Functions of the interneuron that forms the data processing unit of vision

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1. Introduction

The data processing of human vision is interested for the engineer in the field of robotics. The nerve cells in retina have been investigated in detail [1]. But, today's understanding of mechanism of human vision is insufficient. The problem is to find out what is happening to each type of interneuron in the retina. The investigation described in this paper was carried out in order to confirm the presumption that the segmentation of data processing exists in the outer and inner plexiform layer, and the function is realized via horizontal cells and amacrine cells. The nerve cell group that occurs simultaneously forms an area by support of interneuron. That is, the reticular connections to an area of neurons with the same attributes and parallel line of the neuron contribute to increase the reliability of the processing.

The proposing mechanism was confirmed through the inspections based on the functions of neurotransmitters, and the functions of principal cells in a retina were explained.

2. Sensitivity adjustments of a photoreceptor

There are ligand-activated ion channels and voltage-activated sodium ion (Na^+) channels in a photoreceptor. The sensitivity of each ion channel is adapted by plural reactions as follows.

1) The ligand-activated ion channels of photoreceptor are opened by the ligand of cGMP (cyclic Guanosine Mono-Phosphate). Decrease in internal concentration of cGMP is triggered by light via rhodopsin. This decrease closes Na^+ channel, and the cell is hyperpolarized [2] pp.569. On the other hand, the membrane potential of photoreceptor becomes high in the dark, because Na ions flow into the cell via cGMP. So, the cell is depolarized in the dark.
2) Opening of voltage-activated sodium channels emphasizes the depolarization. An adjustment of sensitivity for the voltage-activated sodium channels is carried out by shifting of the membrane potential by cGMP-activated ion channels. The frequency of spike caused by voltage-activated Na^+ channel relies on the potential difference of membrane [4].
3) The production of cGMP is restrained by calcium ion (Ca^{+2}) that mixes to Na^+ via voltage-activated Na^+ channels. Decrease in internal concentration of cGMP closes Na^+ channel, and the cell is hyperpolarized. This reaction transfers the membrane potential toward middle level, and it has effects of the adaptation to brightness i.e. light adaptation.

The cGMP-activated ion channels are embedded in surface of the membrane. In the cone, the channels are on infolded membrane that is continuous with the surface membrane. But, in the rod, the channel is embedded in membranes arranged in the form of disks, not continuous with the outer membrane of the cell. This disk was separated from the constricted portion of the protoplasm membrane. So we can assume that the channel embedded in membranes of disks operates the same function of that in surface membrane.

3. The function of horizontal cell

3.1 Neurotransmitters in outer plexiform layer

The data for pattern recognition in the form of glutamate neurotransmitter are discharged into the outer plexiform layer from photoreceptors. There are bipolar cells and horizontal cells and those cells do not generate impulse but those respond with membrane potentials. Moreover, there are ON bipolar cells and OFF bipolar cells. Here, ON dipolar cells respond with depolarization to light being turned "ON", and OFF dipolar cells respond with depolarization to light being turned "OFF".

The receptor of each cell was decided by electro-physiological analyses [1] /GLU.12. References, Table 2.

Horizontal cell and OFF bipolar cell possess non-NMDA (non-N-methyl-D-aspartate) receptors. ON bipolar cell possesses APB (2-amino-4-phosphobutyric acid)-activated receptors.

In non-NMDA type, there is AMPA (α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid) receptor and kainate receptor. Kainate receptors are involved in excitatory neurotransmission by earlier activating postsynaptic receptors, and in inhibitory neurotransmission by modulating release of the inhibitory neurotransmitter GABA through a presynaptic mechanism later. AMPA receptor mediates fast synaptic transmission. By intencse activation of AMPA receptors, the change in membrane potential pusheses magnesium ion from the channel of NMDA receotor, allowing current to flow through it if it is activated by glutamate. That is, horizontal cell and H bipolar cell are depolarized by increase of glutamate.

On the other hand, APB (2-amino-4-phosphonobutyrate) receptor of ON-bipolar cell is the metabolism type glutamate receptor which is active through an indirect metabotropic process. The APB receptor, found on ON-bipolar cell dendrites, is coupled to the synthesis of cGMP. At these receptors, glutamate increases cGMP formation leading to the open of ion channels. From Slaughter and Miller (1981) [4], APB abolishes light responses in an ON bipolar cell and depolarizes the membrane potential.

3.2 A horizontal cell forms the segmentation for a processing by a positive feedback reaction

Although horizontal cells in area of OFF center are controlled by the photoreceptors, horizontal cells in area of ON center are controlled from ON dipole cells via the effect of APB receptors as described in section 3.1. The interneuron connects with many cells and it outputs an impulse to all connected cells. The effects depend on the membrane potential of interneuron caused by the integrated value from the connected cells. This positive-feedback effect organizes a segmentation of data processing as follows.

[A positive feedback loop via horizontal cell in OFF center]

Decrease of glutamine from photoreceptor due to increase of lighting yields decrease of positive impulses from horizontal cell. The increase of glutamine from photoreceptor in the dark results in increase of positive impulses from horizontal cell. That is, the horizontal cell in OFF center reinforces reaction in the receptive field on OFF center.

[A positive feedback loop via horizontal cell ON center]

In the receptive field of ON center, the existence of APB abolishes the activity of photoreceptors and it depolarizes the membrane potential of ON dipole cell. The abolishment of photoreceptor in ON center induces the antagonized change, i.e. the change of ON center is opposite to that of OFF center. So, the membrane potential of the horizontal cell in the ON center is depolarized at light. Then, the horizontal cell in ON center reinforces the reaction of ON center.

4. The function of amacrine cell

4.1 Neurotransmitter in the inner plexiform layer.

The bipolar axon connects to ganglion cell in inner plexiform layer. OFF bipolar cell axons and OFF ganglion cell dendrites co-stratify in sublamina (a: bipolar cell side). On the other hand, ON bipolar axons and ON ganglion cell dendrites co-stratify in sublamina (b: ganglion cell side).

The amacrine cells serve to modulate the temporal domain in the inner plexiform layer. Neurotransmitters of amacrine cell are non-NMDA and NMDA [1] /GLU.12. References, Table 2.

The output of impulses from ganglion cell is increased by increase of the neurotransmitter of non-NMDA due to glutamate.

On the other hand, activation of NMDA receptor depends on both ligand of glutamine and increase of membrane potential. The removal of Mg from NMDA receptor by activated AMPA receptor allows the influx of Ca^{2+} through glutamate-activated NMDA receptors. The mechanism is an associative LTP (Long-Term Potentiation), and it brings long term memory. The number of NMDA receptor is decreased rapidly after a critical period of neural plasticity.

4.2 Formation of segmentation of data processing

The glutamate-activated amacrine cell is discharging the nerve transmission substance that increases permeability of cation. This cell connects with the bipolar cells those are possessing with the same attribute in the vicinity. Each neuron outputs an action potential by the influx of cation when the total value of stimulations exceeds the threshold value.

An amacrine cell forms an area empirically. The cell outputs an activity potential by the stimulation from all connected cells and the output is provided to all connected cells concurrently and it promotes concurrent depolarization of the connected cells. The amacrine cell plays the role of the filter that that emphasizes each receptive field. The frequency of impulsive outputs depends on the integrated value on connected cells.

4.3 Emphasis for an image of moving

An amacrine cell makes connections among cells on the same attribute of simultaneous activation. There are 3 types of amacrine cells in inner plexiform layer. Those are the OFF amacrine cell in sublamina (a), ON amacrine cell in sublamina (b), and ON-OFF amacrine cell.

The connections of ON-OFF amacrine cell are formed empirically regarding the same attribute. And there is difference on reaction-time between ON bipolar cell and OFF bipolar cell. Then, it is concluded that the ON-OFF amacrine cell plays the role that emphasizes a receptive field on an image of moving. The image of moving is available to control of the eye movement and the movement of eye indicates speed of the object.

4.4 Fast response by gap junction

A Ⅱ amacrine cell connects to ON bipolar cell by excitatory gap junction and it connects to OFF bipolar cell by inhibitory synapses using glycine as a transmitter [2] pp.595. The gap junction is an electrical synaptic transmission. It reacts immediately by the connexon that bridges connecting channels.

Here, the author would like to correct explanation of the function of amacrine cell described in paper [5]. The explanation in [5], the time delay of amacrine cell is used to extract an image moving. In renewal of the explanation, amacrine cell extracts images via responses of ON area together with OFF area.

5. Applications for artificial vision

The visual perception is carried out by many kinds of decoders. A decoder is realized by the pattern-matching. But this processing needs segmentation and the strict adjustment of sensitivity. As for the segmentation for a pattern matching, the minimum segmentation for a visual perception corresponds to the receptive field in human vision. A selection among prepared outputs results in a data compression. That is a decoder in a receptive field.

The output of a lower layered decoder is used as an input of upper layered decoder with wider segmentation. Although there are overlapped segmentations for human vision, upsizing of segmentations are not repeated. The plural segmentations depend on the object. The visual recognition is carried out the combination of plural attributes those are detected concurrently.

6. Conclusions

A reliable data processing is carried out by the plural neurons those link to neurons in an area of same attribute. So, the connections of a neuron form reticular connections.

The investigations were carried out in order to find out the evidence that meets the condition of the assumption that segmentation of data processing exists in a retina. Depending upon knowledge about effects of individual neurotransmitter, we could explain the function of cell including the assumed function.

The author hopes that this report will contribute to understanding of human vision, and it will also contribute to develop the engineering of vision.

References

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