Visual cortical plasticity

• Deprivation-induced changes in representation
  – Ocular dominance plasticity
  – Retinal scotoma and cortical re-organization

• Perceptual learning-related plasticity

• Timing-dependent plasticity
Visual cortical plasticity

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Ocular dominance plasticity

Definition of *ocular dominance index*:

\[
OD = \frac{\text{Response}_{\text{ipsi}}}{\text{Response}_{\text{ipsi}} + \text{Response}_{\text{contra}}}
\]

- \( \text{od} = 1 \), ipsilateral only
- \( \text{od} = 0 \), contralateral only
- \( \text{od} = 0 \sim 1 \), 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

![Graph comparing ocular dominance between deprived and normal conditions for cat and monkey](image-url)
Radioactive tracing
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

(a) Diagram showing the binocular region and connections between the dLGN and V1.

(b) Graphs showing the response strength and cells (%). Two conditions are compared: Normal juvenile and MD 4 days.
OD plasticity also exists in adult rodents

(a) Optical imaging of intrinsic signals

(b) Extracellular recordings

(c) Visually evoked potentials

(d) Visually evoked Arc-expression
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
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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
- ★: 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

Slope at TCO (% change / degree)
Preferred orientation–trained orientation (degrees)
Example 2. Perceptual learning of stimulus localization (vernier and bisection tasks)
Task dependence of contextual modulation

- Side-flank offset tuning in bisection task (task-relevant)
- Side-flank offset tuning in vernier task (task-irrelevant)
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
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STDP in vivo

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

Schuett et al., *Neuron*, 2001
Spike-timing Dependent Plasticity Rat Oc1
Spatiotemporal Visual Receptive Fields

![Graph showing spatiotemporal visual receptive fields with time (s) on the x-axis and 100 ms on the y-axis, and 30 pA on the graph. The figure includes a color scale for the intensity of the responses.]
STDP of Visual Responses

![Graph showing EPSC amplitude (%) vs. Pre/Postsynaptic Time Interval (ms)]
Wolters et al., *J. Neurophys.*, 2004
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)

Ramachandran & Anstis (1990)
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

$\Delta X = \text{blue} - \text{red}$
STDP and motion stimuli

Asymmetric circuit

Effect of motion on V1 RF (1)

Motion-position illusion (1)
Population coding of position

Original RFs

Shifted RFs

Population Response

Percept

Original

Shifted

Shifted

Original
Physiological Basis of Illusion 1

Human Psychophysics

Cat V1

Percep. shift (min arc)

Eccentricity (deg)

RF size (°)

- YF
- HG
- QT
- QF
- Expected

(°)
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**

ΔX = red - blue

**Data**

- Spikes/s
- Time (sec)
- 56 cells

*** p < 0.001
** p < 0.01
STDP and motion stimuli

Asymmetric circuit

Effect of motion on V1 RF (2)

Motion-position illusion (2)
Physiological Basis of Illusion 2

Physical/ Perceived Adaptation

Psychophysics (Snowden, 1998)

Human Psychophysics

Cat V1

Percep. shift (min arc)

Time (s)

56 cells

6.0
5.0
4.0
3.0
2.0
1.0
0.0

0 50 100 150 200

Time (sec)

YF
QF
Expected

***

2.0
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Celikel et al., Nature Neurosci, 2000
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?
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