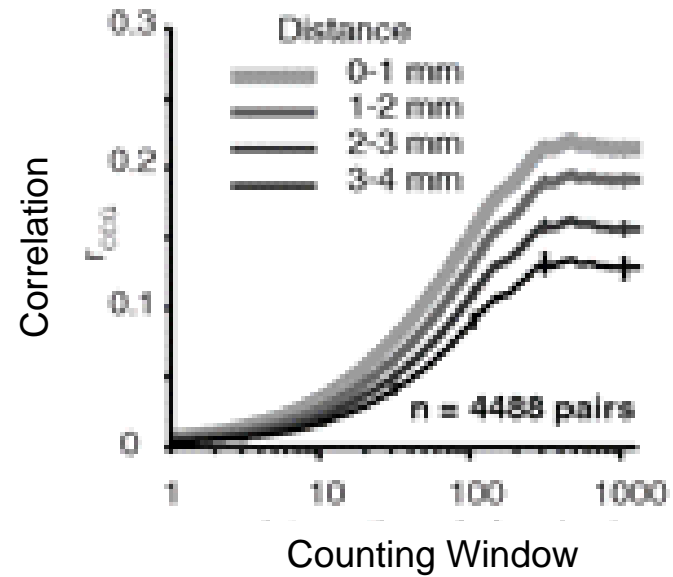
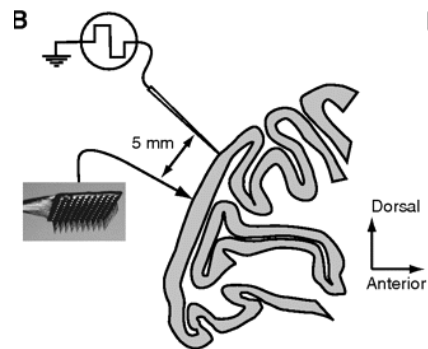
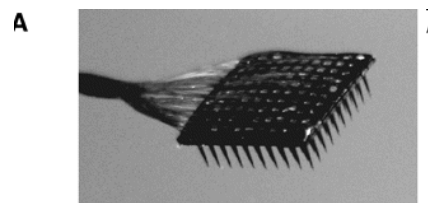
(In a single monkey with pairs 1-3 mm apart)

Population Correlation



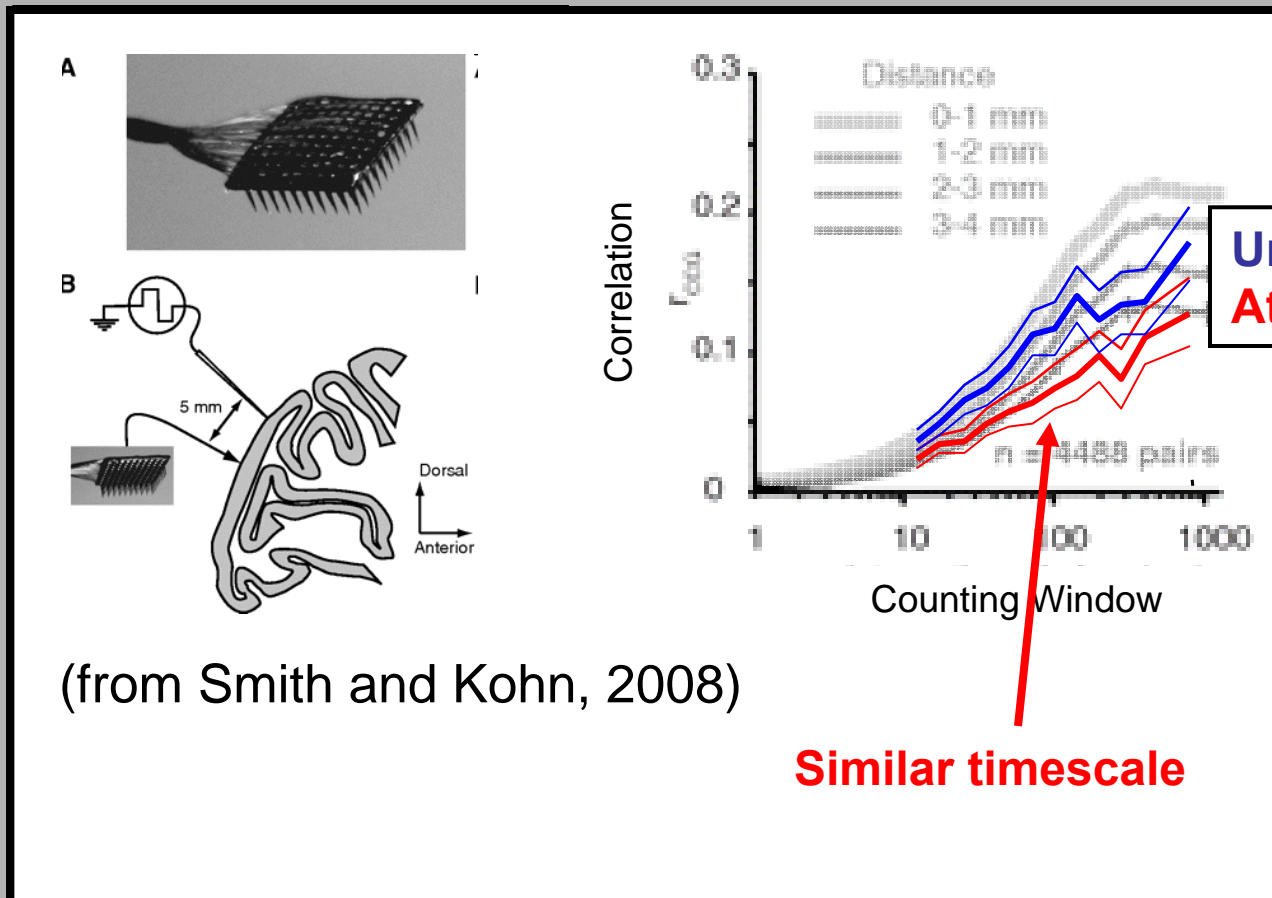
Attention reduces correlations in firing
40% median reduction

Ongoing Cortical Activity?

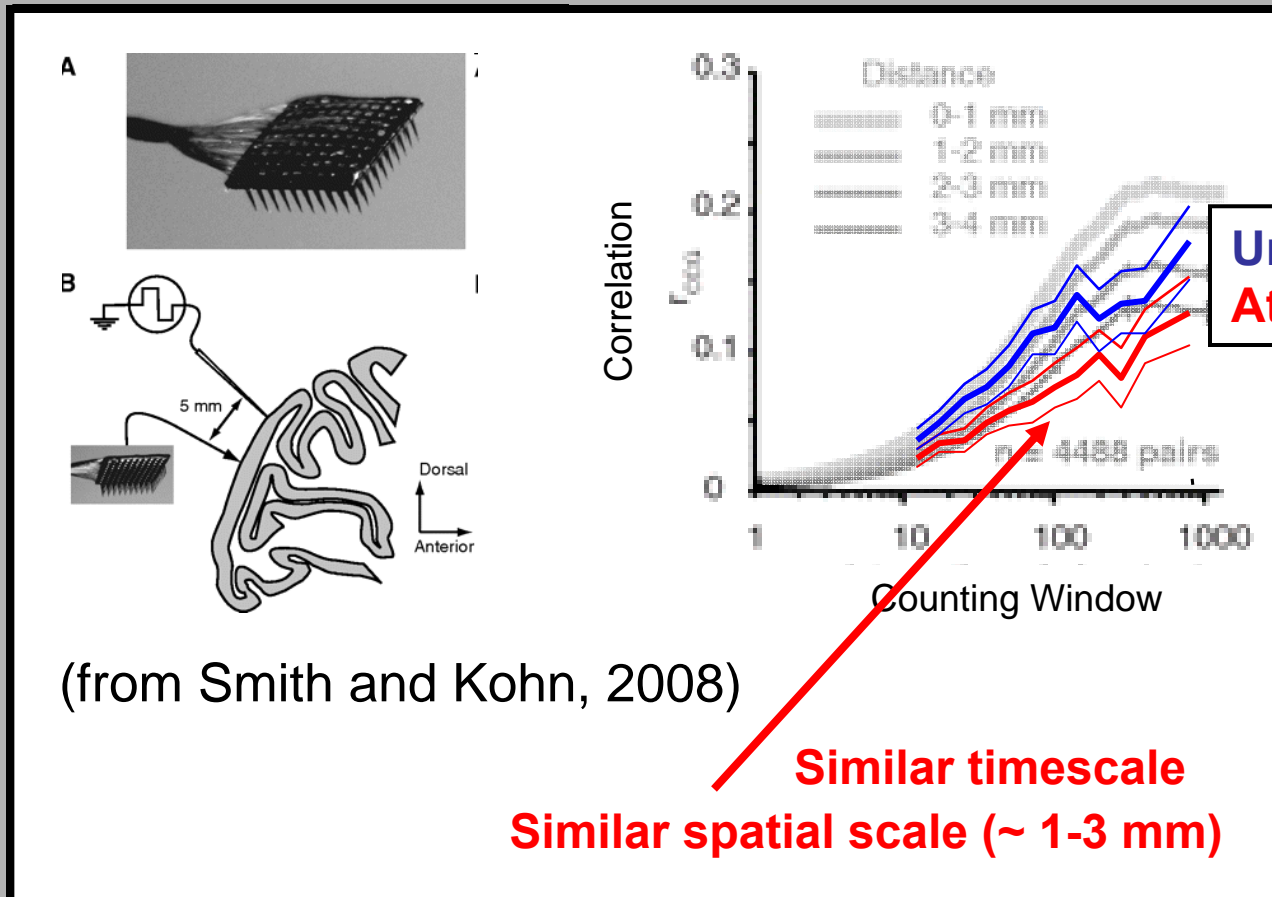


(from Smith and Kohn, 2008)

Ongoing Cortical Activity?



Ongoing Cortical Activity?

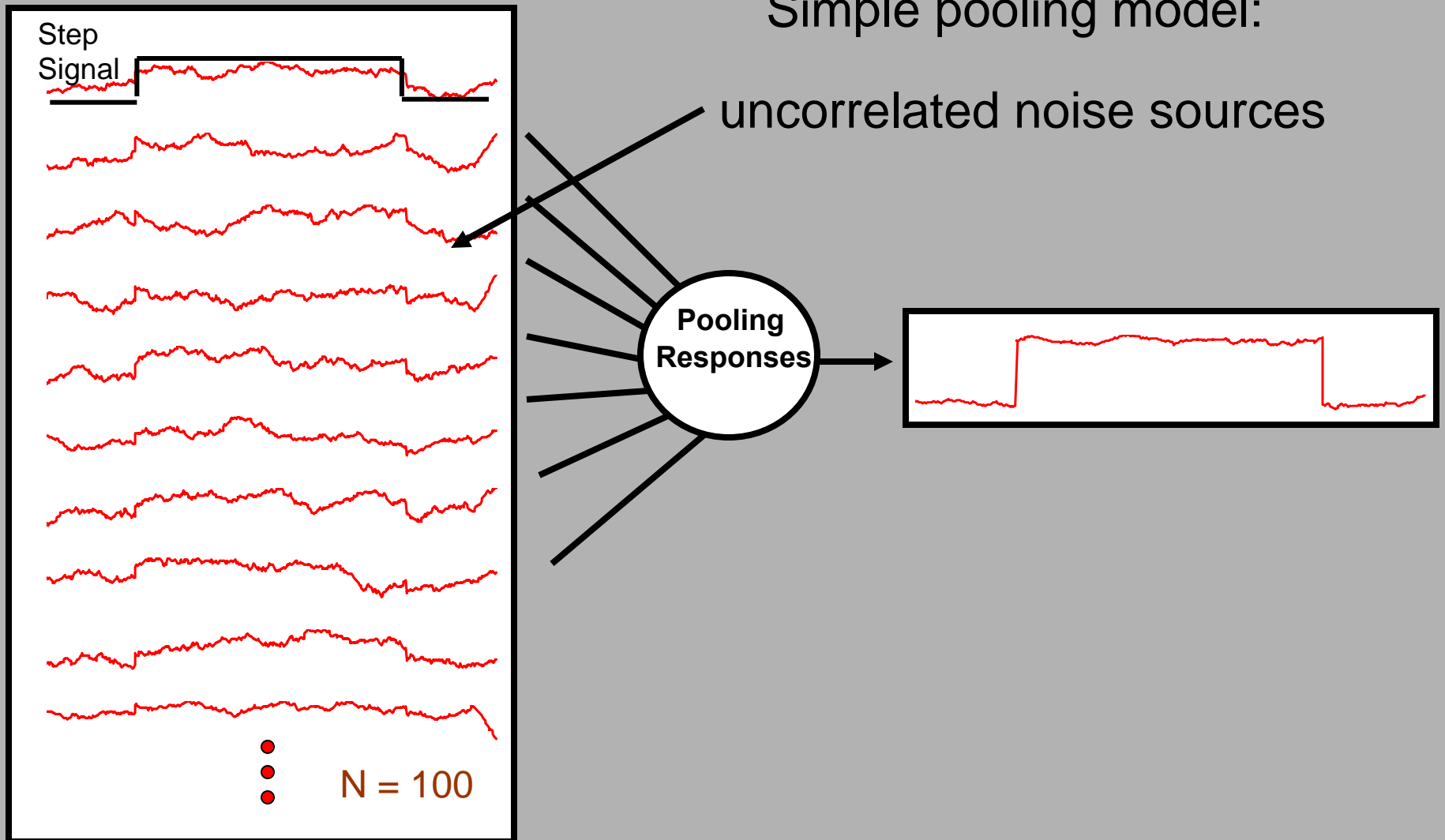


Implications of reduced correlated firing?

Implications of reduced correlated firing?

Simple pooling model:

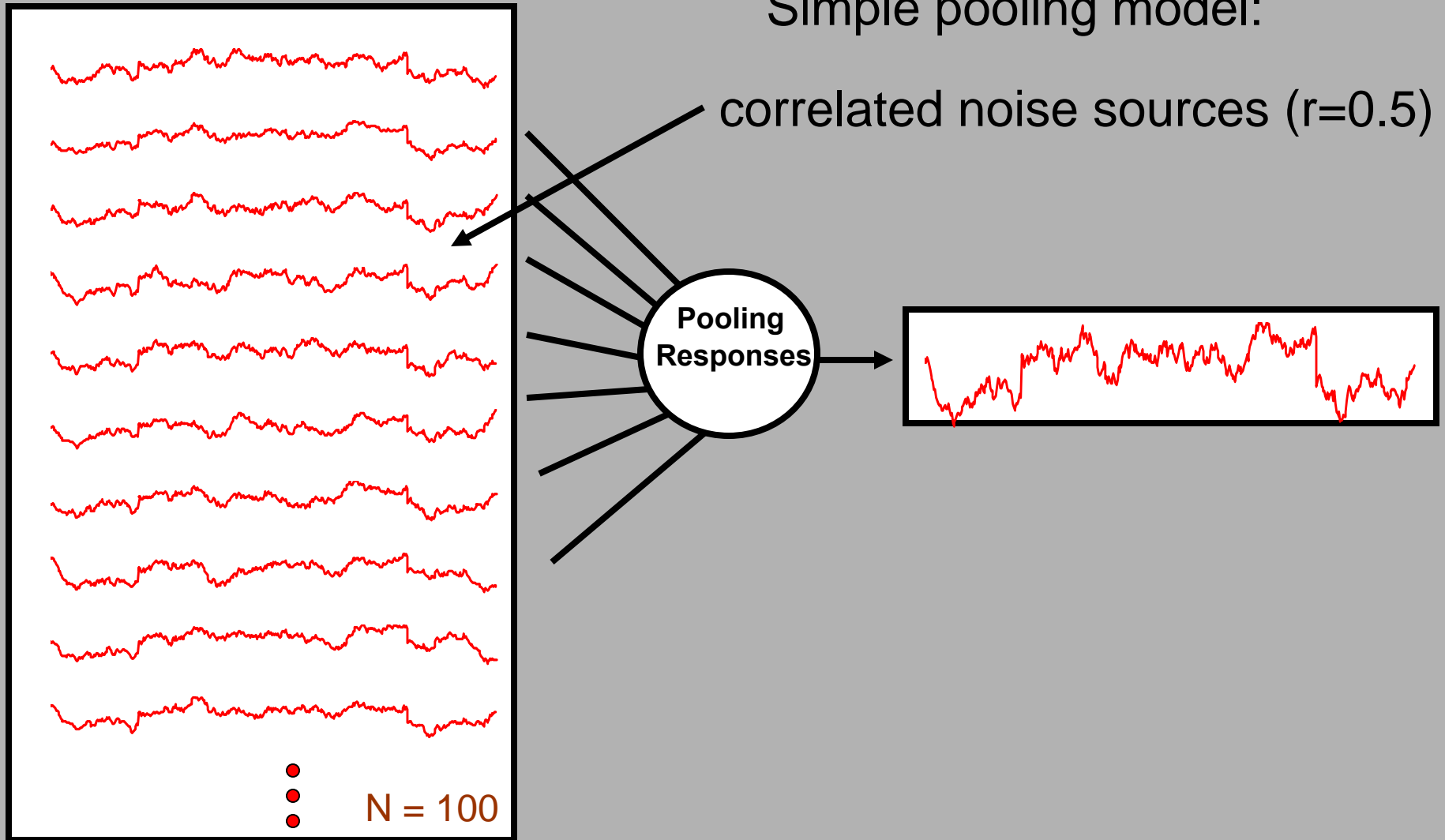
uncorrelated noise sources



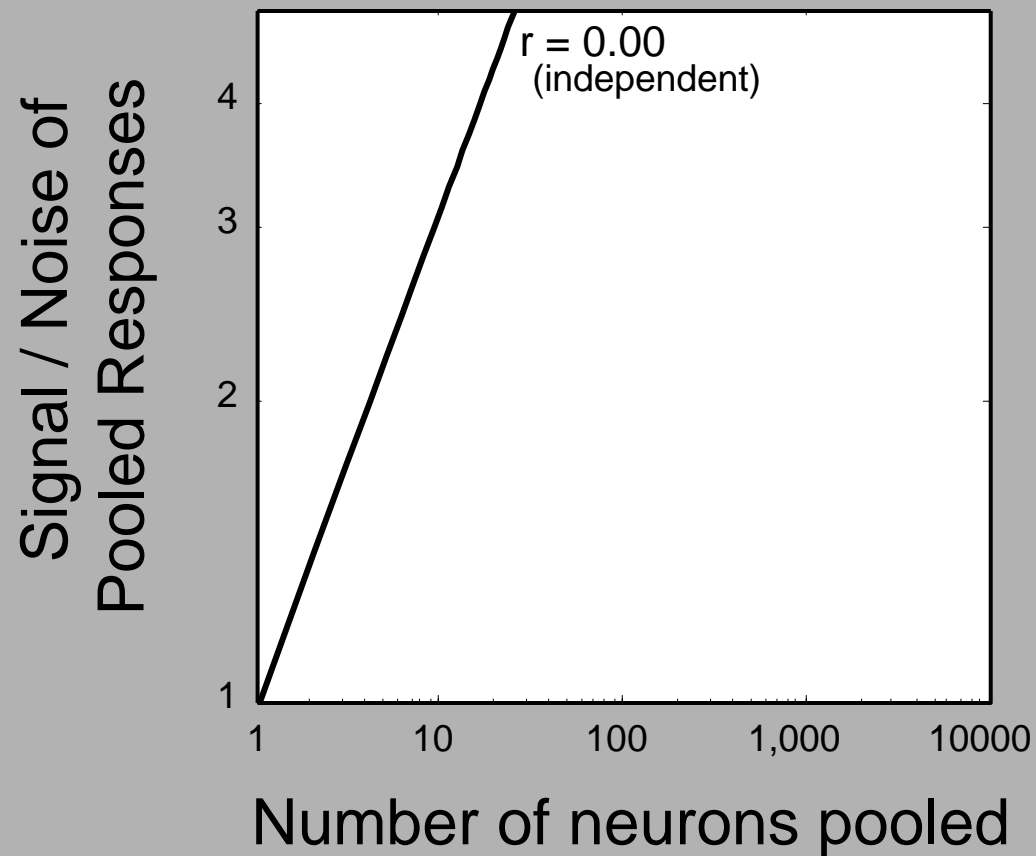
Implications of reduced correlated firing?

Simple pooling model:

correlated noise sources ($r=0.5$)



Correlated noise can limit pooled response quality



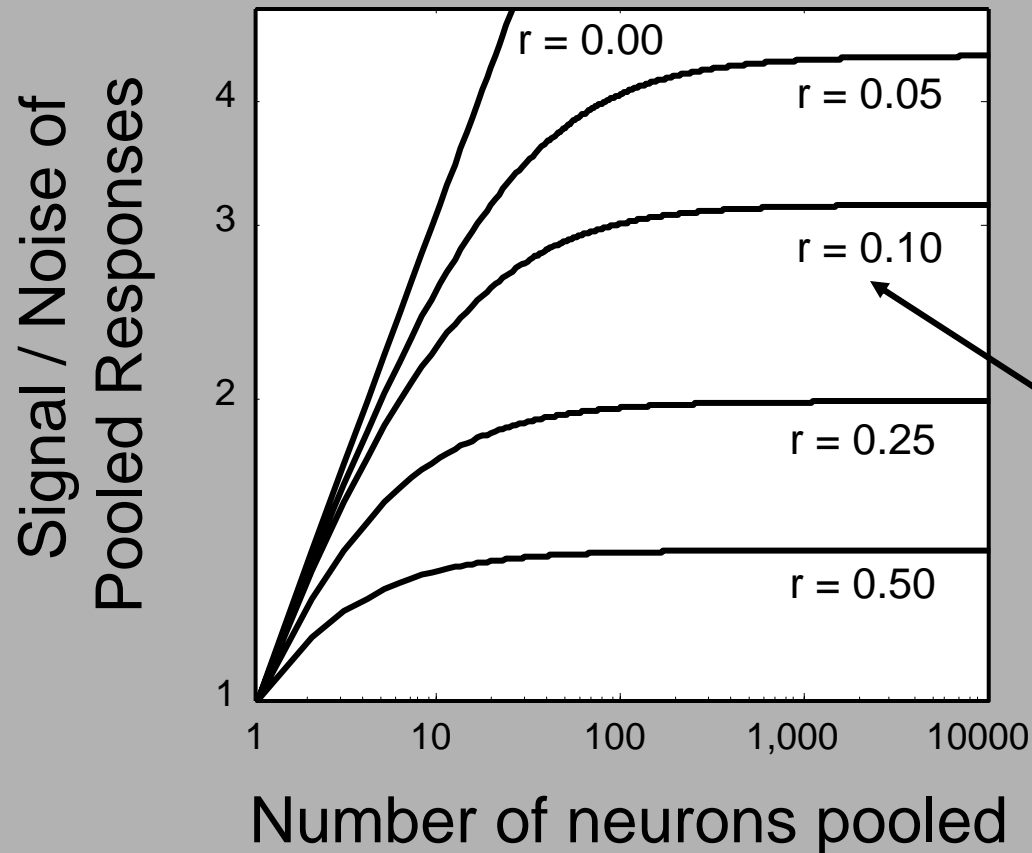
(Britten et al, 1992;

Zohary, Shadlen,
and Newsome, 1994)

Correlated noise can limit pooled response quality

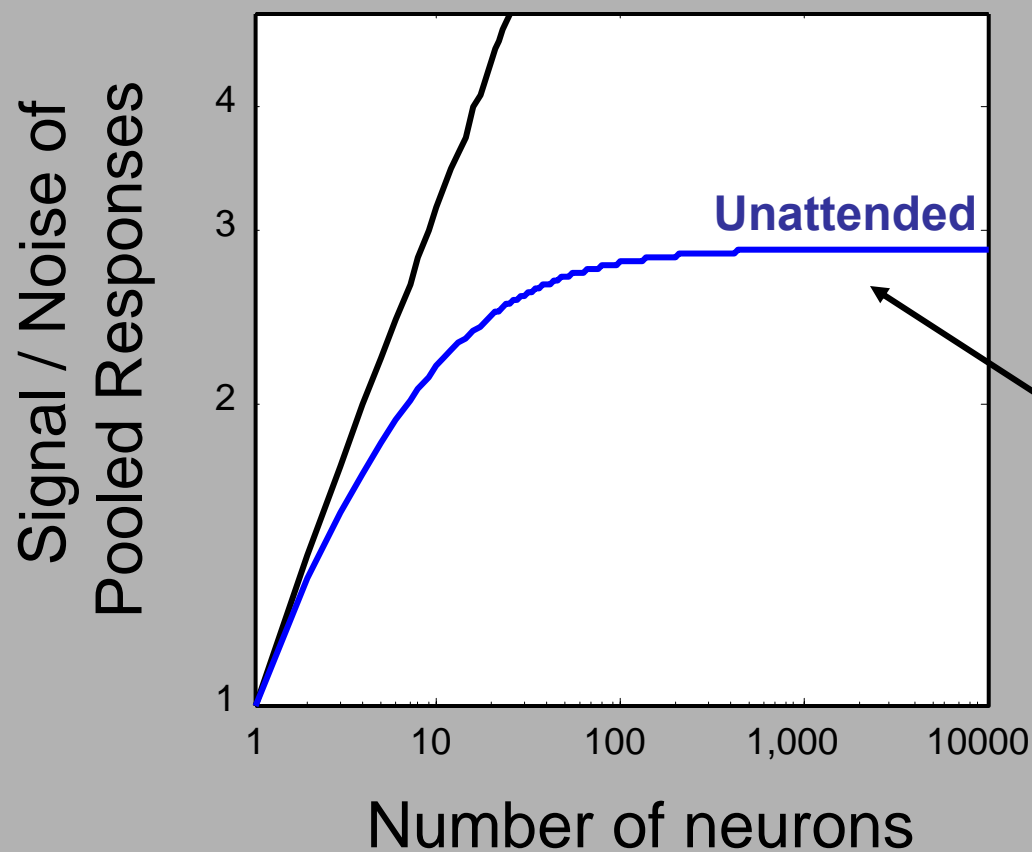
(Britten et al, 1992;

Zohary, Shadlen,
and Newsome, 1994)



Asymptotic
saturation
due to
correlation

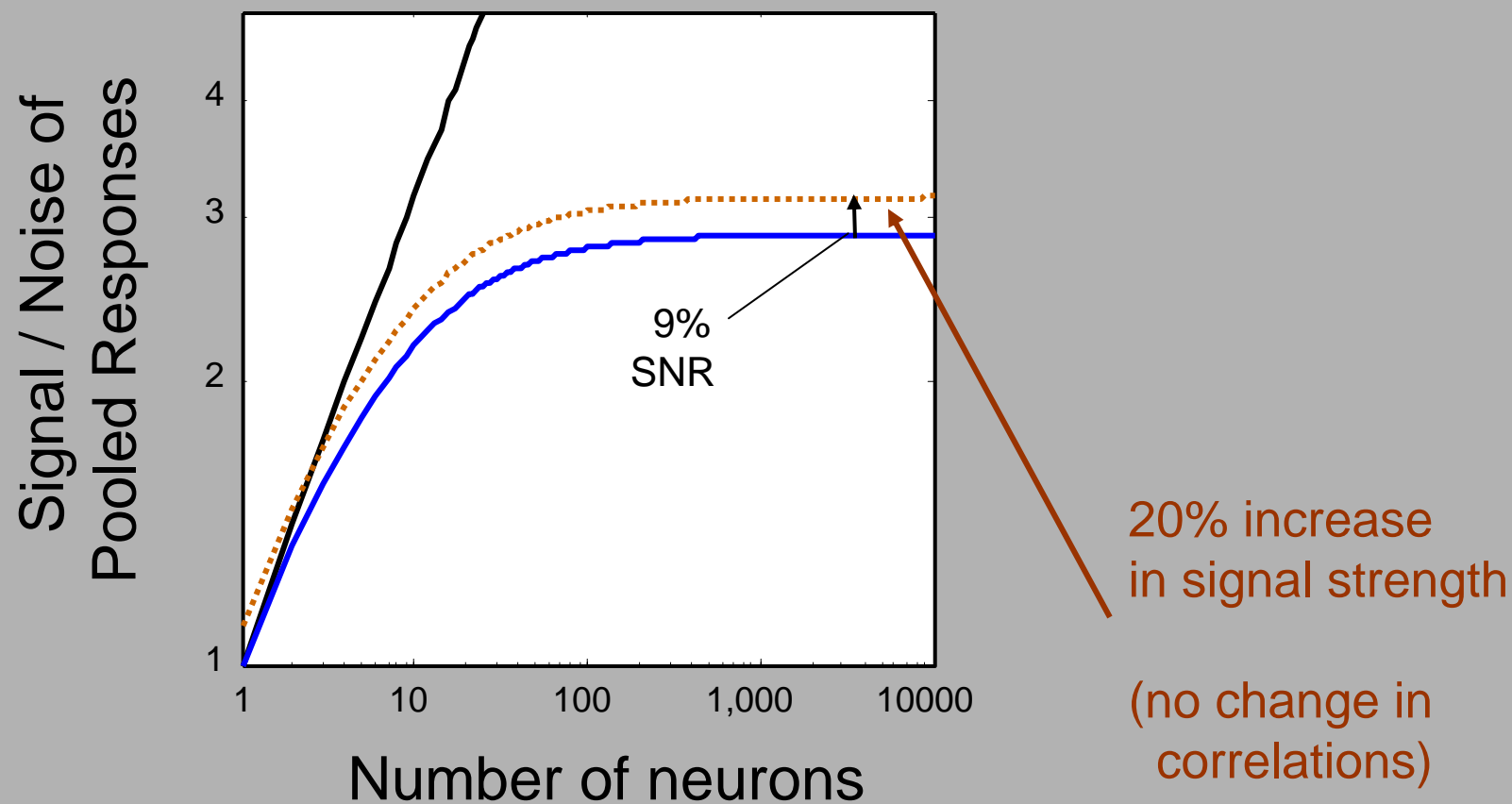
Theoretical saturation calculated from our data:



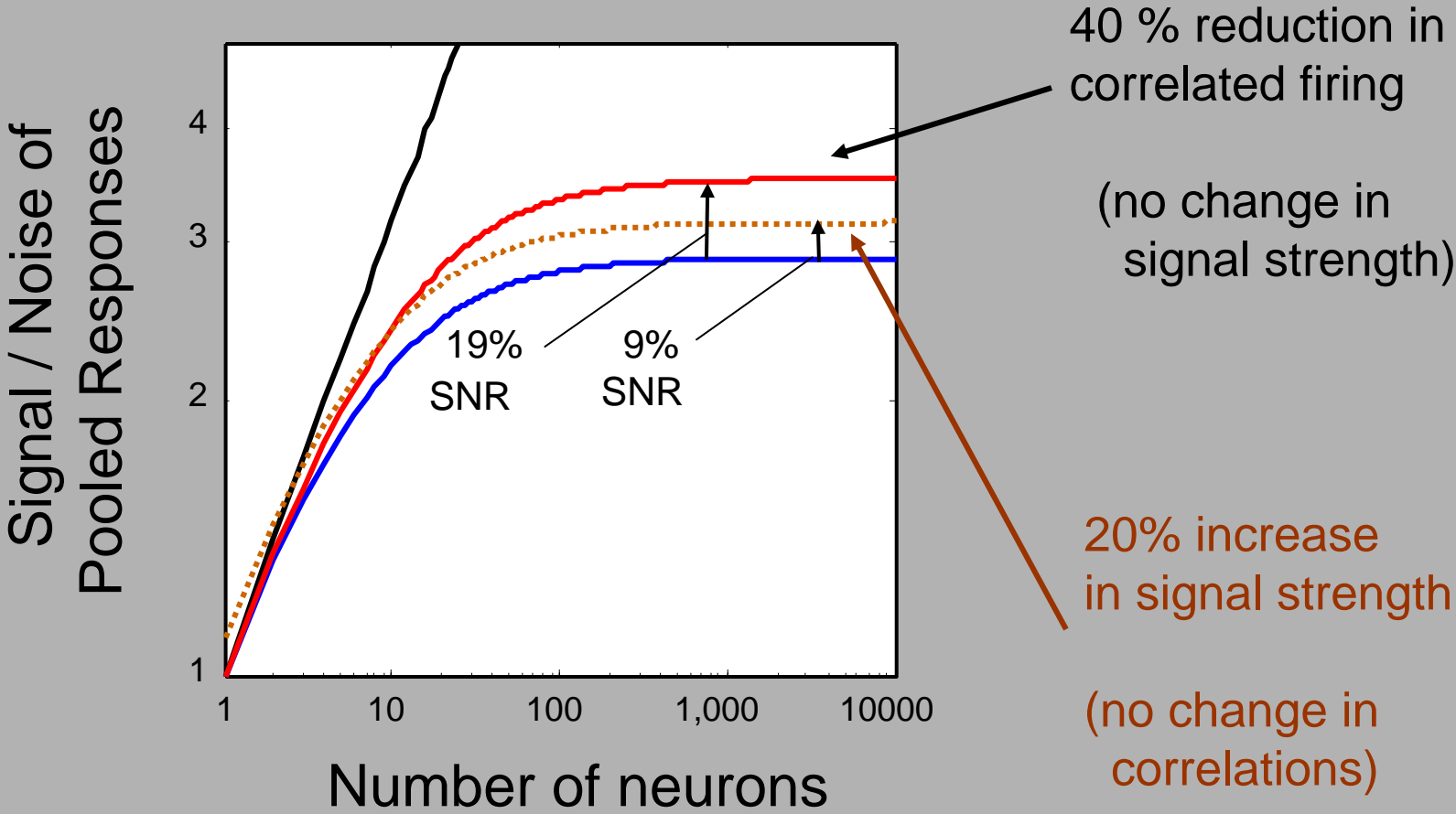
Saturation in unattended signal quality due to correlated firing

(following Zohary et al, 1994)

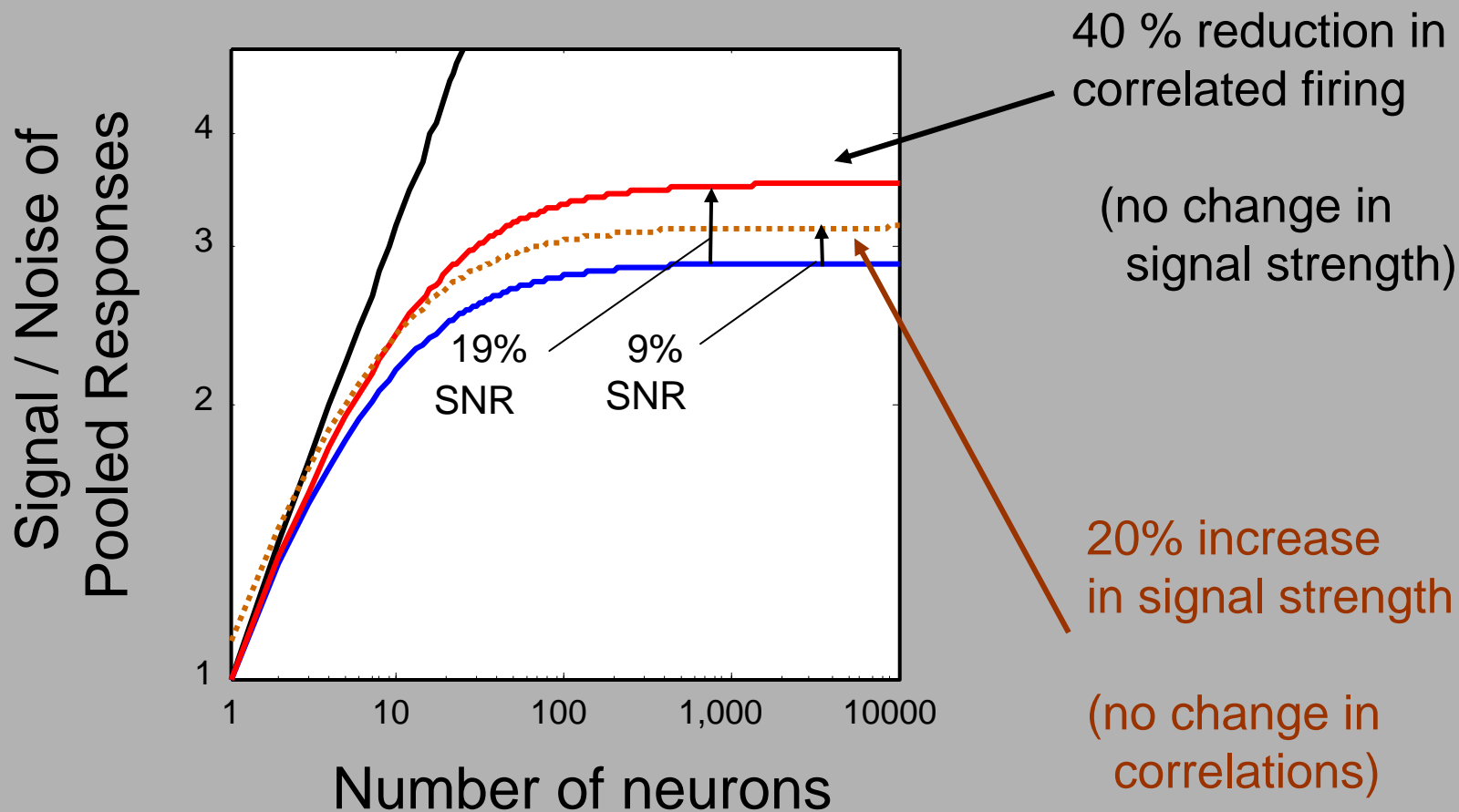
Theoretical saturation calculated from our data:



Theoretical saturation calculated from our data:

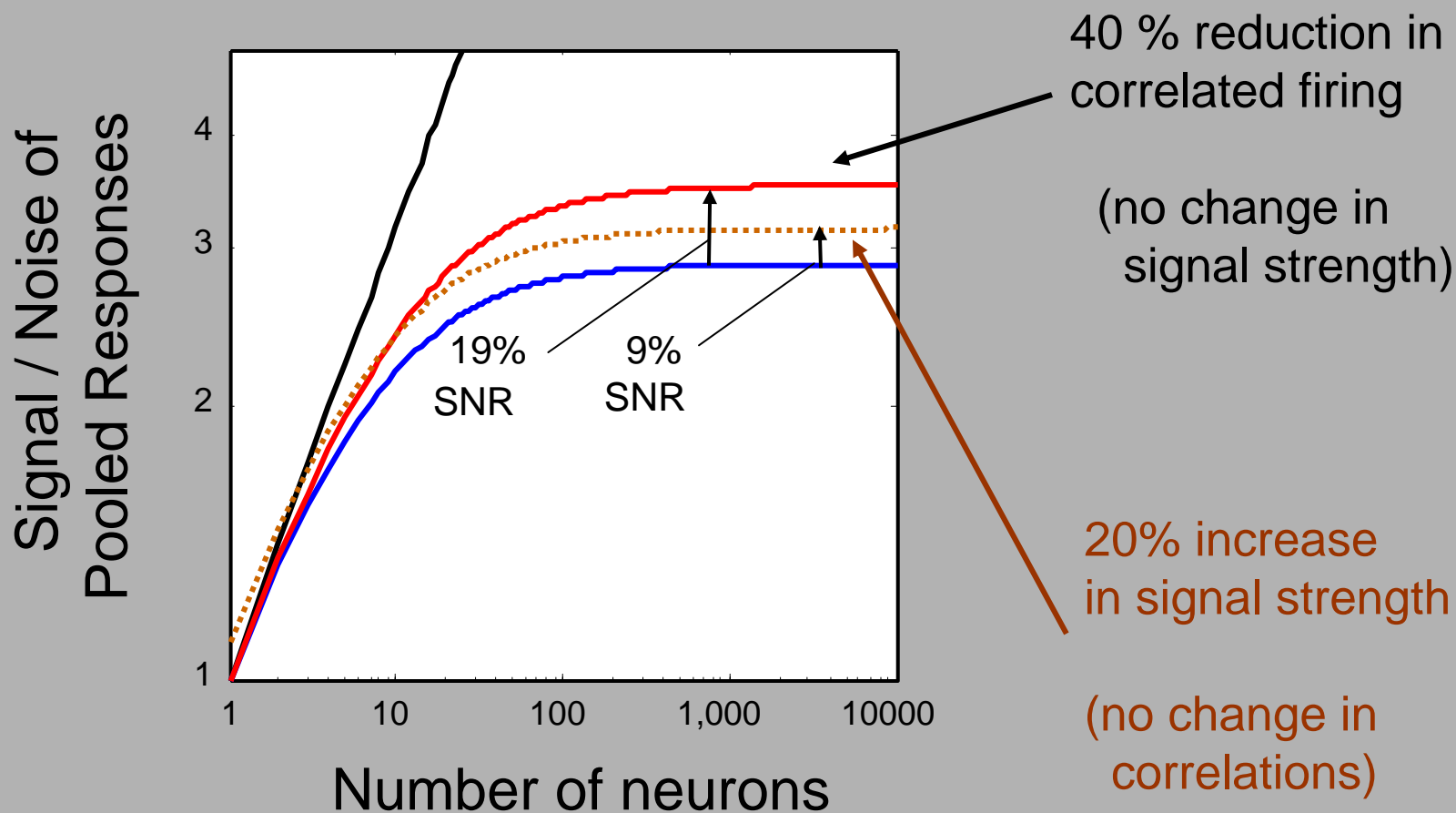


Reductions in correlation **could** improve signal quality more than increases in firing rate:



Reductions in correlation **could** improve signal quality more than increases in firing rate:

Depending on how it is the read-out? (see Chen et al, 2006; 2008)



Summary

- The dominant source of neuronal noise originates from long time scale rate fluctuations consistent with what is known of ongoing cortical activity
- Rate fluctuations are correlated over the population
- Attention acts to
 - 1) increase firing rate
 - 2) decrease correlated fluctuations
- Reductions in correlated firing **could** have a more profound impact on signal quality than rate increases

More Information:
Website (data & code): <http://snl.salk.edu/~jude>

