Visual cortical plasticity

- Deprivation-induced changes in representation
  - Ocular dominance plasticity
  - Retinal scotoma and cortical re-organization
- Perceptual learning-related plasticity
- Timing-dependent plasticity

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Ocular dominance plasticity

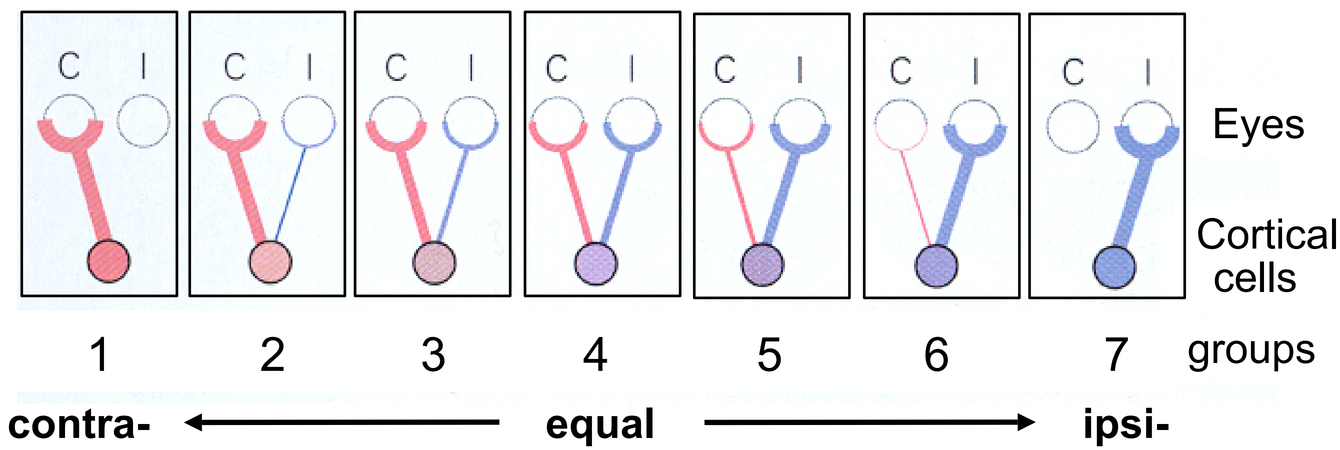
Definition of *ocular dominance index*:

$$OD = \frac{\text{Response}_{\textbf{ipsi}}}{\text{Response}_{\textbf{ipsi}} + \text{Response}_{\textbf{contra}}}$$

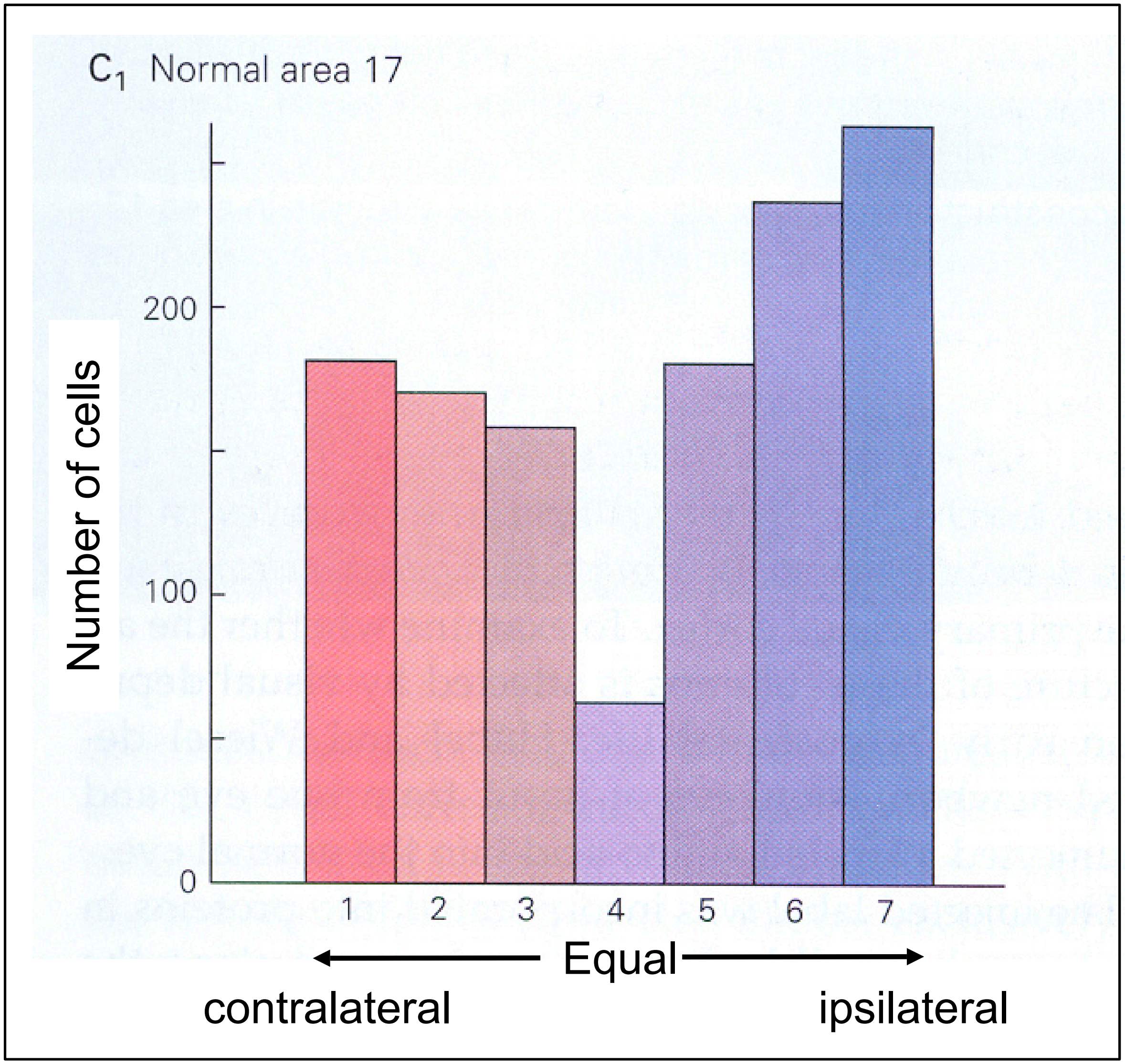
od = 1, ipsilateral only

od = 0, contralateral only

od = 0~1, binocular

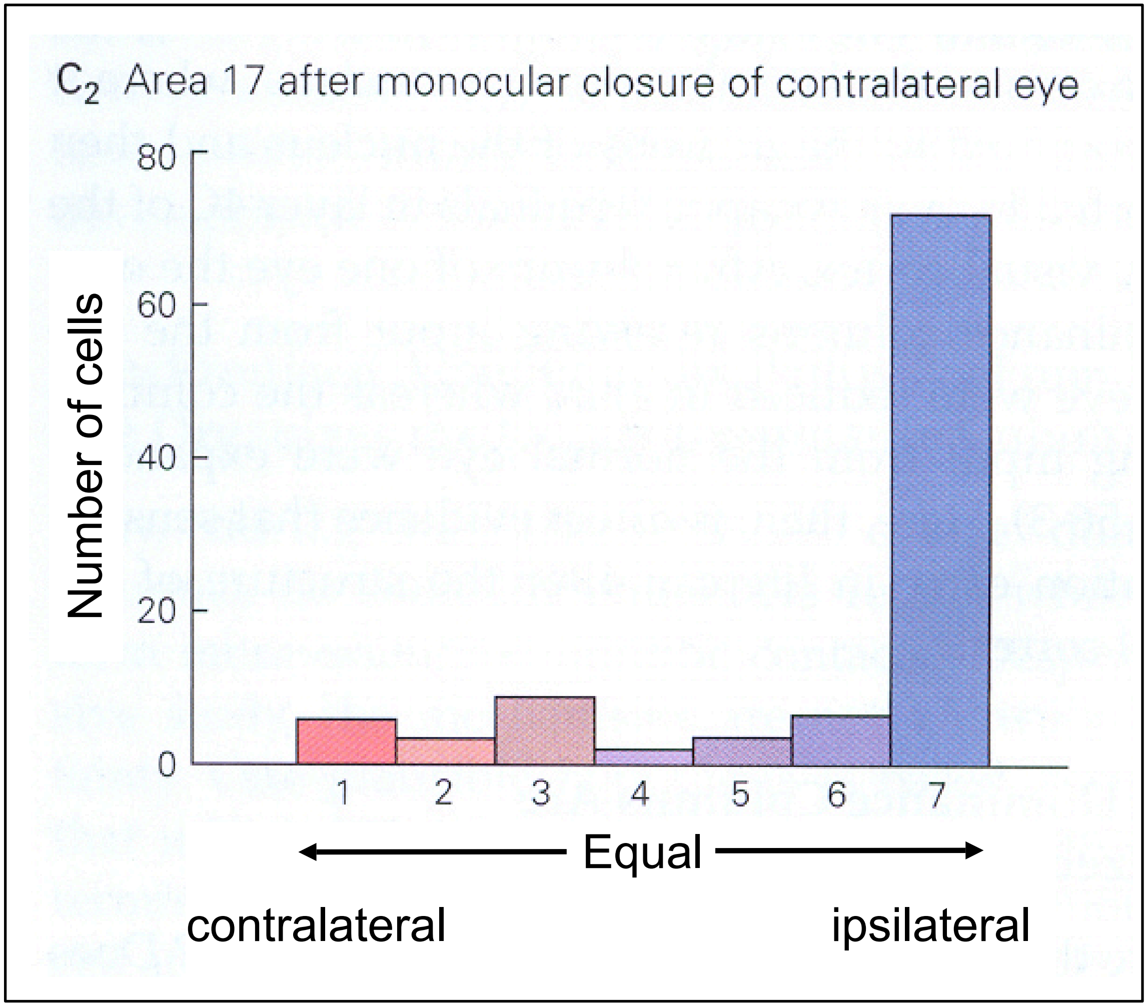


OD distribution in normal adult V1 (monkey)

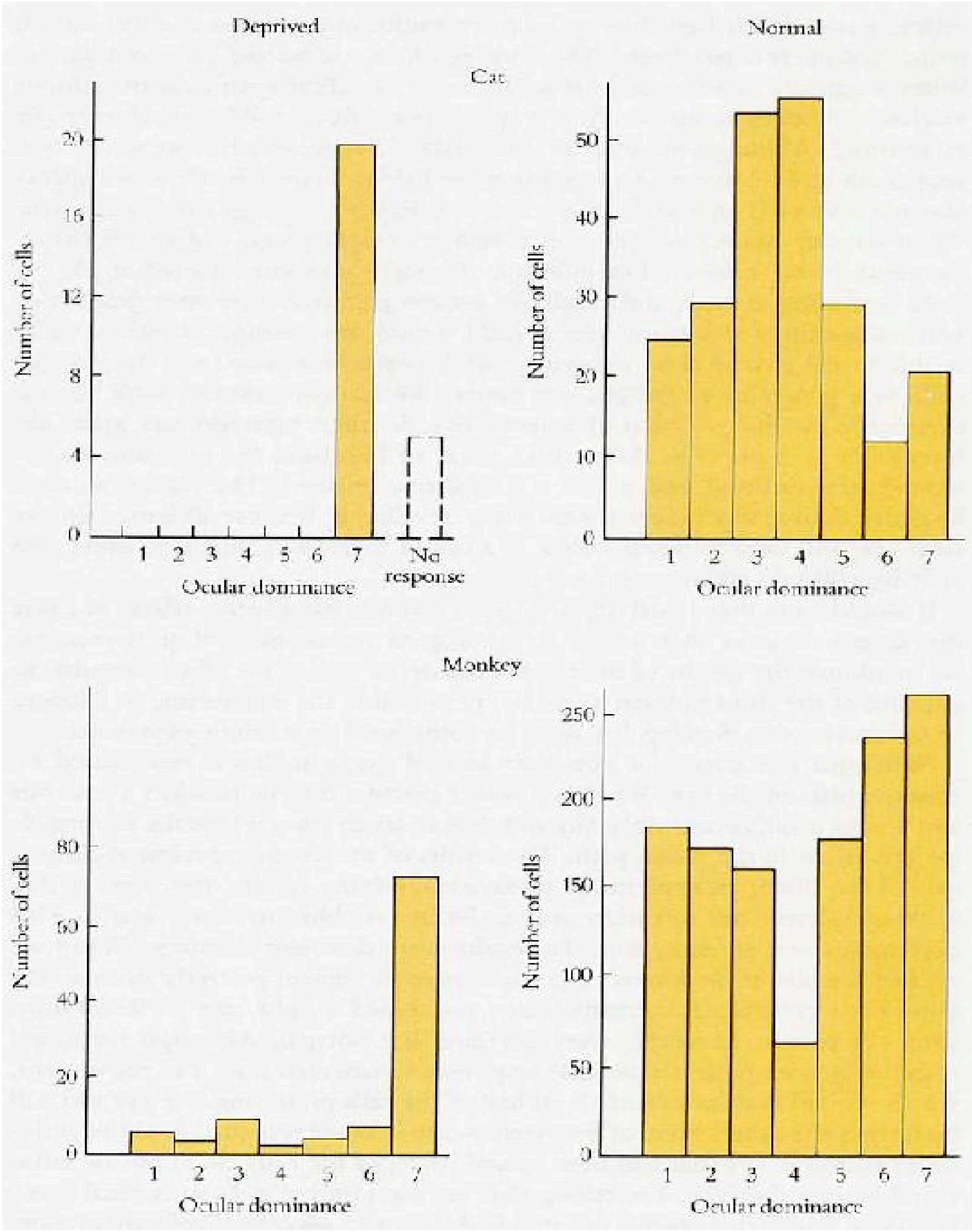


OD distribution in V1 after monocular deprivation

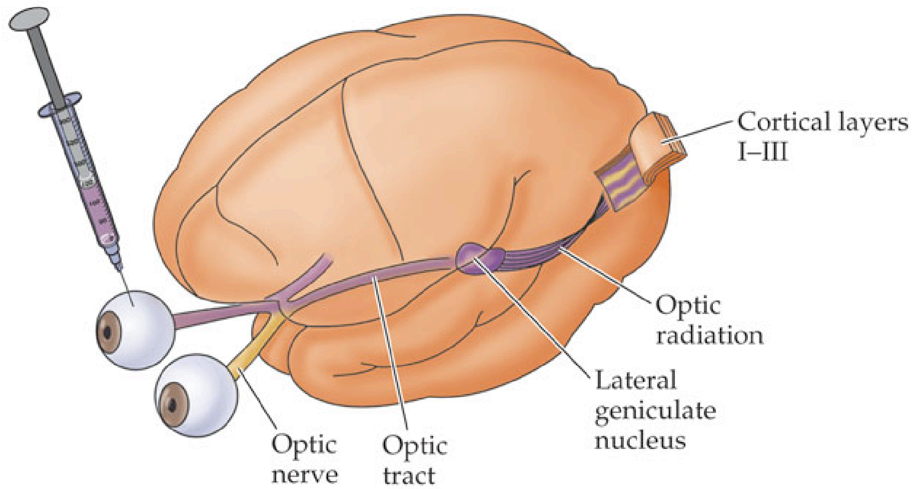
(suture one eye of the newborn monkey for several months)



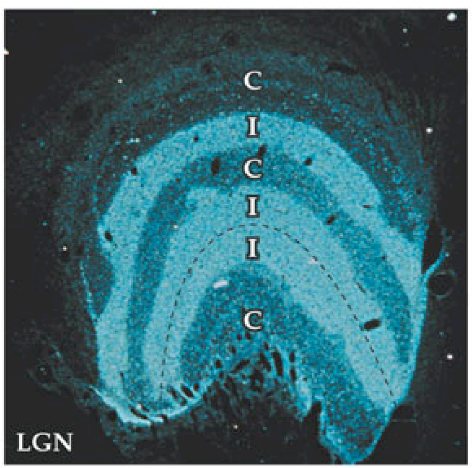
Comparison between cat and monkey

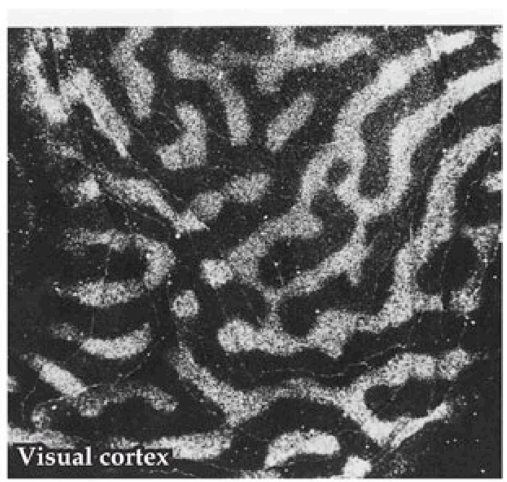


Radioactive tracing

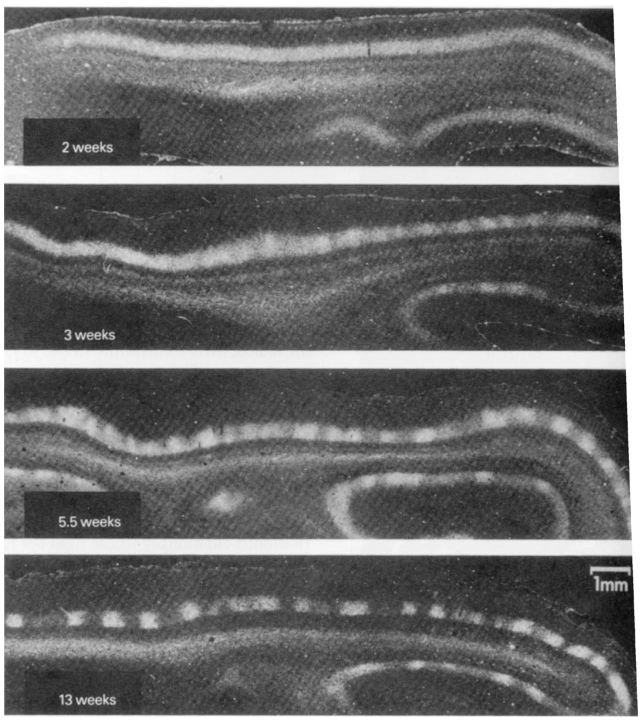


NEUROSCIENCE, Third Edition, Figure 23.3 (Part 1) © 2004 Sinauer Associates, Inc.

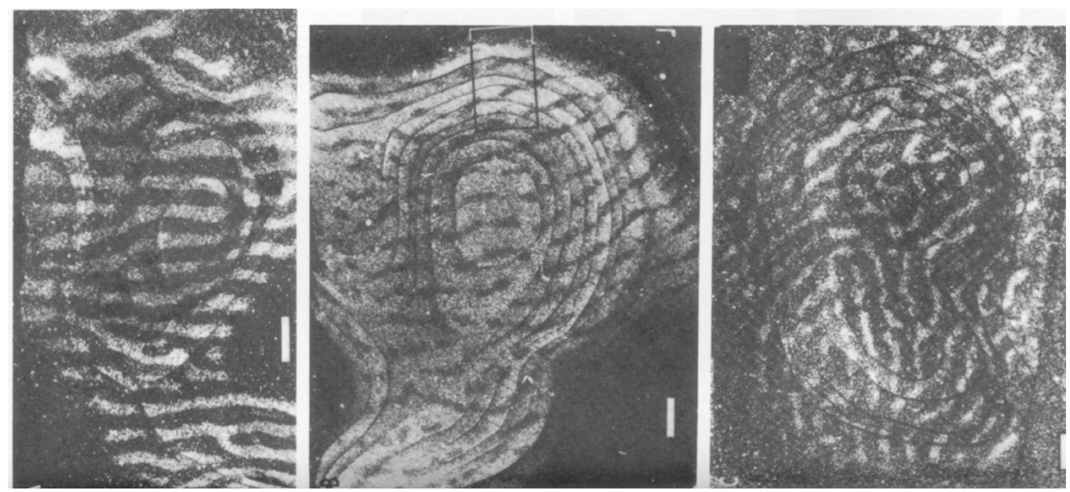




Development of OD columns



Effect of monocular deprivation



Normal

inject non-deprived eye

inject deprived eye

OD column formation is an activity-dependent, competitive process

Experiments:

1. Binocular injection of TTX, blocks segregation of OD columns

- segregation is activity dependent

2. If both eyes are deprived (binocular deprivation), OD columns are normal

- segregation depends NOT on the absolute level of activity, but on the balance between the input from the two eyes, thus seems to be competitive

Critical period

Monocular deprivation (MD) causes a shift of OD toward the non-deprived eye. This is effective only before certain age. MD has no effect (???) in adult animals

Critical period: a period in early life that the neural circuit is susceptible to external sensory inputs (e.g. MD). This period depends on the species and the neural circuit.

OD in V1:

cat: 3rd week -- 3 months

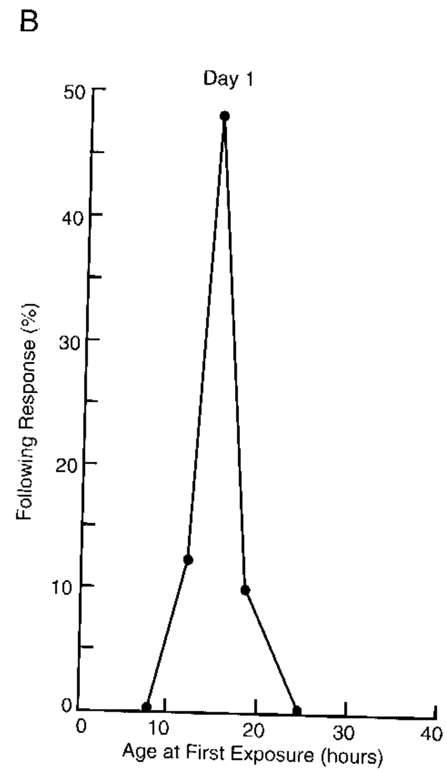
monkey: first 6 months

human: 1st year most important, but extends to 5-10 years

After the critical period, the effect is permanent (???)

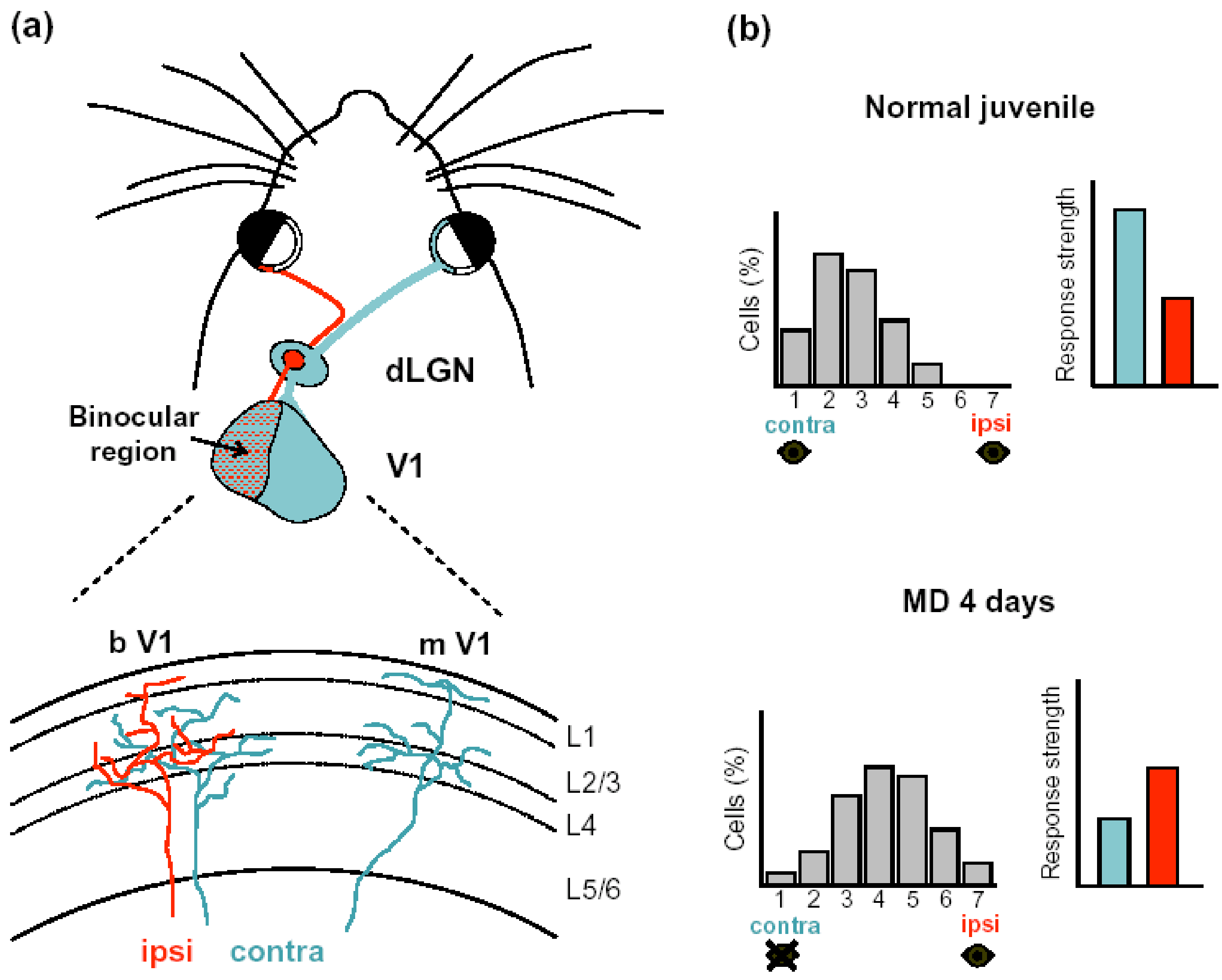
Within the critical period, the effect can be reversed by reverse suture

Critical period for behaviors

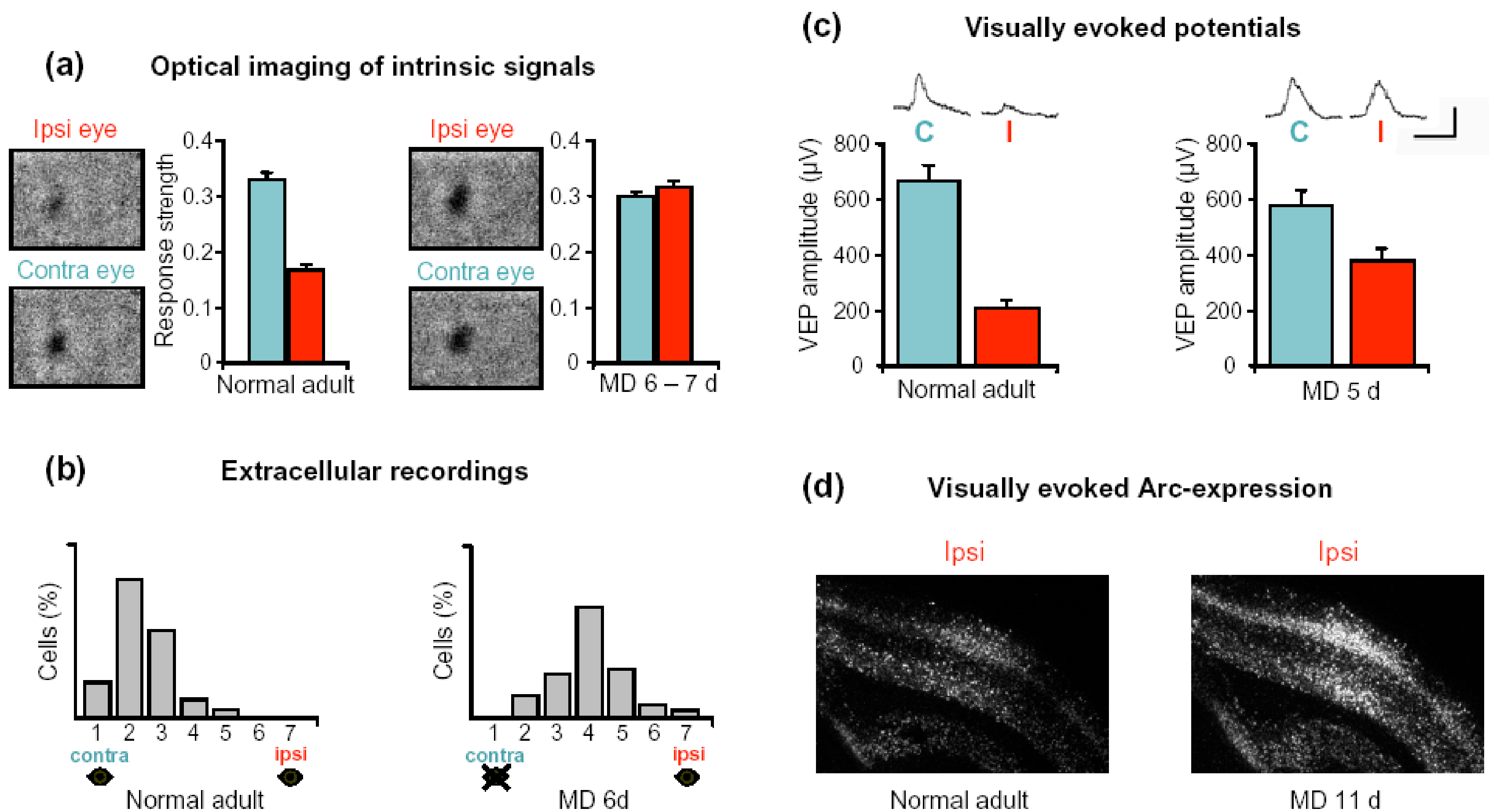


Konrad Lorenz: critical period for parental imprinting in ducklings

OD plasticity in rodent model



OD plasticity also exists in adult rodents



Conditions to induce OD shift in adult rodent

- Prolonged monocular deprivation
- Dark rearing (binocular deprivation) followed by monocular deprivation
- Pharmacological degradation of extracellular matrix or genetic deletion of Nogo receptors
- Prior monocular deprivation during development

Mechanisms OD shift

- Developing: First weakening of deprived eye (may involve thalamocortical LTD), then strengthening of open eye
- Adult: Strengthening of open eye (may involve reduction of inhibition)

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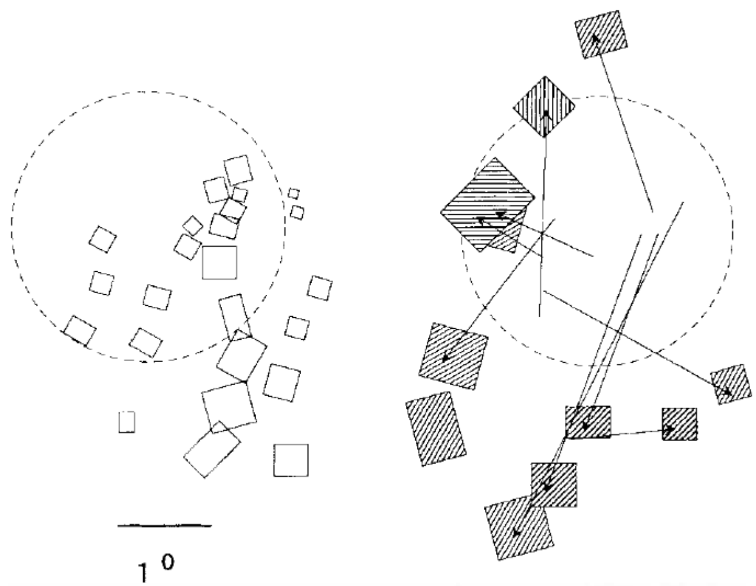
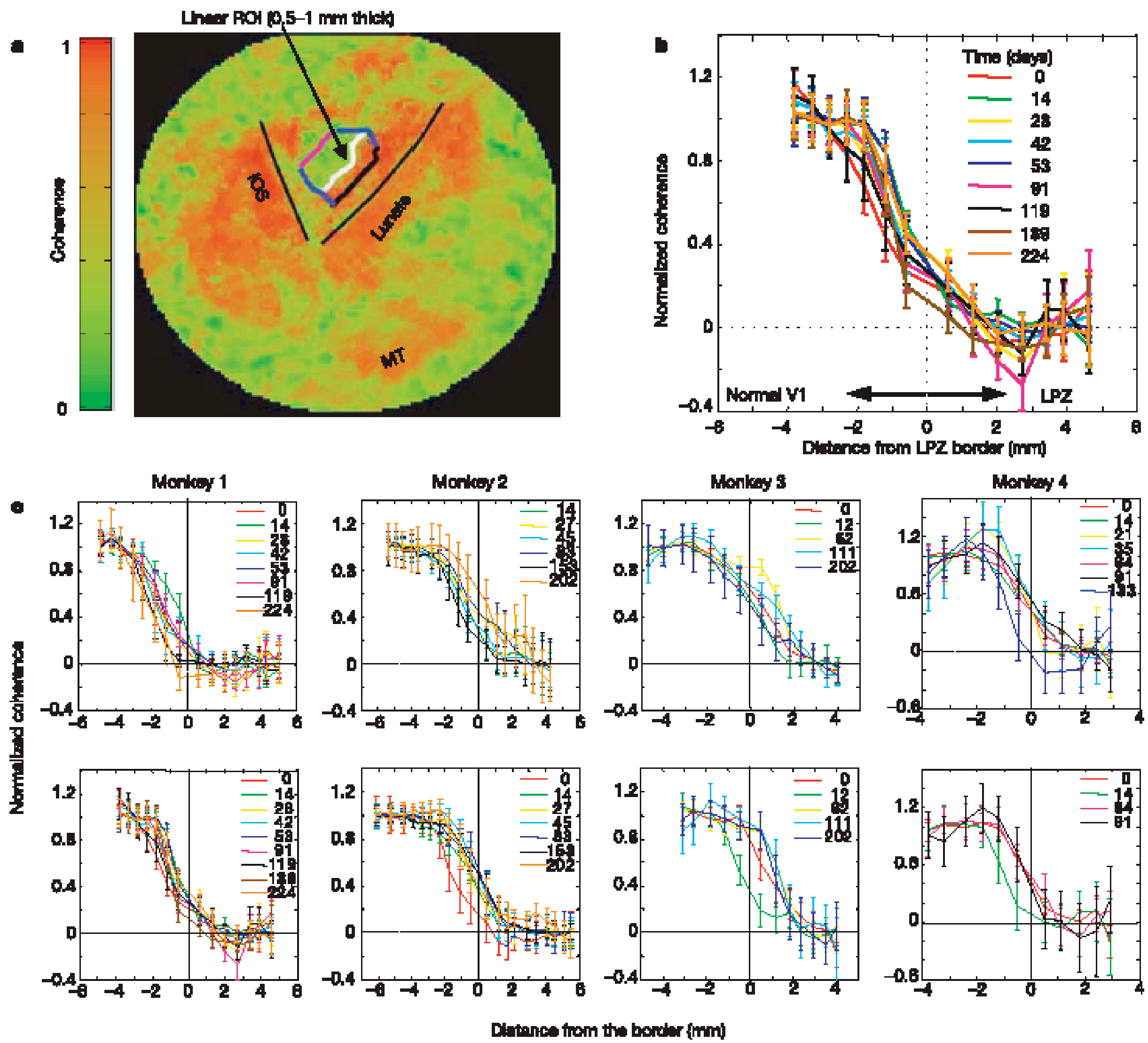
Receptive field shift of cortical cells mapped to the scotoma

before after



Gilbert and Wiesel, Nature, 1992

But some recent studies show no re-organization



Smirnakis et al., Nature, 2005

Visual cortical plasticity

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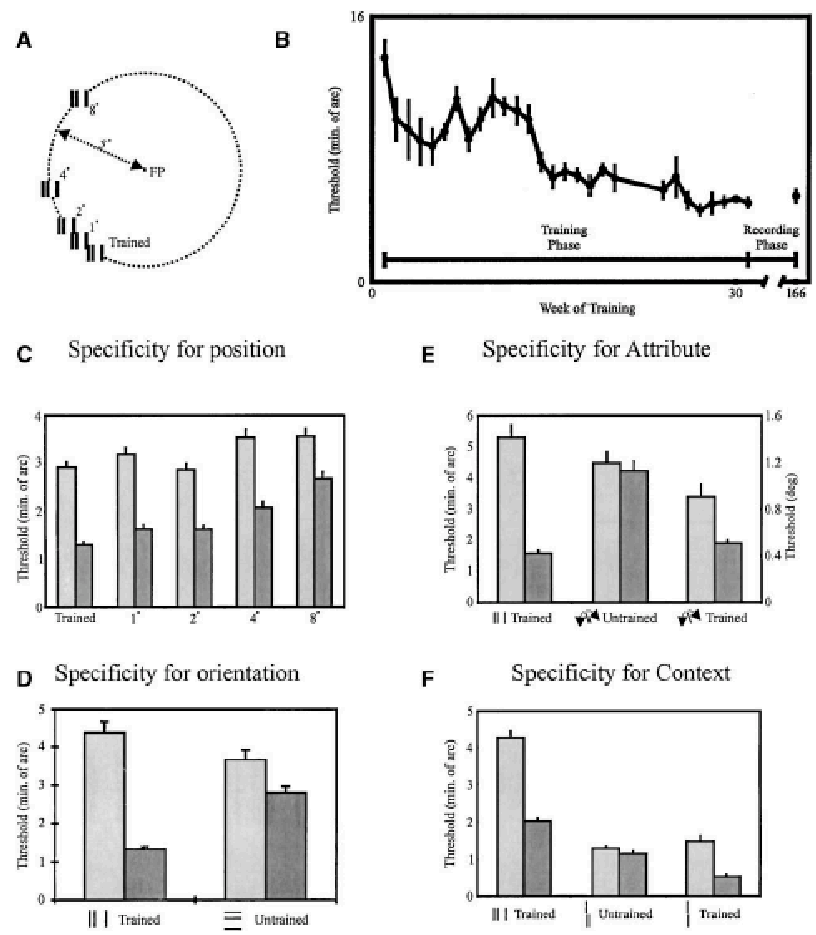
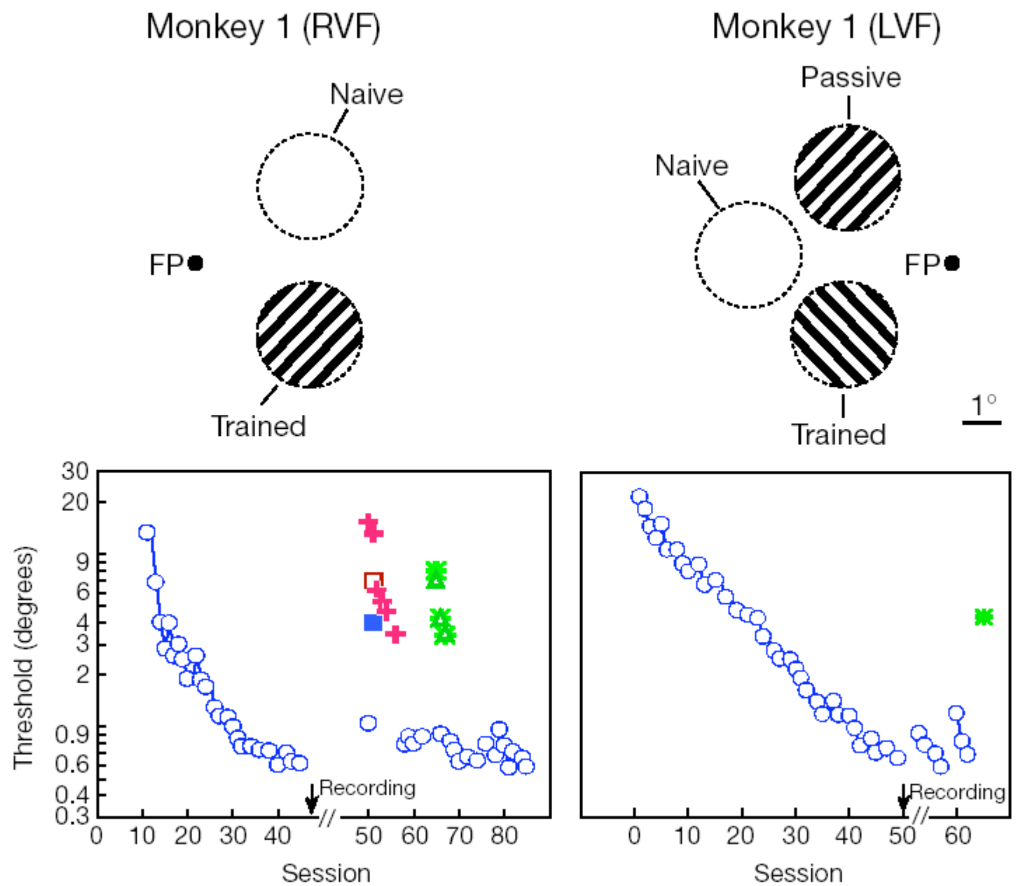
Localization of perceptual learning in the visual pathway

- Inter-ocular transfer: cortical vs. pre-cortical
- Stimulus specificity: early vs. late visual pathway
- Are there changes in V1?



Example 1. Perceptual learning in orientation discrimination



O: trained location and orientation

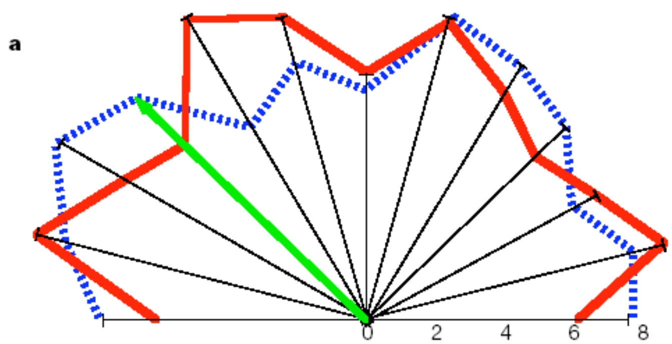
g: trained location, but different orientation

*: naïve location

+: passively stimulated position

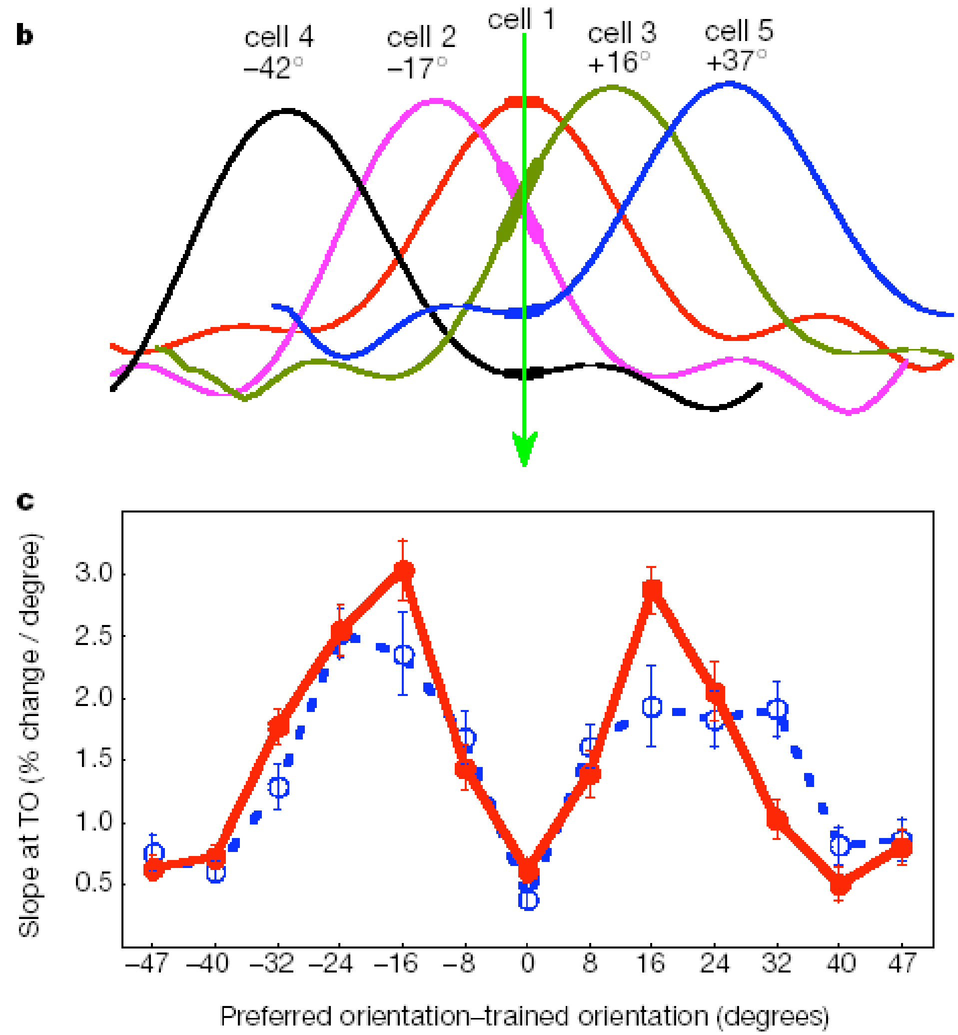
Learning-induced changes in V1 orientation tuning

Distribution of preferred orientation



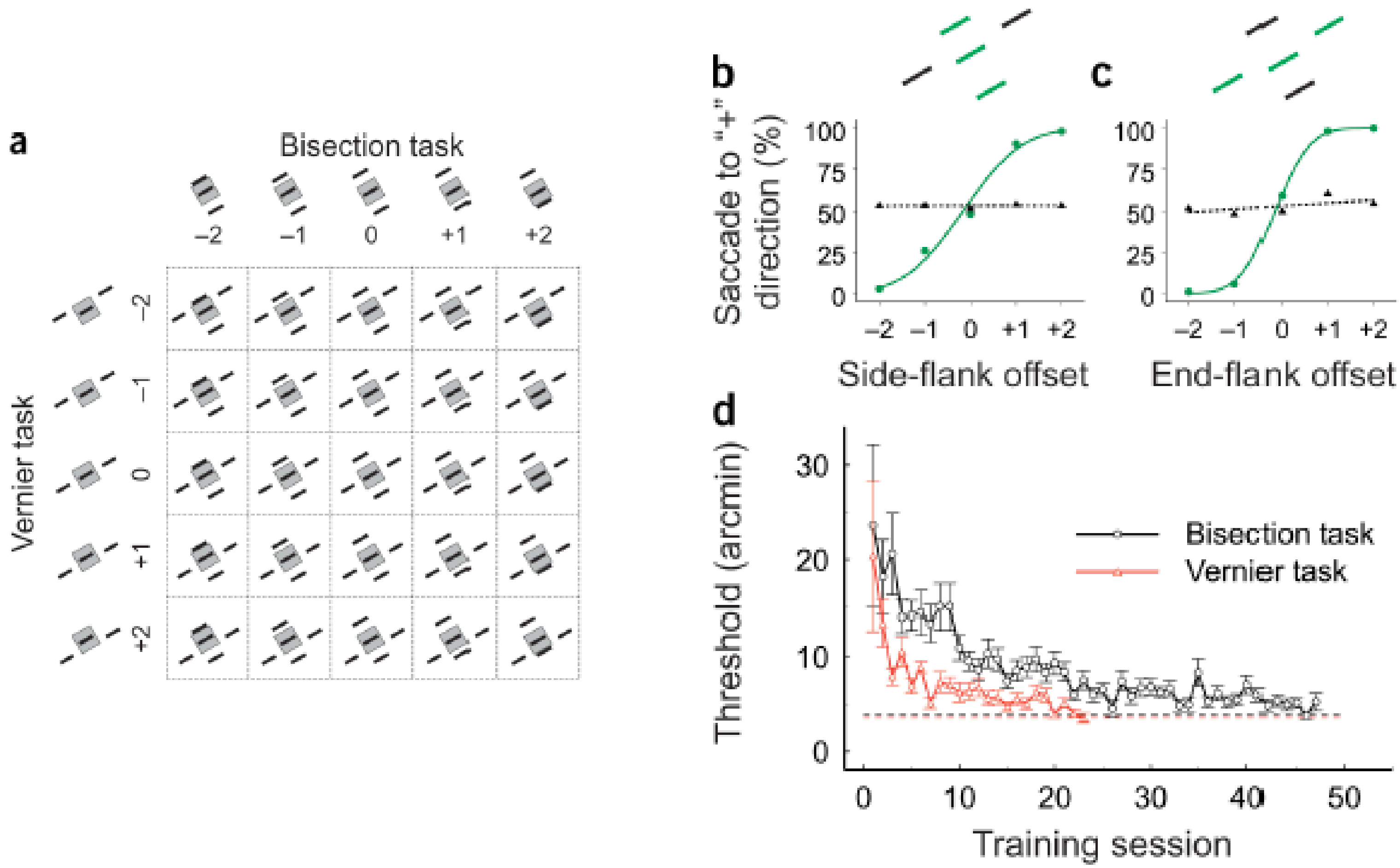
Blue: before learning
Red: after learning
Green: trained orientation

Change in slope of tuning at trained orientation

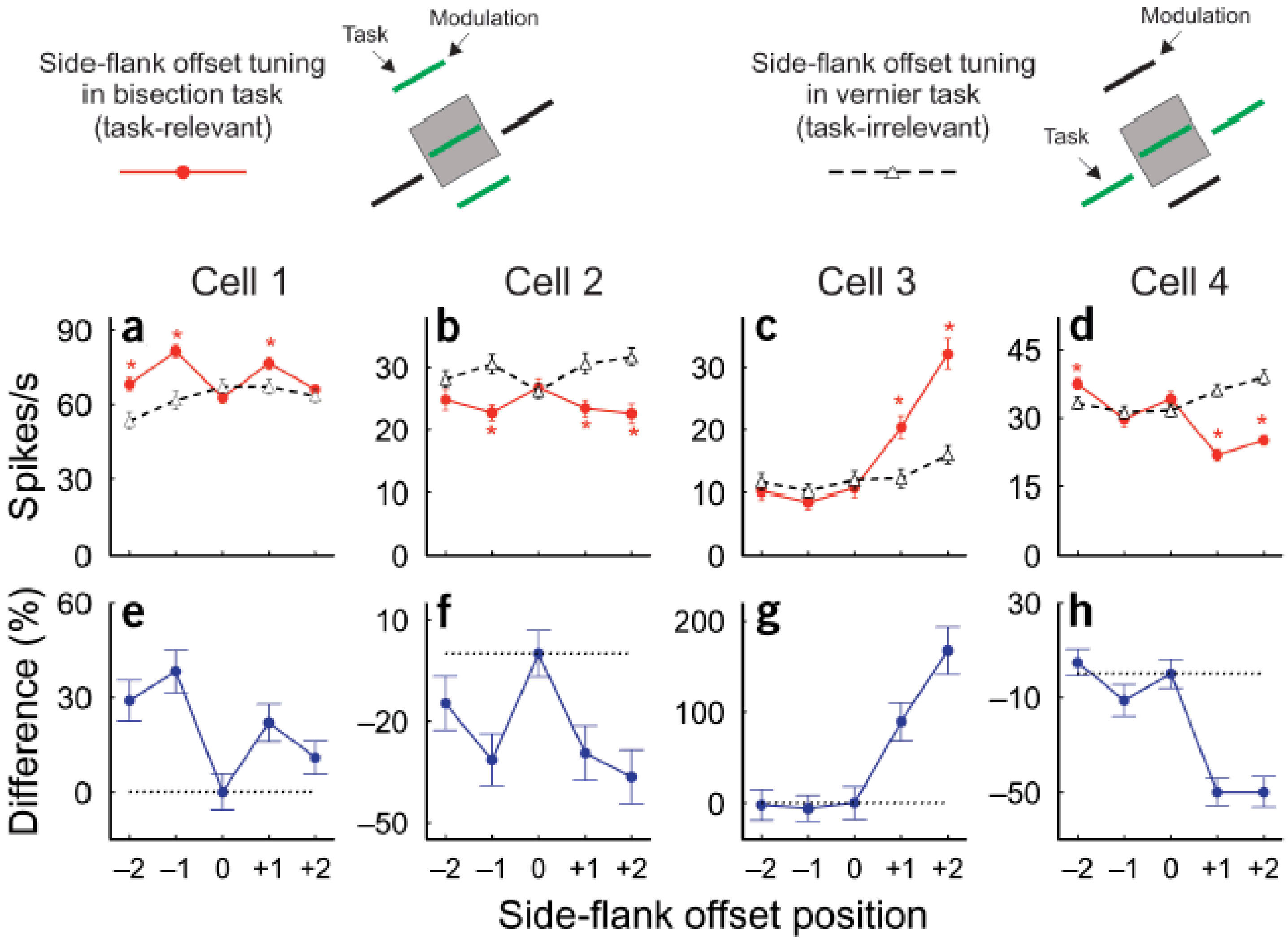


Example 2. Perceptual learning of stimulus localization

(vernier and bisection tasks)



Task dependence of contextual modulation



Neural mechanisms for perceptual learning

- Some forms of perceptual learning may involve changes in V1 receptive field properties
- V1 changes may be dynamically regulated by top-down influences

Visual cortical plasticity

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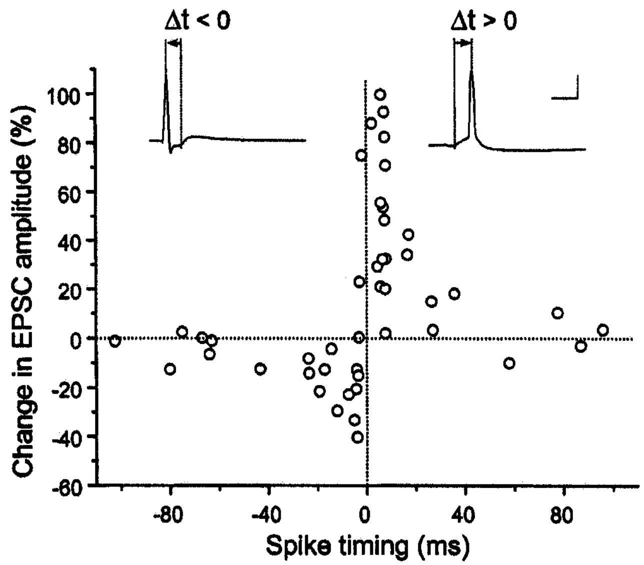
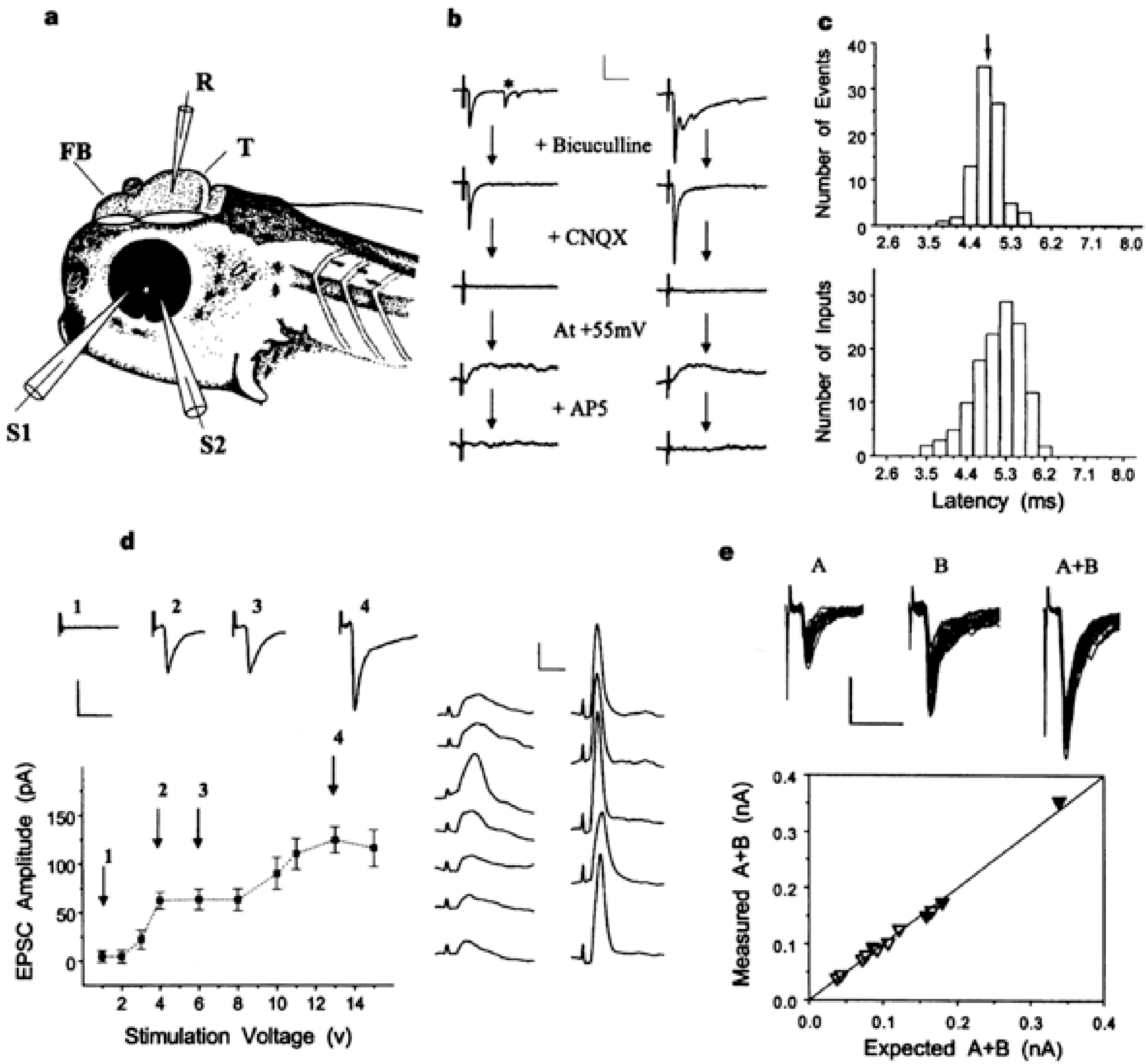
STDP in vivo

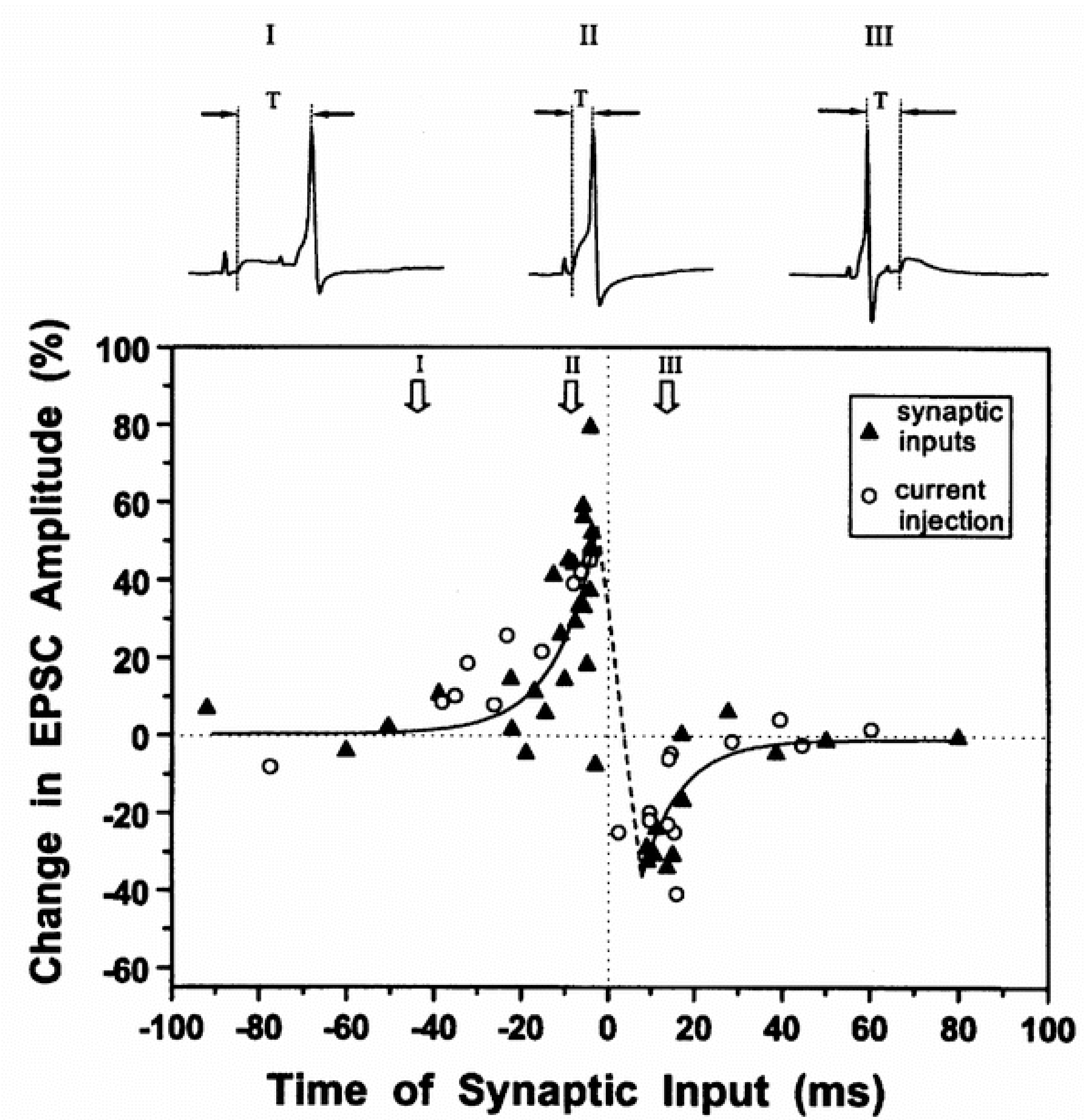


Bi & Poo, Journal of Neuroscience, 1998, 18(24): 10464-72

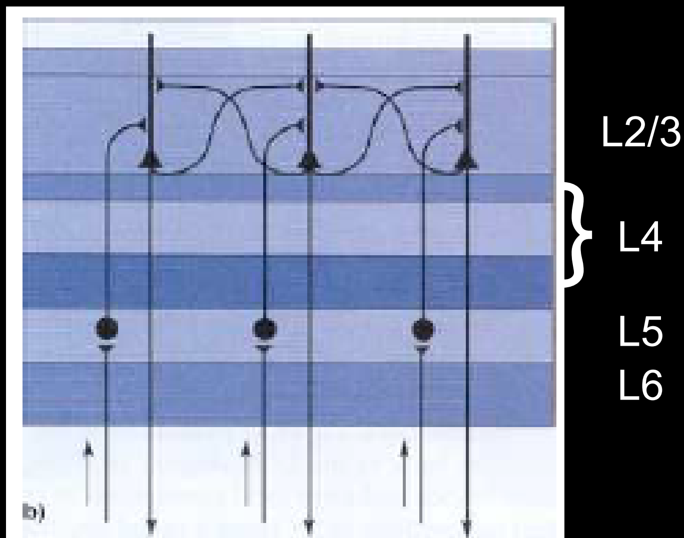
1. Electrical stimulation
2. Sensory stimulation
3. Natural stimulation

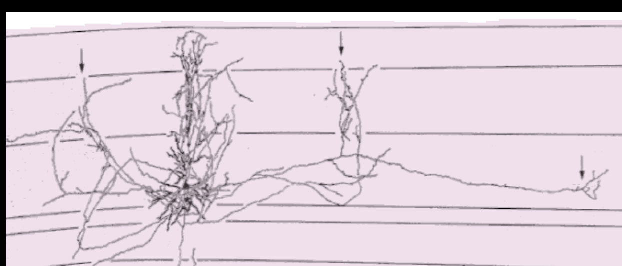


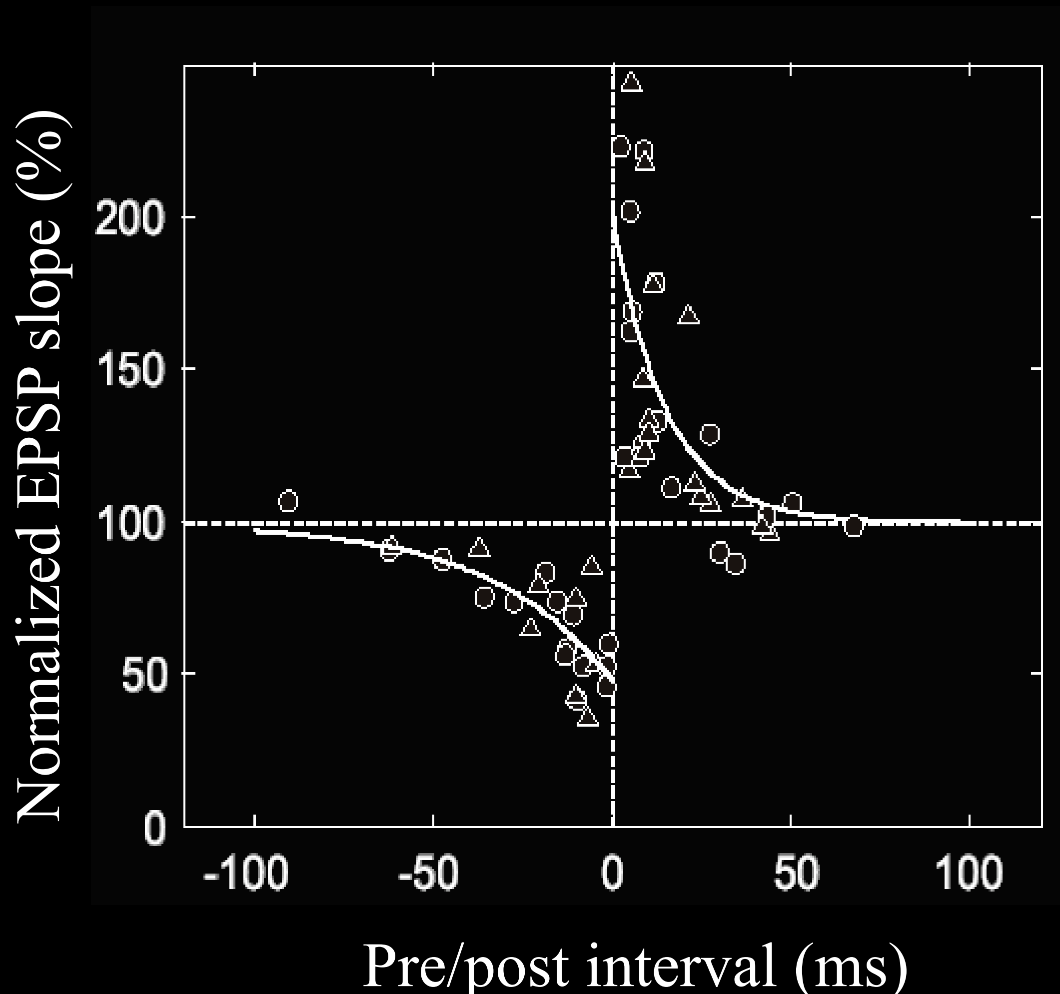
Zhang et al., Nature, 1998



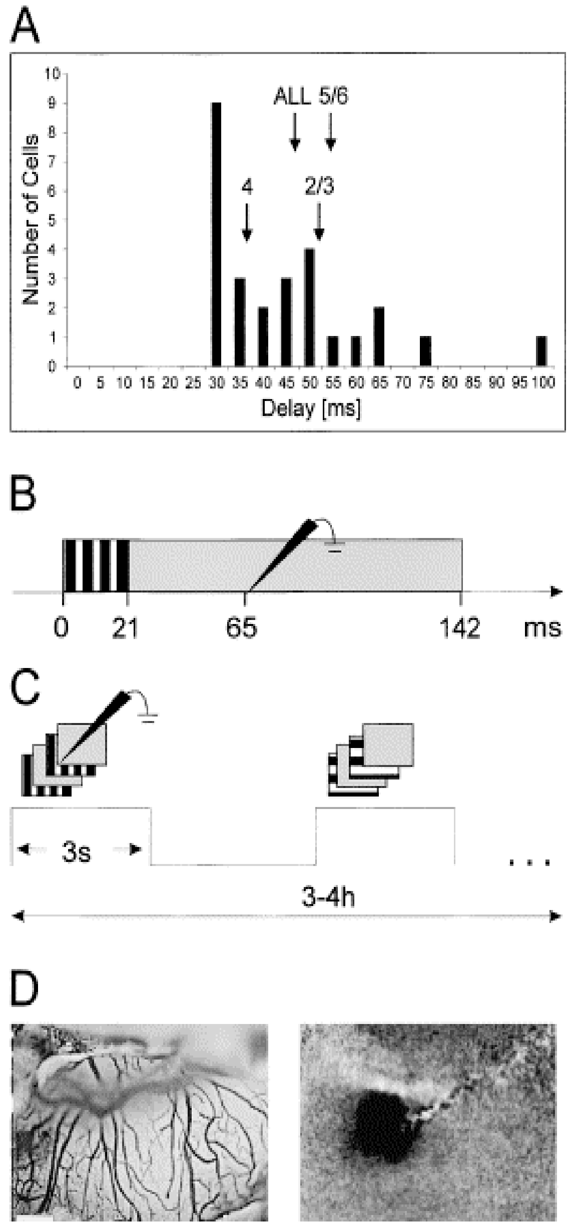
Zhang et al., Nature, 1998



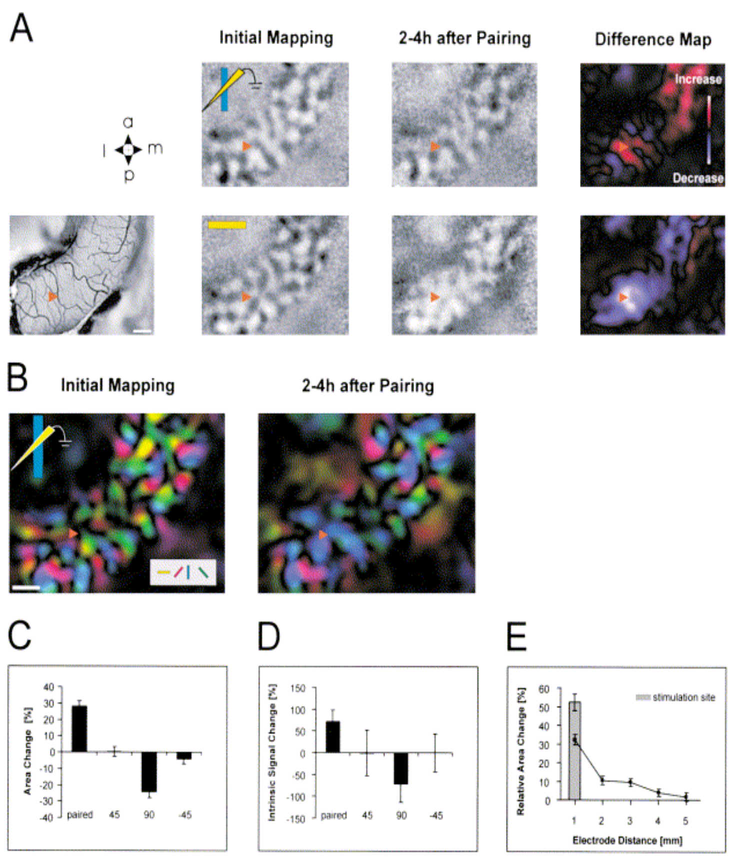


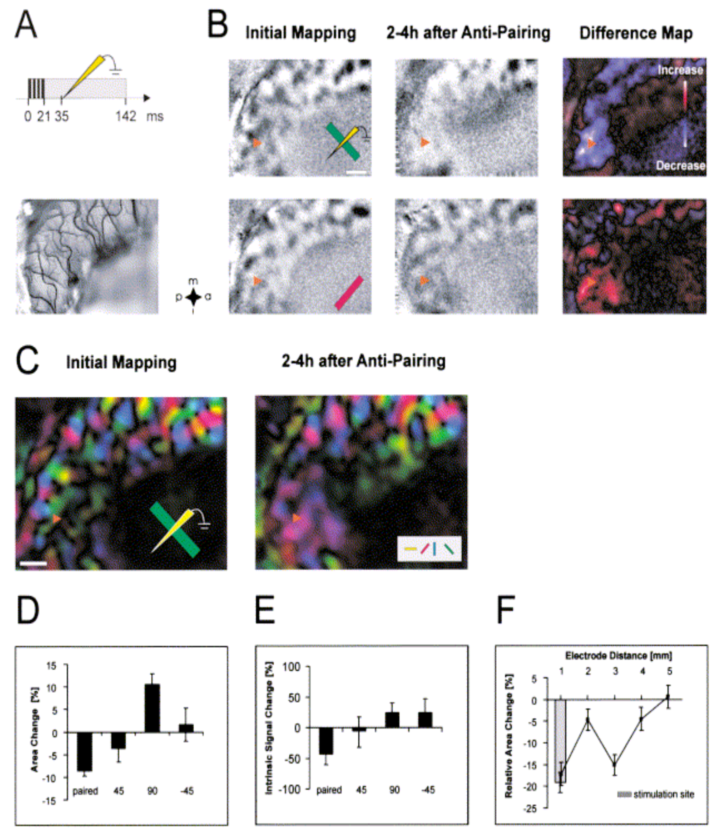


Froemke & Dan, Nature, 2002



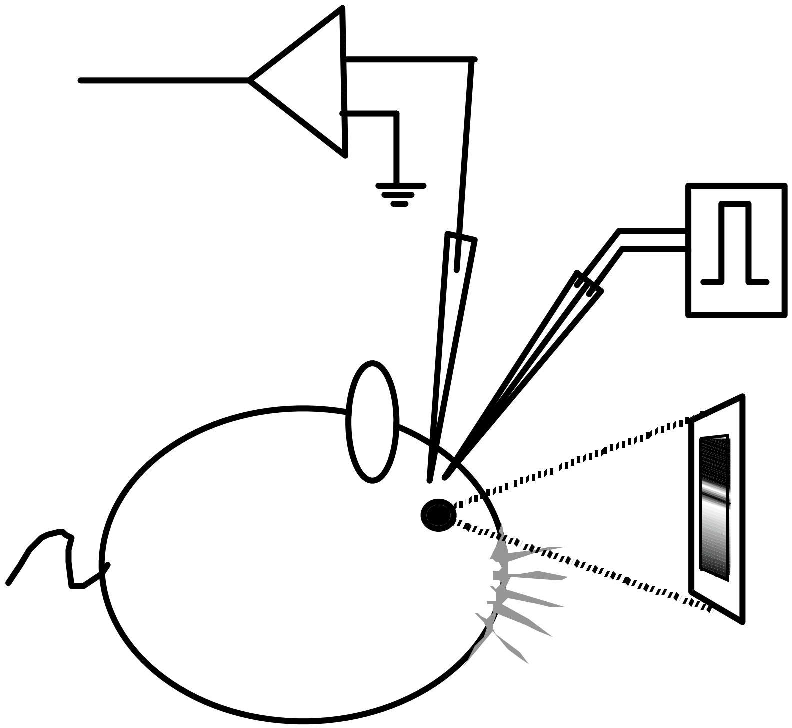
Schuett et al., *Neuron*, 2001

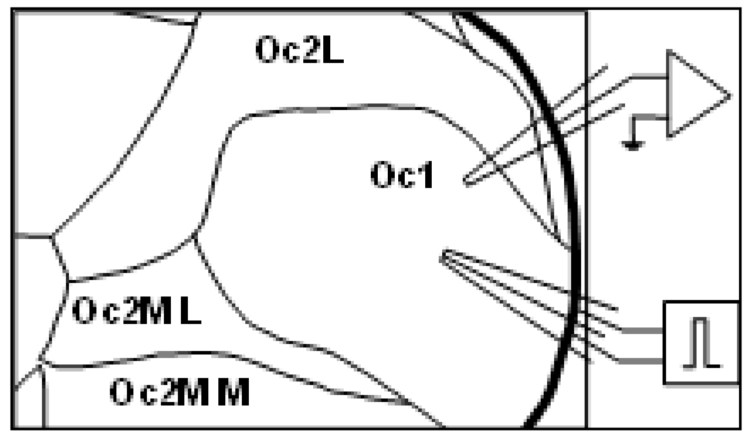




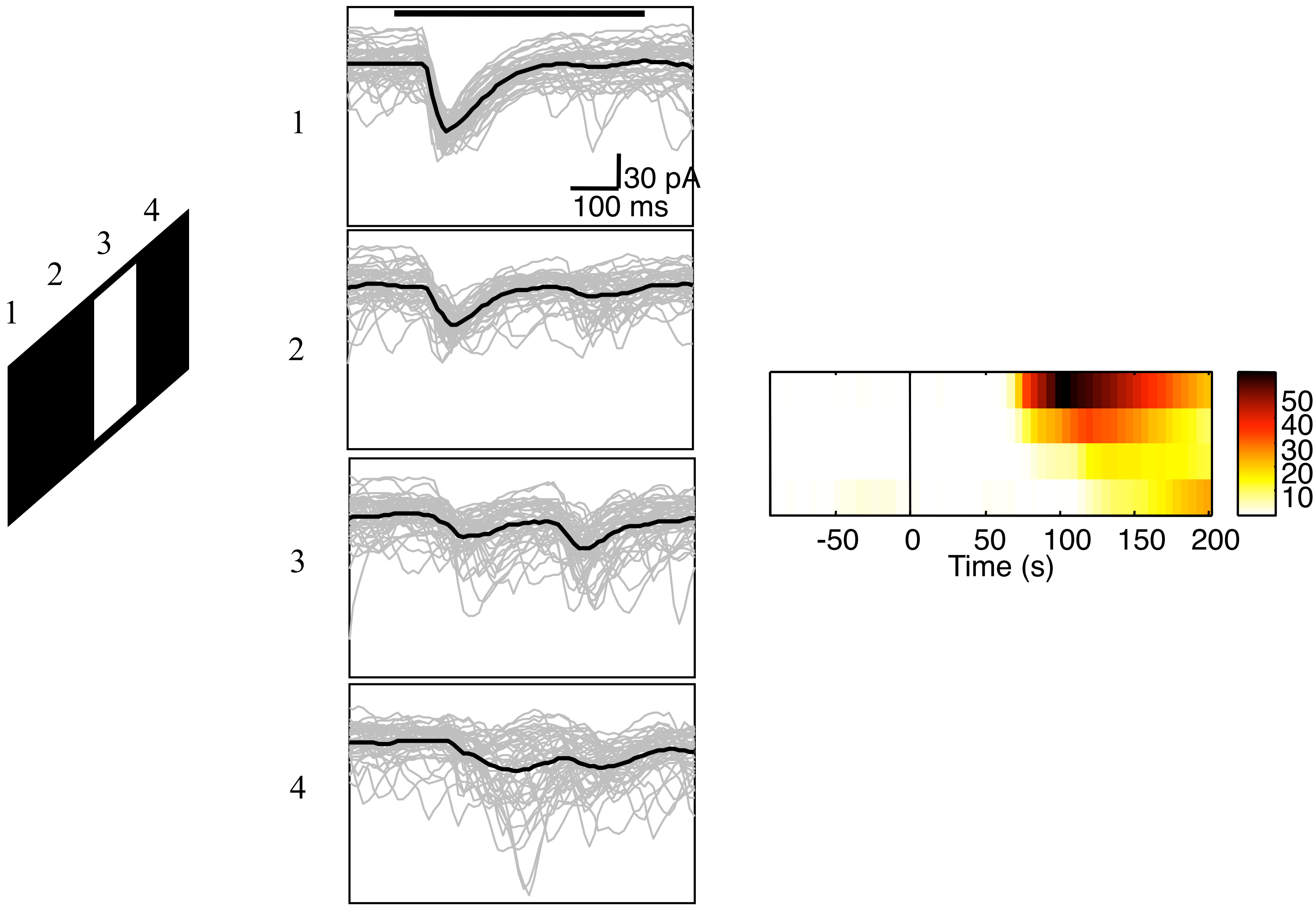
Schuett et al., *Neuron*, 2001

Spike-timing Dependent Plasticity Rat Oc1

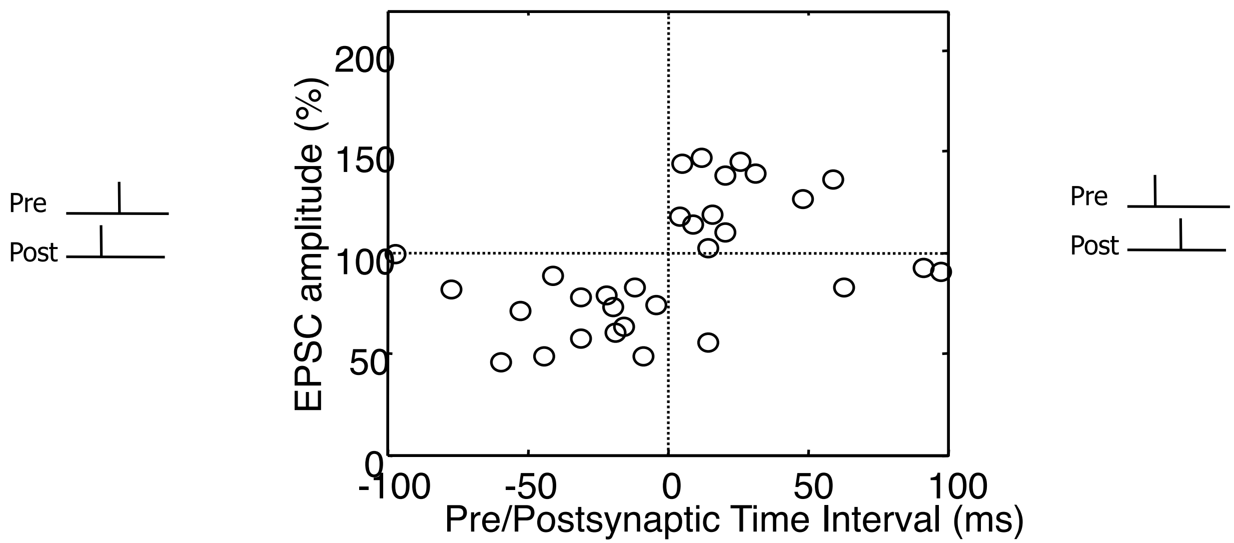


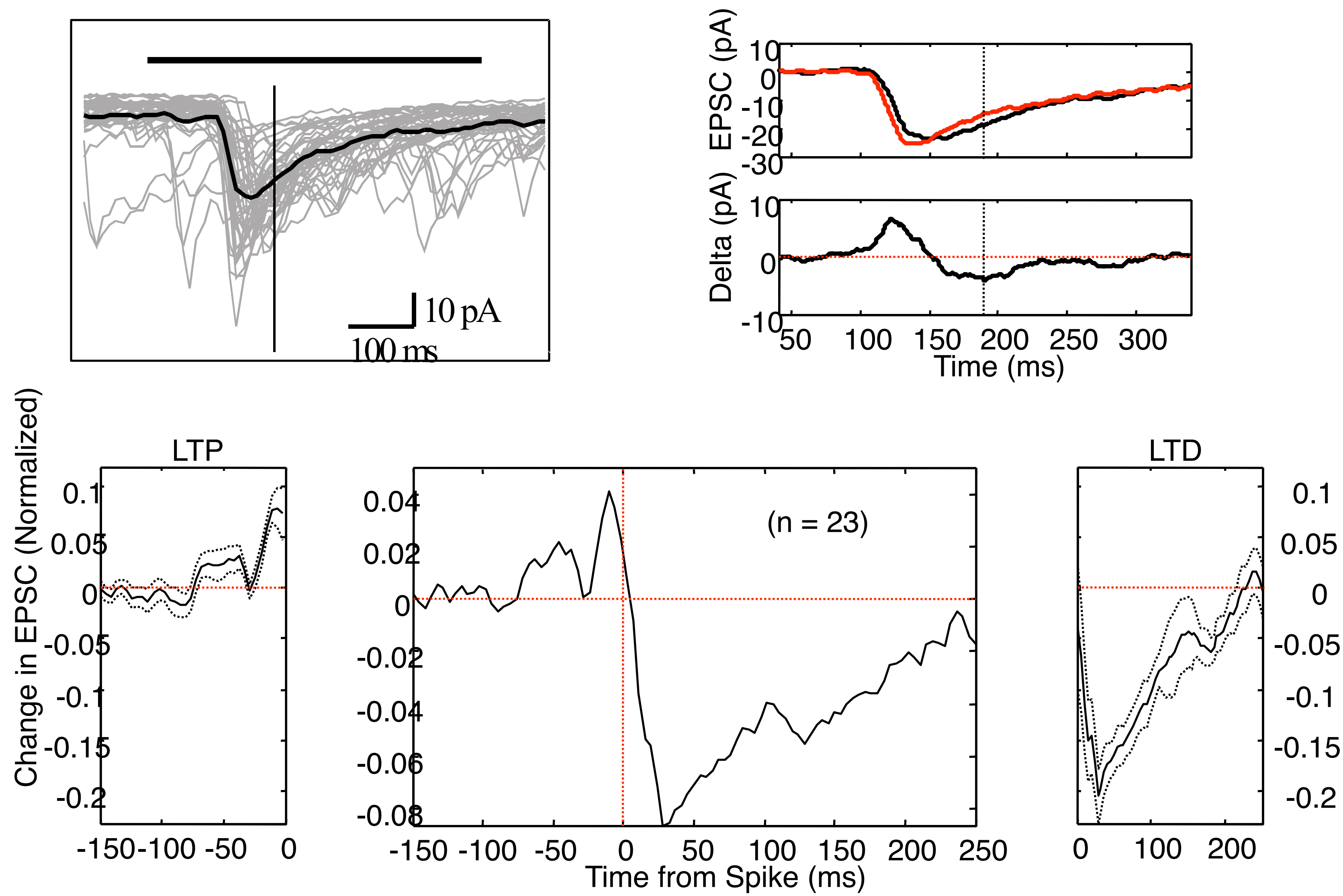


Spatiotemporal Visual Receptive Fields

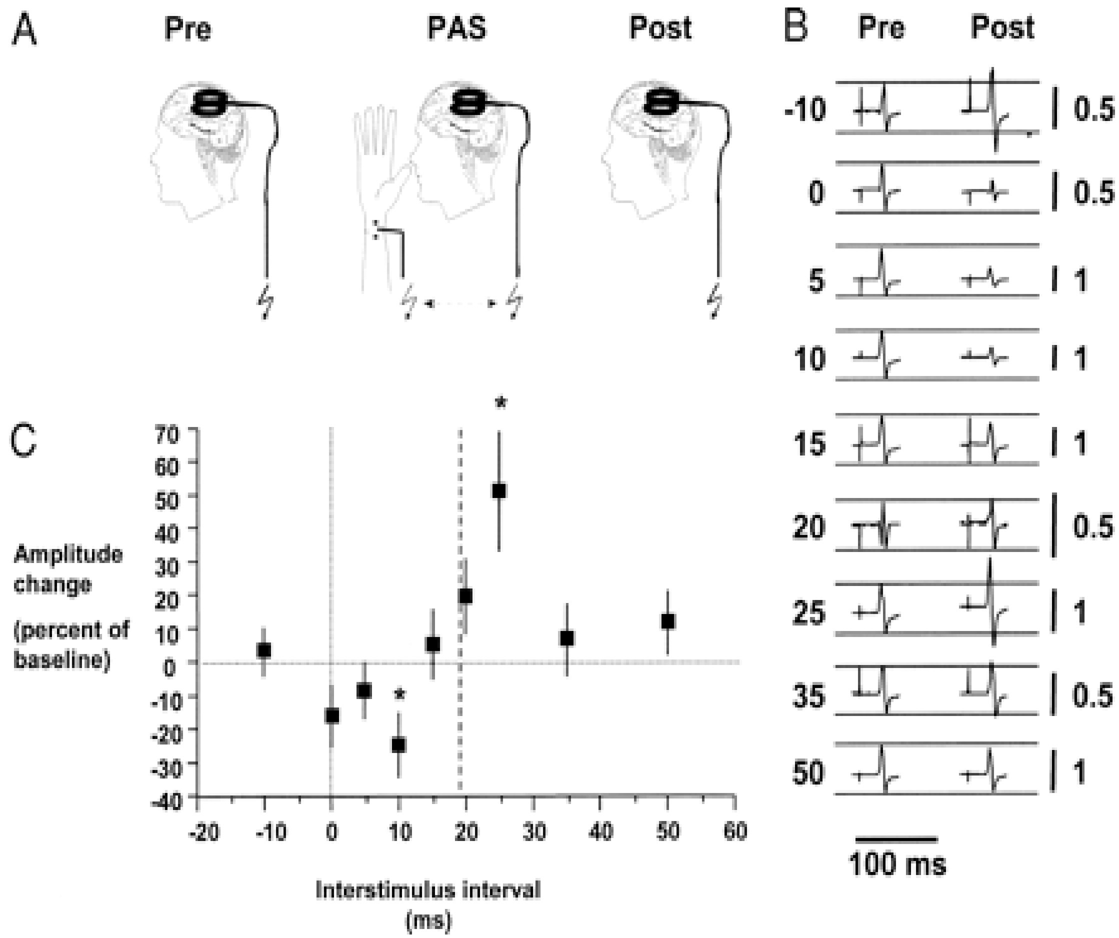


STDP of Visual Responses

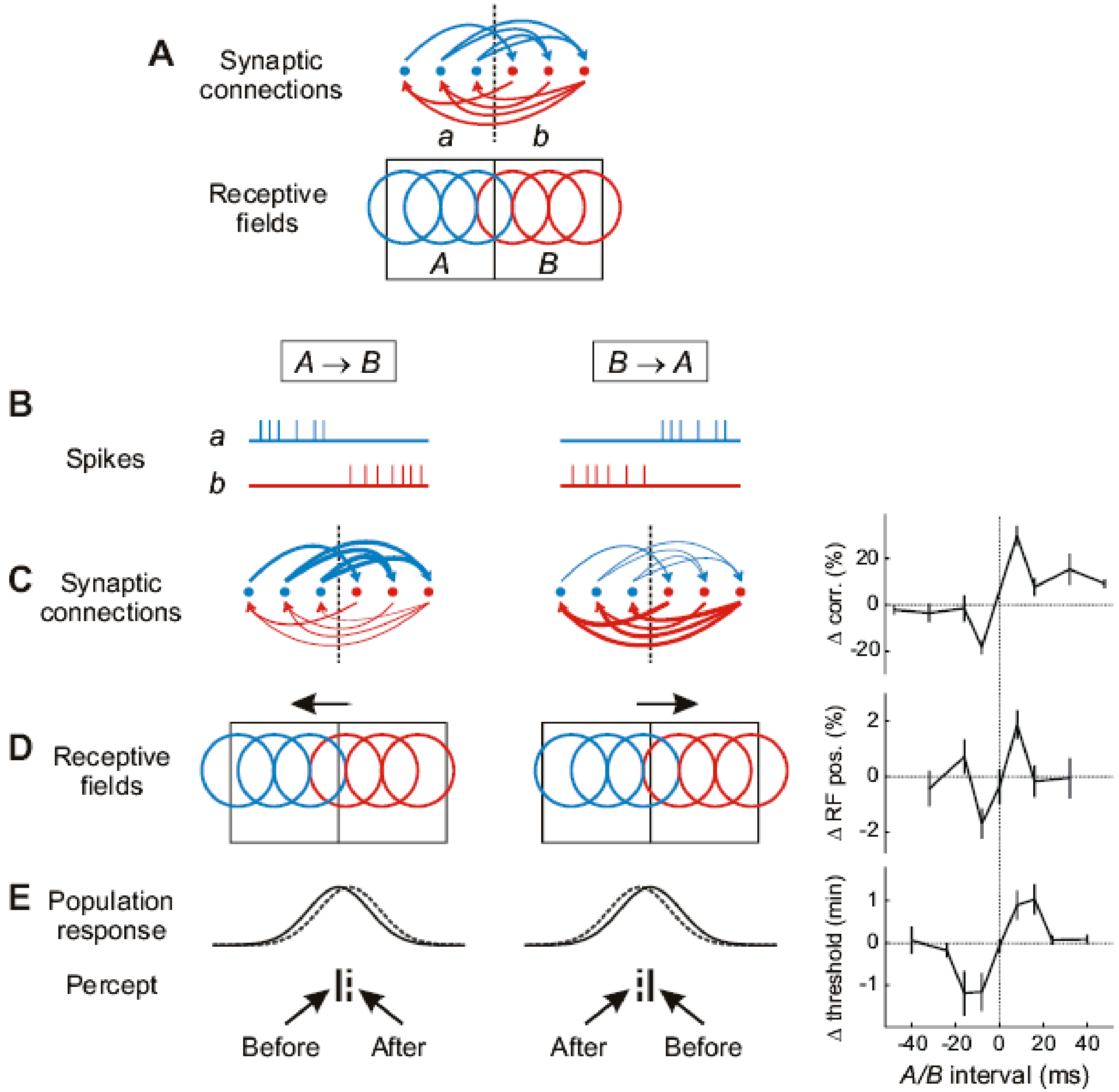




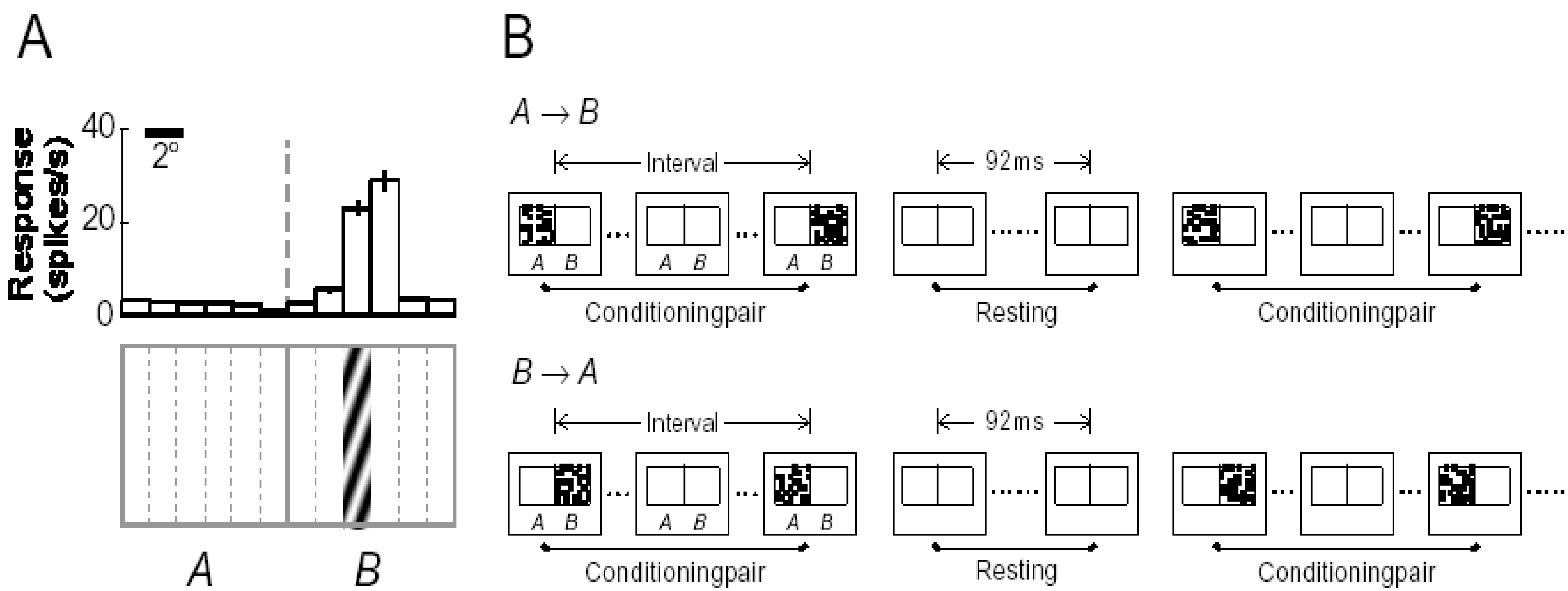
10 pA
100 ms
EPSC (pA)
10
0
-10
-20
-30
Delta (pA)
10
0
-10
50
100
150
200
250
300
Time (ms)
LTP
Change in EPSC (Normalized)
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-150
-100
-50
0
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
(n = 23)
-150
-100
-50
0
50
100
150
200
250
Time from Spike (ms)
LTD
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
100
200



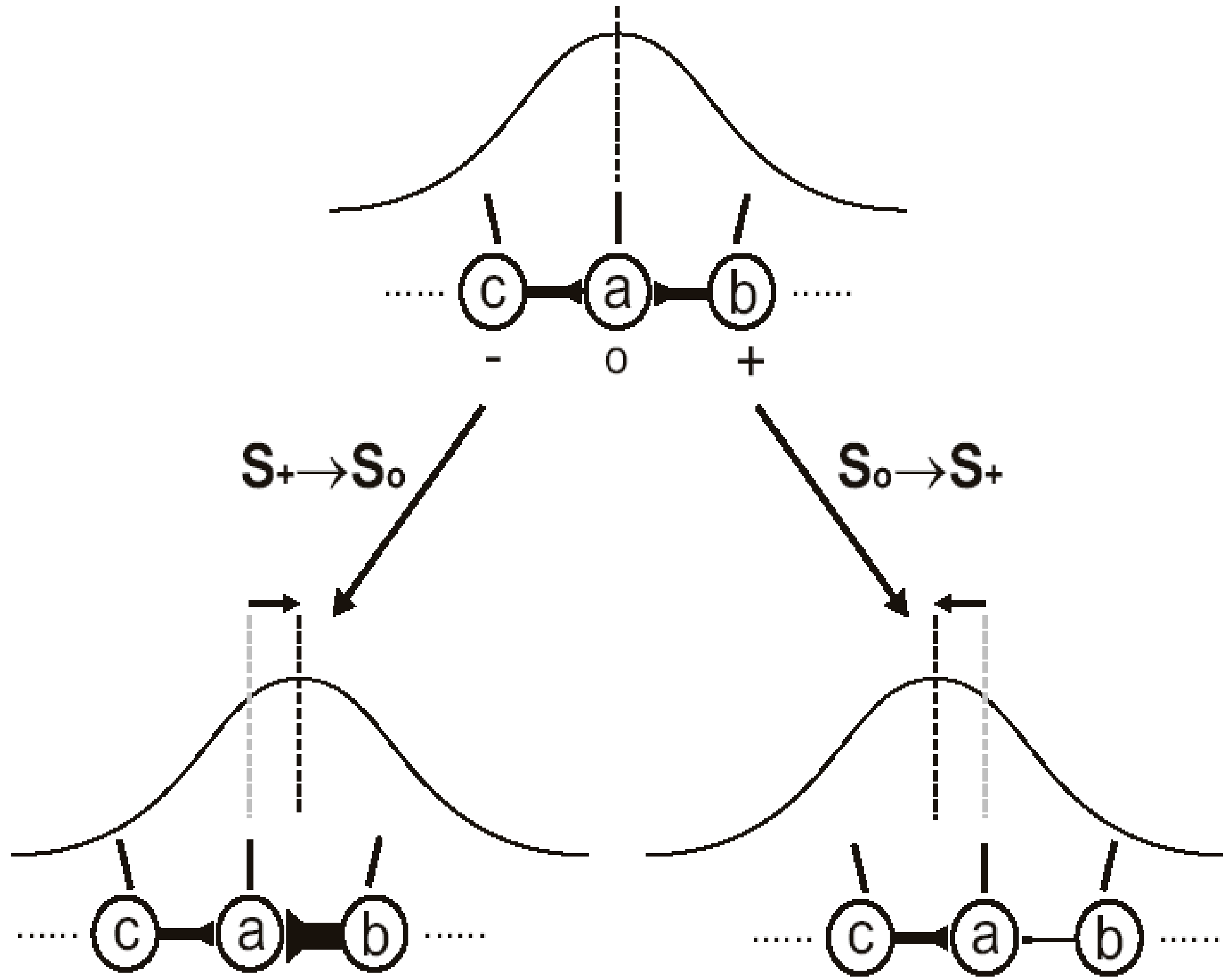
Wolters et al., *J. Neurophys,*, 2004



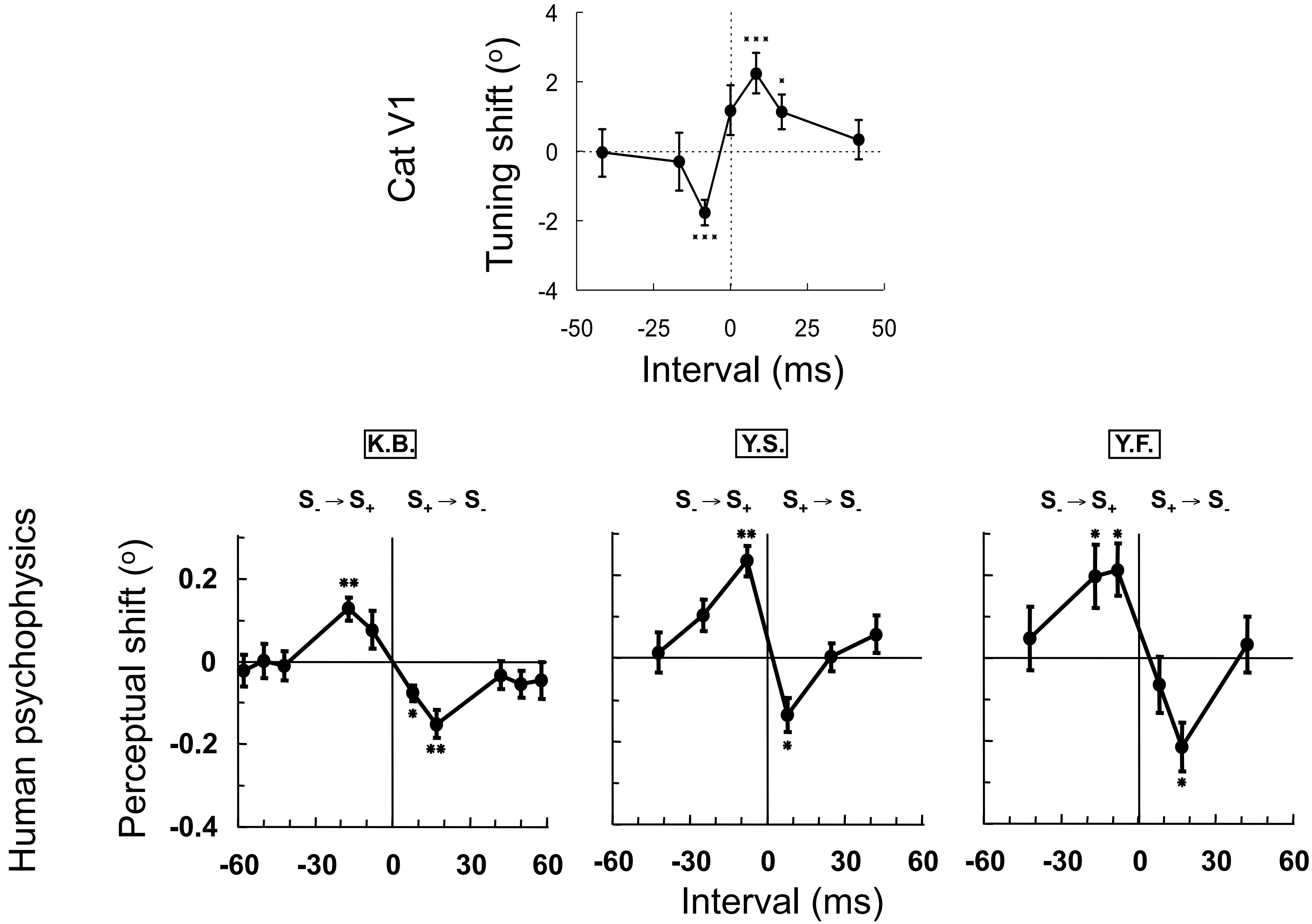
Fu et al., *Science*, 2002



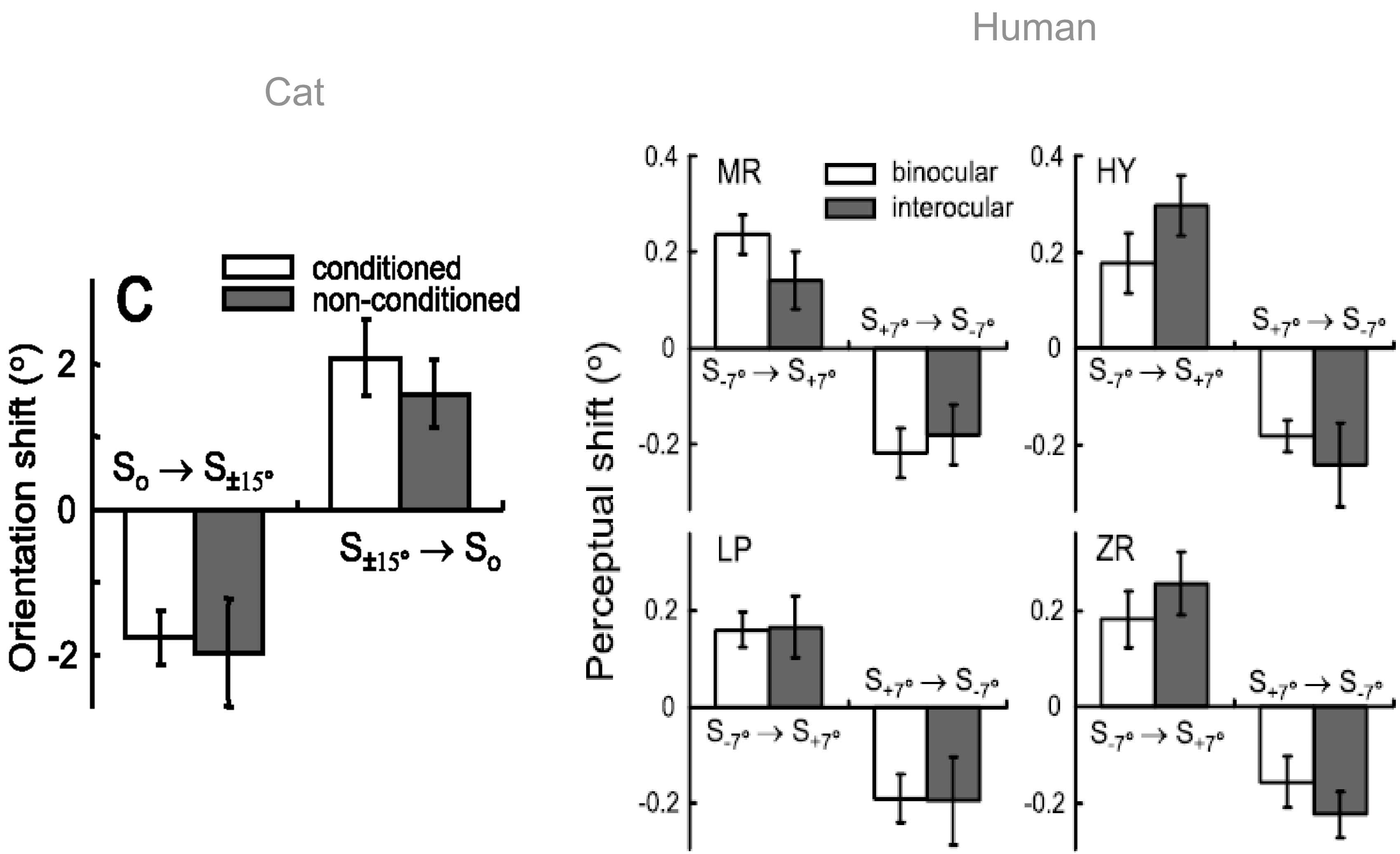
A
B
Response (spikes/s)
40
20
0
2°
A
B
A → B
Interval
92ms
Conditioningpair
Resting
Conditioningpair
B → A
Interval
92ms
Conditioningpair
Resting
Conditioningpair

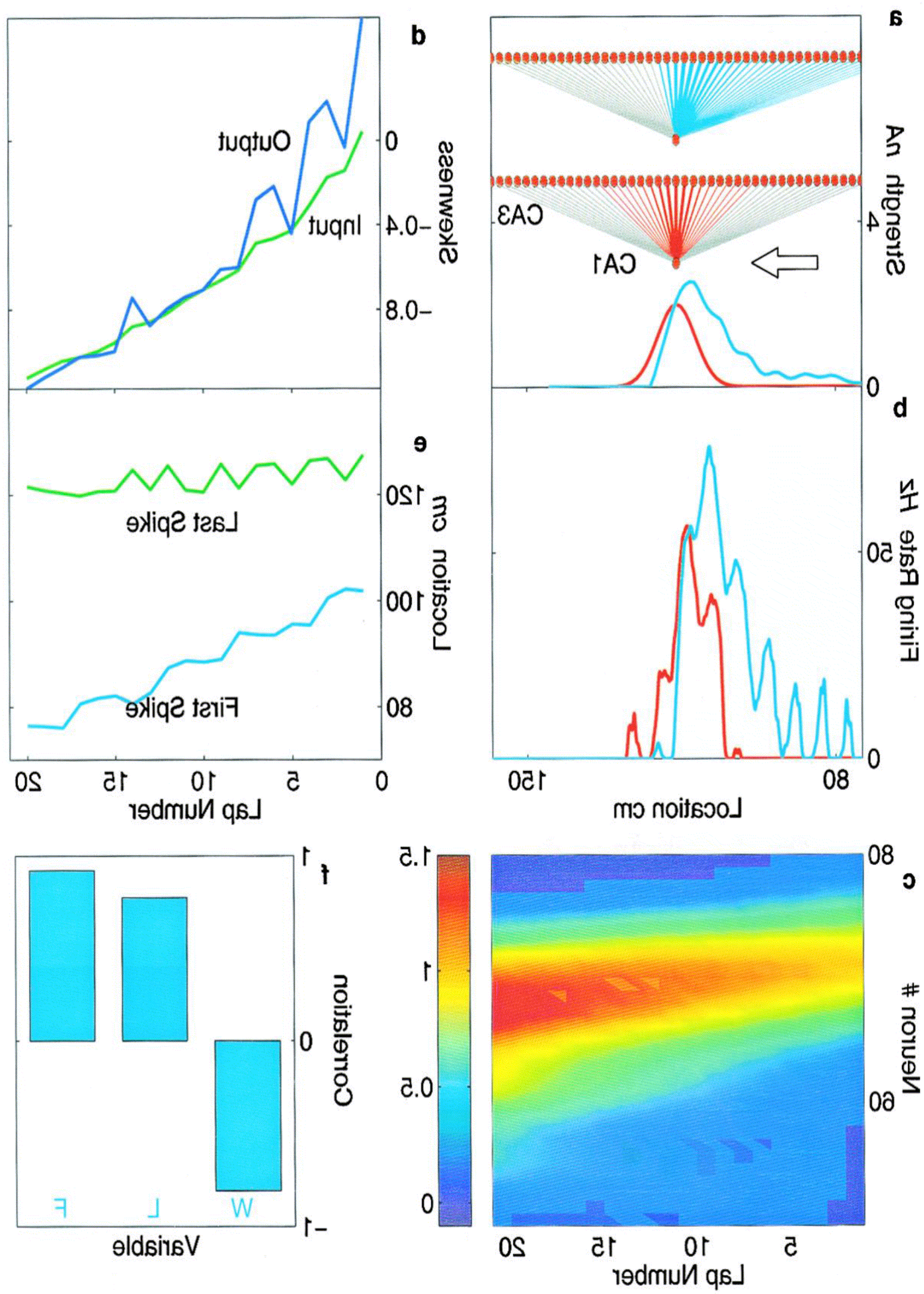


c
a
b
-
o
+
S+→So
So→S+
c
a
b
c
a
b



Yao et al., *Neuron*, 2001


Human
Cat
C
conditioned
non-conditioned
Orientation shift (°)
2
0
-2
$S_o \rightarrow S_{\pm15°}$
$S_{\pm15°} \rightarrow S_o$
Perceptual shift (°)
MR
HY
LP
ZR
binocular
interocular
0.4
0.2
0
-0.2
$S_{-7°} \rightarrow S_{+7°}$
$S_{+7°} \rightarrow S_{-7°}$



Mehta et al., *Neuron*, 2000

STDP and motion stimuli

⇓

Asymmetric circuit

⇓

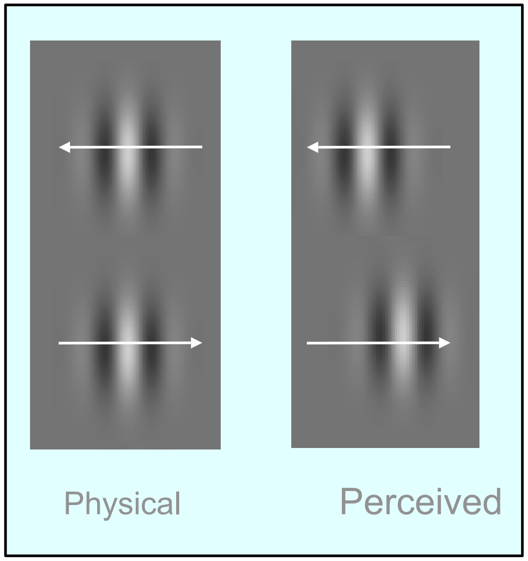
Effects of motion on V1 RF

⇓

Motion-position illusions

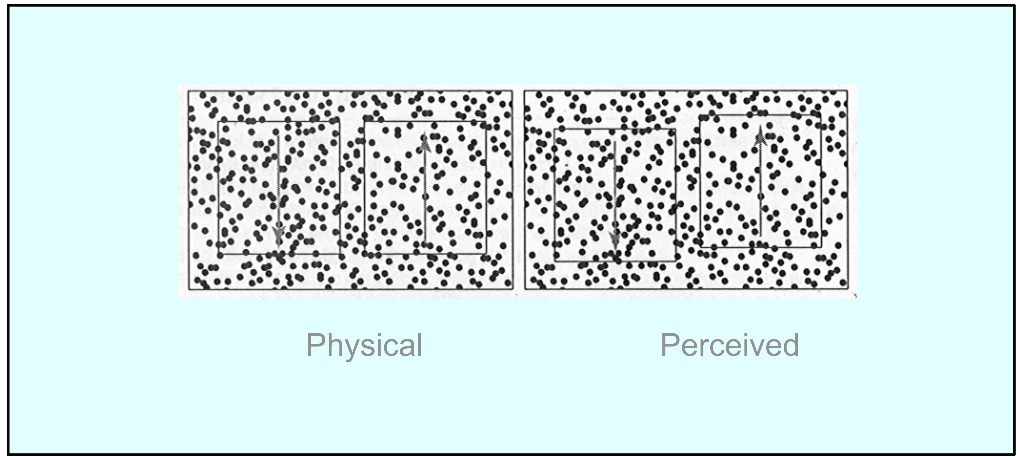
Illusion 1: Shift in Perceived Target Position Induced by Local Motion

De Valois & De Valois (1991)

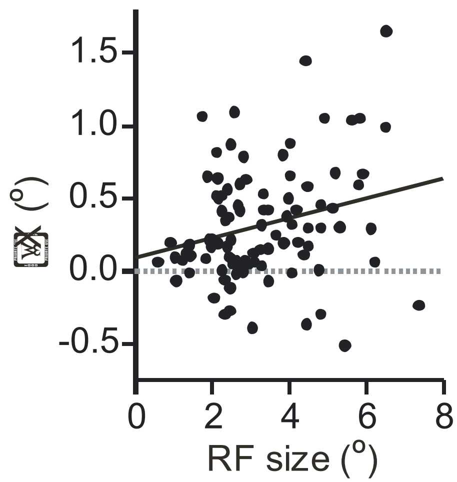


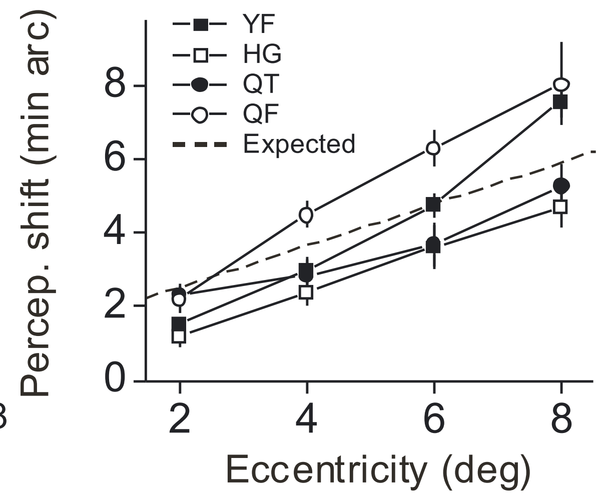
Demo

Ramachandran & Anstis (1990)



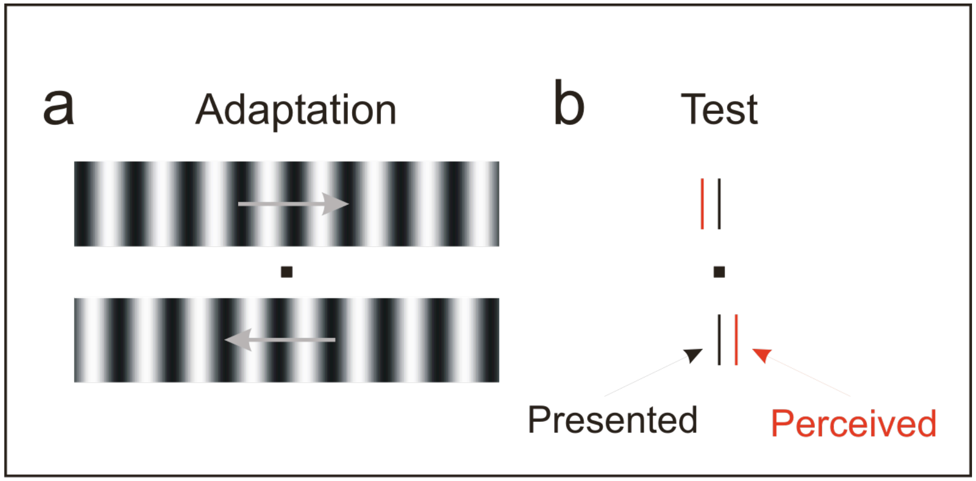
Demo



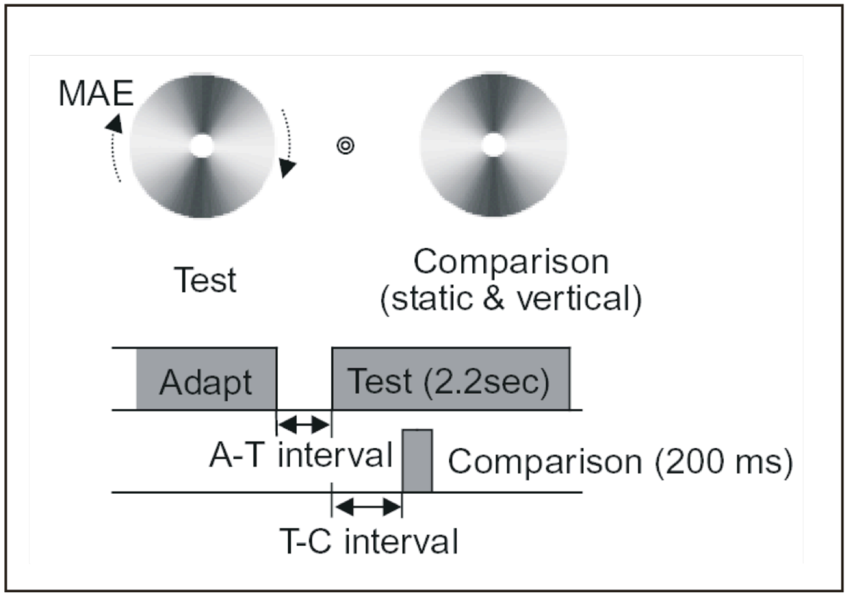


Illusion 2: Shift in Perceived Target Position Induced by Motion Adaptation

Snowden, 1998



Nishida & Johnston, 1999



STDP and motion stimuli

⇩

Asymmetric circuit

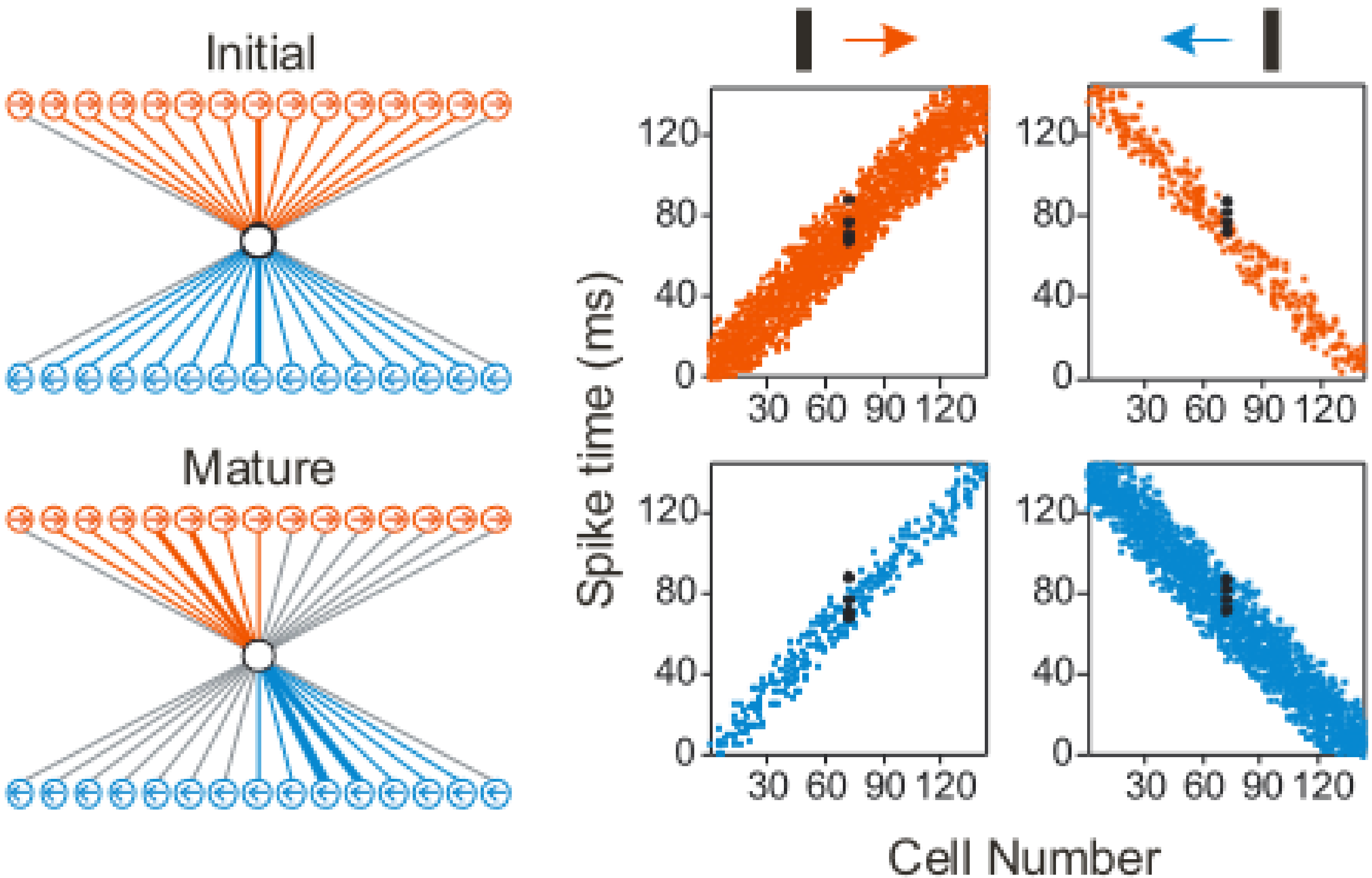
⇩

Effects of motion on V1 RF

⇩

Motion-position illusions

STDP and motion stimuli during development of cortex circuit



STDP and motion stimuli

↓

Asymmetric circuit

↓

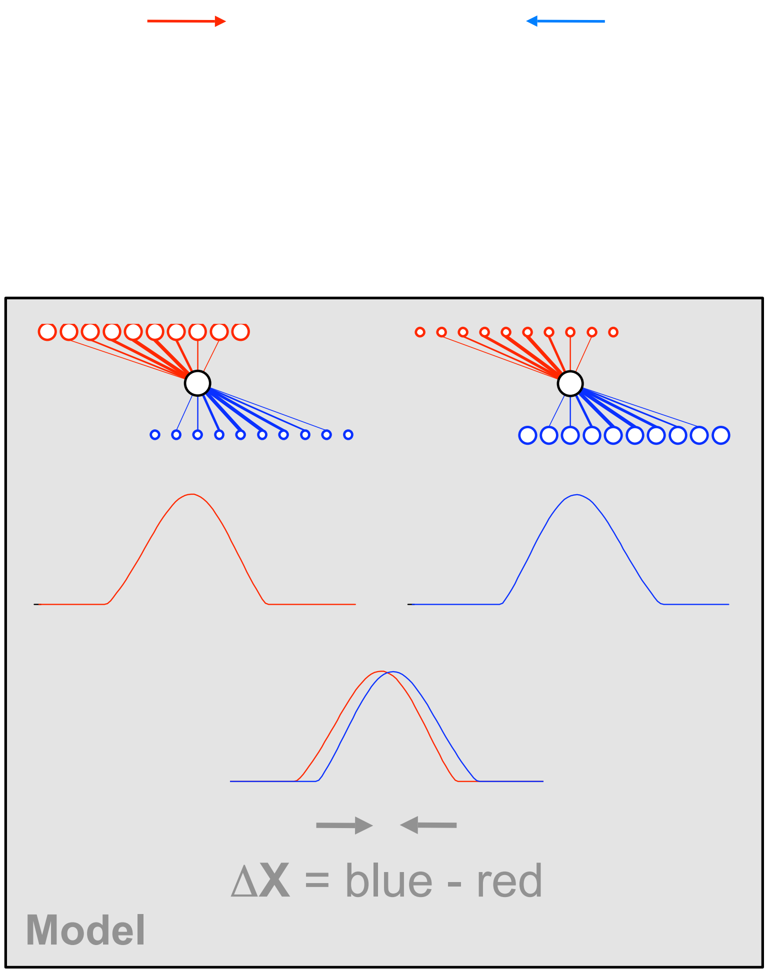
Effect of motion on V1 RF (1)

↓

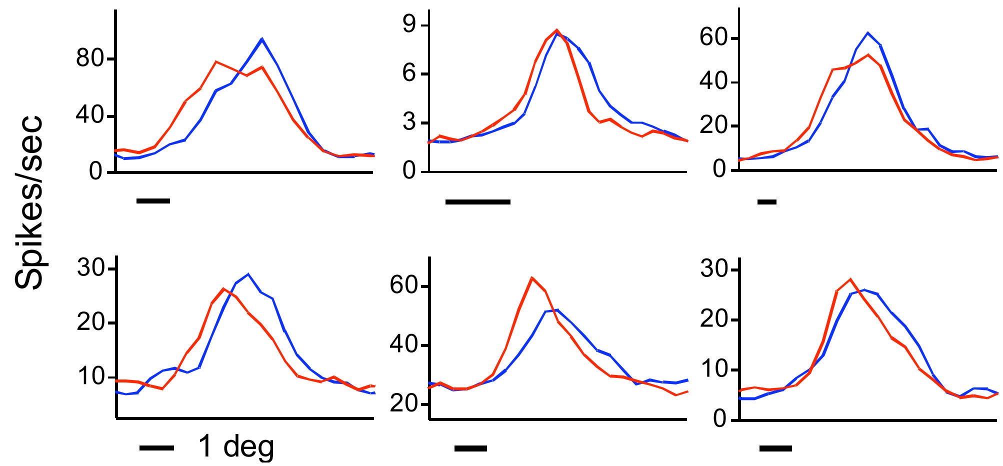
Motion-position illusion (1)

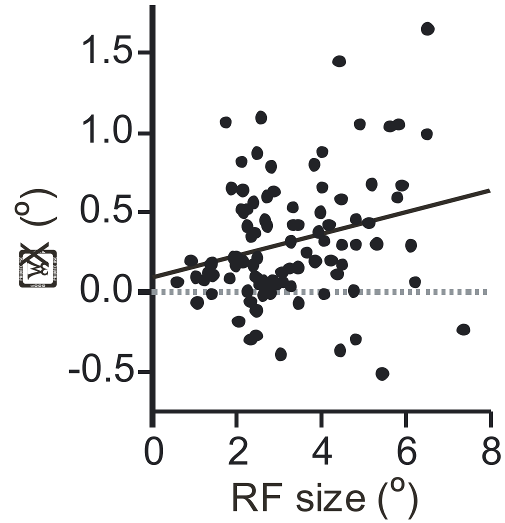
Prediction 1: Dependence of Cortical RF on Local Motion

RF Mapping w/ Local Motion



Data





Fu et al.,
J. Neurosci,, 2004

STDP and motion stimuli

⇩

Asymmetric circuit

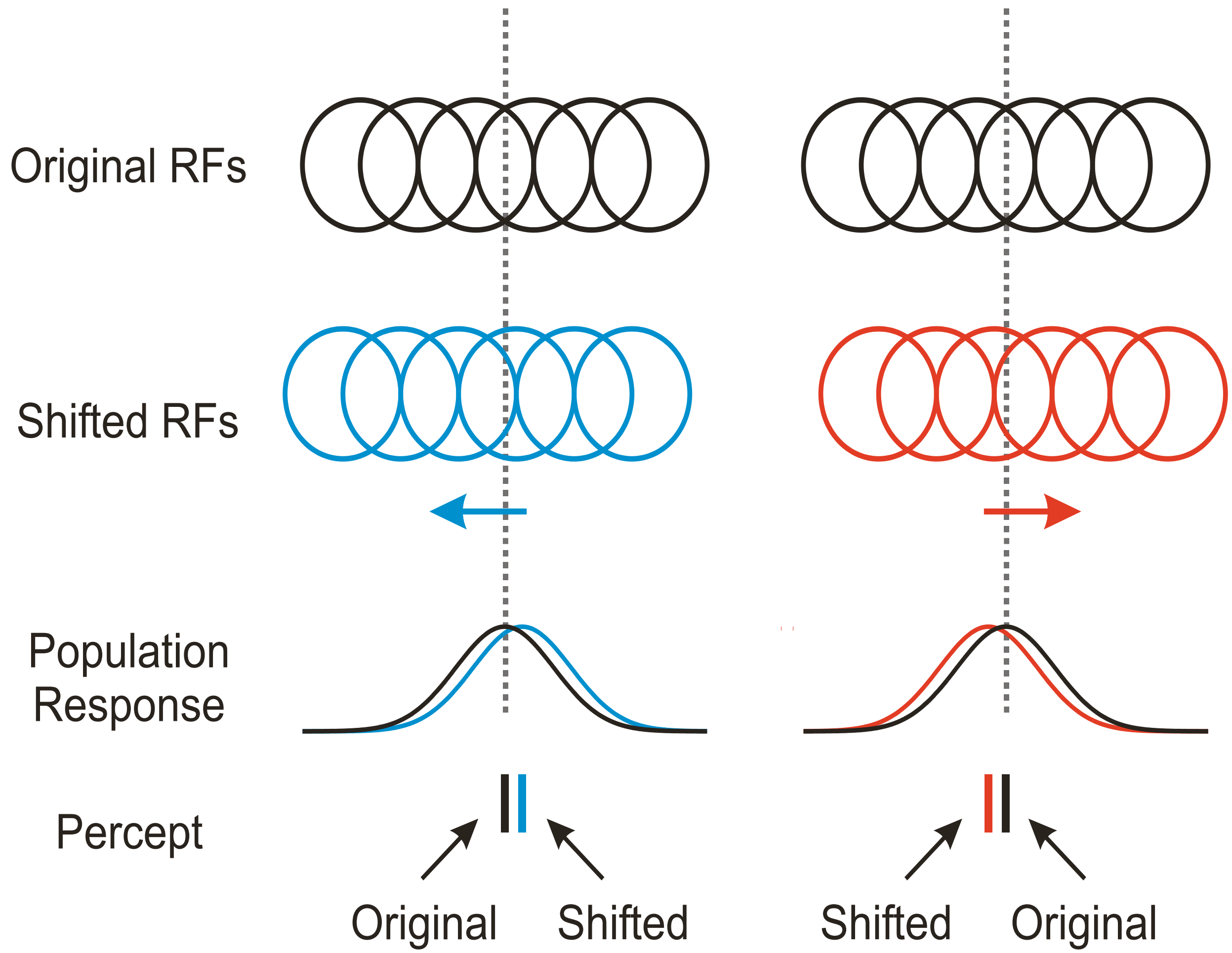
⇩

Effect of motion on V1 RF (1)

⇩

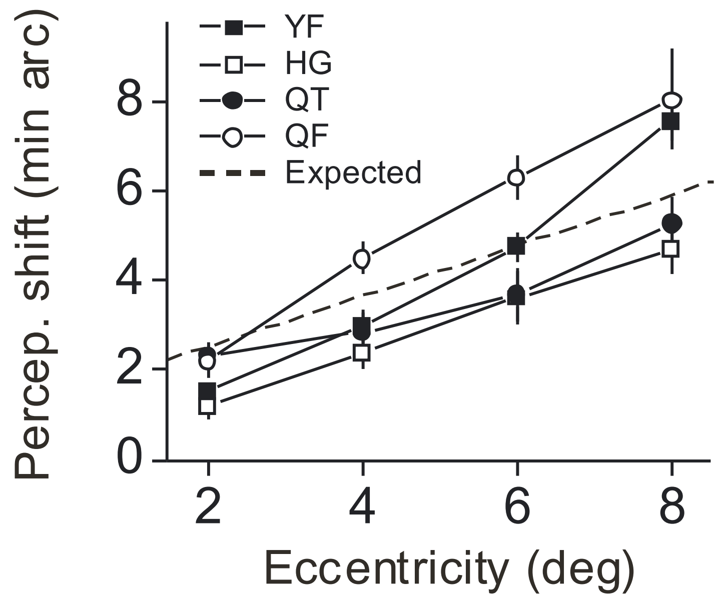
Motion-position illusion (1)

Population coding of position

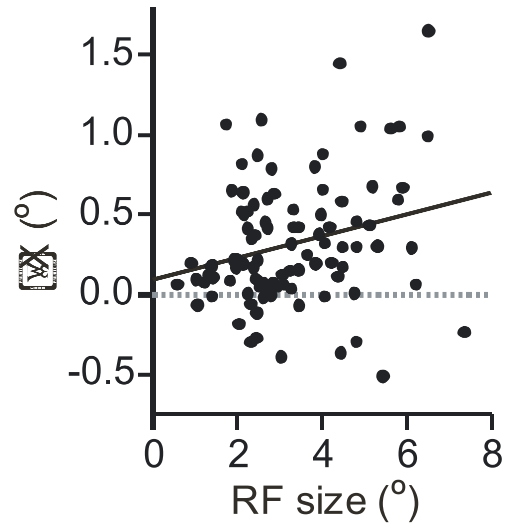


Physiological Basis of Illusion 1

Human Psychophysics



Cat V1



STDP and motion stimuli

⇩

Asymmetric circuit

⇩

Effect of motion on V1 RF (2)

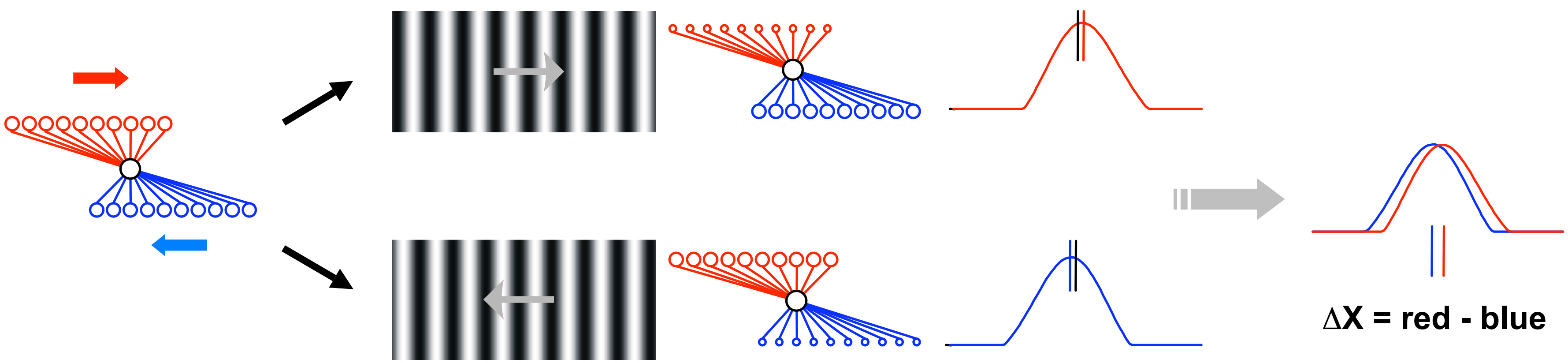
⇩

Motion-position illusion (2)

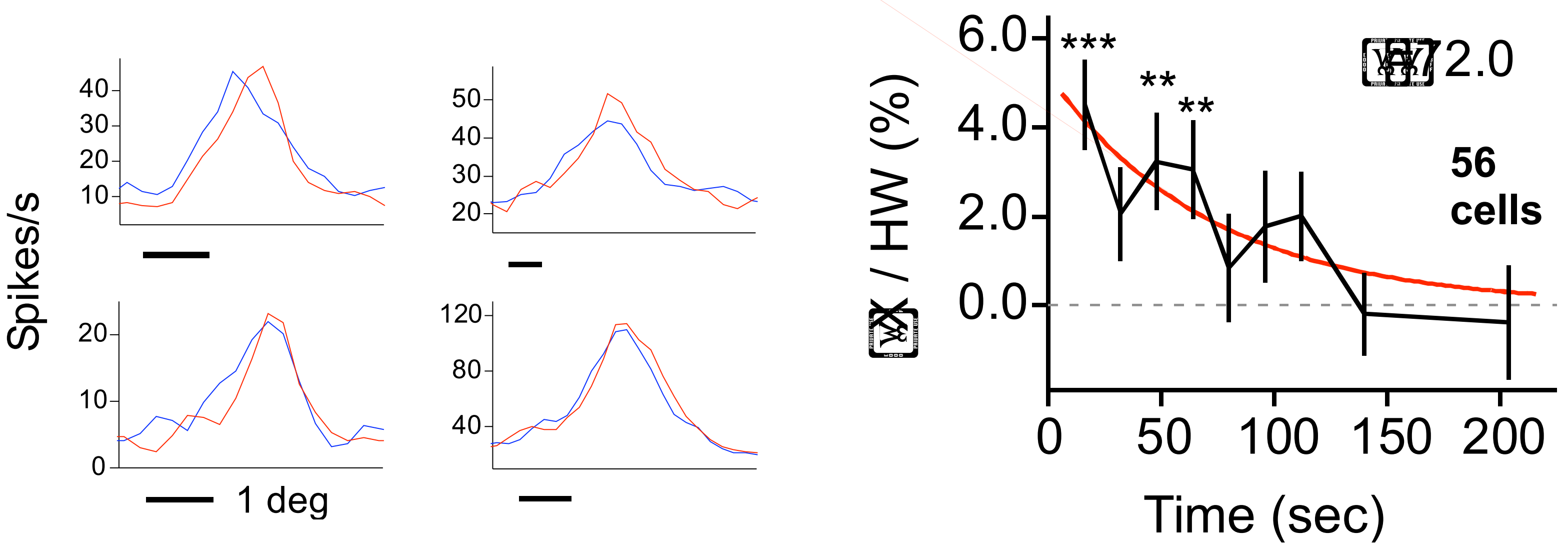
Prediction 2: Dependence of Cortical RF on Motion Adaptation

Model

Motion Adaptation **RF Mapping: Flash Bar**



Data



STDP and motion stimuli

⇩

Asymmetric circuit

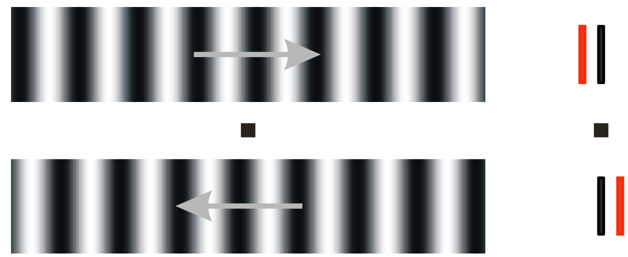
⇩

Effect of motion on V1 RF (2)

⇩

Motion-position illusion (2)

Physiological Basis of Illusion 2

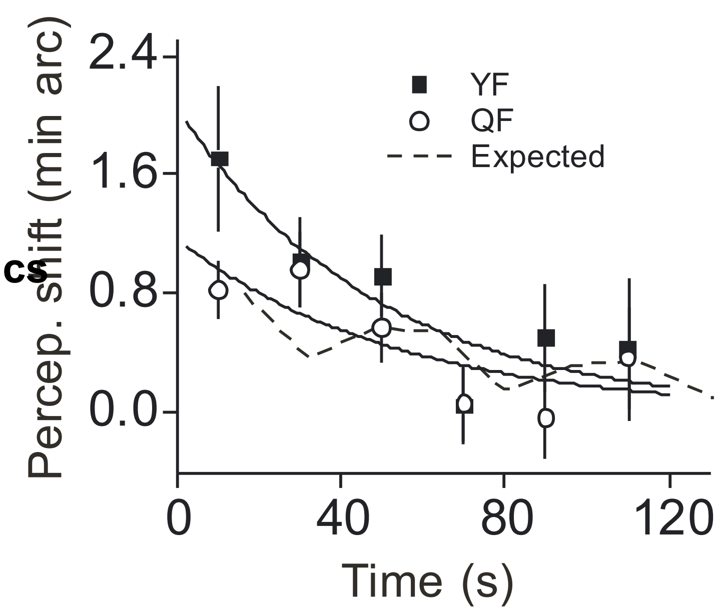


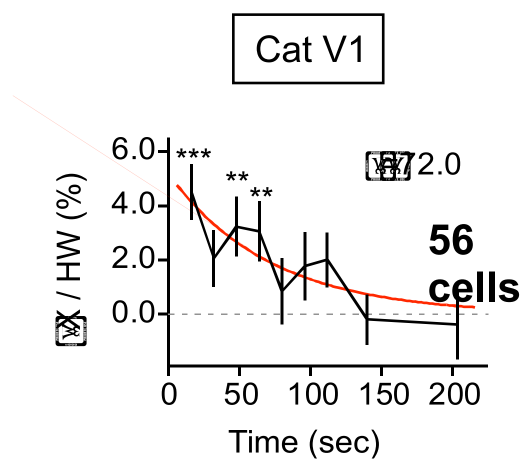
Adaptation

Physical/ Perceived

Psychophysics (Snowden, 1998)

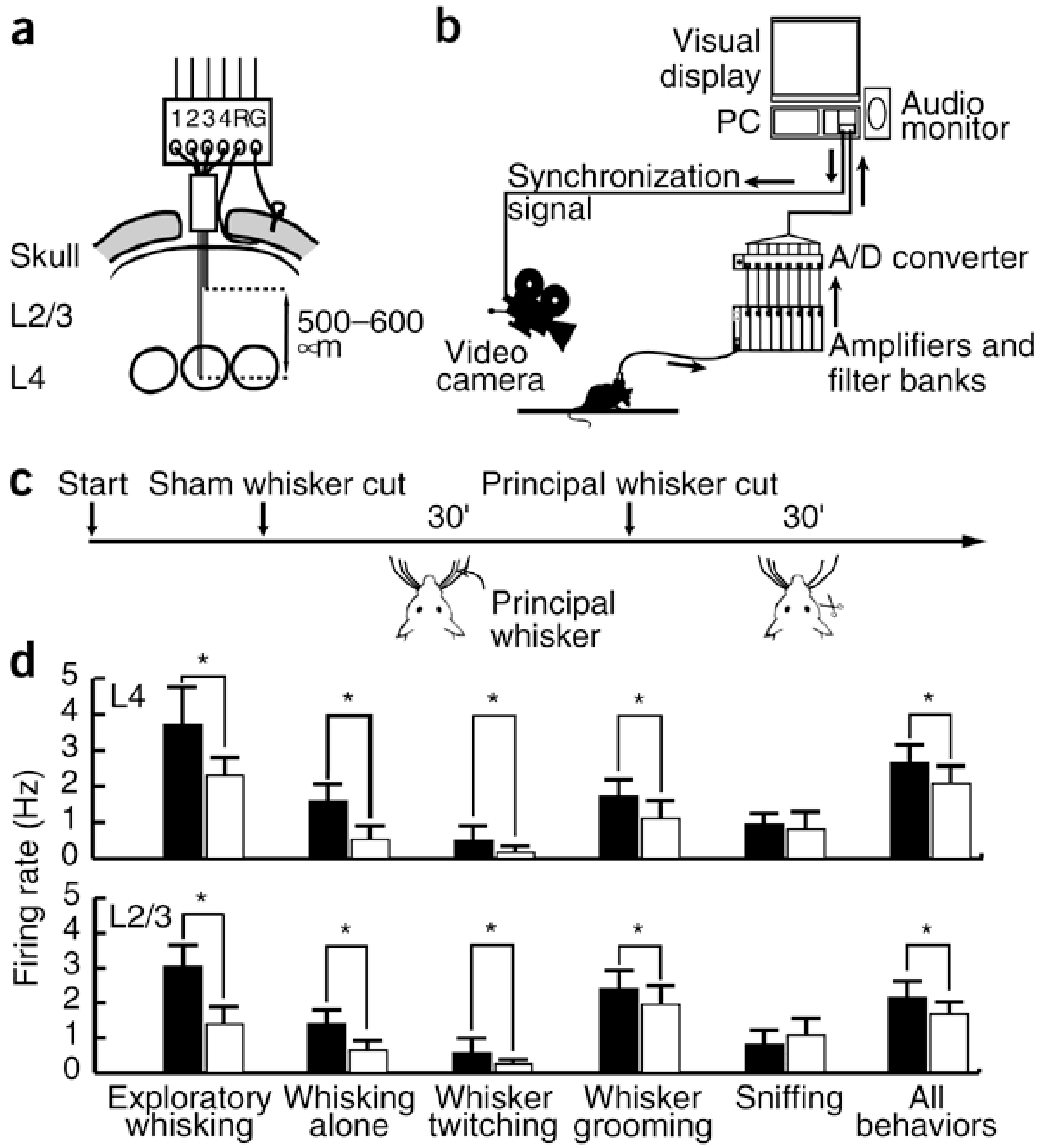
Human Psychophysics



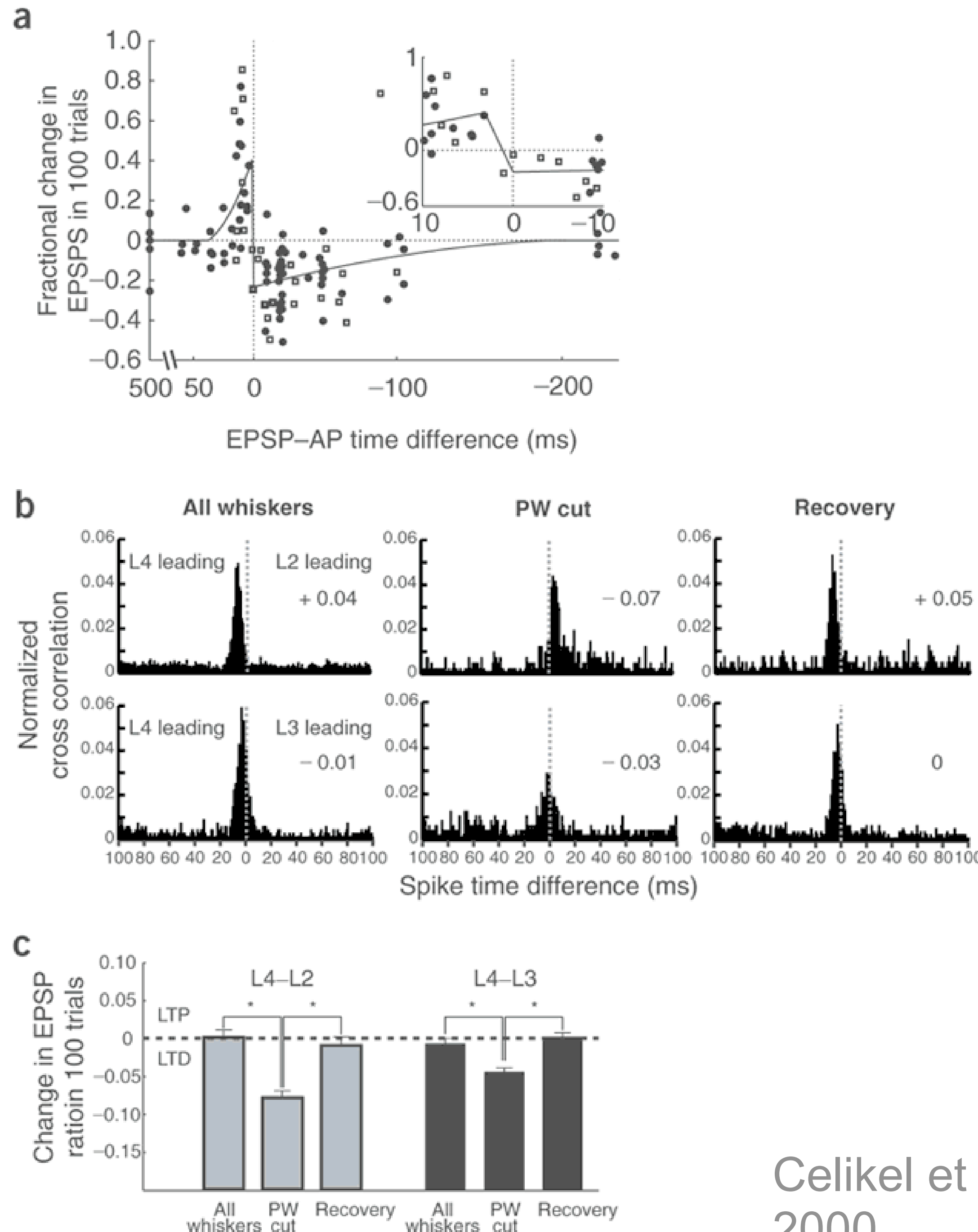


Visual cortical plasticity

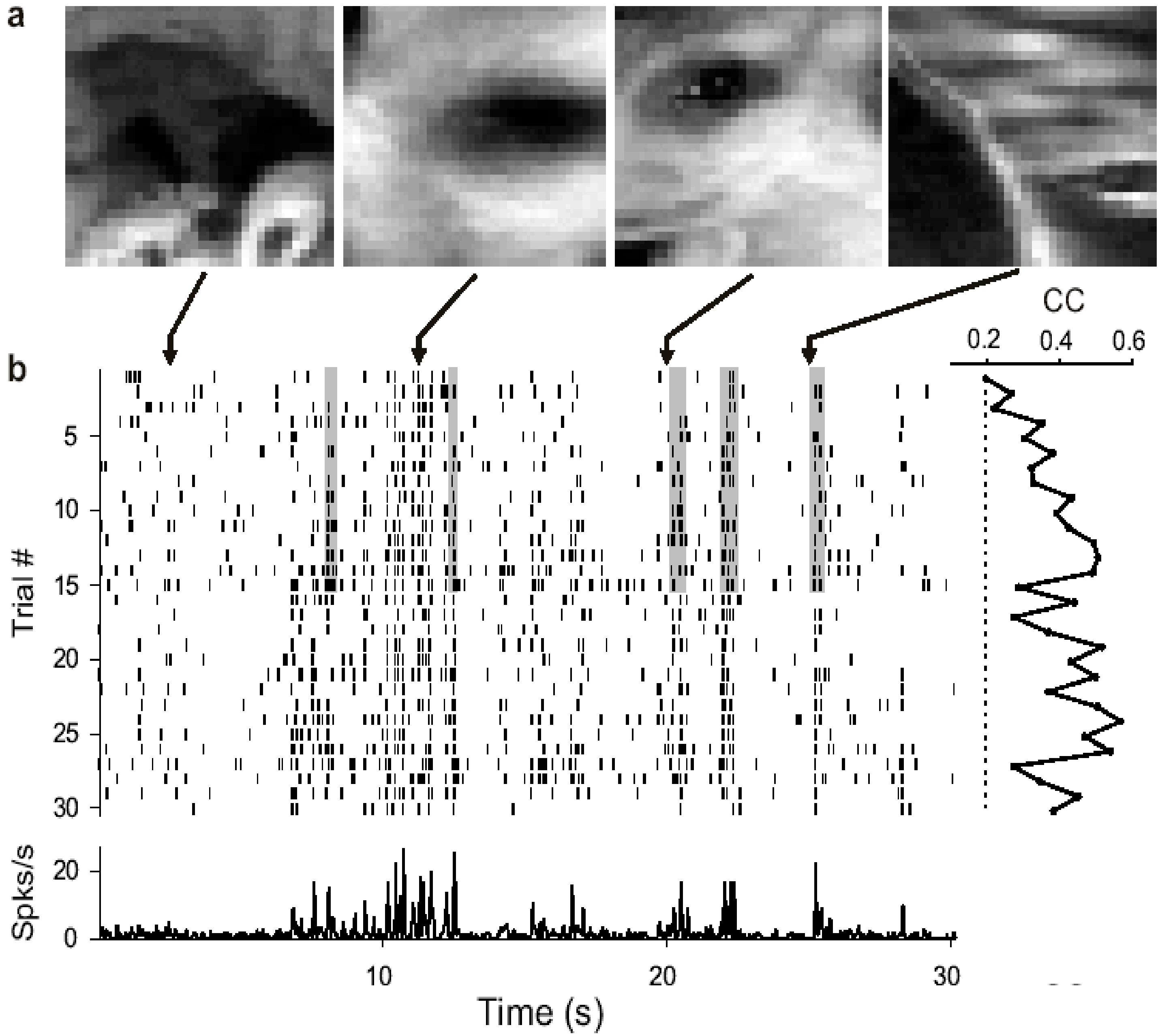
- Deprivation-induced changes in representation
  - Ocular dominance plasticity
  - Retinal scotoma and cortical re-organization
- Perceptual learning-related plasticity
- Timing-dependent plasticity



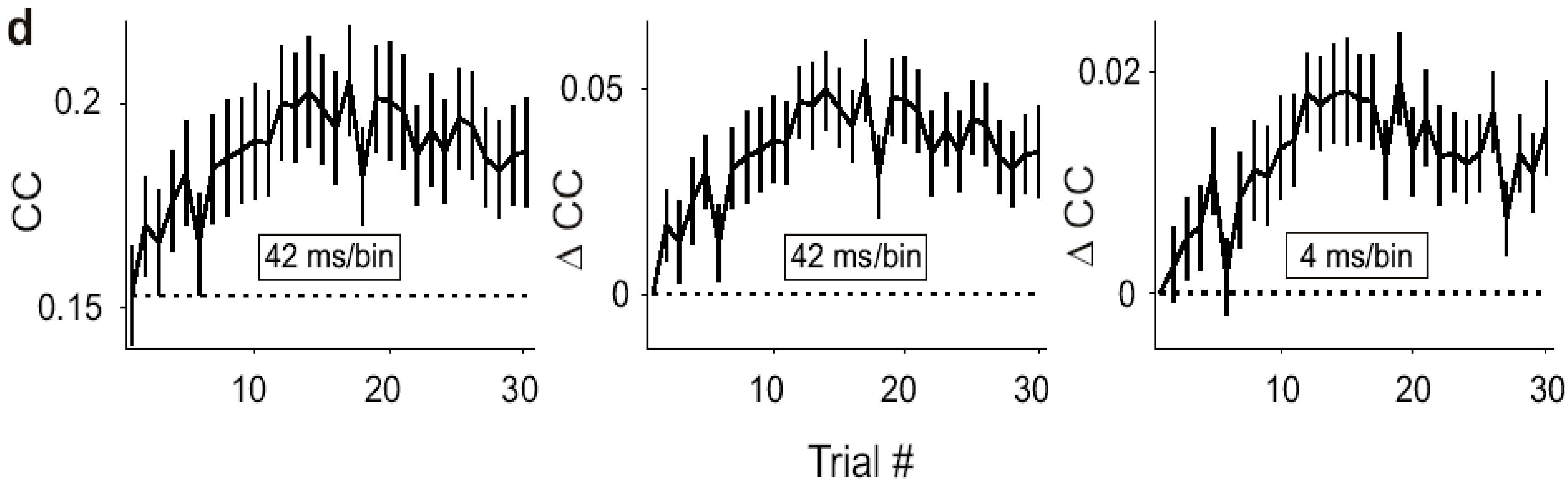
Celikel et al., Nature Neurosci, 2000



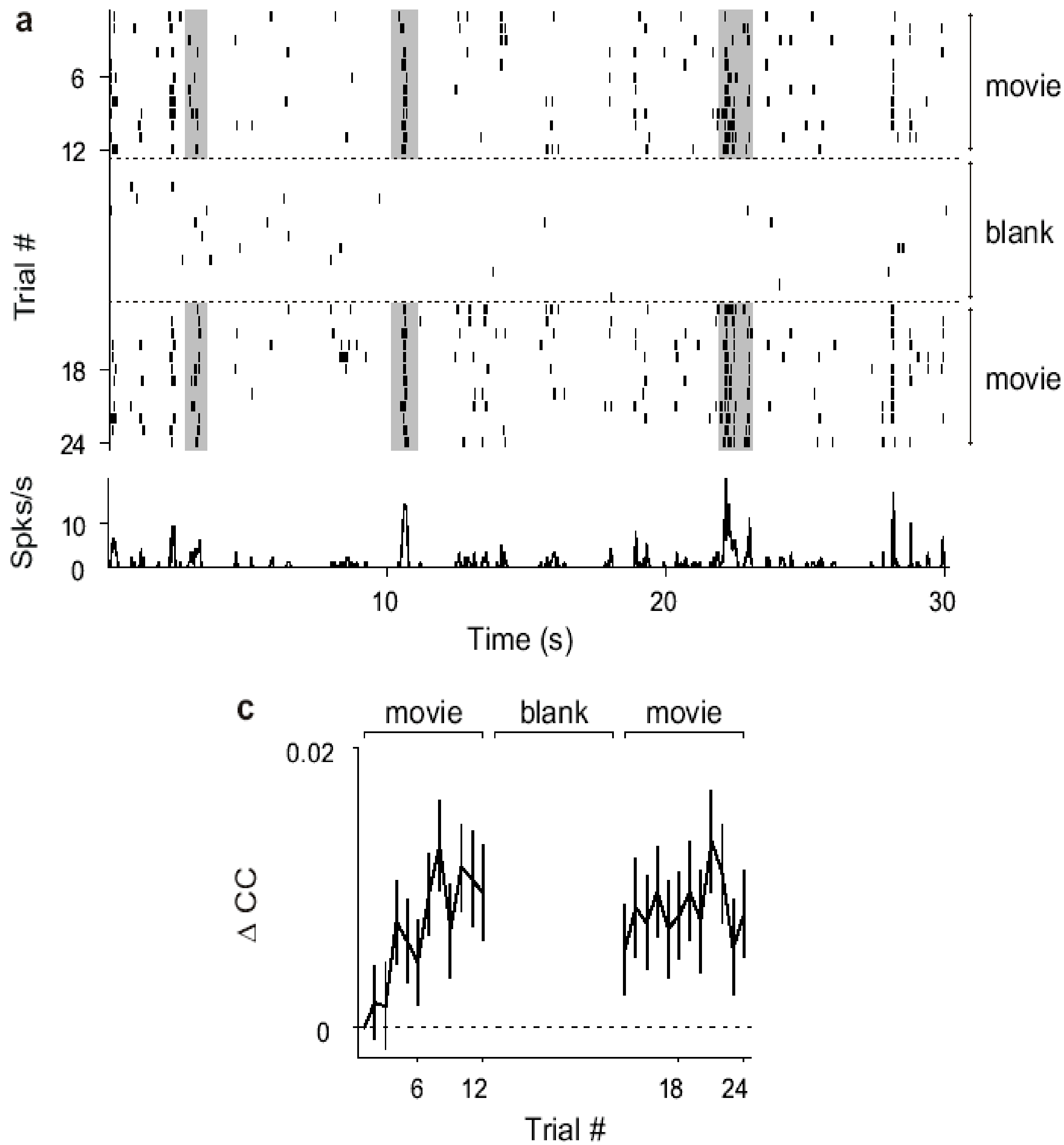
Celikel et al., Nature Neurosci, 2000



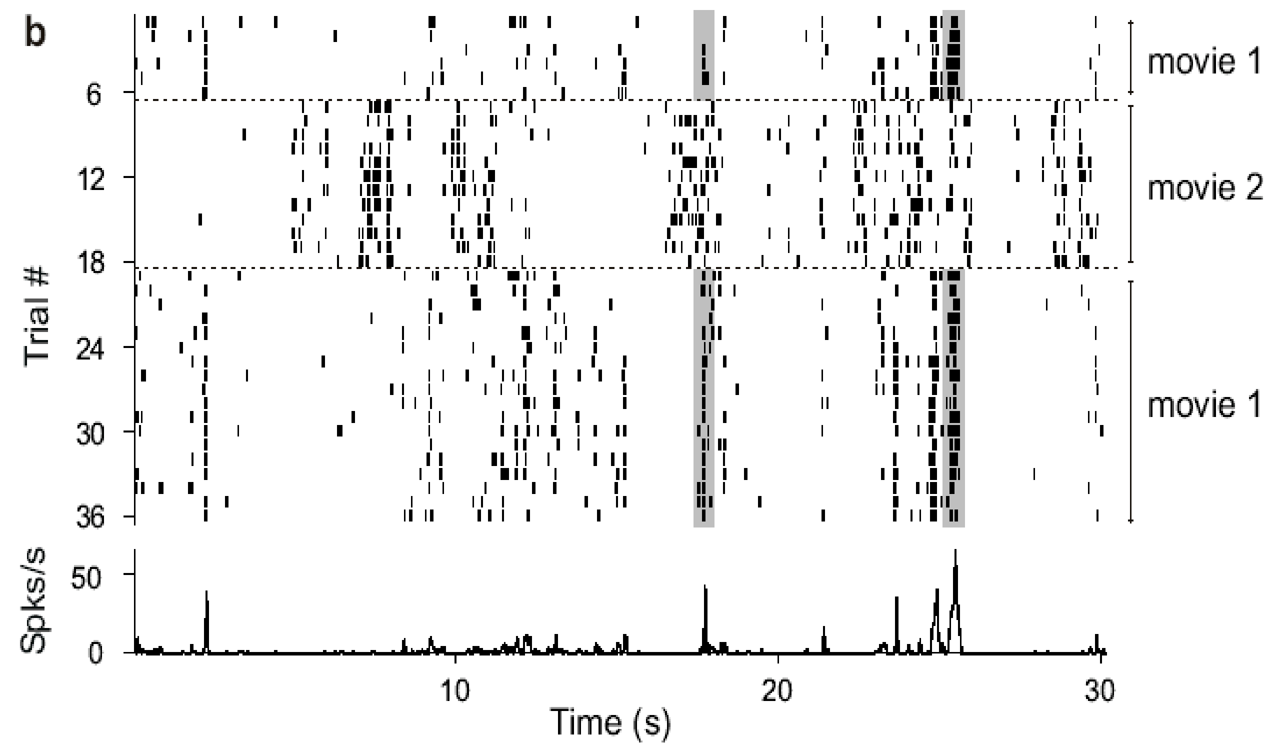
a
b
CC
0.2
0.4
0.6
Trial #
5
10
15
20
25
30
Spks/s
20
0
10
20
30
Time (s)

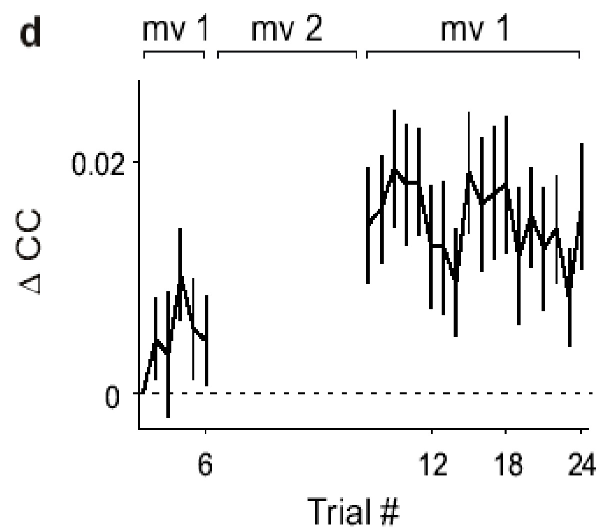


d
CC
0.2
0.15
42 ms/bin
10
20
30
Δ CC
0.05
0
42 ms/bin
10
20
30
Δ CC
0.02
0
4 ms/bin
10
20
30
Trial #



a
Trial #
6
12
18
24
movie
blank
movie
Spks/s
10
0
10
20
30
Time (s)
c
movie
blank
movie
0.02
0
Δ CC
6
12
18
24
Trial #


b
movie 1
movie 2
movie 1
Trial #
6
12
18
24
30
36
Spks/s
50
0
10
20
30
Time (s)


d
mv 1
mv 2
mv 1
Δ CC
0.02
0
6
12
18
24
Trial #

What we found so far

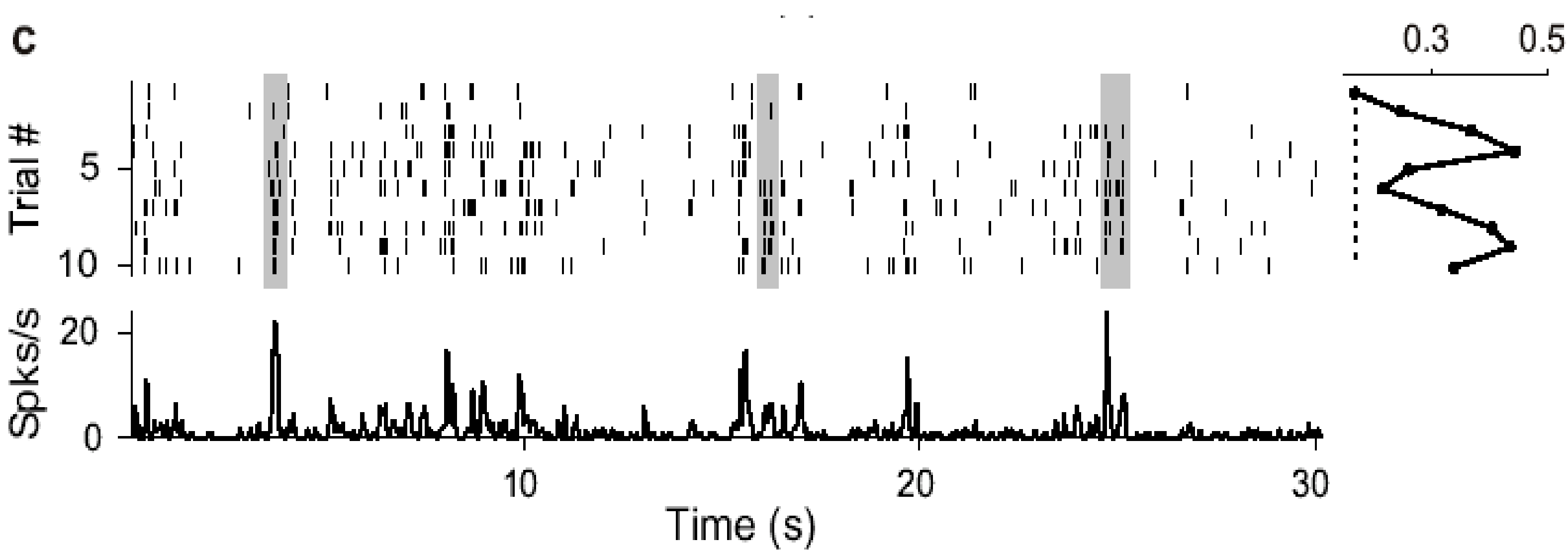
1. Repeated exposure to natural stimuli (and possibly other types of stimuli) enhances response reliability

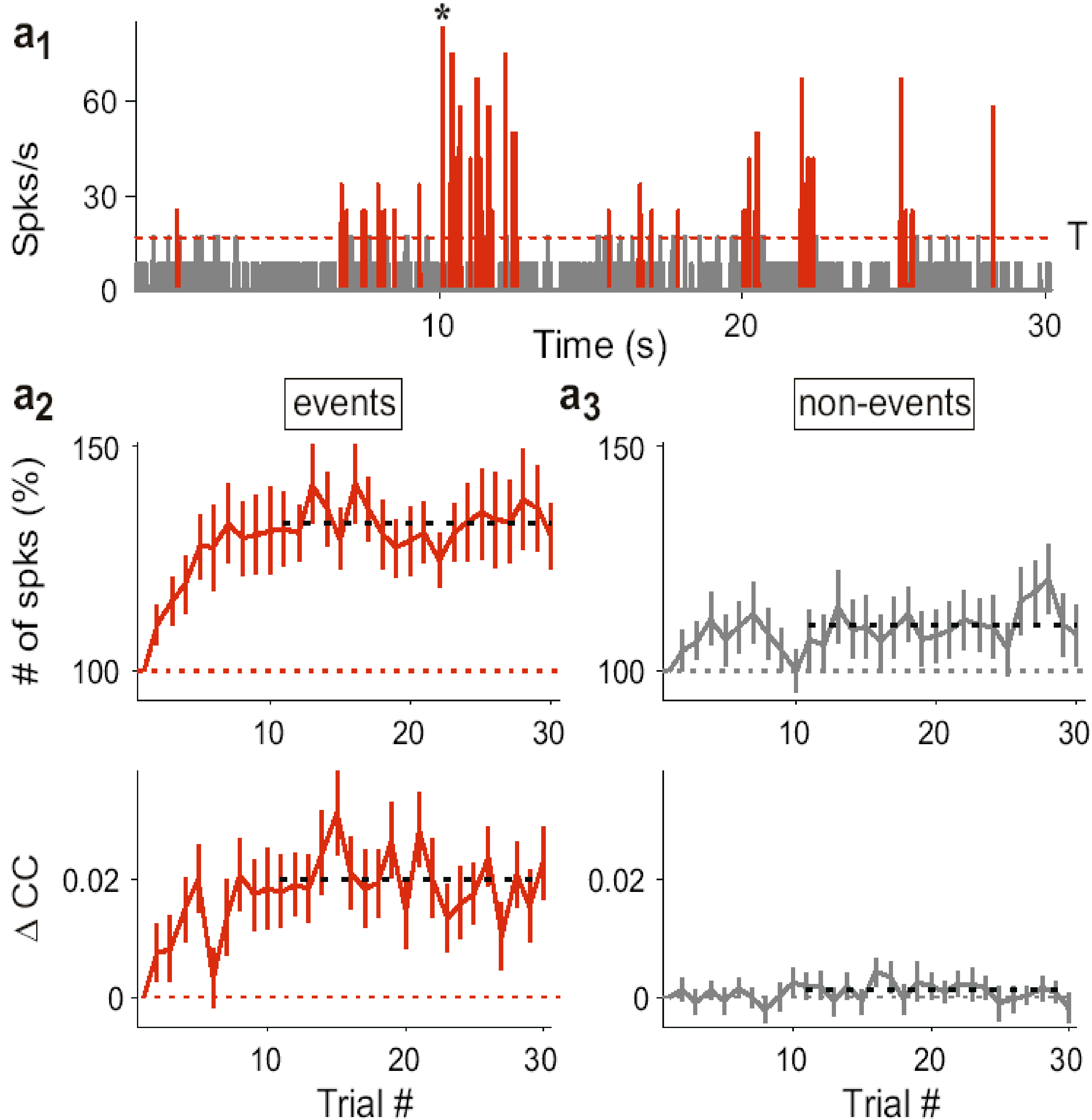
2. The effect lasts for at least 6 minutes

Questions

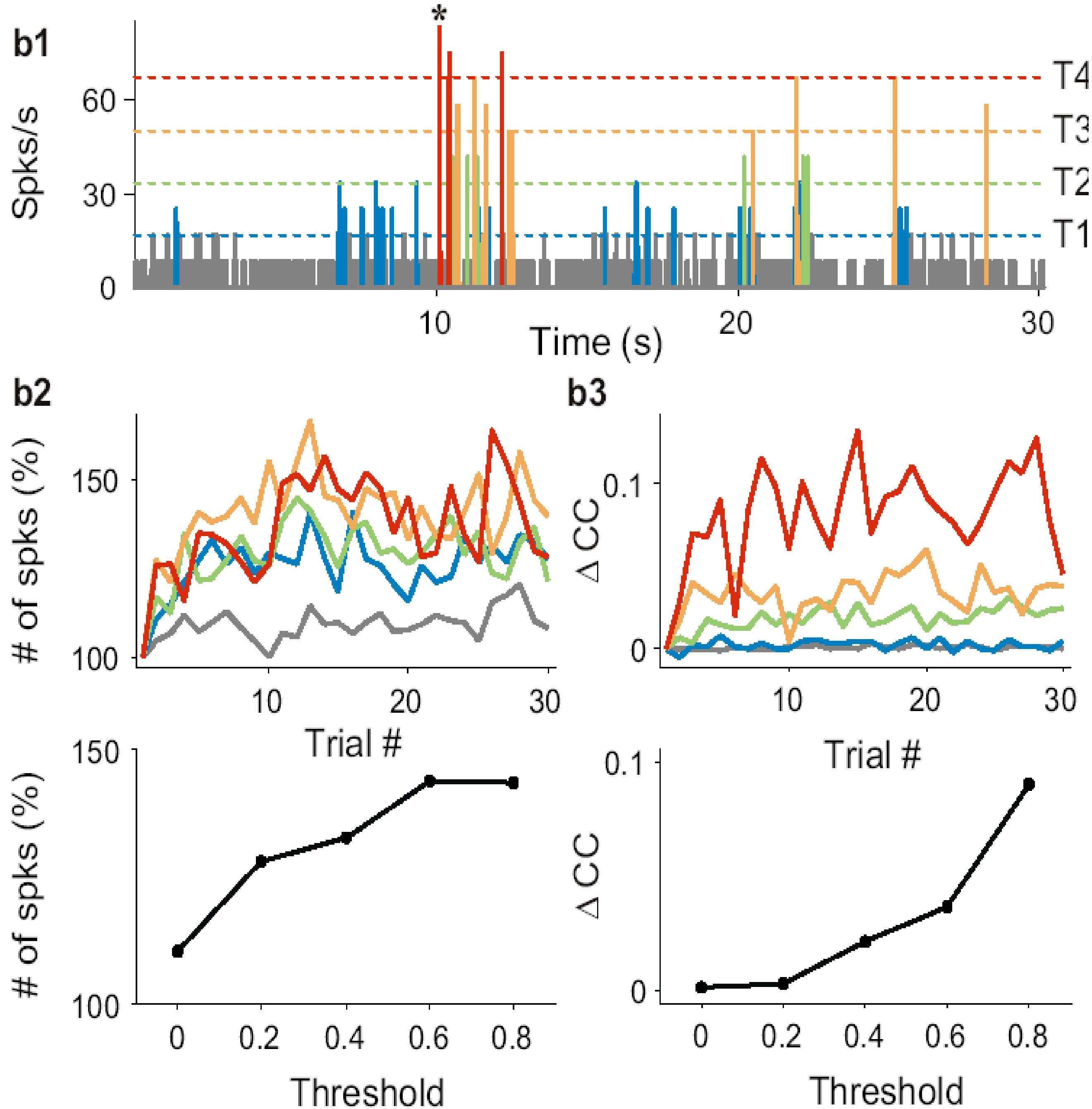
- Which part of the natural stimuli induce the changes in cortical neurons?

- What changes in response properties underlie the improvement in reliability?


c
Trial #
5
10
Spks/s
20
0
10
20
30
Time (s)
0.3
0.5



a1
*
Spks/s
60
30
0
T
10
20
30
Time (s)
a2
events
# of spks (%)
150
100
10
20
30
ΔCC
0.02
0
10
20
30
Trial #
a3
non-events
150
100
10
20
30
0.02
0
10
20
30
Trial #

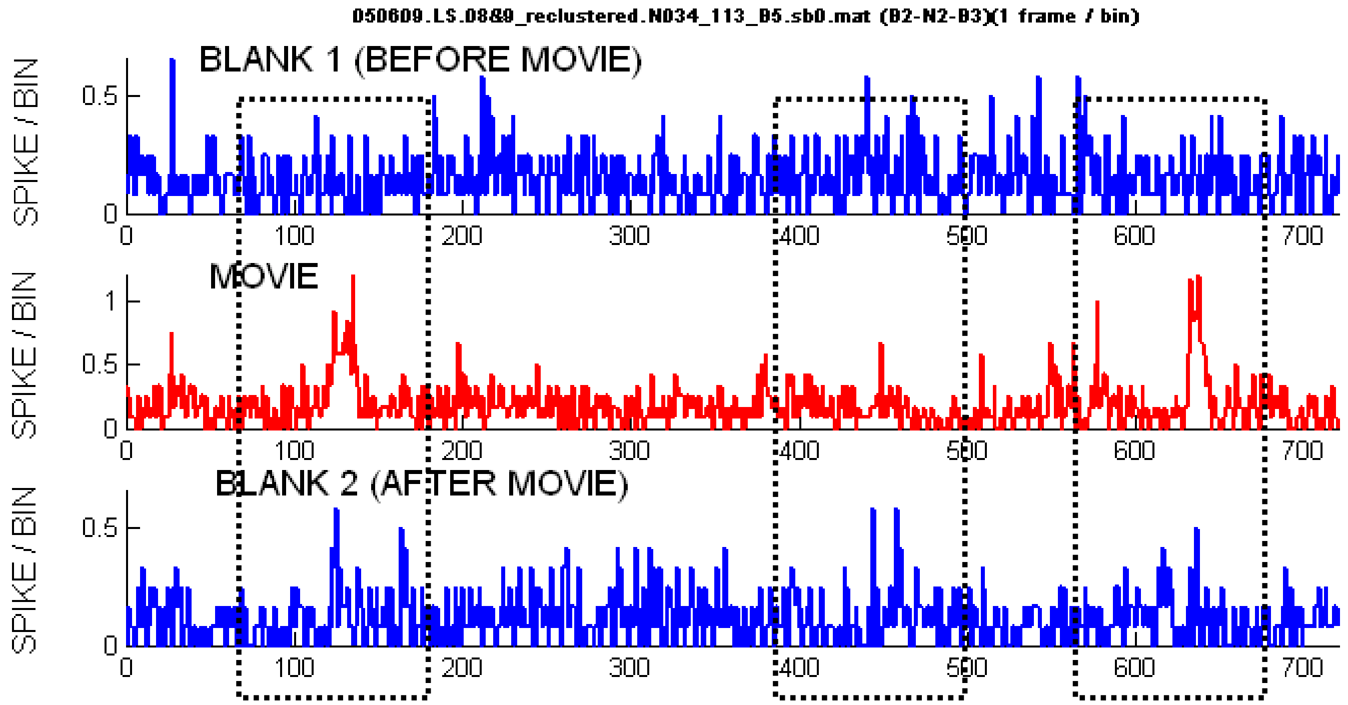


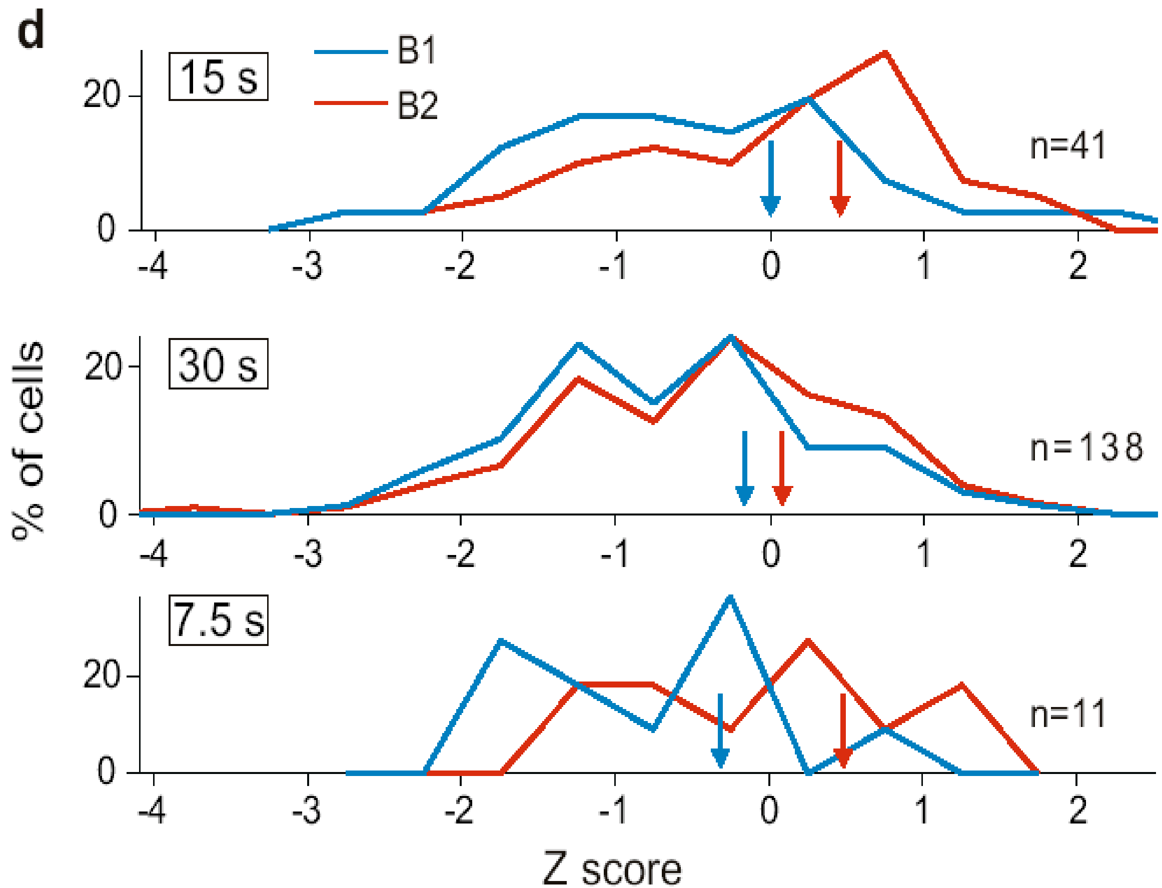
b1
Spks/s
60
30
0
*
T4
T3
T2
T1
10
20
30
Time (s)
b2
# of spks (%)
150
100
10
20
30
Trial #
b3
Δ CC
0.1
0
10
20
30
Trial #
150
# of spks (%)
100
0
0.2
0.4
0.6
0.8
Threshold
0.1
Δ CC
0
0
0.2
0.4
0.6
0.8
Threshold

1. Which part of the natural stimuli induce the changes in cortical neurons?
    1. Preferred stimuli (?)

2. What changes in response properties underlie the improvement in reliability?
    1. Point process adaptive filtering, but we haven’t found anything consistent...

CC between movie motifs and spontaneous motifs




d
15 s
B1
B2
n=41
30 s
n=138
7.5 s
n=11
% of cells
Z score
20
0
-4
-3
-2
-1
0
1
2

Hongfeng Gao

Kaj Djupsund

Kai Shen

Ben Hayden

Yaosong Shen