Learning and Memory

The cerebral cortex is responsible for the depth of the thoughts and also for the degree of awareness of our surroundings.

Definition of Thought: *"a pattern of stimulation of many parts of the nervous system at the same time, probably involving most importantly, the cerebral cortex, the thalamus, the limbic system and upper reticular formation of the brainstem"*[1]

Consciousness can be described as the continuing stream of awareness of either our surroundings or our sequential thoughts.

Structures of the brain involved

The thalamus, limbic system, reticular formation and cerebral cortex are involved in the processes of learning and memory, each serving a different function. The thalamus, limbic system and reticular formation work together and determine:

1. general nature of thought
2. the qualities such as pleasure, displeasure, paint, comfort, etc.
3. crude modalities in general (mainly in the amygdala, mesencephalon and hypothalamus)

Whereas, the cerebral cortex determines:

1. specific localization of sensation on body surface and in the field of vision (labeled line principle)
2. the feeling of texture of silk
3. visual recognition patterns (e.g.: face)
4. other individual characteristics that might enter one’s awareness at a particular instant

Memory storage

Memory is stored by changing the basal sensitivity between synapses in a neuronal pool, which has occurred due to previous neural activity (e.g.: rehearsal of new incoming information). These new facilitated (i.e., "paved") pathways are called memory traces.

The “positive” and “negative” memories

- Positive Memory: incoming information that elicits stimulation of either punishment (e.g.: pain) or reward (e.g.: pleasure) centers, promotes subsequent facilitation of the synaptic pathways → memory sensitization.
- Negative Memory: incoming information that elicits no stimulation to punishment nor reward centers, promotes subsequent inhibition of synaptic pathways → habituation.

Types of Memories

- **Short-Term**:
  - lasts seconds or maximum a few minutes
  - typified as remembering 7-10 numerals in a phone number
  - it can last for up to a few minutes only if the person actively thinks about them

Possible explanations underlying the way this type of memory works is by continual neural activity → signals travelling around a memory trace in a circuit of reverberating neurons, in conjunction with presynaptic facilitation and/or inhibition.

- **Intermediate Long-Term**:
  - last many minutes to weeks
  - eventually is lost, unless consolidated
  - can arise from temporary chemical or physical changes (or both), in either the synapse’s presynaptic terminals or postsynaptic membrane.

Possible explanations underlying the way this type of memory works are:

1. **Habituation** (progressive closure of calcium channels through the terminal membrane → less Ca^{2+} intracellularly → decrease in amount of neurotransmitter released)
2. **Facilitation**
   1. Axo-axonal synapse: Facilitator-Presynaptic terminal is stimulated at the same time as the sensory-presynaptic terminal is released → serotonin released from the facilitator terminal on the sensory terminal.
   2. Serotonin binds on the receptors that activate adenyl cyclase.
   3. Adenyl cyclase forms cAMP, inside the sensory-presynaptic terminal.
   4. cAMP activates cAMP-depended protein kinase which in turn phosphorylates a protein that is part of the

K^+ channels. These channels are situated on the sensory-presynaptic terminal. The phosphorylation blocks the channels.
5. This blockage can last for minutes up to several weeks.
6. Lack of K^+ conductance → prolonged action potential, since it is much harder for the sensory terminal to repolarize.
7. The prolonged AP → opens continually Ca^{2+} voltage-gated channels, so the conc. of Ca^{2+} inside the sensory presynaptic terminal raises so much → continuous release of neurotransmitter towards the post-synaptic terminal.
8. Fatigue of the synapse (such as from neurotransmitter shortage) is one of the causes that this facilitation ceases at one point.

- **Long-term**: this type of memory is a result of actual structural changes, some of which could be:
  1. increase in vesicle release sites for neurotransmitter secretion
  2. increase in the number of vesicles released
  3. increase in the number of presynaptic terminals
  4. changes in the structure of the dendritic spines (→plasticity) that permit transmission of stronger signals

During the 1st year of life, an excess number of neurons exist, which extend their axons' branches up to another neuron/muscle/gland, in order to establish a synapse. If this process fails, the axon dissolutes (degenerates). Furthermore, the number of neuronal connections is determined by specific nerve growth factors that are released retrogradely from the stimulated cells. That is when a neuron is stimulated, it will release growth factors that will help it extend its axon until a successful synapse occurs. If the entire neuron fails to establish sufficient synapses, then the entire neuron dissolutes.

Memory Consolidation

Memory consolidation is the process of conversion of short-term to long-term memory. The mechanism underlying this process is Long-Term Potentiation. The process of Long-term potentiation requires some time in order to be effective - typically 5-10 minutes for minimal consolidation, 1 hour for stronger consolidation. This can occur by the rehearsal technique:

- Brain has a natural tendency to rehearse newfound information
- Rehearsal causes the mind to accelerate the process of consolidation
- Progressively over time, more and more information is fixed in memory spaces.

This explains why a person can better remember in depth information on a single subject, rather than superficial information on vast amounts of different subjects. This also explains why a person who is wide awake can consolidate memories better than a person who experiences mental fatigue.

New memories are codified during consolidation. Codification takes place by comparing new "incoming" memory with older memories of similar information. The difference between the two is stored only (similarly to how differential computer backups work), instead of storing the new information as raw, random chunks. This also helps in indexing, for future recalls (searches/anterograde memory), since information is natively grouped by similarity.

Groups of memory according to their information content

1. **Declarative Memory** (reflexive memory): memory of an integrated thought, which includes surroundings, time relationships, causes of experience, meaning of the experience and any conclusions/deductions that remained from the experience. It is sub-divided into:
2. **Semantic Memory**: contains information that is abstract (names of things/people, numbers). Storage is individual for each of these items. There is a large brain capacity for such type of memory, it is usually long-term and can be recalled easily. It is probably stored near language areas.
3. **Episodic Memory**: contains causal, temporal and spatial information of different events. It serves for space-time orientation. Needs to be refreshed (i.e. rehearsed), otherwise it might vanish (intermediate long-term memory).
4. **Recognition Memory**: enables recognition of faces, locations and objects. Damage in the ability of storing this type of memory might result in inability to recognize objects (agnosia). It is usually localized at the cortical association areas.
5. **Skill Memory**: memory associated with patterns of motor activities, specifically controlled and sequenced for accomplishing a purpose (e.g.: hand movement in tennis serving).

Hippocampus and its contribution to memory

In hippocampus, no skill memories are processed or stored. It communicates with the punishment and rewards centers of the limbic system (and dorsal medial nuclei of the thalamus at a lesser extent), making it important for conducting 'decision-making' (operant conditioning), on which information is important and should be stored and which is not. Hippocampus is highly excitable and thus can take part in long-term potentiation (i.e., consolidation of memory). Hippocampal lesions cause inability for the person to initiate long term storage of new reflexive/declarative/intellectual memory. This is called anterograde amnesia. Some retrograde amnesia will also result from a hippocampal lesion (inability to remember recent events). However, native language and names are not disturbed. It is believed (but not proven) that the thalamus has the special capability of "searching" memories.[2]

Links

Related articles

References

1. HALL, John E – GUYTON, Arthur Clifton. *Guyton and Hall Textbook of Medical Physiology.* 11. edition. Saunders/Elsevier, 2005. ISBN 0721602401.
2. WINOCUR, – OXBURY, S – ROBERTS, R. , et al. Amnesia in a patient with bilateral lesions to the thalamus. *Neuropsychologia* [online]. 1984, vol. 22, no. 2, p. 123-43, Available from <http://www.ncbi.nlm.nih.gov/pubmed/6728177>. ISSN 0028-3932.

Sources

- Lecture Notes: Prof. MUDr. Jaroslav Pokorný DrSc.

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