Biosystems II: Neuroscience

Sensory Systems

Lecture 6

Neural Plasticity and Neural Correlate of Perception

Dr. Xiaoqin Wang

Outline

1. Brodmann's designation of cortical areas in humans (Fig.6-1).

2. Sensory inputs during development are necessary for the formation of cortical maps (Fig.6-2, 6-3, 6-4).

3.Cortical maps are continuously modified by sensory experience throughout the adulthood due to cortical plasticity (Fig.6-5).

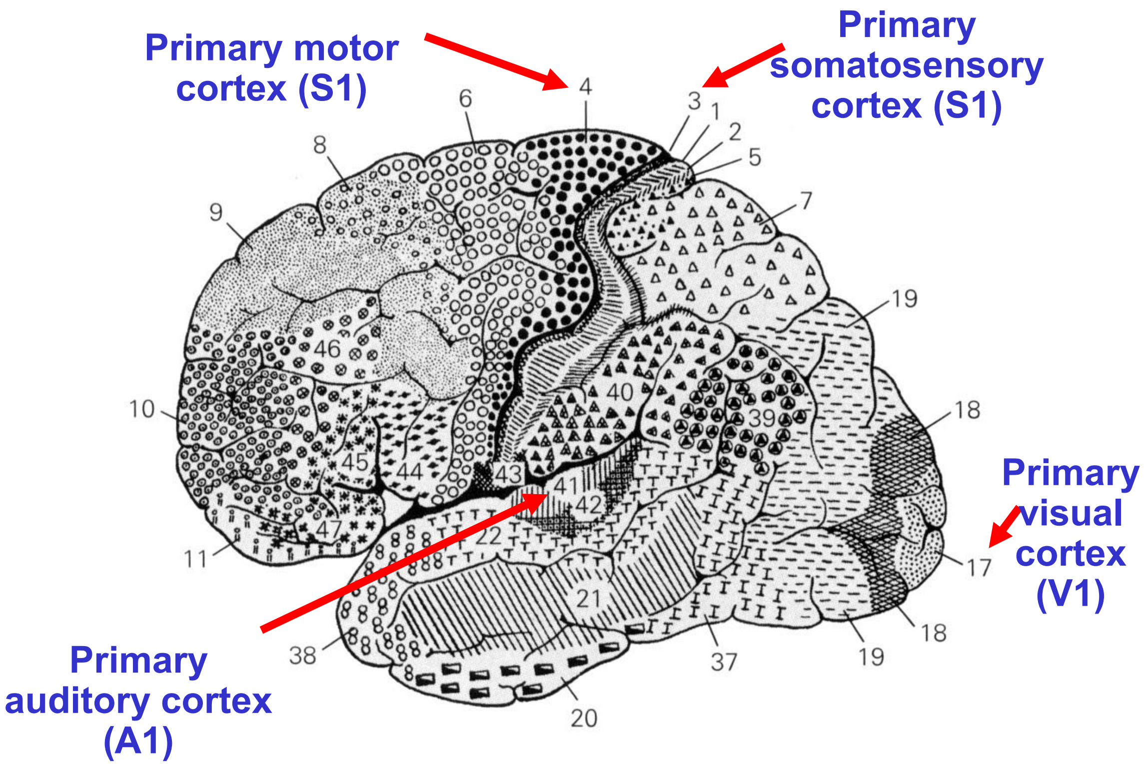
4.Cortical responses to sensory stimuli are modulated by selective attention (Fig.6-6).

5.Cortical neurons respond to actual as well as illusory features of a sensory stimulus (Fig.6-7).

6. Perception is directly correlated with neural activities in the brain.

Example: Motion processing by visual cortical neurons (Fig.6-8, 6-9).

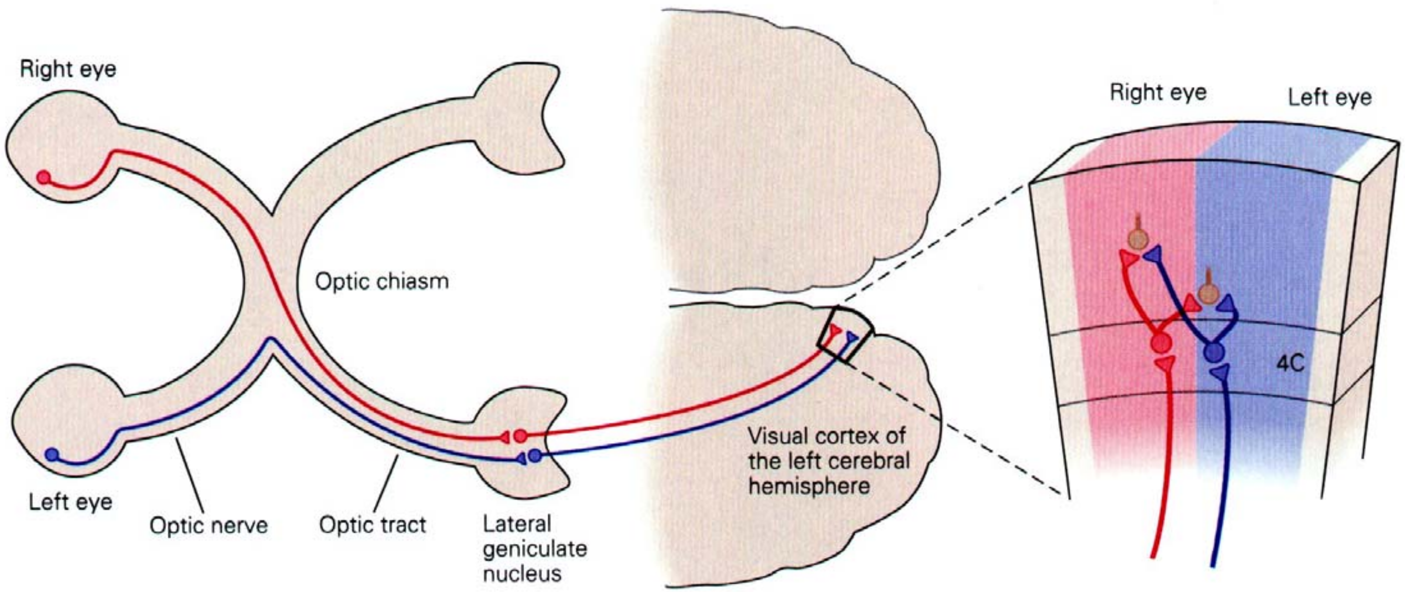
Brodmann's naming convention



In the early part of the twentieth century Korbinian Brodmann divided the human cerebral cortex into 52 discrete areas on the basis of distinctive nerve cell structures and characteristic arrangements of cell layers. Brodmann's scheme of the cortex is still widely used today and is continually updated. In this drawing each area is represented by its own symbol and is assigned a unique number. Several areas defined by Brodmann have been found to control specific brain functions. For instance, area 4, the motor cortex, is responsible for voluntary movement. Areas 1, 2, and 3 comprise the primary somatosensory cortex, which receives information on bodily sensation. Area 17 is the primary visual cortex, which receives signals from the eyes and relays them to other areas for further deciphering. Areas 41 and 42 comprise the primary auditory cortex. Areas not visible from the outer surface of the cortex are not shown in this drawing.

Fig.6-1

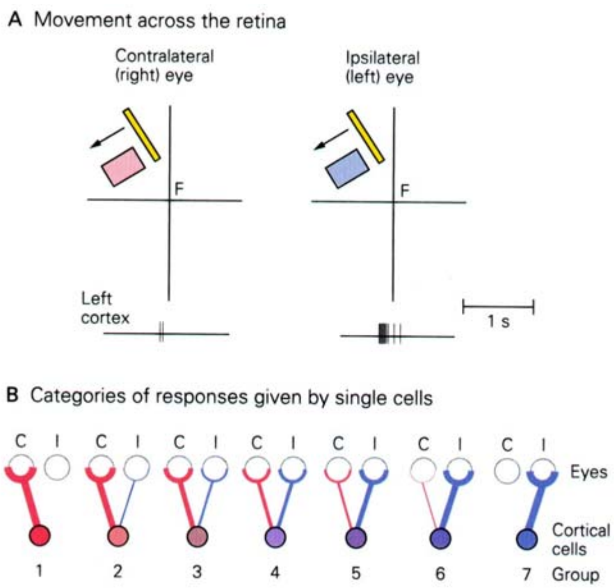
Ocular dominance columns in V1

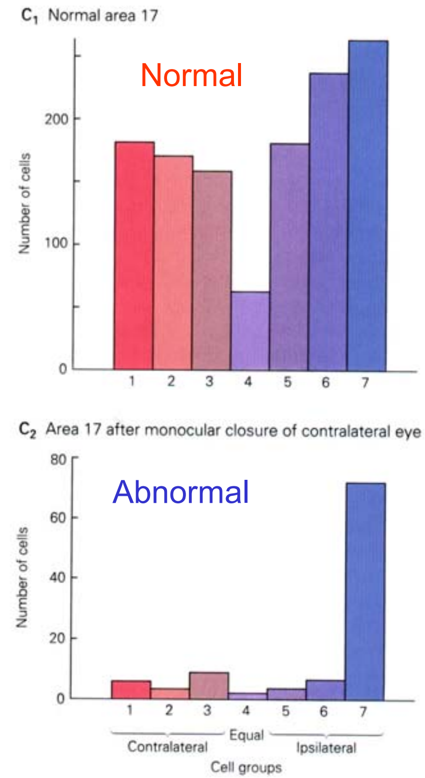


Afferent pathways from the two eyes remain segregated as they project to the visual cortex. Retinal ganglion neurons from each eye send axons to separate layers of the lateral geniculate nucleus. The axons of neurons in the lateral geniculate nucleus project to and form synaptic connections with neurons in layer 4C of the primary visual cortex, also known as area 17. Neurons in layer 4C are organized in alternating sets of ocular dominance columns; each column receives input from only one eye. The axons of the neurons in layer 4C project to neurons in adjacent columns (not shown) as well as to neurons in the upper and lower layers of the same column. As a result most neurons in the upper and lower layers of the cortex receive information from both eyes.

Fig.6-2

Neural response preference in V1



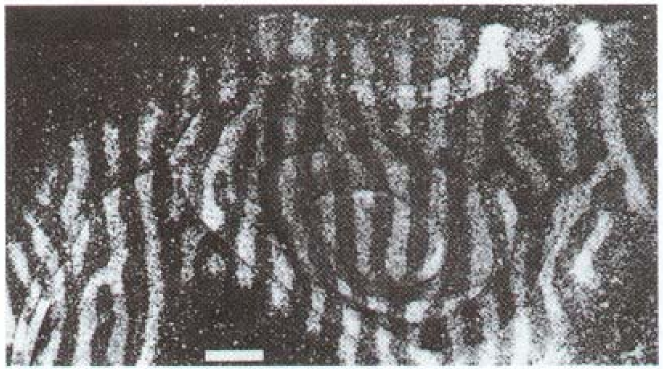


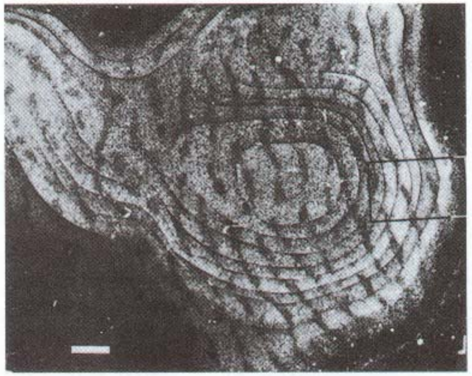
Responses of neurons in area 17 of the monkey visual cortex to visual stimuli. A). A diagonal bar of light is moved leftward across the two eyes in the path of the receptive fields (colored rectangles) of two cells, each conveying input from one eye. The receptive fields of the two cells are similar in orientation, position, shape, and size, and they respond to the same form of stimulus. The center of the visual field falls on the fovea (F), the region of the retina with greatest acuity. Retinal images for the right and left eyes are drawn separately for clarity. The inputs from these cells converge on a single neuron in area 17 of the cortex. Recordings from the cortical neuron (below) show that the neuron responds more effectively to input from the ipsilateral eye than from the contralateral eye. B). The responses of single cortical neurons in area 17 can be classified into seven groups. Neurons receiving input only from the contralateral eye (C) fall into group 1, whereas neurons that receive input only from the ipsilateral eye (1) fall into group 7. Other neurons receive inputs from both eyes, but the input from one eye may influence the neuron much more than the other (groups 2 and 6), or the differences may be slight (groups 3 and 5), Some neurons respond equally to input from both eyes (group 4). According to these criteria, the neuron shown in part A falls into group 6. C). Responsiveness of neurons in area 17 to stimulation of one or the other eye. 1. Responses of over 1,000 neurons in area 17 in the left cerebral cortex of normal adult and juvenile monkeys. The neurons in layer 4C that normally receive only monocular input have been excluded. Most neurons respond to input from both eyes. 2. Responses of neurons in the left cerebral cortex of a monkey in which the contralateral (right) eye was closed from the age of 2 weeds to 18 months and then reopened. Most neurons respond only to stimulation of the ipsilateral eye.

Fig.6-3

Ocular dominance columns in V1: Normal vs. abnormal animals

Normal





Abnormal

Visual deprivation of one eye during a critical period of development reduces the width of the ocular dominance columns for that eye. A). A tangential section through area 17 of the right cerebral cortex 10 days after the right eye of a normal adult monkey was injected with a radiolabeled amino acid. The autoradiograph shows the radioactivity as localized stripes (white areas) in layer 4C of the visual cortex, indicative of areas innervated by afferents from the lateral geniculate nucleus that carry input from the injected eye. The alternating unlabeled dark stripes correspond to regions innervated by afferents from the uninjected eye. Labeled and unlabeled regions form stripes of equal width. (Scale bars in micrographs A, B, and C = 1 mm.) B). A comparable section through the visual cortex of an 18- month-old monkey whose right eye had been surgically closed at 2 reeks of age. The label was injected into the left eye. The wider white stripes of label correspond to the terminals of afferent axons carrying signals from the open (left) eye; the narrower dark stripes correspond to inputs for the closed (right) eye. C). A section comparable to that in part B from an 18-month-old monkey whose right eye had been shut at 2 weeks. In this case the label was injected into the closed right eye, giving rise to narrow white stripes and expanded dark stripes of label in the visual cortex D). Reconstruction of the ocular dominance columns in area 17 of the right brain hemisphere of a normal monkey, showing the intricate organization of the columnar map.

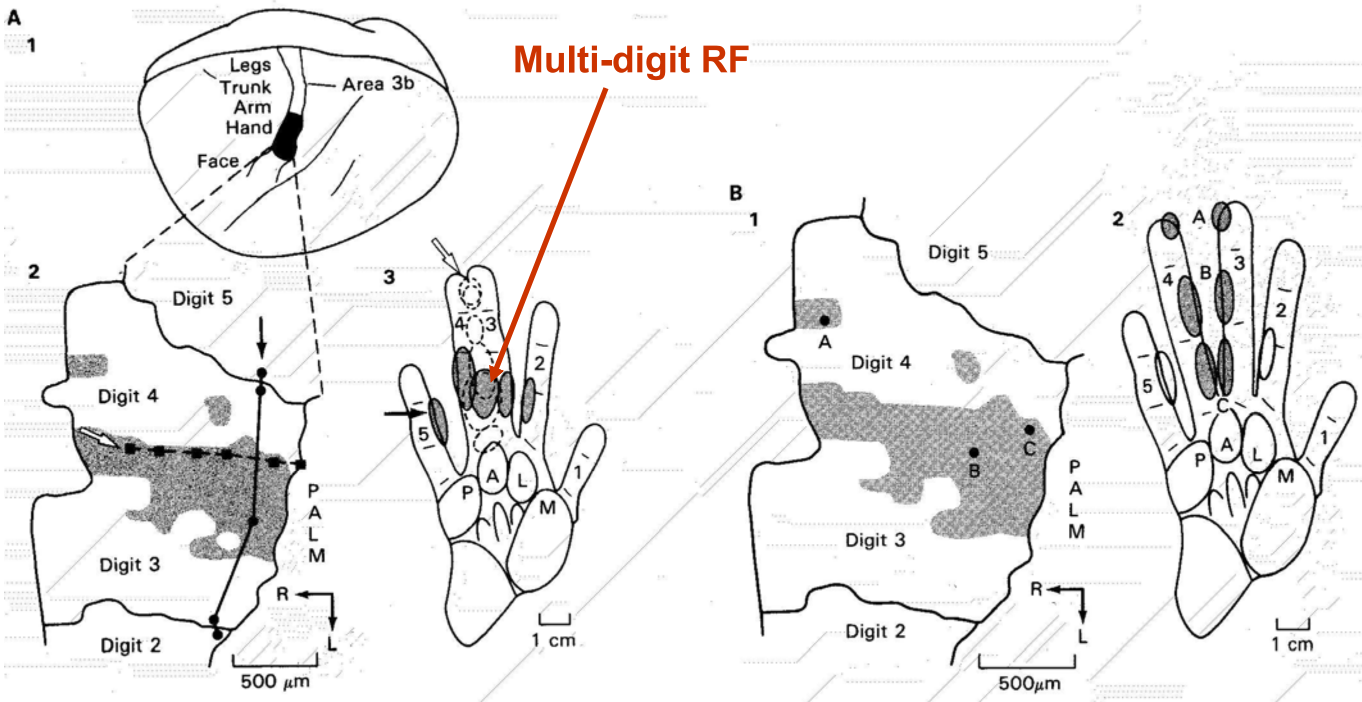
Fig.6-4

Summary (1)

- Sensory inputs during development are necessary for the formation of cortical maps

Deprivation of normal sensory inputs during early development results in both functional and anatomical changes in the cortex.

Topographic maps are shaped by behavioral experience in adult animals



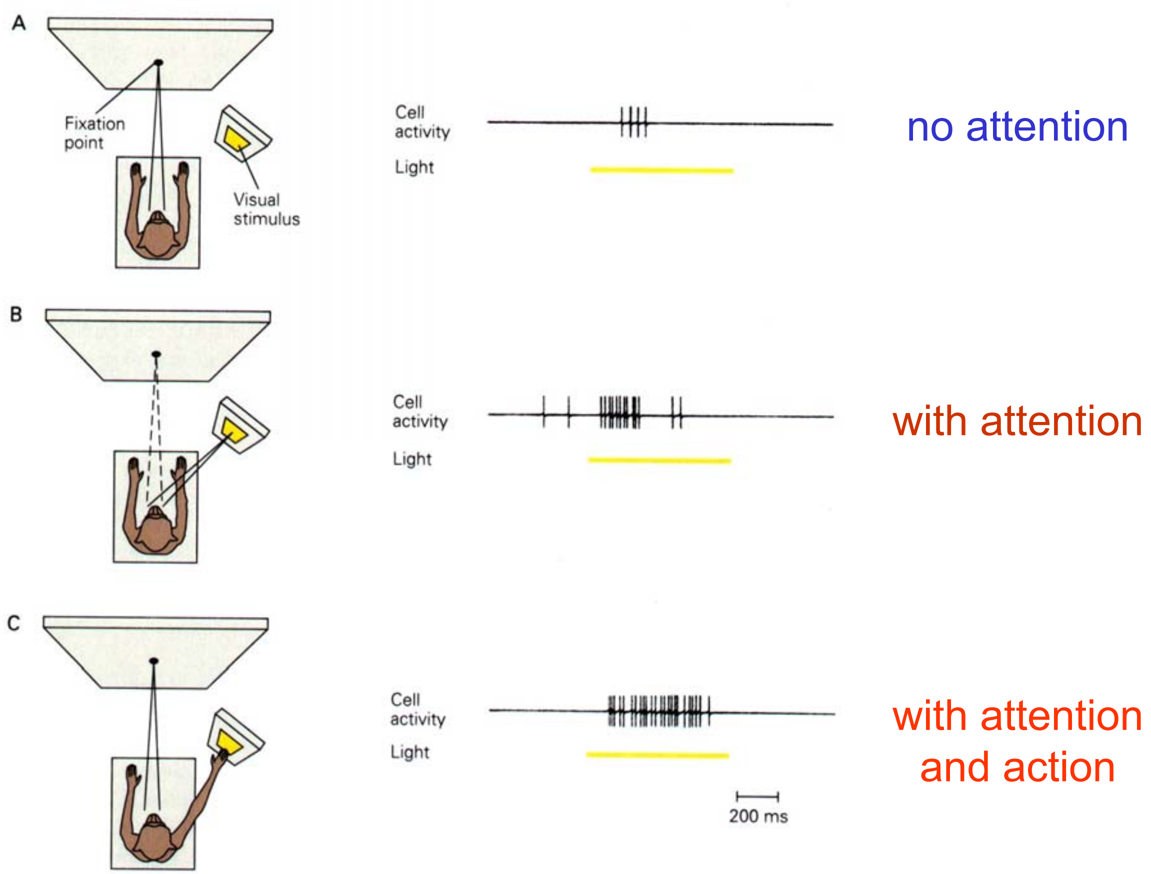
Cutaneous fusion of digits 3 and 4 in the adult owl monkey leads to loss of the normal discontinuities in the cortical representation of these digits. A). 1. Dorsolateral view of the neocortex of an owl monkey showing the representation of the contralateral skin surface, including that of the hand (shaded), in area 3b of the primary somatosensory cortex. 2. Reconstruction of the cortical zones of representation of digits 3 and 4 and surrounding skin surfaces five and a half months after surgical fusion of these digits. The shaded area marks the representation following digit fusion. Instead of the discontinuities normally present between digits, there is now a large common area, which represents the parts of the digits that are jointly fused. Threshold stimulation of the surfaces of either one of the two fused digits evoked a cortical neuronal response within this zone. This zone ranged from 340 um to 1000 um in width. In contrast, the representation of the borders of the fused digits (3 and 4) with the adjacent free digits (2 and 5) remains sharp. Filled dots (●) and squares (□) represent recording sites in the rostral-to-caudal direction (white arrows) and in the medial-to-lateral direction (black arrows). 3. The receptive fields for the neurons at the recording sites shown in A2. B). Even after the fused digits are separated (2) the fused representations remain (1). Thus, the fusion of the representation of the common borders of digits 3 and 4 is achieved centrally, and does not result from peripheral regeneration that spares the site of contact. .

Fig.6-5

Summary (2)

- Cortical maps are continuously modified by sensory experience throughout the adulthood due to cortical plasticity.

Cortical responses to sensory stimuli are modulated by selective attention



Neurons in the posterior parietal cortex of a monkey respond more effectively to a stimulus when the animal is attentive to the stimulus.

A). A spot of light elicits only a few action potentials in a cell when the animal's gaze is fixed away from the stimulus.

B). The same cell's activity is enhanced when the animal takes visual notice of the stimulus through saccadic eye movement.

C). The cell's activity is further enhanced when the monkey touches the spot but without moving his eyes.

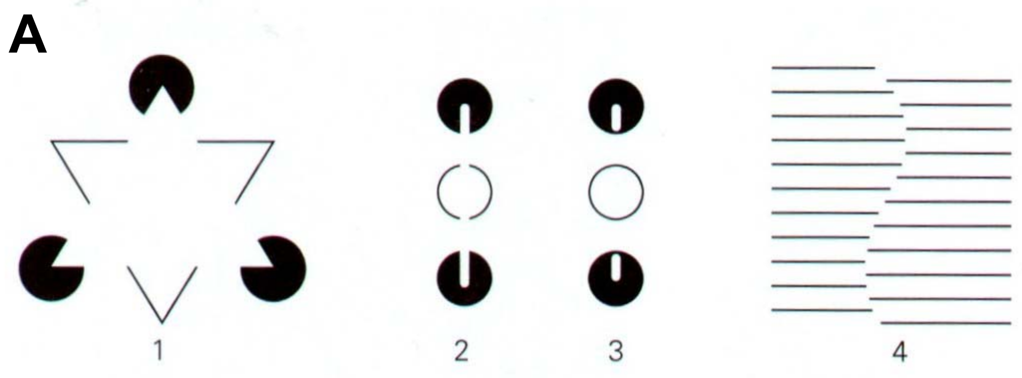
Fig.6-6

Cortical neurons respond to illusory contours of sensory stimulus

Illusions of edges used to study the higher level information processing in V2 cells of the monkey.

A). Examples of illusory contours. 1. A white triangle is clearly seen, although it is not defined in the picture by a continuous border. 2. A vertical bar is seen, although again there is no continuous border. 3. Slight alterations obliterate the perception of the bar seen in 2. 4. The curved contour is not represented by any edges or lines.

B). A neuron in V2 responds to illusory contours. The cell's receptive field is represented by an ellipse in the drawings on the left. 1. A cell responds to a bar of light moving across its receptive field. Each dot in the record on the right indicates a cell discharge and successive lines indicate the cell's response to successive movements of the bar. 2. The neuron also responds when an illusory contour passes over its receptive field. 3, 4. When only half of the stimulus moves across the cell's receptive field, the response resembles spontaneous activity.



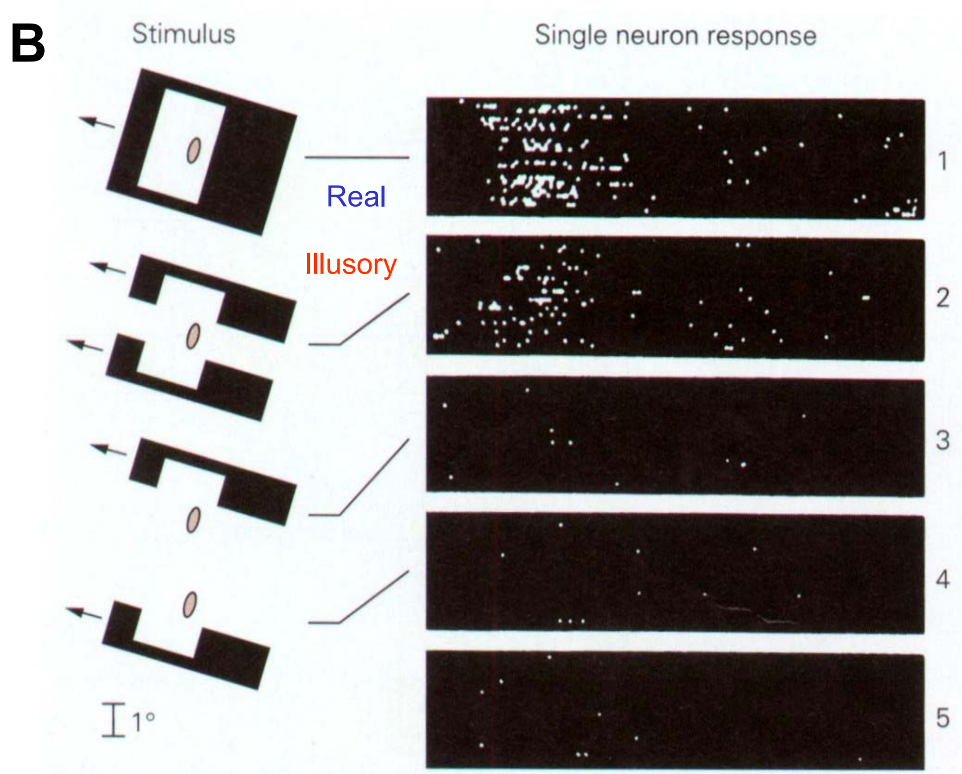


Fig.6-7

Summary (3)

- Cortical responses to sensory stimuli are modulated by selective attention.
- Cortical responses correspond to both real and perceived sensory environment.

Cortical area MT is responsible for motion perception

A monkey with an MT lesion and a human patient with damage to extrastriate visual cortex have similar deficits in motion perception.

A) Displays used to study the perception of motion. In the display on the left there is no correlation between the directions of movement of several dots, and thus no net motion in the display. In the display on the right all the dots move in the same direction (100 % correlation). An intermediate case is in the center; 50% of the dots move in the same direction while the other 50% move in random directions (essentially noise added to the signal).

B) The performance of a monkey before and after an MT lesion (left). The performance of a human subject with bilateral brain damage is compared to two normal subjects (right). The ordinate of the graph shows the percent correlation in the directions of al moving dots (as in part A) required for the monkey to pick out the one common direction. The abscissa indicates the size of the displacement of the dot and thus the degree of apparent motion. Note the general similarity, between the performance of the humans and that of the monkey and the devastation to this performance after the cortical lesions.

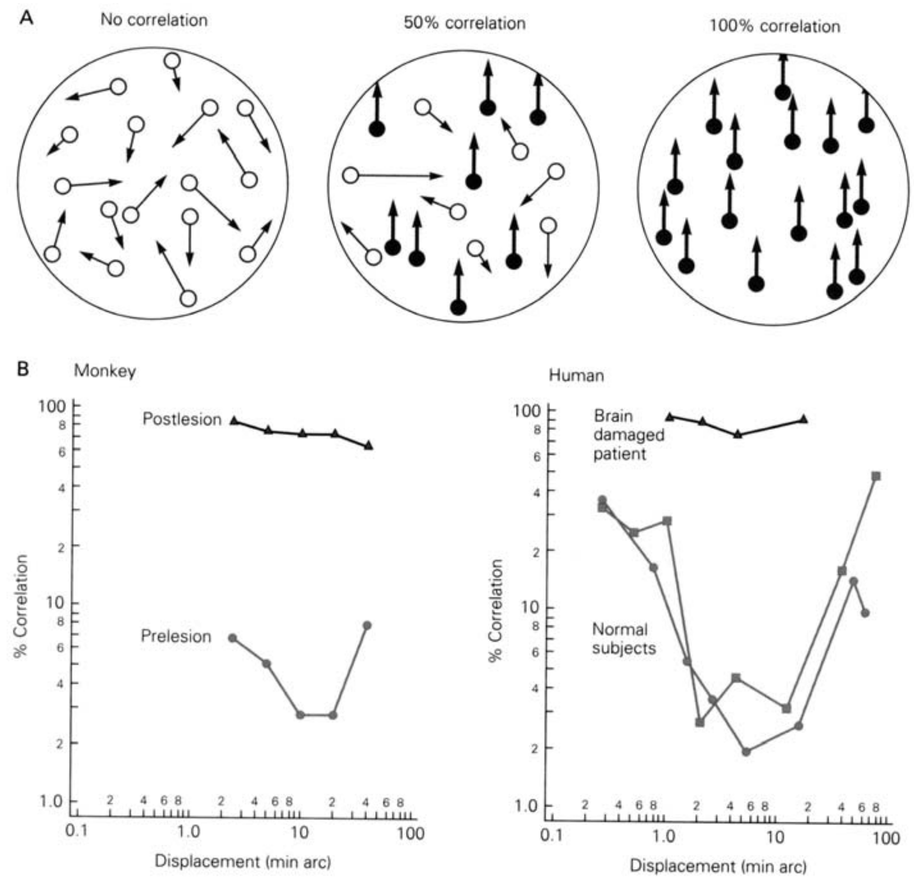
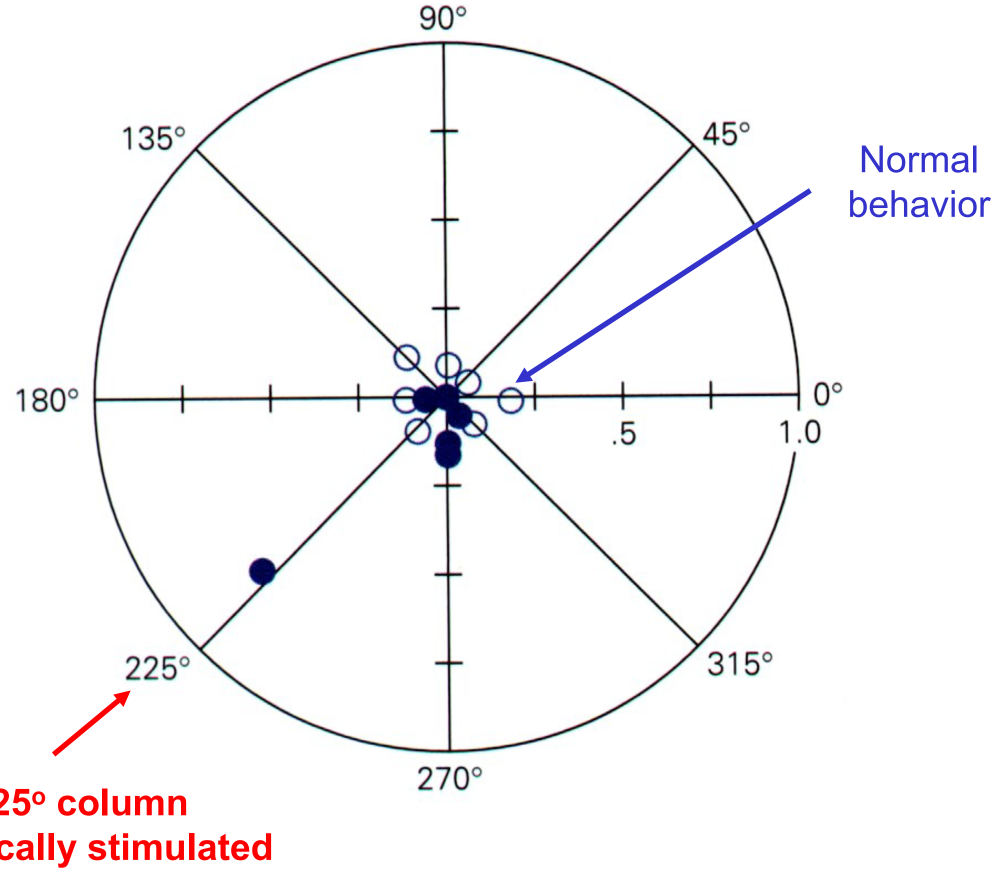


Fig.6-8

Electric stimulation of the cortex biased monkey's decision on detecting the direction of motion

Alteration of perceived direction of motion by stimulation of MT neurons. A monkey was shown a display of moving dots with a relatively low correlation of 25.6% and instructed to indicate in which of eight directions the dots appeared to be moving. The open circles show the proportion of decisions made for each direction of motion- about equal choice for all directions. Electric current was passed through a microelectrode positioned among cells that responded best to stimulus motion in one direction, 225° on the polar plot. The microsimulation was applied for 1 second, beginning and ending with the onset and offset of the visual stimulus. Filled circles show the response of the monkey when the MT cells were stimulated at the same time the visual stimulus was presented. Stimulation increased the likelihood that the monkey would indicate seeing motion in the direction preferred by the stimulated MT cells (225°).



Summary (4)

- Perception is directly correlated with neural activities in the brain.

Summary of Lecture 6

- Sensory inputs during development are necessary for the formation of cortical maps
- Cortical maps are continuously modified by sensory experience throughout the adulthood due to cortical plasticity
- Cortical responses to sensory stimuli are modulated by selective attention.
- Cortical neurons respond to actual as well as illusory features of a sensory stimulus.
- Perception is directly correlated with neural activities in the brain.

Summary by Each Sensory System

	AUDITORY	SOMATOSENSORY	VISUAL
Receptor	Inner ear (2-1) Cochlea (2-2, 2-3) Hair cell (2-4, 2-5)	Somatic receptors (2-13)	Retina (2-6 ~ 2-12) Ganglion cell (4-4, 4-6)
Neural response	RF (1-5, 1-6) Discharge rate (4-3) Temporal discharge pattern (3-6, 3-7, 3-8, 3-9) ITD (4-12), IID (4-13)	RF (1-2, 1-6, 2-14 ~ 2-16, 3-11, 5-11, 5-16) Discharge rate (1-8)	RF (4-5, 4-10) Discharge rate (3-5) Temporal discharge pattern (5-20)
CNS	CNS pathway (4-11, 5-3) Cortical responses (5-20, 5-21, 5-22)	CNS pathway (5-2) Cortical maps (5-8, 5-9, 5-12) Cortical responses (5-17, 5-18, 5-19) Plasticity (6-5)	CNS pathway (5-1, 5-18) Cortical maps (orientation columns: 5-13 ~ 5-15; ocular dominance columns: 5-14, 6-2) Cortical responses (5-23, 6-6, 6-7) Plasticity (6-3, 6-4)
Behavior	Categorical perception (1-13)	Two-point discrimination (2-16) Vibration threshold (2-17)	Illusion (1-12, 6-7) Motion processing (6-8, 6-9)