Cognition and Neuroscience - Module 01 exam questions

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1. Describe Neural Signaling

Neural signaling is the process by which neurons transform information into other cells. Neural signaling is divided into two processes: signaling within a neuron and signaling to other cells.

Signaling Within a Neuron

Inside a neuron, the information is received at the dendrites, conducted through the cell, transmitted down the axon, and passed to other cells through the synapses at the end of the axon. The cell that transforms the information is called the presynaptic cell, and the cell that receives the information is called the postsynaptic cell. This transfer involves transmitting an electrical impulse through the cell.

Nerves have the resting potential of -70 mV. The postsynaptic cell receives postsynaptic potentials, which are small changes in the membrane potential, and sums them up at the axon hillock. If the sum is large enough to depolarize the neuron and bring its potential to -55 mV (the threshold for starting an action potential), it will generate an action potential.

The process of creating an action potential: The neurons are full of K^+ ions and the fluid around the neurons is full of Na^+ ions. The density of the Na^+ ions is greater than the K^+ ions in the cell, and therefore the interior of a neuron has −70 mV potential. When the summed PSPs cause the potential to pass the threshold, the Na^+ ion gates at the membrane open, and sodium ions flow into the neuron, causing the neuron's potential to increase. The sodium continues to flow into the cell until the membrane potential reaches +30 mV. This is the threshold where the Na^+ gates close and the K^+ gates open, causing potassium to flow out of the cell. This causes the neuron's potential to decrease until it reaches the resting potential again, but because the K^+ gates are slow to close, the potential becomes a little bit more negative than −70 mV. This is called the refractory phase, during which neurons cannot create an AP anymore. After that, ion pumps activate and bring the neuron back to its original state.

The PSPs received at the dendrites are:

- Depolarization, which is excitatory PSPs and increases the neuron's ability to create an AP.
- Hyperpolarizing, which is an inhibitory PSP decreases the neuron's ability to create an AP.

Signaling Among Cells

Signaling between two cells is done through synapses, which are located at the end of the axon. There are two types of synapses in the body:

1. Electrical Synapses: In an electrical synapse, cells are connected through pores at gap junctions. The cytoplasm of the two neurons is completely touching, and they have the same potential. Signaling is done through a fast transmission of a flow of ions from the pre- to postsynaptic cell.

Transmission in this type of synapse is really fast, but they are less plastic and less specific. The signals can't be modulated.

2. Chemical Synapses: In chemical synapses, information transfer is done through the release of neurotransmitters. When an AP reaches the end of an axon, it causes the voltage-gated Ca^{2+} to open, flowing the Ca^{2+} in the neuron. The overflow of Ca^{2+} in the neuron causes synaptic vesicles to open, releasing neurotransmitters at the synaptic cleft. The neurotransmitter binds to receptors of the postsynaptic cell, causing different influences. It can have an excitatory effect, or an inhibitory effect, depending on the postsynaptic receptor. The neurotransmitter is then inactivated in different ways. The chemical synapses are slower in transmitting information but are more plastic and more specific. The signals can be modulated.

2. Describe Dopamine as a Matter of Prediction Error, Referring to Existing Evidence

Dopamine is a neuromodulator, which is a neurotransmitter that has effects beyond excitatory and inhibitory effects. It has an important role in movement, action selection, motivation, and learning.

The prediction error is the signed difference between the reward we thought we were going to receive and the reward we actually received.

Dopamine has a close relationship with prediction error. Experiments have shown that dopamine doesn't encode reward but encodes the prediction error of that reward. The dopamine system shows changes to the phasic response to an unexpected reward and:

1. Discriminate between reward and no reward:

   When we don't expect a reward, but we receive a reward, the dopamine neurons get more activated, and when we expect a reward and don't receive it, the dopamine neurons get inhibited. This is also shown in animal experiments. When monkeys touch food on a wire that they can't see, their dopamine neurons are excited, and when they touch an empty wire, they get inhibited.

2. Discriminate between the magnitude of the reward:

   This discrimination is done relatively and not in an absolute way. When the reward is more than expected, the dopamine neurons increase their firing rate, and our expectations are updated (they increase). When the reward is less than expected, the dopamine neurons decrease their firing rate and decrease the expectations.

3. The reward transfers back to the cue that predicted the reward:

   Experiments show that before learning when a stimulus is presented, the firing rate of the neurons increases after the reward is presented.

During training, dopamine firing rates start to transfer back to the stimulus. After training, the increased firing rate happens after the stimulus, and there is no major change in the firing rate after the reward is received because the reward is already predicted.

4. Discriminate between the probability of the reward:

   Experiments show that the lower the probability of a reward, the more the firing rate increases after receiving the reward and doesn't change much after the cue. At maximum uncertainty (50%), the dopamine neurons show activity increases right after the stimulus and then show ramp-like increases until receiving the reward. If the reward is very likely to happen, the increase in activity happens more right after the stimulus.

5. Sensitivity to timing:

   Dopamine cells are sensitive to temporal prediction errors. If a reward happens earlier than predicted, the firing rate of the neurons increases after the reward. If a reward happens later than predicted, the firing rate of the neurons is inhibited at the predicted time and then increases after receiving the reward. The depression of the neurons after not receiving the signal is not because of the cue, but it is because of an internal clock of the dopamine system.

3. Goal-Directed/Model-Based and Habitual/Model-Free

Model-Based

A model-based algorithm selects actions by using a model to predict the consequences of the possible actions and the rewards expected to arise from those actions.

Model-Free

A model-free algorithm chooses actions based on the previous actions made and their consequences over many learning trials.

Experiments: The ones with the Markov decision process.

4. Explain About Continuity and Contingency and the Experiments

Contiguity: The closeness in time between the stimulus and outcome. Stimuli that are close to one another in time become associated.

The closer in time two events are, the more likely they will become associated. There are two types of conditioning based on time:

- Delay conditioning: The CS extends from the time it starts until the reward is presented.
- Trace conditioning: The stimulus happens and then stops; then, after some time, the reward happens. Learning does not happen over long trace intervals.

Hypothesis: The longer the interval between the reward and stimuli, the more trials it takes for the conditional response to appear.

Experiment: Two groups of mice are trained. A tone was played, and then a pellet delivery of food happened. The first group received the food after 6s, and the second group received the reward after 18s. In the second group, learning took more time to happen.

Contingency: The causal relationship between the stimulus and outcome. If a stimulus shows evidence that it is possible to cause an outcome, it will be linked to that outcome.

Experiment: Two groups of rats are trained. In group A, a bell is rung, and then an electric shock occurs with a probability of 70%. If no bell rings, the probability of the shock is 30%. In group B, a bell is rung, and an electric shock happens with a probability of 50%. If there is no bell, the probability of the shock is still 50%.

5. Explain About Goal-Directed and Habitual Behavior

Habitual

Habitual Behavior: Habitual behavior is a type of behavior in which actions are performed automatically because they were successful in the past. These actions require minimal computation, are fast, and are inflexible to environmental changes. Habitual actions are performed regardless of the current value of their outcome and will persist even if the outcome is devalued.

Goal-Directed Behavior: Goal-directed behavior involves actively choosing actions based on the anticipated rewards. These actions require extensive computation, occur with active deliberation, and are adaptable to changes in the environment. An action is considered goal-directed if:

- Knowledge exists about the consequences and rewards of potential actions.
- The outcomes of the actions are currently desirable.

Experiment: To test whether an action is habitual or goal-directed, a mouse is trained to press a button to receive a reward. Later, the reward is devalued (e.g., by overfeeding the mouse). When tested again:

- If the mouse continues to press the button, the action is habitual since it does not consider the devalued reward.
- If the mouse stops pressing the button, the action is goal-directed, as it evaluates the reward's current value.

Studies in humans show that habitual and goal-directed actions can occur simultaneously and compete. In one study, participants trained for one day responded adaptively to reward devaluation (goal-directed), whereas participants trained for three days exhibited habitual responses, persisting with actions for devalued rewards.

6. How Do Neurons Ensure Fast Conduction Over Long Distances?

The longest axons in the human body, such as motor neurons from the spine to the toe, span over a meter. However, passive current flow within neurons can only cover about 1 mm. To ensure rapid and effective conduction over such long distances, neurons utilize two key mechanisms:

Action Potentials: Action potentials are rapid depolarizations and repolarization of small regions of the cell membrane. This active process enables the electrical signal to travel across the neuron without losing strength.

Saltatory Conduction: Neurons are insulated by a substance called myelin, produced by Oligodendrocytes in the CNS and Schwann cells in the PNS. Myelin prevents voltage loss and increases conduction speed. Along the axon, unmyelinated regions known as nodes of Ranvier contain voltage-gated ion channels that regenerate the action potential. This allows the signal to "jump" between nodes, significantly speeding up conduction.

7. Example from Cognitive Neuroscience: How Function Emerges from the Nervous System

An example illustrating how cognition emerges from the nervous system is the process of learning. Learning involves the manipulation and integration of new information with prior knowledge. It occurs through changes in the nervous system, which can be short-term or long-term:

Short-Term (Hebbian Plasticity): Short-term changes involve temporary modifications in synaptic strength, lasting for minutes or hours.

Long-Term: Long-term changes involve structural modifications, such as the formation of new neural connections or the pruning of existing ones, enabling lasting learning and memory.

Learning, as a cognitive process, directly arises from these dynamic changes within the nervous system.