Activity-Dependent Development I
April 23, 2007    Mu-ming Poo

1. Development of OD columns
2. Effects of visual deprivation
3. The critical period
4. Hebb’s hypothesis
5. Hebb’s mechanism for OD plasticity

Transneuronal dye to study the structure of OD columns

Areas which get inputs from the injected eye are labeled
Development of Ocular Dominance Column:
Radioactive amino acid injected into one eye resulted in diffuse distribution of activity in layer 4 of V1 in 2 wk-old cat, but discrete bands in 13 wk-old cat.

Segregation of LGN afferents
- new borns
  layer 4
  - normal adults
    layer 4
    - MD animals
      layer 4
      open eye
      deprived eye

1. single LGN afferent has lots of branches, covers a big area
2. axon terminals from the two eyes overlap extensively

1. selective elimination of axon branches
2. local outgrowth of new axon branches

1. Axon terminals from the closed eye retract more
2. Axon terminals from the open eye take over more areas

OD distribution in V1 after monocular deprivation
monocular deprivation (MD) -- suture one eye of the newborn animal (monkey) for several months, reopen.

V1 after monocularly depriving the contralateral eye

contralateral

Equal

ipsilateral

OD groups

OD V1 --
Ocular dominance shifts to the non-deprived eye.
Animal blind in the sutured eye.
Sections of V1 at layer 4, showing stripes of OD columns

**Normal:** equal width of stripes for L and R eyes

**Monocular Deprivation:**
Open eye stripes widened
Closed eye stripes shrinked

---

Compare OD columns in newborns, adults and MD animals

- **Normal adults** - labeled and unlabeled alternate
- **Newborns** - no OD column, all areas are labeled
- **MD animals** - deprived eye columns shrink, non-deprived eye columns expand

---

**OD column formation is an activity-dependent, competitive process**

**Two important 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. It is a competitive process.
Critical Period
- Postnatal period during which nerve connections are shaped by activity (experience) and most sensitive to perturbation.
- Different among various brain regions, species, and functions

1. Monocular deprivation (MD) causes a shift of OD in V1 toward the non-deprived eye. This is effective only before certain age. MD has no effect on adult animals.
   - monkey: first 6 months (even one week deprivation causes defects)
   - human: 1st year most important, but may extend to 5 years

2. MD within the critical period, the effect is permanent and irreversible.
   - implication for treatment of congenital cataracts and strabismus (crossed-eye) in children

3. MD within the most sensitive part of the critical period (e.g., first 6 wk for monkey), a few day’s MD results in a complete loss of vision in the sutured eye.

---

Critical period varies among different brain functions

- **Visual System**
  - OD
    - cat: 3rd week ~ 3 months
    - monkey: first 6 months
    - human: 1-5 year?
  - More complex visual functions (e.g., contour integration) have longer critical period

- **Human Language**
  - 2-7 years of age
  - Phoneme recognition during the first year, an ability lost later

- **Social Interaction**
  - Newborn monkeys reared in isolation for 6-12 months become behaviorally abnormal

---

Hebb’s Hypothesis for Learning

When an axon of cell 1 is near enough to excite a cell 2 and repeatedly and persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that 1’s efficacy, as one of the cells firing 2, is increased. (Hebb, 1949)

“Cells that fire together wire together”
“neurons out of synch lose the link”

Hebb’s hypothesis provides a synaptic basis for learning and memory, and has been the guiding principle for neurophysiological studies for the past several decades.
A property of Hebbian synapse

Hebb’s rule and OD development

A. Normal OD development
- Small differences in either the activity level or the initial strength causes the postsynaptic cell activity to be more similar (correlated) to the activity of the more active/strong input. This input will be strengthened and will win the competition.
- Inputs from the same eye are likely to be more correlated, thus are stabilized together, whereas the inputs from the opposite eyes are weakened and driven away, leading to segregated zones of inputs from opposite eyes.

B. Monocular deprivation
- Deprived eye input is uncorrelated with cortical cell activity, and will lose the competition.

C. Binocular deprivation
- Similar to normal development. The outcome of competition is determined by small differences in initial input strengths or spontaneous activity levels of the two inputs. Relatively normal OD columns.

Further tests of Hebb’s rule in OD development

- If you force inputs from the two eyes to be correlated (synchronous stimulation), you can prevent competition and OD segregation.
- If you make the inputs from the two eyes even less correlated (asynchronous stimulation or strabismus), you enhance competition and OD segregation (there will be very few binocular cells in V1).