Intro to Behavioral Neuroscience (B)
Lecture 12: Development/Evolution

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https://youtu.be/0Hef8PqsgYY

Lecture video at above link.

Today:

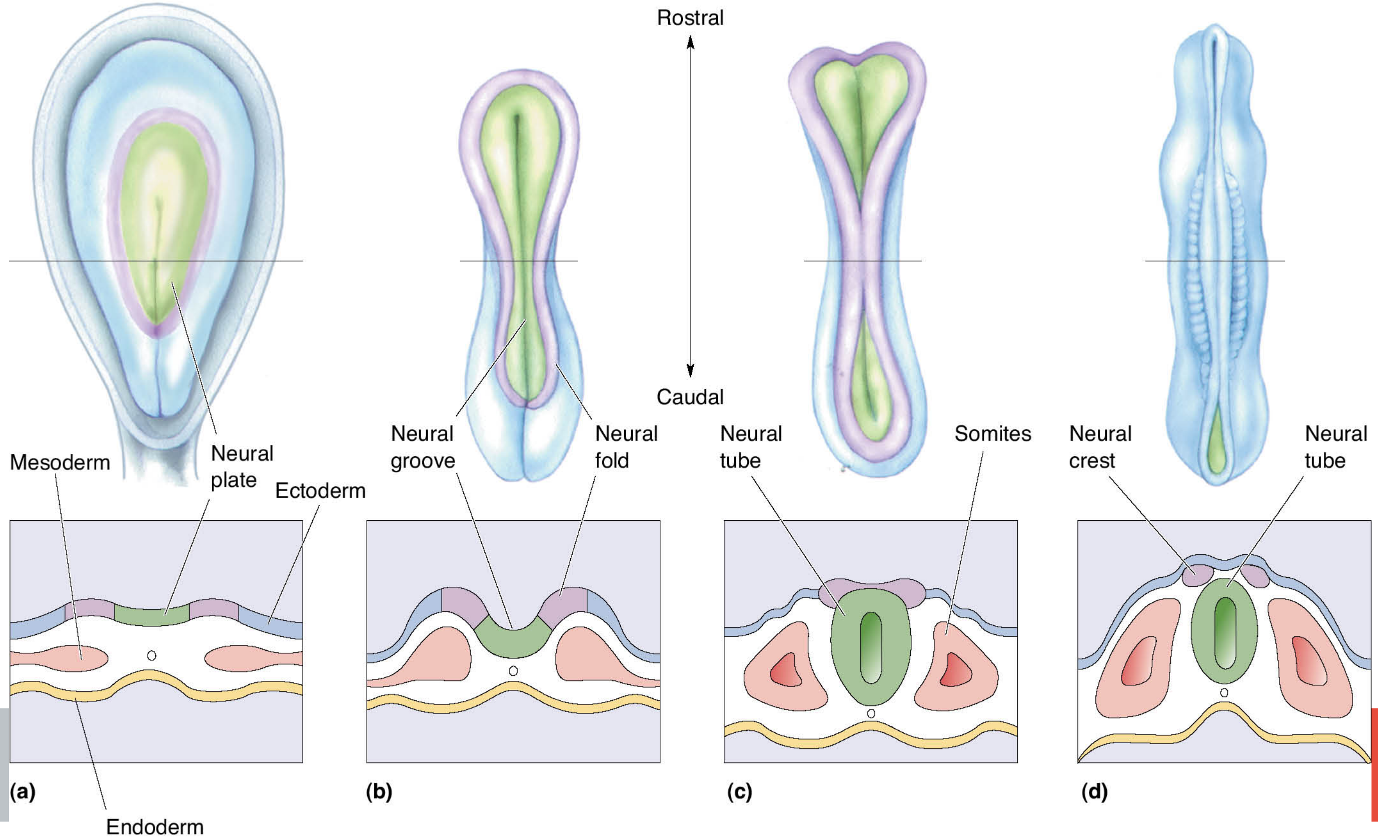
Development of the brain

1) Prenatal brain development
2) Postnatal development: synaptic pruning
3) Critical period of development in the visual system

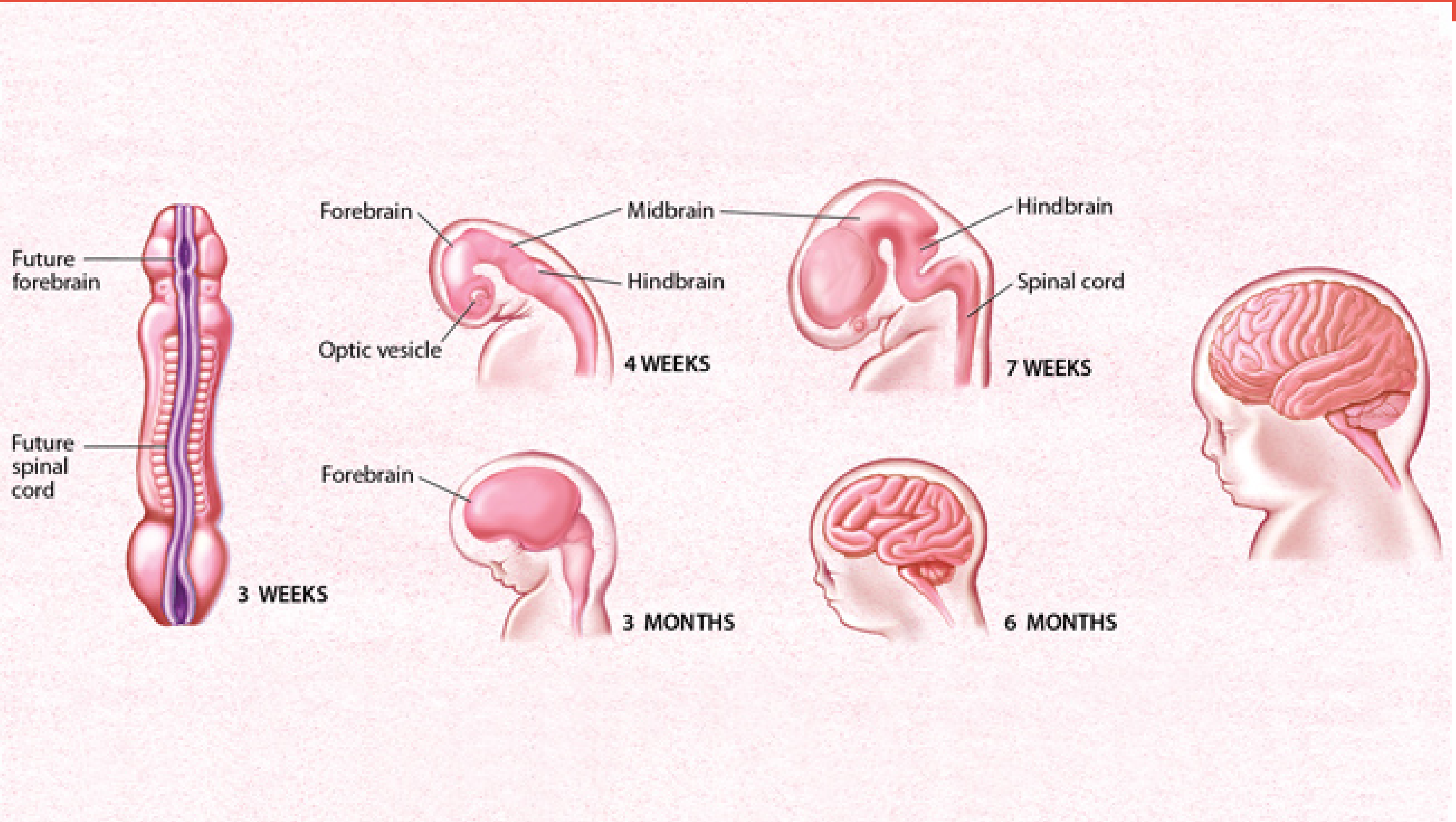
Brain Development

The human embryo develops three cell layers, the endoderm (→ internal organs), mesoderm (→ muscles, skeleton), and the ectoderm (→ skin, nervous system).

Around three weeks after conception, the embryo forms the neural tube (below).
The neural tube will later develop into the central nervous system, the neural crest gives rise to the peripheral nervous system. The mesodermic somites will develop into the vertebrae.



Brain Development



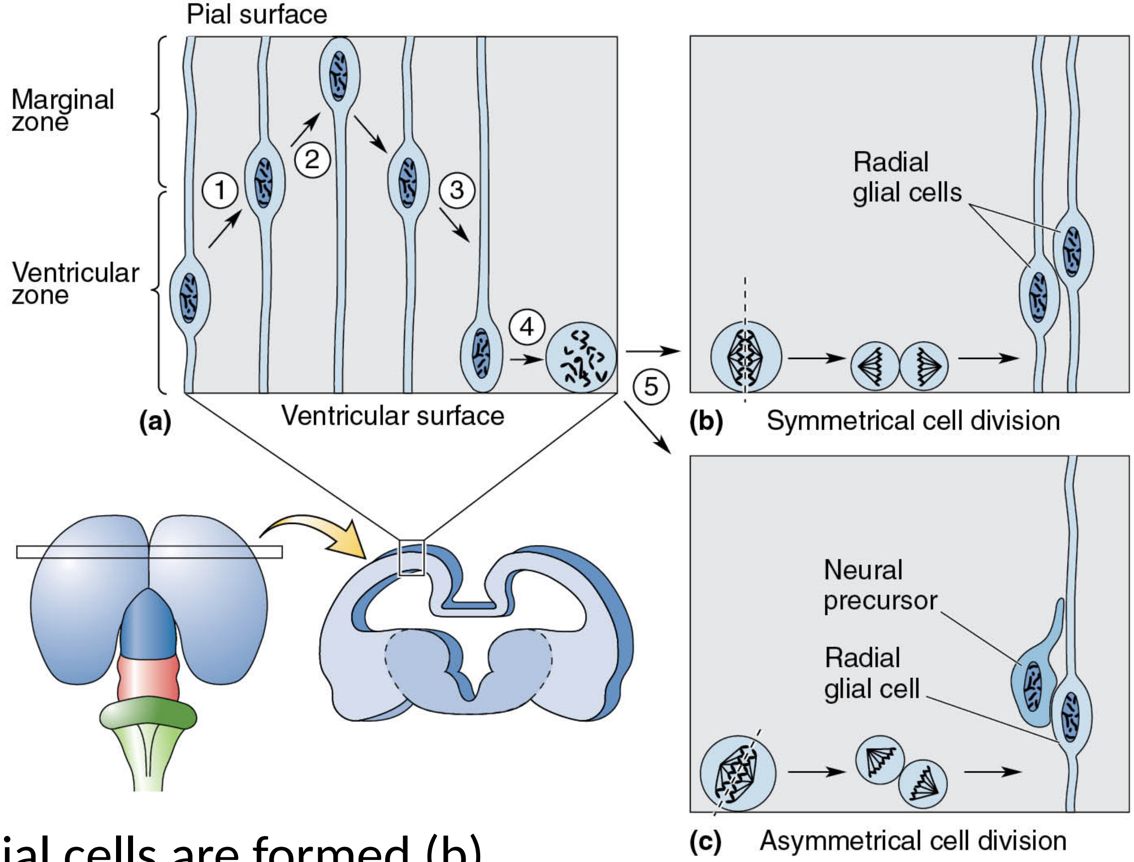
Signaling molecules from the mesoderm induce development of neurons and glial cells in the ectoderm (**neural induction**).

Neocortical neurons are born mainly from 5 weeks of gestation to the 5th month of gestation.

Cortical Development

Cortical cells are born in a process called **cell proliferation**.

(a1) Neural progenitor cells (radial glial cells) extend a process from the ventricular zone to the pial surface,
(a2) the nucleus migrates and DNA is copied,
(a3) the nucleus returns to the ventricular surface,
(a4) and retracts its process. (a5) Then the cell divides.

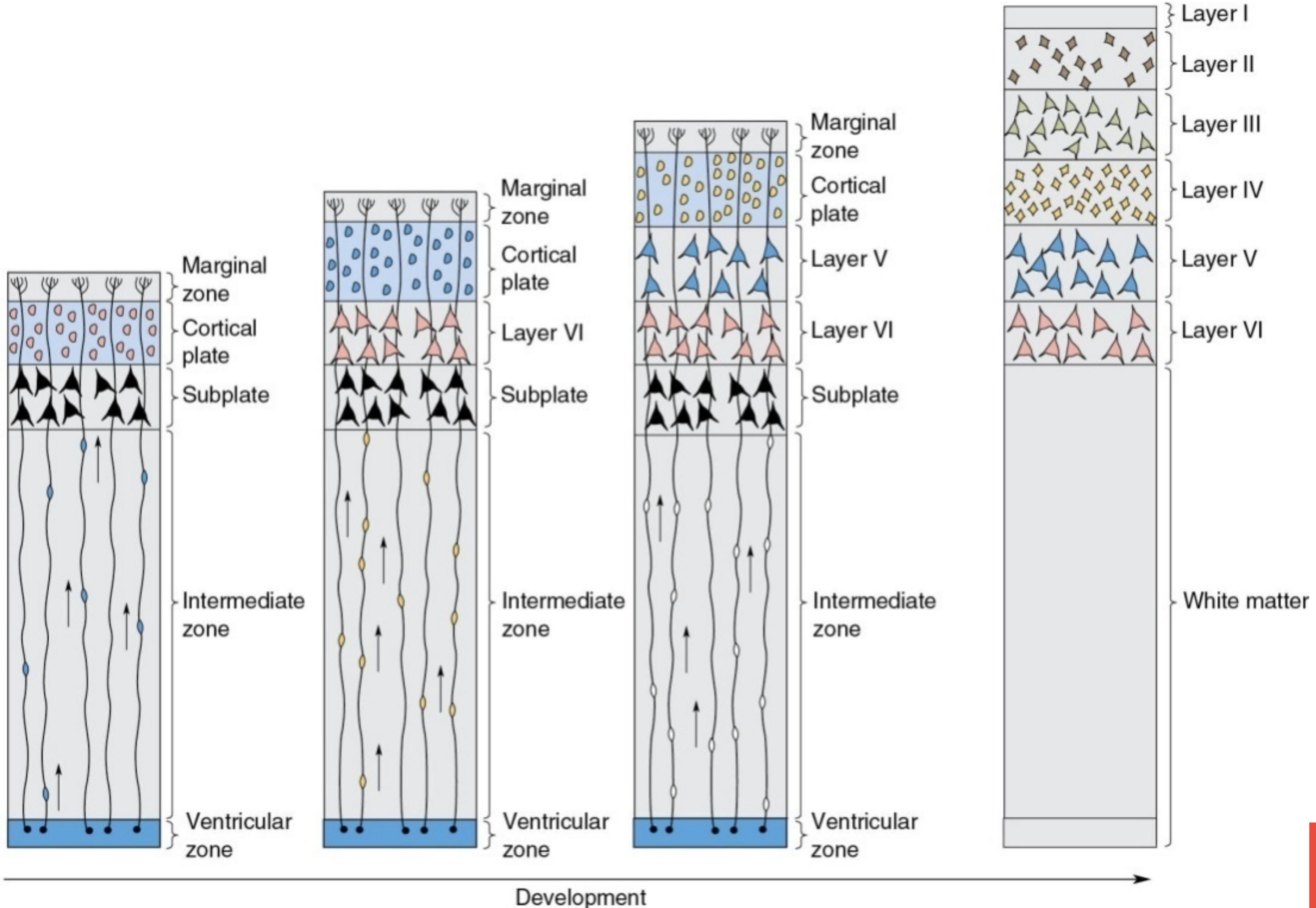


In <u>symmetrical division</u>, new <u>radial glial cells</u> are formed (b).

In <u>asymmetrical cell division</u> (c), that occurs when the cell plane is tilted, a <u>neural precursor cell</u> (immature neuron) is formed that migrates along the scaffolding of the radial glial cells to the pial surface.

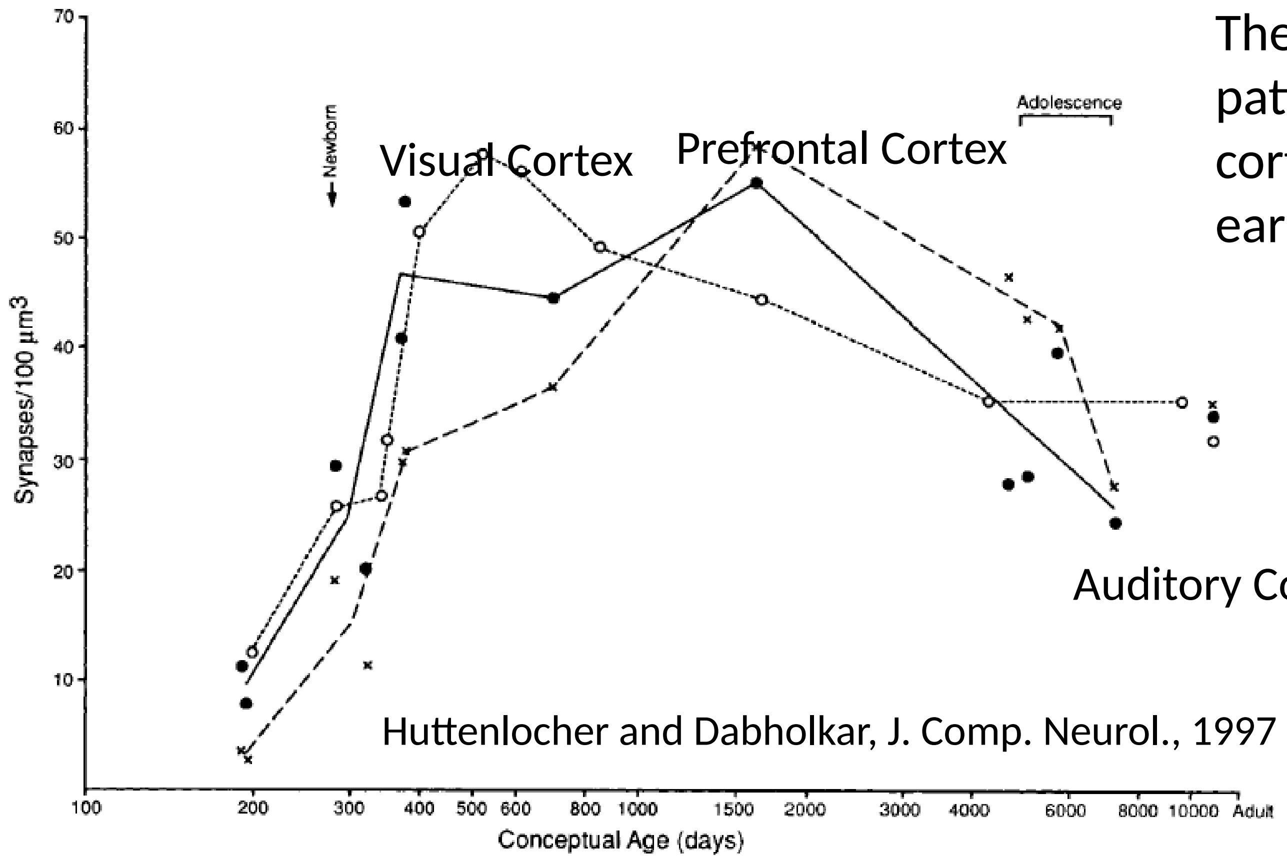
Cortical Development

Migration: In cortex, cells that migrate first are in the deeper layers and are then overtaken by following neural precursor cells that build the outer layers. Neurons are thus generated in an <u>inside-out</u> manner.



Postnatal Development: Synaptic Pruning

While the generation of neurons mainly occurs before birth, brain development continues postnatally. From the third trimester of gestation (pregnancy) to 2 years after birth many synapses are built.
After that, synapses are eliminated down to a level of 60% of the maximum (synaptic pruning).



Huttenlocher and Dabholkar, J. Comp. Neurol., 1997

The timing of this rise-and-fall pattern depends on the cortical area: sensory cortex is earlier, prefrontal cortex later.

Visual Pathway:
Experience-dependent plasticity

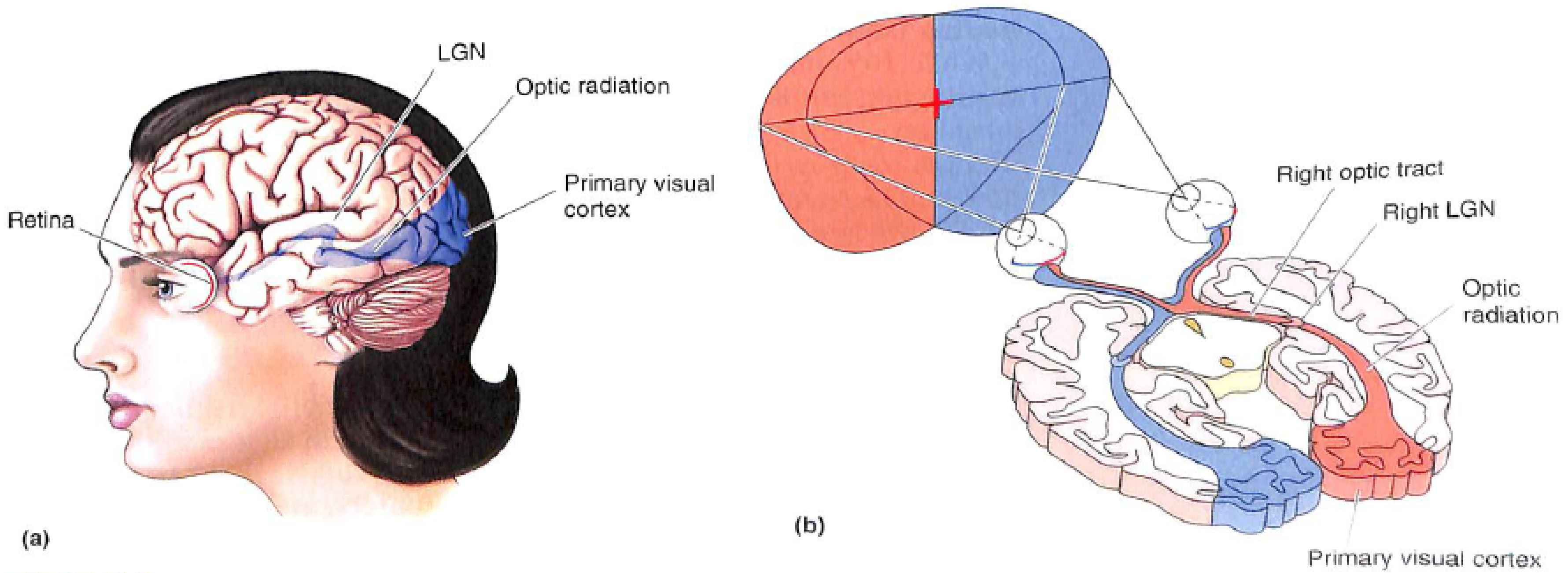


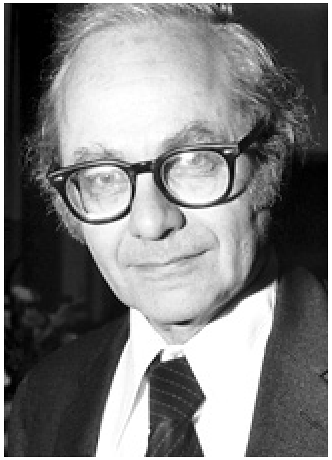
FIGURE 10.4

LGN: Lateral geniculate Nucleus in the Thalamus

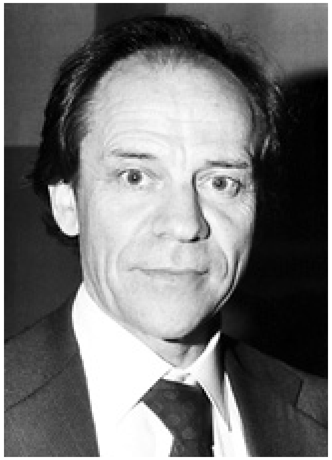
Visual cortex (V1) receives information from both eyes in a way that the left visual hemifield is represented in right visual cortex (red) and the right visual hemifield is represented in left visual cortex (blue).
Information from the two eyes is integrated in visual cortex to allow for stereo vision (possible because the eyes are located at different positions).

Nobel Prize 1981

David H. Hubel

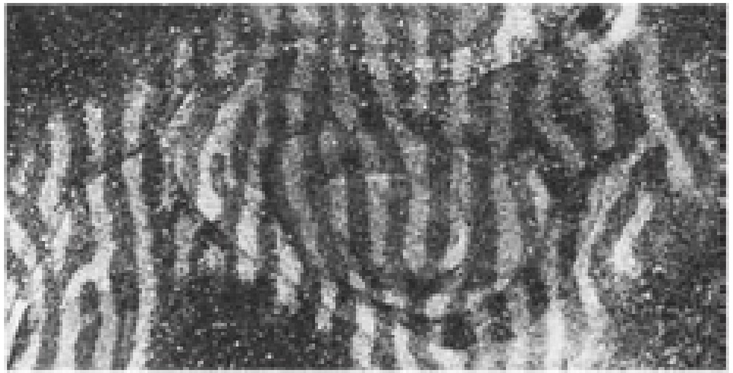


Torsten N. Wiesel

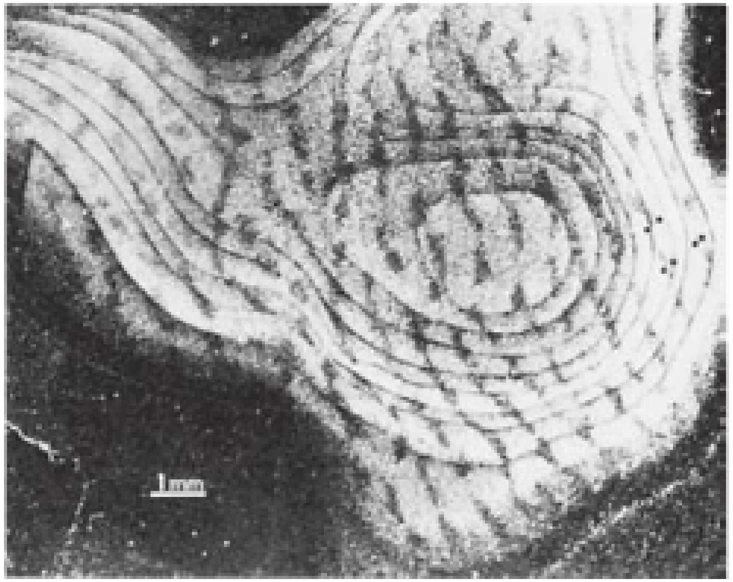


"…for their discoveries concerning information processing in the visual system."
(www.nobelprize.org)

Ocular Dominance Columns



(a)



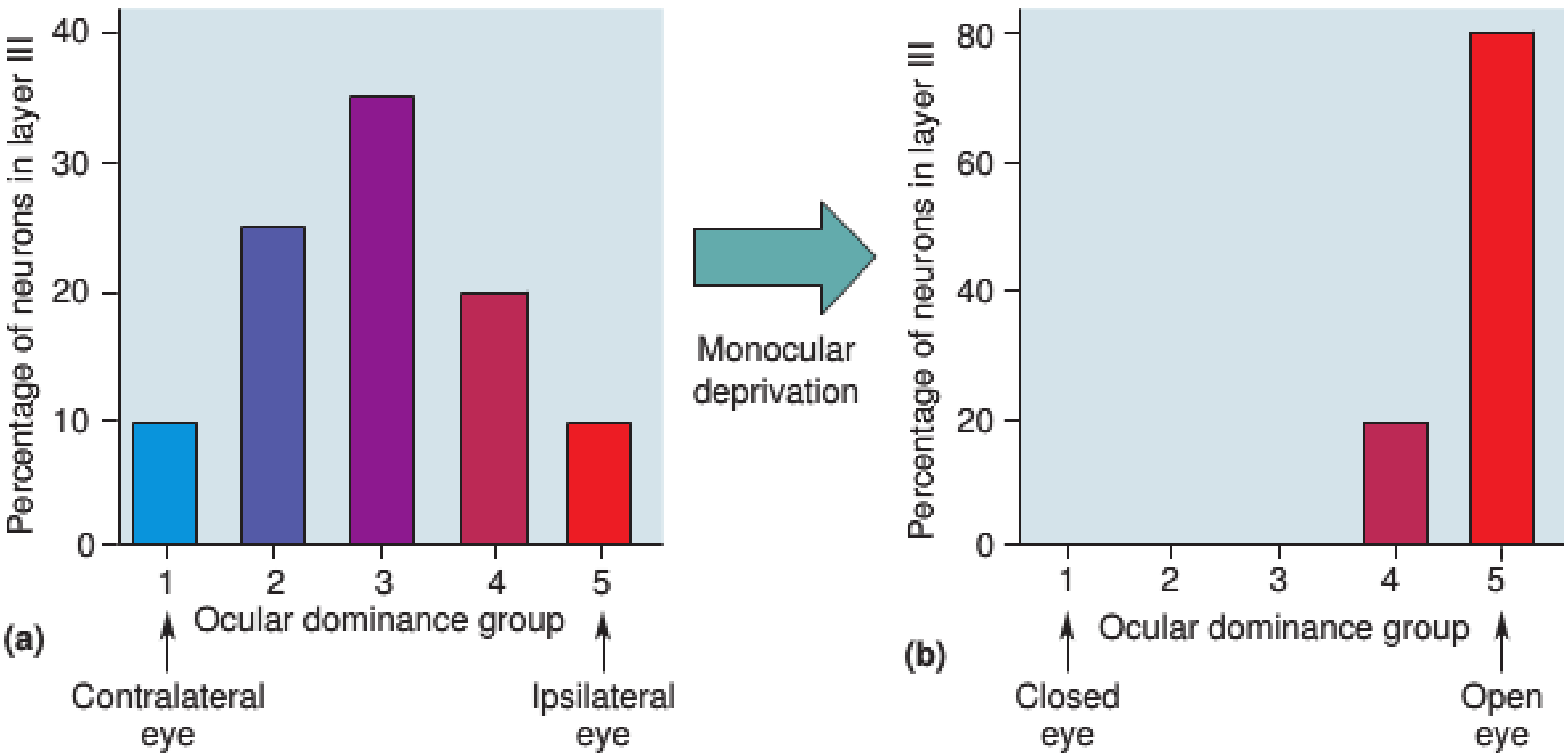
(b)

The input of the two eyes into primary visual cortex is segregated into "ocular dominance columns" in layer IV: within such a column, neural responses in response to stimulation of one eye (e.g., left) are dominant. This can be visualized by injecting a radioactive tracer into one eye (light color in a, macaque monkey V1).

If one eye is deprived (by sealing it) in development, the ocular dominance columns of the non-deprived eye (b: monkey has been deprived for 22 months, starting at age 2 weeks) "invade" the columns of the deprived eye (light color: non-deprived eye).

Bear, Neuroscience

Ocular Dominance Columns



Ocular dominance group

1, 5: response to one eye only;

3: both eyes equally;

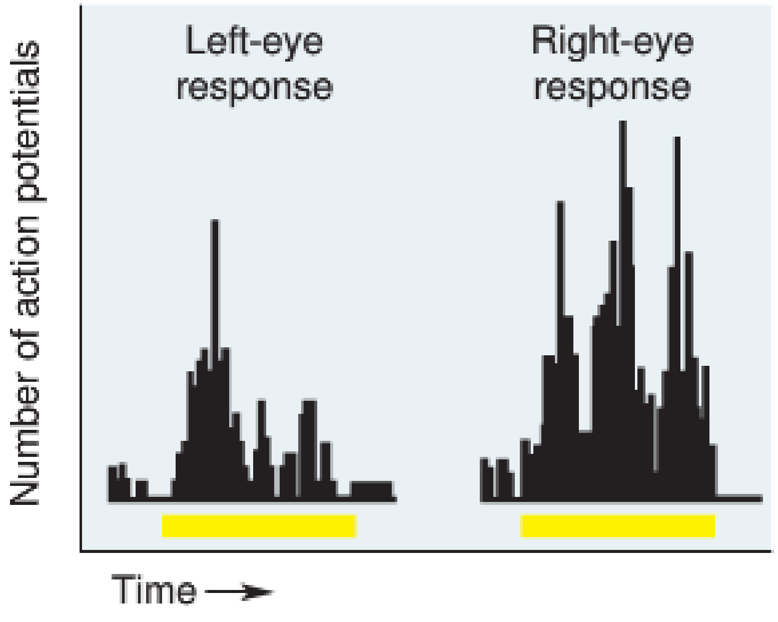
2, 4: both eyes, but preference for one.

This histogram shows the percentage of neurons in layer III responding to the contralateral or ipsilateral eye or both (cats). Most neurons in layer III respond to input from both eyes which is important for stereo vision.
Monocular deprivation leads to dominance of the open eye.

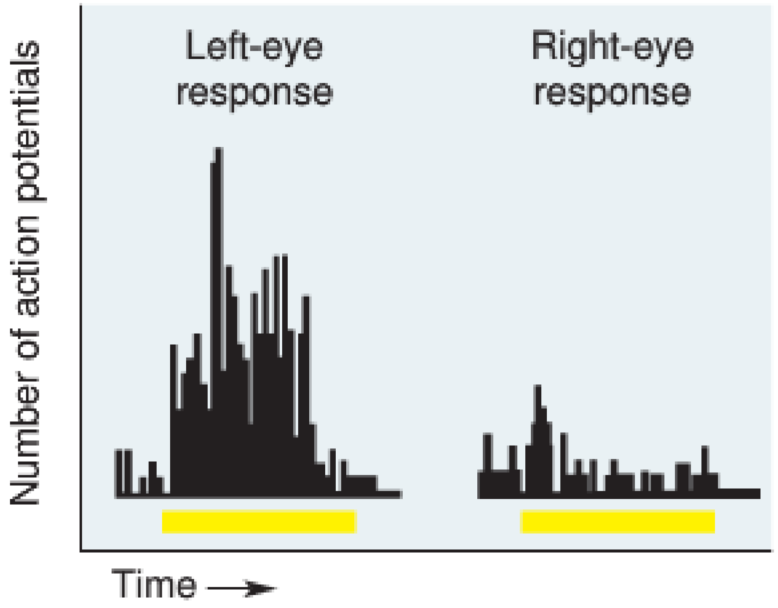
Ocular Dominance Columns

Here we see responses of a single neuron in visual cortex (kitten) to stimulation (yellow bar) of the two eyes.

After short right-eye deprivation, responses to right-eye stimulation are decreased.

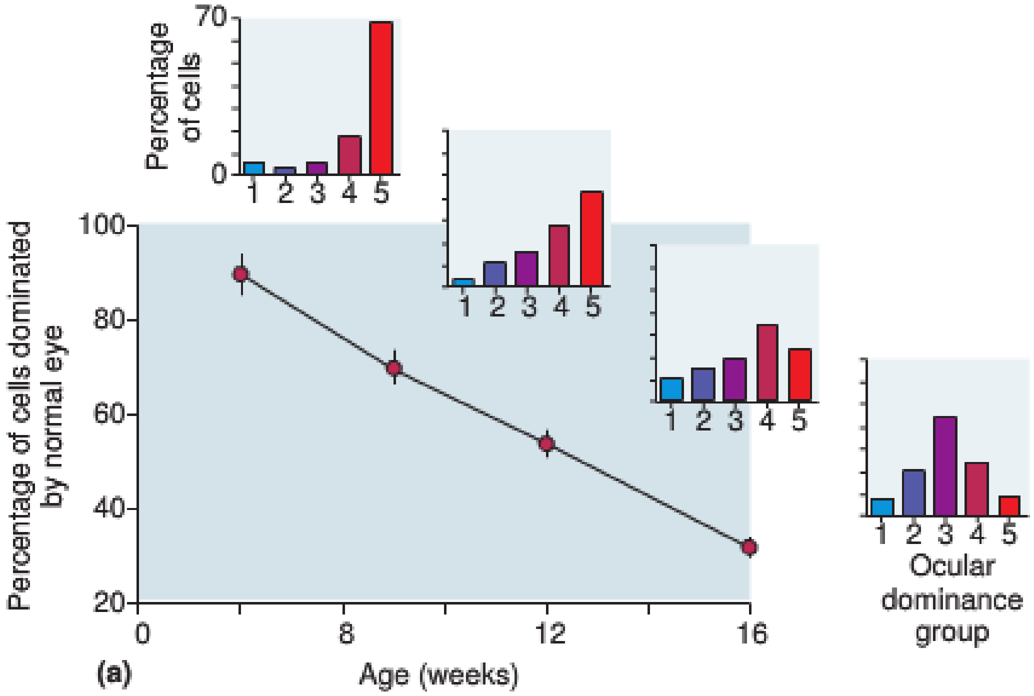


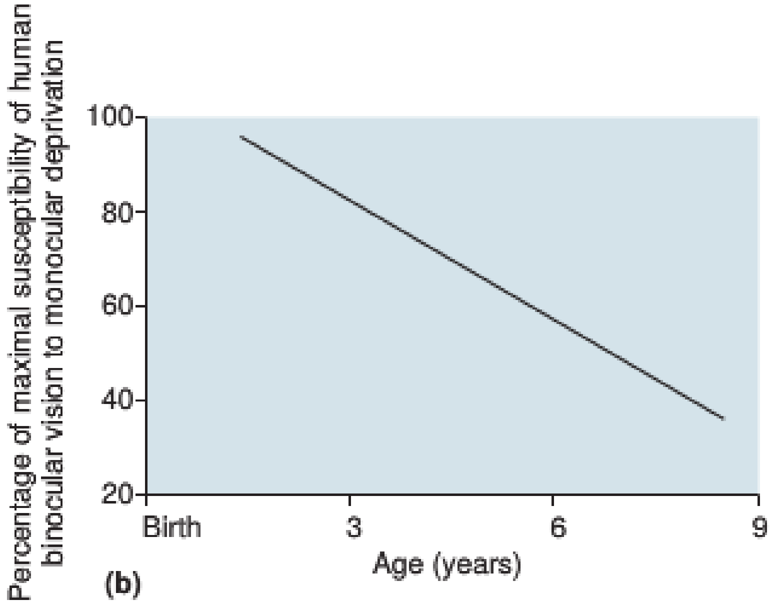
(a) Initial state



(b) After 17-hour right-eye deprivation

Ocular Dominance Columns



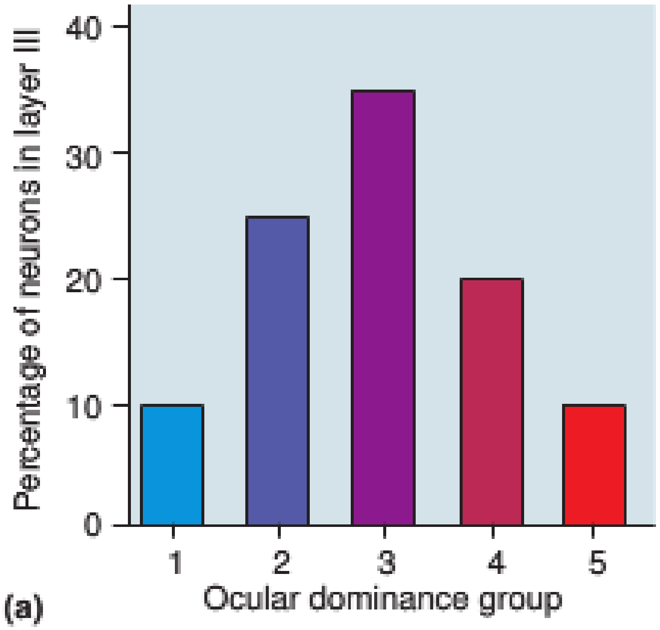


When kittens are deprived of input to one eye for 2 days, the change of the ocular dominance depends on their age: the effect of deprivation becomes smaller when deprivation occurs later in life.

Also, in humans the influence of monocular deprivation (one eye not used) depends on age.
After a "**critical period**", these changes cannot be reversed.

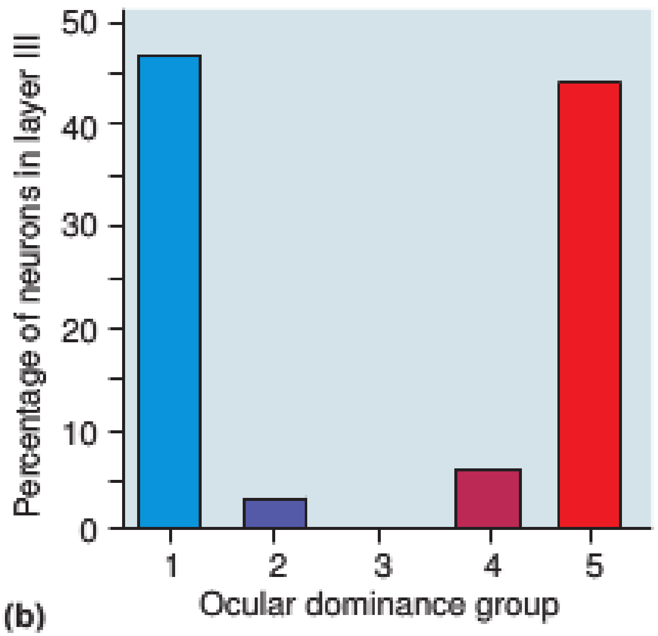
Strabismus

In strabismus, the two eyes are misaligned (cross-eyedness).



In experimental animals, misalignment of the two eyes during development leads to a loss of binocular responses in primary visual cortex (b).

Thus, in humans early management of strabismus (before age 7) is advised to ensure normal development of stereo vision.

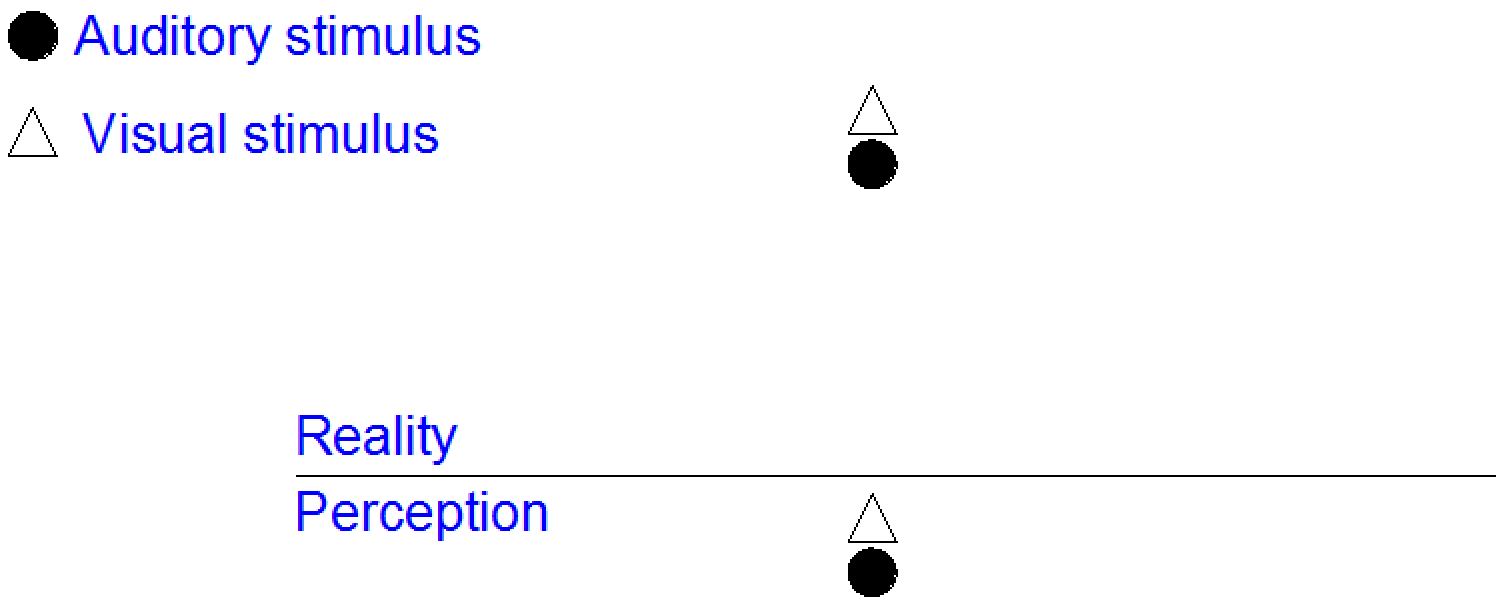


Remapping of Audiovisual (space) Perception

Knudsen, 2002

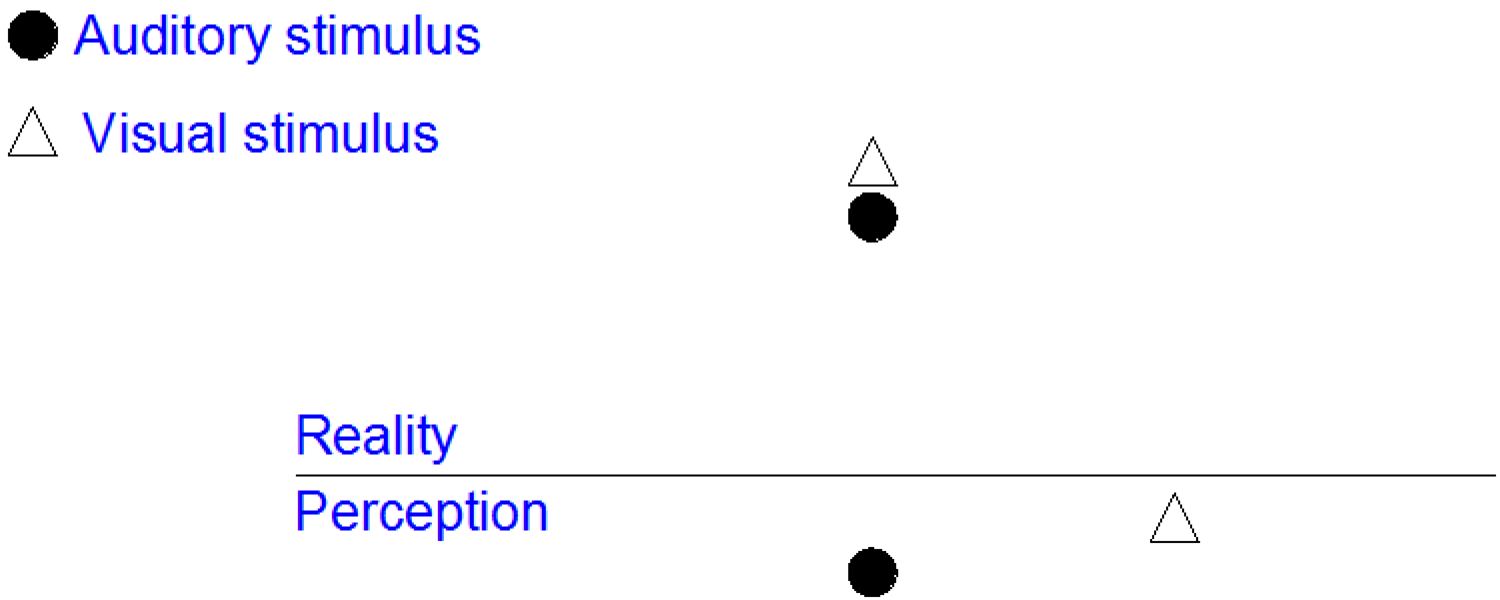
The **barn owl** uses vision for hunting prey during day-time, hearing during the night and both senses during dusk.
The main cue for horizontal sound localization is interaural time difference (ITD): the runtime difference of sound between ears.
ITD depends on head size which changes during development, so the mapping of vision and audition should be changeable (plastic) during development.

Remapping of Audiovisual Perception

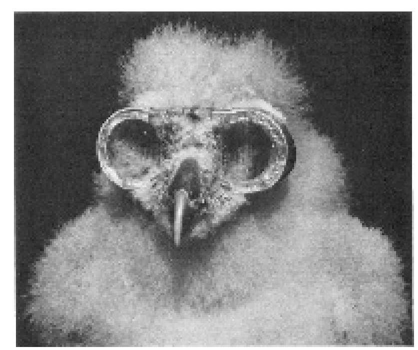


Knudsen and Knudsen (J. Neuroscience, 1990) tested barn owls' space perception with loudspeakers and LEDs (light emitting devices) attached to the loudspeakers. Barn owls oriented their heads either to the visual or auditory stimuli to get a reward.

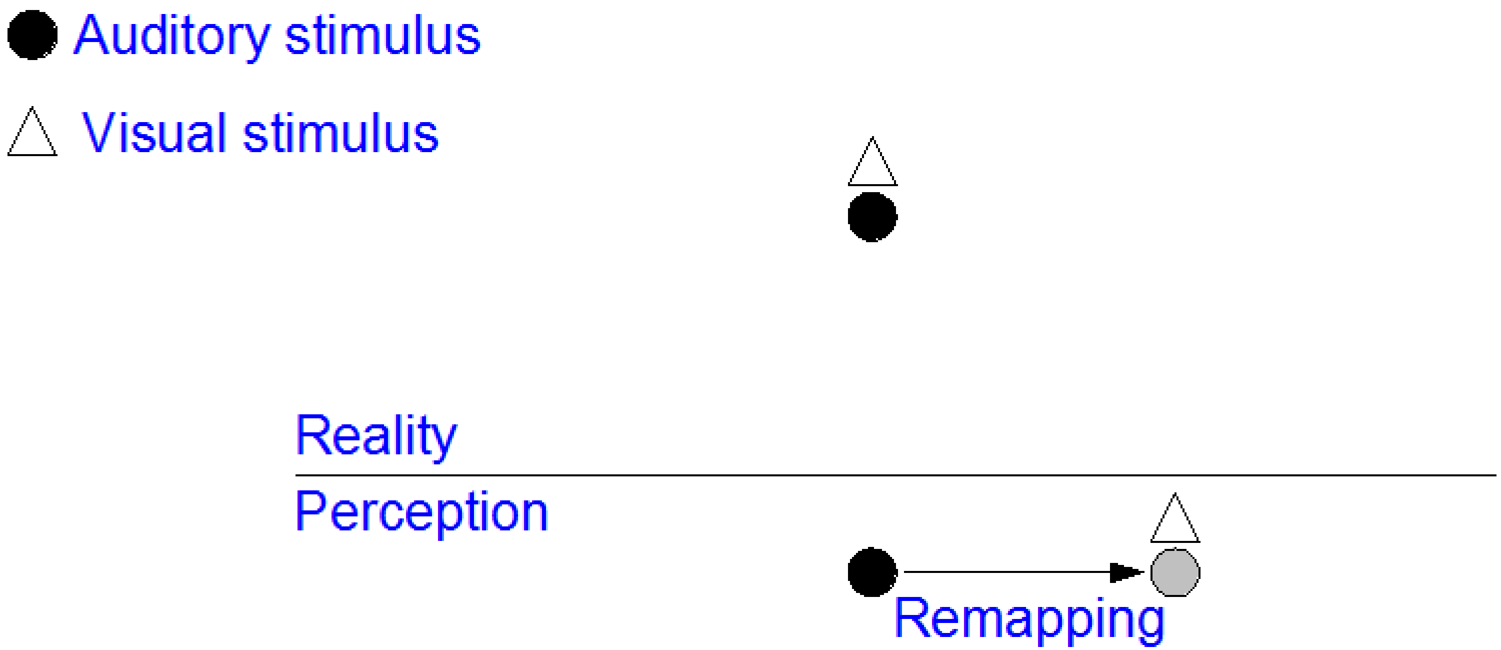
Remapping of Audiovisual Perception



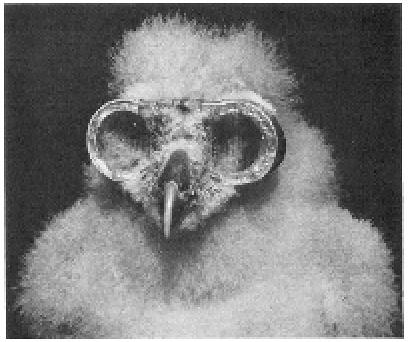
19 barn owls were reared with prism goggles that shifted the position of visual objects by 23° to the right.
The ages of the barn owls fitted with prism goggles ranged from 10 to 272 days.



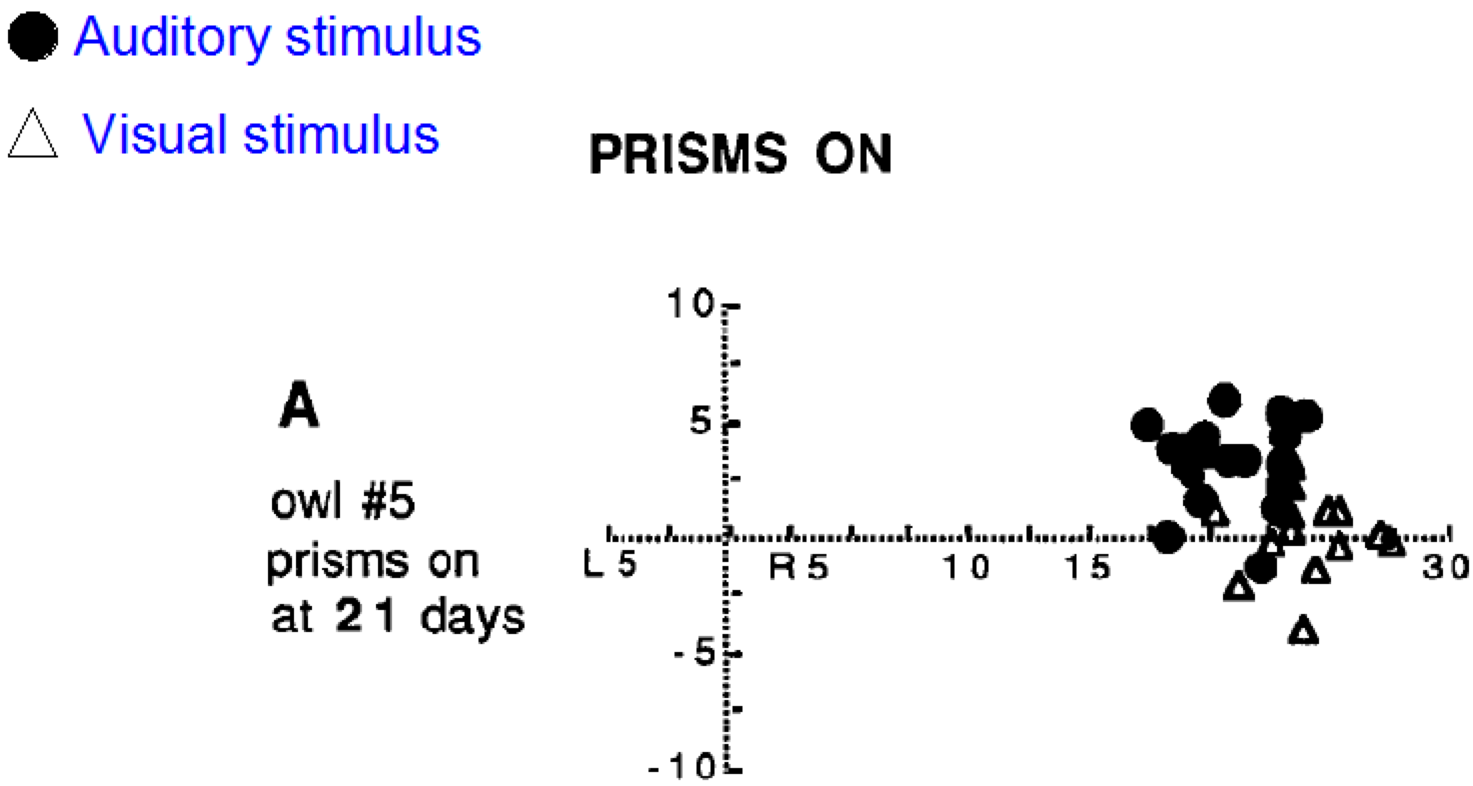
Remapping of Audiovisual Perception



Due to growing up in an environment in which the visual objects are always shifted compared with the sound source, “remapping” occurs: sound source localization also shifts.
Vision guides sound source localization.



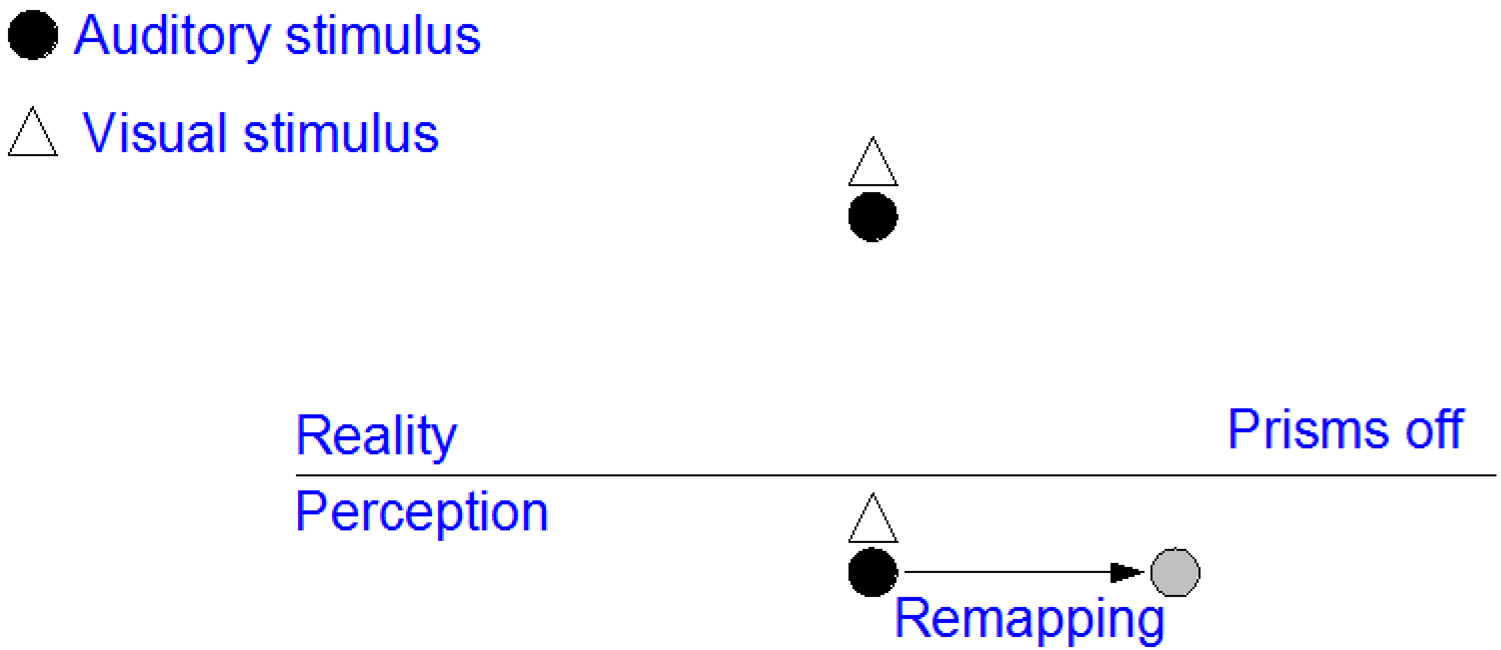
Remapping of Audiovisual Perception



Knudsen, 1990

This graph shows visual and auditory localization in a barn owl that was fitted with prism goggles at a young age. Both are shifted by ~23°.

Remapping of Audiovisual Perception



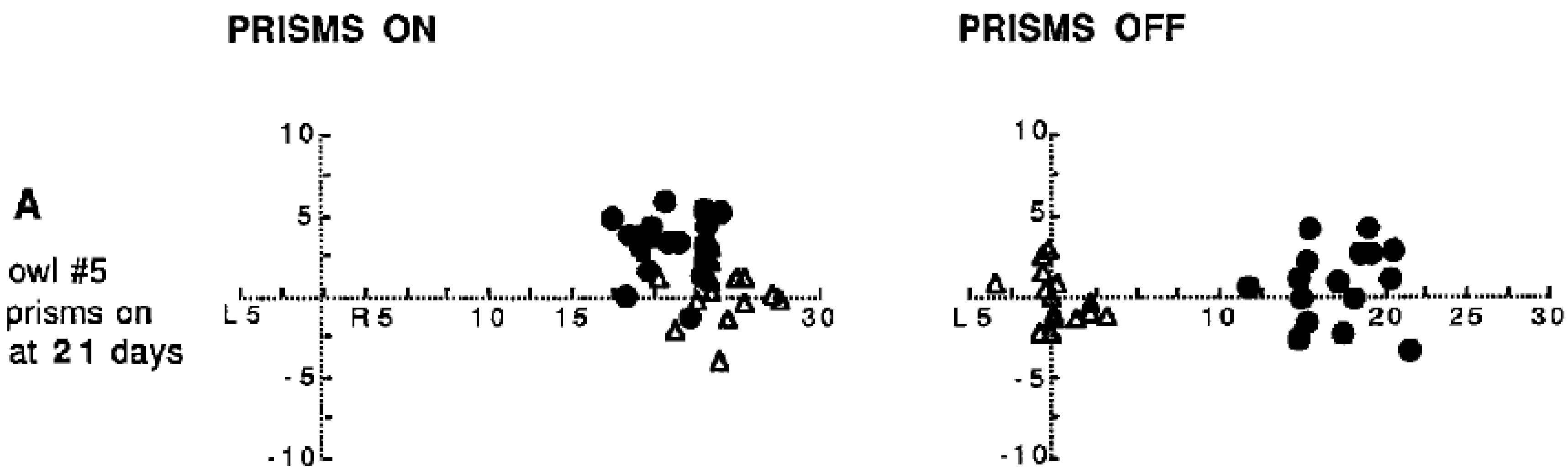
Now, once the barn owl has grown up, one can test whether the remapping persists when the visual shift (prism goggles) is removed.

Remapping of Audiovisual (space) Perception

● Auditory stimulus

△ Visual stimulus

Knudsen and Knudsen, 1990



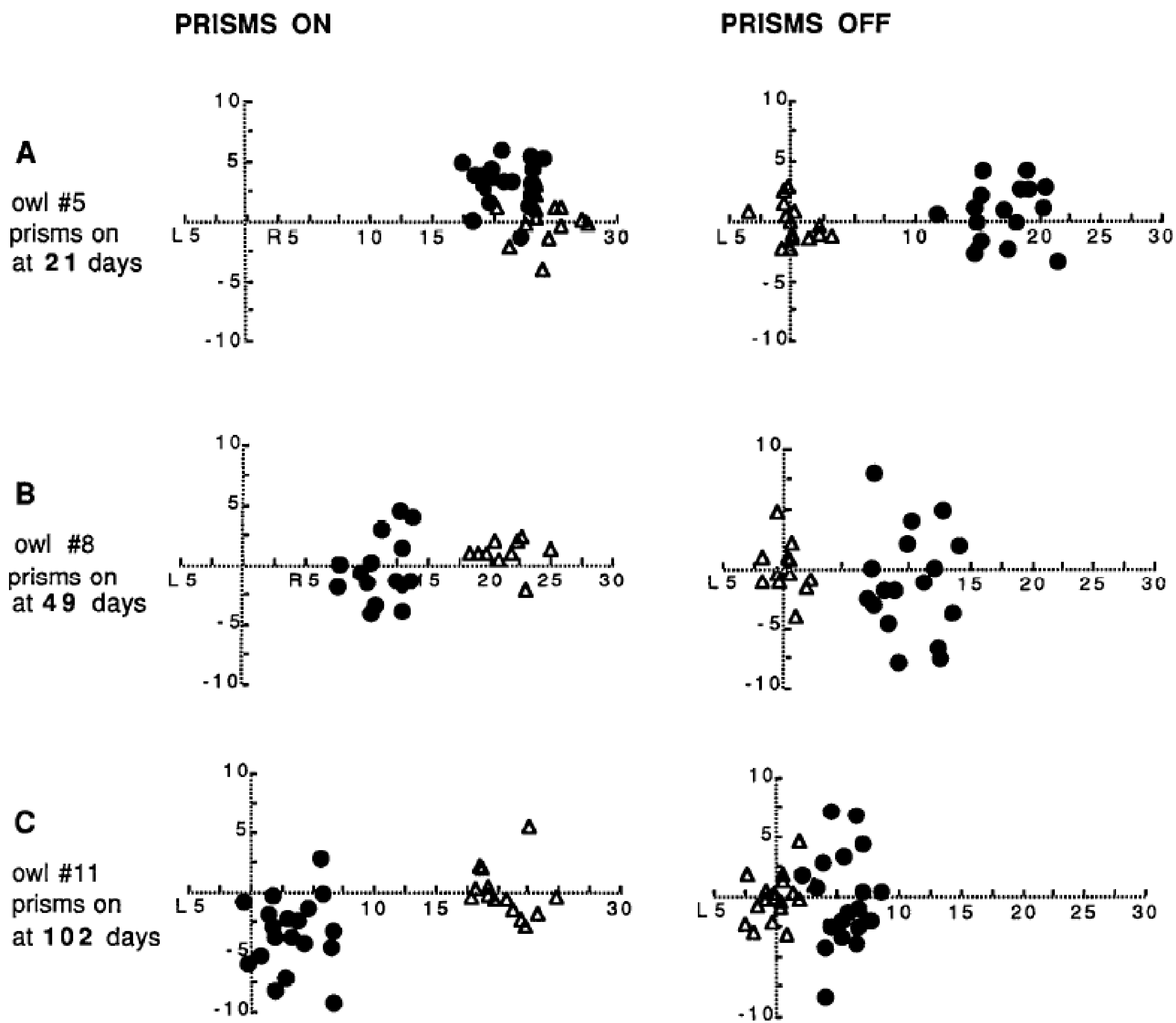
This barn owl exhibits the remapping with prisms on, and after taking off the prism goggles there is no visual shift, but the auditory shift persists.

Remapping space perception

● Auditory stimulus

△ Visual stimulus

The extent of audiovisual remapping depends on the age when prisms are applied.

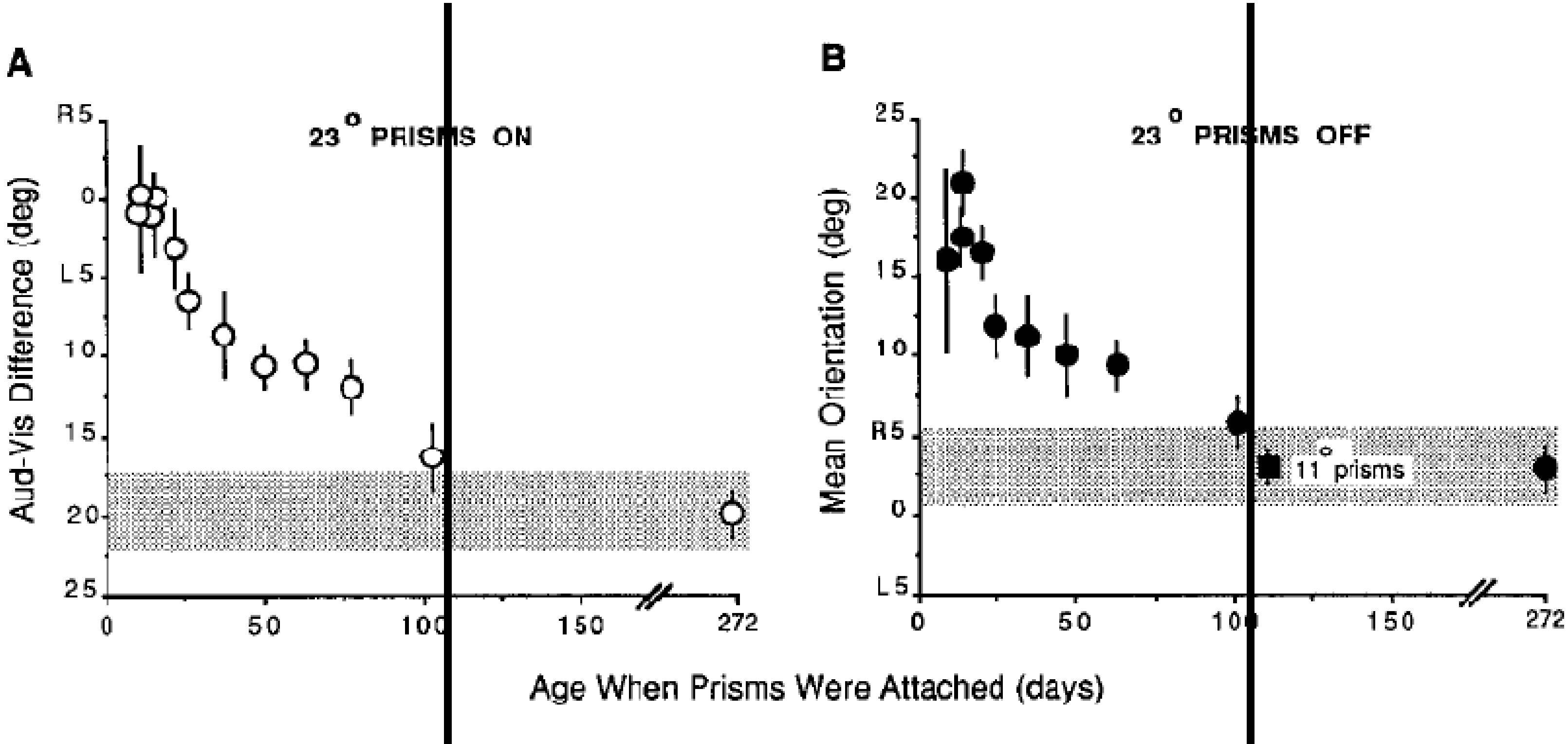


Knudsen and Knudsen, 1990

Sensitive Period

The extent of audiovisual remapping depends on the age when prisms are applied. Barn owls fitted with prism goggles at young age fully remap, so that there is no audiovisual inconsistency (0°, left graph). Their auditory remapping persists after the prisms are taken off (~23°, right graph).

Sensitive period: a period in in development during which an environmental factor (visual shift) can affect development.



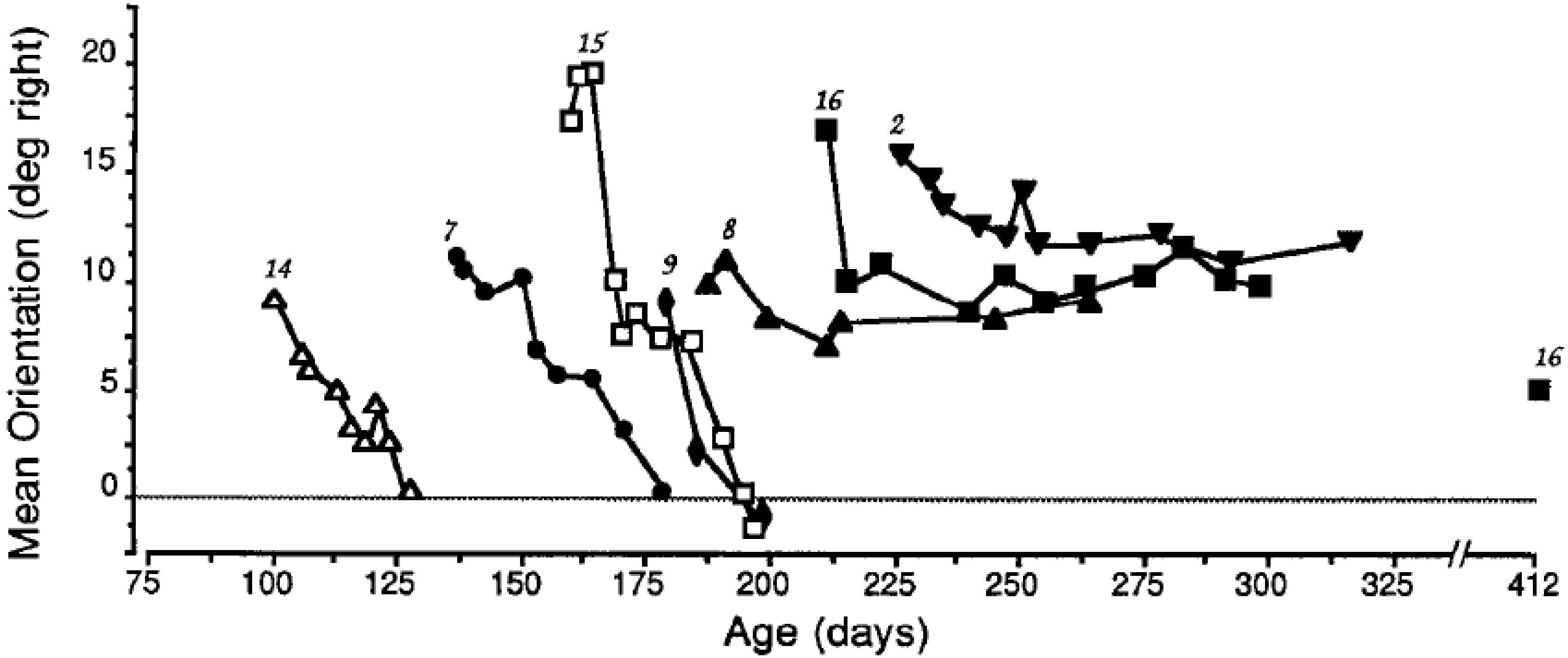
Knudsen and Knudsen, 1990

Critical Period

A reversal of remapping occurs when prism goggles are taken off. For example, owl 14 (above) had an auditory displacement error of about 10°, within ~30 days without prisms this returned to 0°.

Owl 8 also had an auditory displacement error of about 10°, prisms were taken off at 200 days of age, it did not return to 0°.

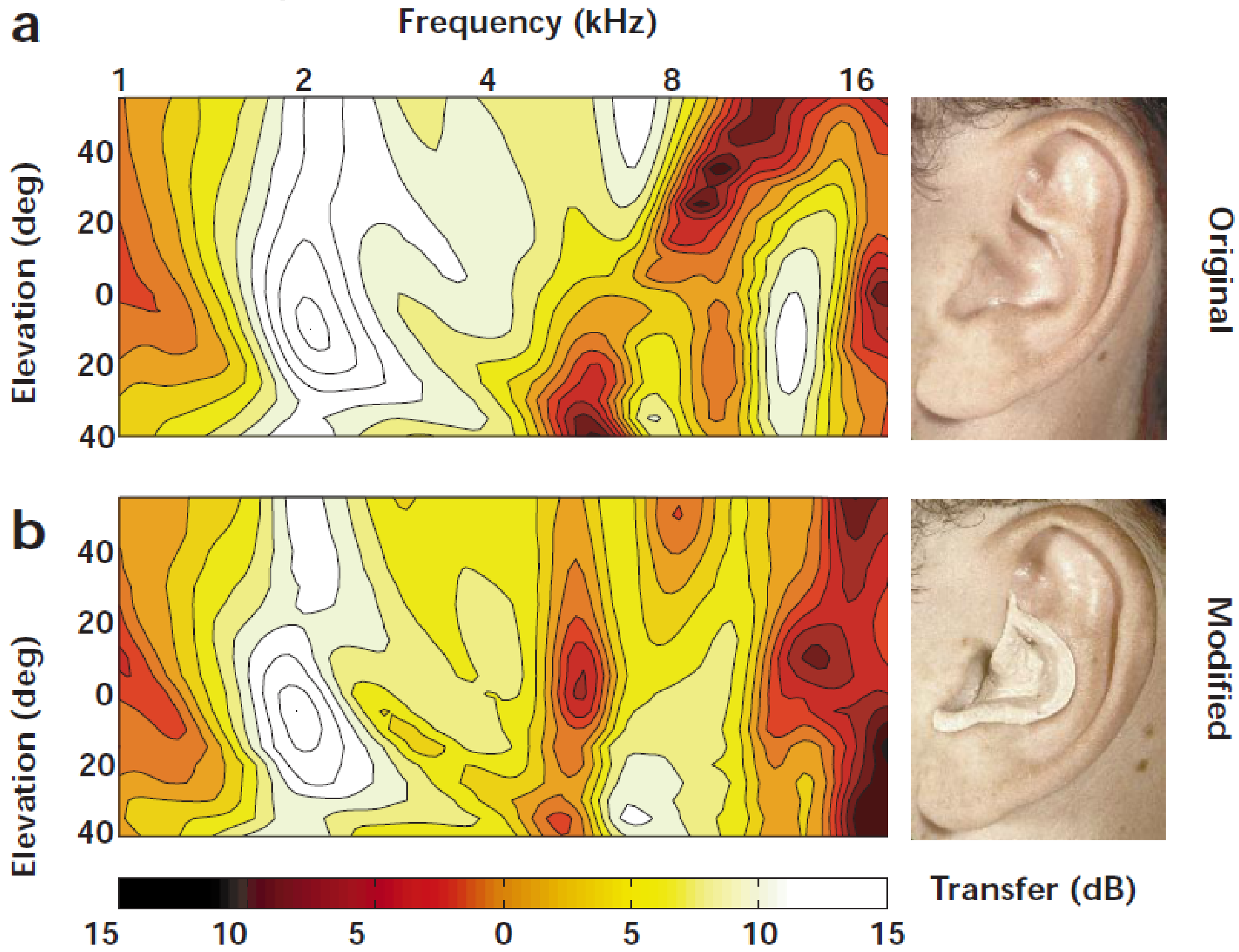
Critical period: a period in development during which the influence of an environmental factor (visual shift) can be reversed.



(Human) ear modification

Some aspects remain plastic even in adulthood, e.g., sound localization in the vertical plane (above, below). Vertical sound localization relies on how our ears (pinnae) filter the incoming sound, it relies on ear shape.

What if this ear shape changes?



Hofmann et al., Nature Neuroscience, 1998

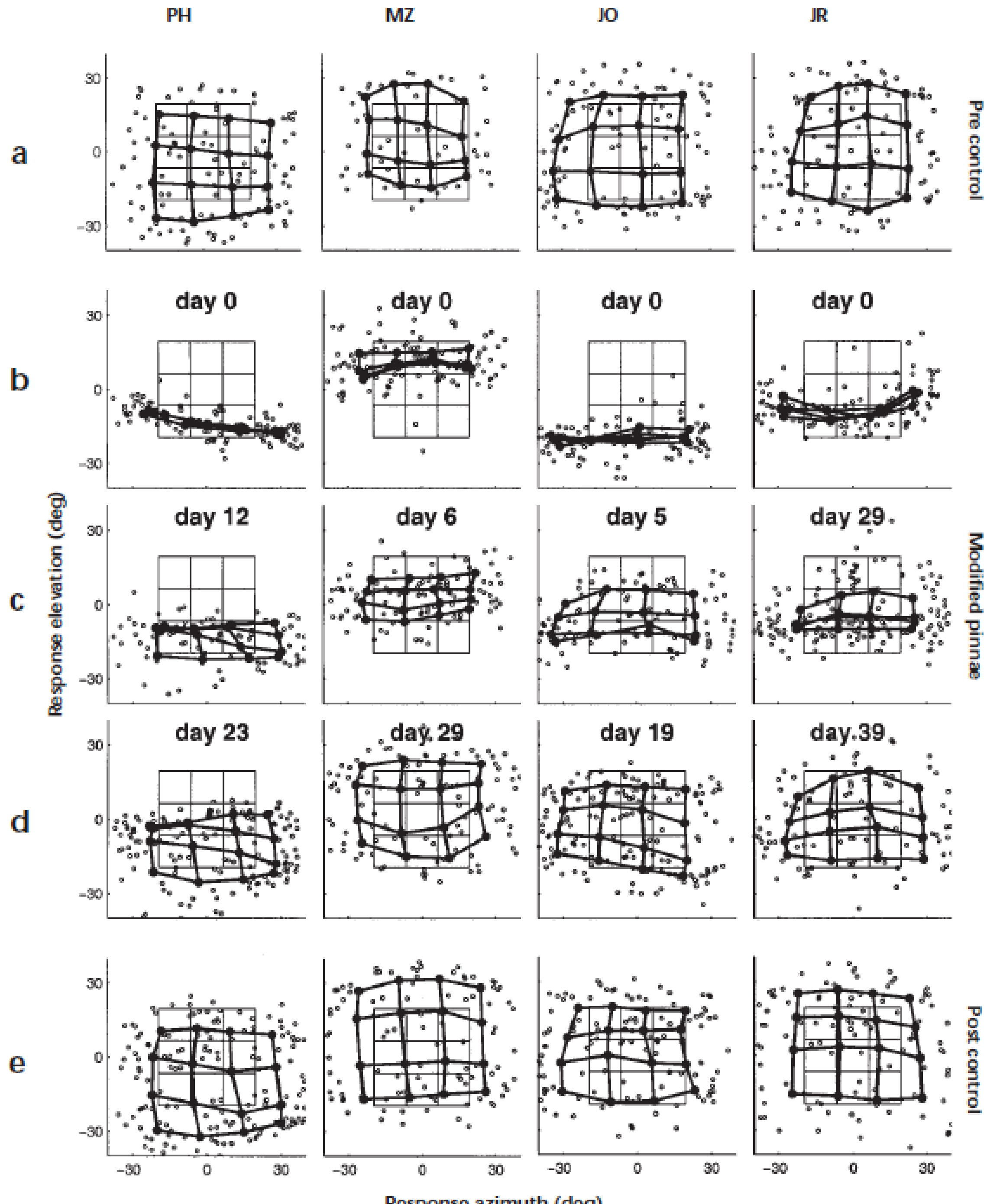
Ear Modification

In this experiment, subjects wore ear molds to change their ear shape. The graph shows whether sound localization is veridical (square).

First (day 0), vertical sound localization breaks down (line-shape).

But after some days, localization becomes (normal).

When molds are removed, localization is instantly accurate again (lowest row).



Hofmann et al., Nature Neuroscience, 1998

Summary: Development

Development of the brain

1) Prenatal brain development
   neurogenesis from about 5 weeks to 5 months after conception;
   inside-out pattern of neocortical development shapes layer structure
2) Postnatal development: synaptic pruning
   rise-and-fall pattern of synaptic density after birth
   other postnatal changes are selective neural cell death (apoptosis) and myelination
3) Critical period of development in the visual system
   some developmental changes are driven by experience = experience-dependent plasticity
   time windows for experience to have an effect = critical periods