Physiology of Learning and Memory

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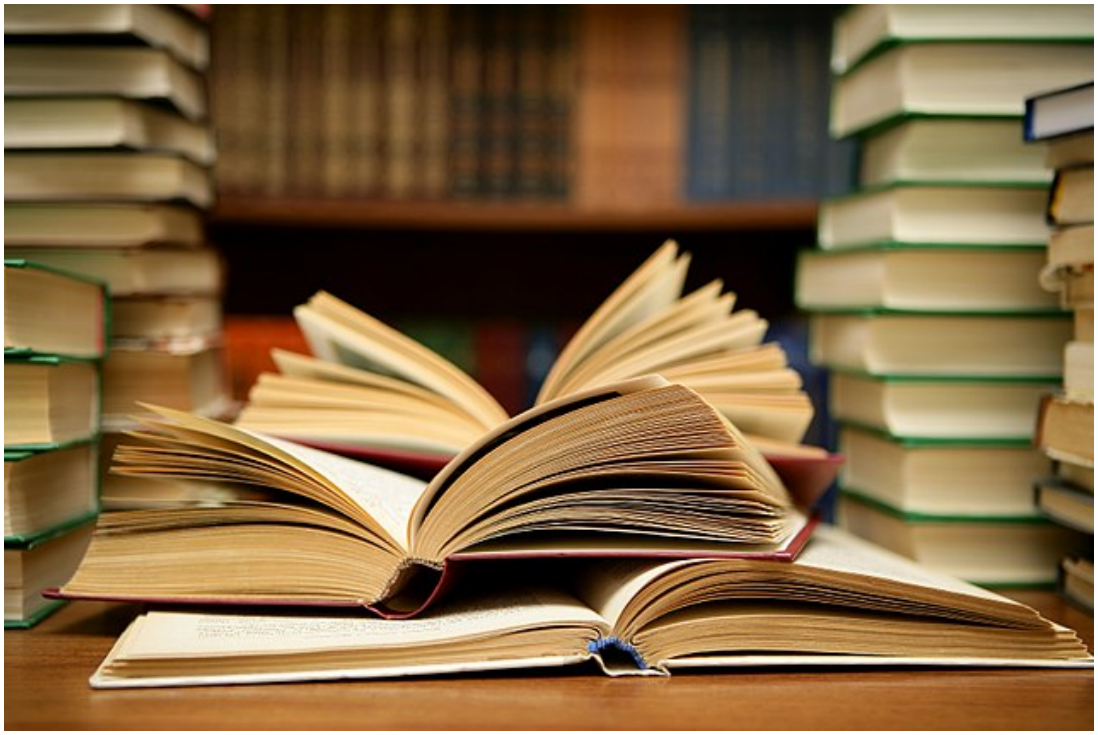
Learning and the development of memory are processes that cannot be strictly separated from psychology and sociology. Thus, this article deals with the physiology of learning and memory. Topics include understanding the relationship between experience and storage of acquired knowledge, how the brain deals with “useless” knowledge, and how a baby starts to understand its surroundings.



What Is Learning?

The word learning is originally related to ‘teaching somebody’ and ‘trick’. Furthermore, learning is also etymologically related to ‘tracing something’. The conclusion is that **learning** is a process to acquire new knowledge. Learning is the precondition for the brain to store experiences and to use those experiences in our actions to gain benefits and prevent damage.

Formation of synapses

Learning processes during the first 6 months of a baby’s life hold great significance for the development of the nervous system. Environmental stimuli and experiences also play a role in this process since they lead to the formation of new synapses and the improvement of already existing synaptic connections. The ability of the brain to form and improve these connections are referred to as **neuroplasticity**, whether they are

based on physiological or neuroanatomical conditions.

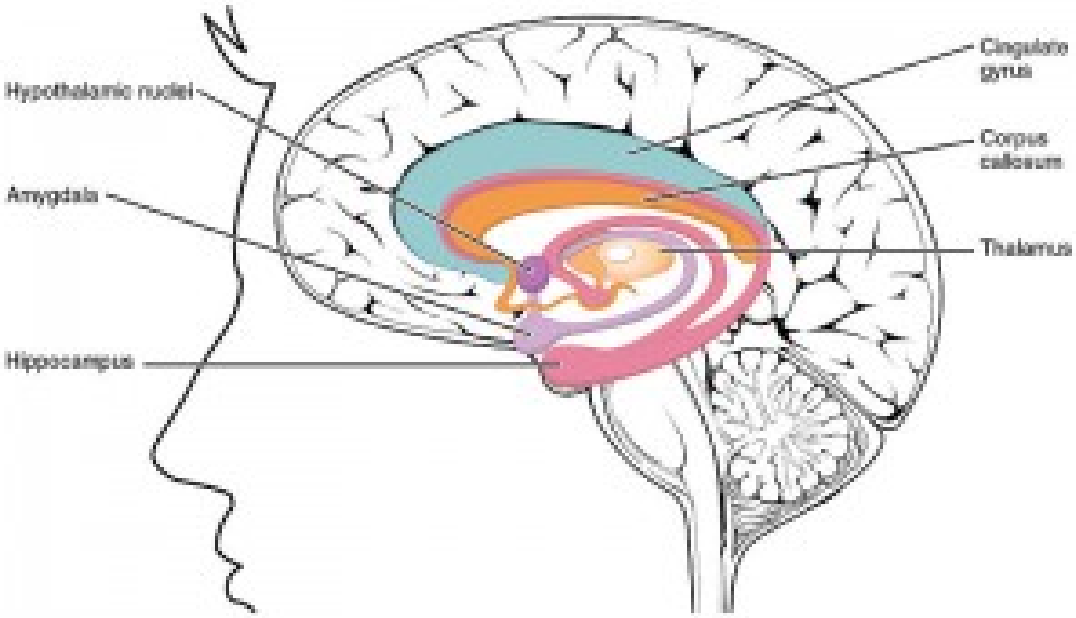


Image: Illustration from Anatomy & Physiology. By Anatomy & Physiology, Connexions Web site, Licence: CC-BY 3.0

How do infants learn?

Most brain cells are already formed during pregnancy. However, an infant's nerve cells still cannot communicate at the time of birth, since they are not yet connected. These connections are developed during the 1st 3 years of life. This process takes place by developing **dendrites**, which enable cells to absorb information. Moreover, **synaptic connections**, which are responsible for relaying information, are formed. The extent of these connections is far greater than what is required, which makes it easy to adjust later if needed.

Learning capacity of babies

Babies react strongly to **stimuli**, which is also an important indication that a learning process is being carried out. Besides, these stimuli are necessary for the brain to develop, meaning that an environment with few stimuli hinders the development of babies.

During this development stage, the ability to differentiate faces and vocal sounds are better developed than in adults, which enables the baby to distinguish between familiar people and strangers. After imprinting their personal surroundings, the baby loses a certain amount of flexibility concerning their mental abilities. However, learning processes become more specific. This development takes place during the first 6 months of life.

How Does the Brain Work?

The brain uses **neurons** to communicate and, to a large extent, manage itself. However, the development of neurons and the resulting brain capacities depend on environmental and sensory stimuli. The brain works in connection with the **spinal cord** to send and receive information via the neurons. The brain processes all perceptions, which are also connected. For this process, the brain uses already stored experiences. However, most

perceptions are suppressed. The brain differentiates perceptions that must be processed during the learning process according to:

- Relevance
- Value of new knowledge
- Significance
- Meaningfulness

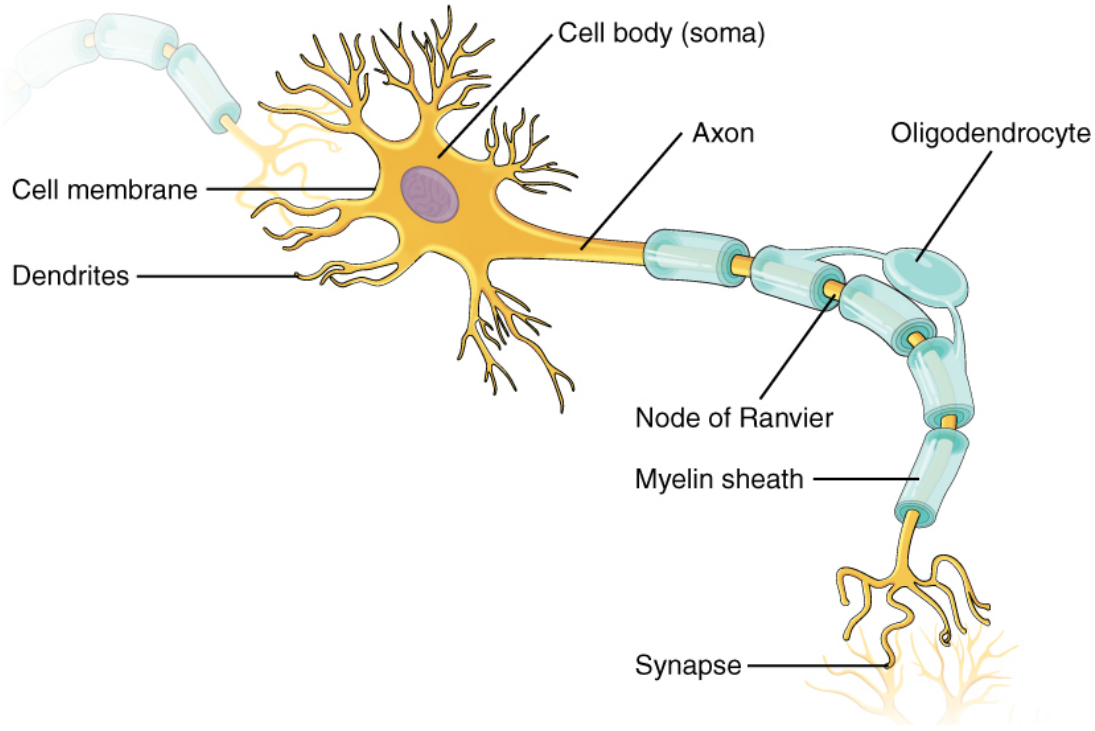


Image: Parts of a neuron. By philschatz.de, License: CC-BY 4.0

Importance of Emotions during the Learning Process

Cognition and emotions play a major role in the process of learning. **Sensations** are used as **somatic markers**, which influence **processing**, **storage**, and **memory**. Learning also includes the strengthening of the most used **neuronal pathways,** so they can be used longer and above all faster.

Learning as Formation and Deformation inside the Brain

The process of learning starts with processing external influences. Learning leads to changes in the brain that can be classified into 4 categories: **expanding**, **tuning**, **reconstructing**, and **pruning**.

Expanding means to improve the number and strength of **neuronal connections** by developing a network of already existing information. **Tuning** describes the process of creating new connections. During the process of **reconstructing**, **relearning** takes place. In this time-consuming and exhausting process, preexisting learning achievements (motor patterns and routine processes) are replaced by new ones that are better suited

for the respective task. **Pruning** describes the regression of **neuronal potential**, which is used little or not at all. During this process, connections can be changed in such a way that they cannot be activated anymore.

Learning is differentiated into:

- Intentional learning
- Individual learning
- Collective learning
- Physical learning
- Social learning

Significance of social interaction and physical activity

Humans need social interactions, and this also applies to the brain. **Mirror neurons** inside the brain are responsible for the development of the required cognitive orientation pattern. Physical activity is important for brain performance as well, and this particularly applies in the 1st years of life.

Localization of Learning Processes and Memory

Image: Cerebellum. By Database Center for Life Science(DBCLS), License: CC-BY-SA-2.1

Image: Temporal lobe. By Database Center for Life Science(DBCLS), License: CC-BY-SA-2.1

Motor learning is located in the neurons of the **cerebellum** and **basal ganglia**. The **declarative memory** is located in the **medial temporal lobe**. A lesion of the **hippocampus** leads to **anterograde amnesia,** meaning that new information cannot be stored anymore.

Memory Systems

The **procedural memory** is in the **striatum** and uses the **pathway** of the **neocortex**. **Associative learning** takes place inside the **amygdala** for emotional processes and in the **cerebellum** for motor processes. **Non-associative learning** occurs in the form of **habituation** and **sensitization** (both via reflex circuits).

Hebbian theory

The Hebbian theory explains how the connection between certain neurons can be strengthened.

If an axon of neuron A is located close enough to neuron B so that neuron B can be stimulated by neuron Repeatedly or continuously, the efficiency of neuron A for the stimulation by neuron B is increased by growth processes or changes in metabolism in both or 1 of the 2 neurons. This means that experience-related changes in the nervous systems depend on certain conditions.

Development of Memory and the Papez Circuit

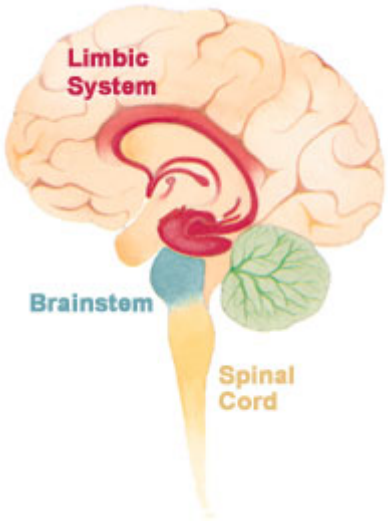


Image: Limbic system. By CFCF, License: CC BY-SA 3.0

The Papez circuit is important for the development of memory. The circuit is located in the center of the limbic system. The **limbic system** is located above the brain stem and exists in all mammals. It has a vital role in social behavior, solicitude, love, fear, and learning by imitation.

Papez circuit

The **Papez circuit** is a chain of neurons, named after its discoverer, James Papez. Research on the tasks of the Papez circuit for memory performance is still ongoing. However, the assumption that the circuit controls anger and rage is already outdated since it has been discovered that the circuit is even more complex than Papez thought.

These days, it is assumed that the **Papez circuit** serves the storage of memories by transferring information from the **primary memory** (short-term memory) to the **secondary memory** (long-term memory) or the **tertiary memory** (an independent part

of the long-term memory).

The **Papez circuit** proceeds as follows: **hippocampus → fornix → mammillary body inside the hypothalamus (corpora mammillaria) → cingulate cortex → hippocampus**

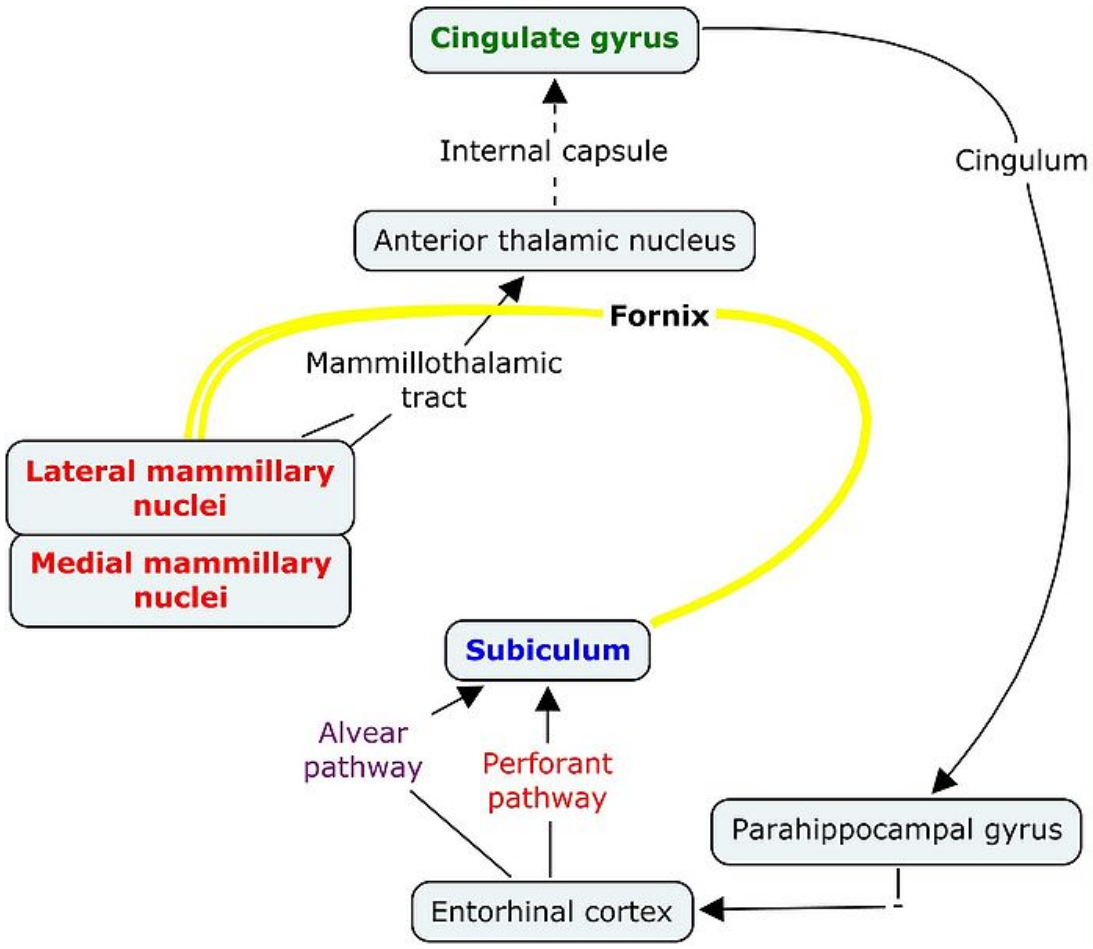


Image: Papez circuit. By NotMySecondOpinion, License: Public domain

The Different Types of Memory

The specialist term for mind and memory is called the **mnestic function**. Some things are easier to remember than other things. For example, important things are easier to remember than events that hold no meaning, and positive experiences are easier to remember than neutral experiences. Moreover, the process of remembering is easier in a prevailing positive mood, which also means that remembering things is more difficult in a state of fatigue or grief.

Process of encoding information

Note: Encoding is the process of transferring sensory information into a construct which is then stored in our memory system.

Working memory stores information for immediate use as part of mental activity (i.e. learning or problem solving).

Image: Schematic of the encoding/decoding model of communication, in which the sender or 'encoder' uses verbal and non-verbal symbols to deliver a message. The decoder or receiver then interprets the message. By Lecturio

It is thought to include phonological loop, visuospatial sketchpad, central executive, and episodic buffer.

- It allows for manipulation and organization of information vs. short-term **memory.**

The primary effect is a cognitive bias that results in a subject recalling the 1st items on a list.

- Theory: These items have had the most time to be encoded and transferred into long-term memory.

The recency effect is a cognitive bias that results in a subject recalling the last items on a list.

- Theory: These items are in the phonological loop and are highly accessible.

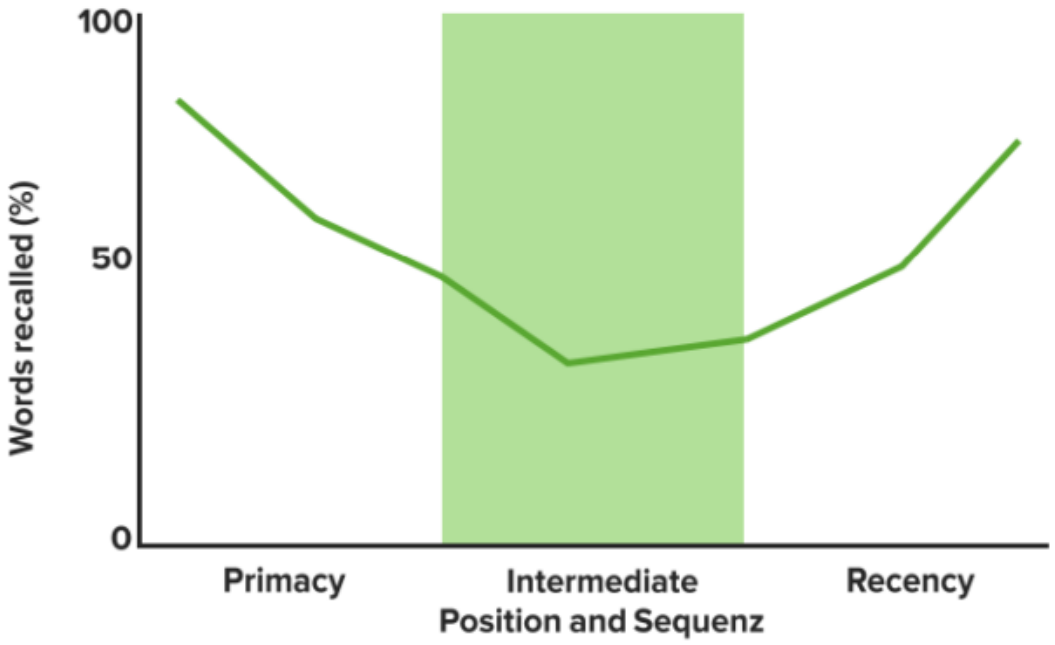


Image by Lecturio

Humans have a **declarative memory** (explicit memory) and a **procedural memory** (implicit memory). The declarative memory stores information that can be reproduced because we are conscious of the experience/information. The procedural memory, on the other hand, contains experiences for which one has no direct memory of the learning

process. Still, this type of memory influences our behavior. The classic example is the process of learning a new language.

Sensory memory (ultra-short-term memory)

The **ultra-short-term memory** receives stimuli from **sensory organs** in the form of **neuronal excitation**. This process has a duration of less than 1 second, and the perception can take place via the eyes or ears. The ultra-short-term memory via the eye is also referred to as **iconic memory**, and via the ears, **echoic memory** (and it perishes just as fast). Only stimuli that reach the short-term memory remain because the ultra-short-term memory has no storage capabilities.

Short-term memory (primary memory)

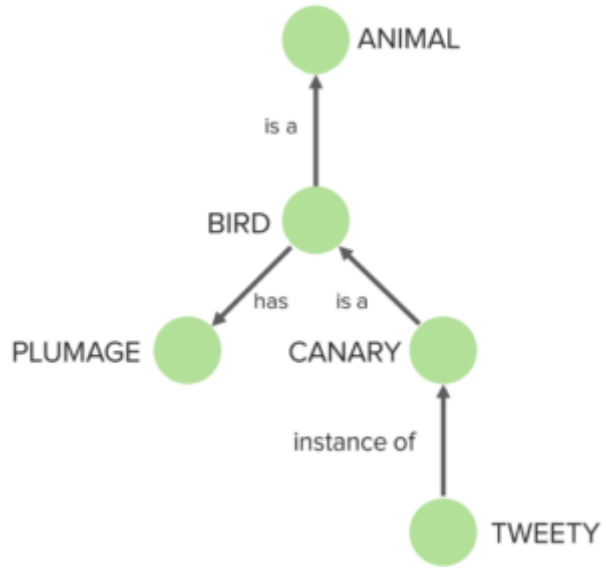
Memories in the **primary memory (short-term memory)** are available as long as we occupy ourselves with them. If that process is interrupted, the memory is lost too. Memories that begin in the primary memory can be available permanently, but only if they are transferred to **long-term memory**. It is assumed that short-term memory is a **transit** for experiences into long-term memory.

The **hippocampus**, located in the cerebral cortex, is involved in the process of transmitting information from the primary memory to the long-term memory. The hippocampus is thought to be involved in this process because when lesions appear in the hippocampus, only the short-term memory remains intact. Another term for primary memory is '**labile memory'** since it is very unstable. One distraction is enough to forget the perceived or heard information. Calcium has a major role in these processes.

Long-term memory

For storing memories in long-term memory, repetition is particularly important. This concept is easily understandable when one considers the high amount of repetition required to learn new movement patterns, e.g., when learning a new sport.

Semantic networks and spreading networks



- Image: Example of a semantic network, as a way to store information by representing the semantic relations between concepts. By Lecturio

Information is stored in our long-term memory as an organized network.

- Individual ideas or hubs are called nodes (i.e. cities on a map).
- Nodes are connected by links or associations (i.e. roads between cities).
- The strength of the association is related to how frequently and deeply the connection is made.
- Processing material in different ways leads to the establishment of multiple connections.
- Nodes are only activated once they reach a response threshold.
- The response threshold is reached by the summation of input signals from multiple nodes.
- Activation of a node leads to the stimulation of neighboring connecting nodes.
- The activation of a few nodes can lead to a pattern of activation within the network that spreads inward (known as spreading activation).
- It explains contextual cues, priming, and associations.

Process that aid in encoding memories

- **Mnemonic** is any technique for improving retention and retrieval from memory.
- **Rehearsal**: use of the phonological loop
- **Chunking** is a strategy that organizes information into discrete groups of data.
- **Hierarchies** organize words or information into categories
- **Depth of processing:** deeper level, semantic content leads to better recall
- **Acronym** (i.e. AIDS, CD-ROM, FAQ)

Dual coding hypothesis indicates that it is easier to remember words with associated images.

- **More connections** made to the memory
- **Deeper content**

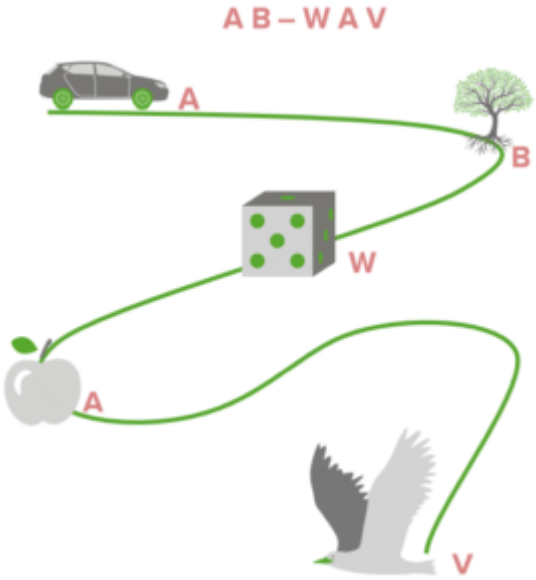


Image: Schematic example of the method of loci, also called the journey method or the memory journey, which is a strategy of memory enhancement based on visual imagery that enhances the recall of information. By Lecturio

The method of loci involves imagining moving through a familiar place and having stops or loci.

- Items to be recalled are mentally associated with these **physical locations** or loci
- Provides a **deeper representation**
- Also known as the **'Journey method'**

Self-reference effect involves making new information personally relevant

- E.g., "I live on Beatrice Ave…"

The Process of Learning inside the Brain

The **hippocampus** also plays an important role in the process of learning. There exists a connection between nerve cells and the neuronal mechanism, which is assumed to be the **physiologic substrate** of learning. This physiologic substrate consists of continuous **electrophysiologic**, **morphologic,** and **molecular changes** of nerve cells. For information to be available long-term, **long-term potentiation (LTP)** is necessary. LTP facilitates the stimulation of **afferent axons** over a period of weeks as well as a stronger calcium influx.

Everything stored in the long-term memory is available during one's entire life. The processes of the long-term memory take place under the influence of the **neurotransmitter glutamate** (glutamic acid).

Pathology of Memory Performance

The highly complex system of learning and memory is susceptible to malfunctions. If anomalies occur, the differential diagnosis must be made with the greatest care, because even changes in the mineral balance of the body can lead to disorders that give the impression of a disease (e.g., calcium deficiency). Furthermore, cases of **dementia** are increasing, which is partly due to an increase in life expectancy.

Amnesia

Amnesia is a type of memory disorder in which a patient loses access to stored information. The term ‘amnesia’ originates from the Greek *a* (without) and *mnémē* (memory). Amnesia is not an independent disease but is the symptom of a disease or the consequence of an influence on the brain. This influence can be internal or external.

In the case of **amnesia**, patients cannot store experiences or learned knowledge, and this can affect all types of information or only certain parts. For example, patients can lose access to memories from certain stages of their lives. In most cases, the patient can remember events that happened long ago rather than events that occurred just lately. There are different forms of amnesia. However, they cannot be strictly separated from each other. The following forms are of importance:

- **Retrograde amnesia**
- **Global amnesia**
- **Transient global amnesia**
- **Anterograde amnesia**
- **Psychogenic amnesia**

Alzheimer’s Disease

Alzheimer‘s disease is characterized by a regression of nerve cells, which can result in the brain shrinking up to 20%. The consequence is an impaired relay of information. Furthermore, Alzheimer’s may make processing information nearly impossible. At the same time, plaques of protein fragments form. Brain regions responsible for processing information and memory performance are particularly affected by Alzheimer’s disease.

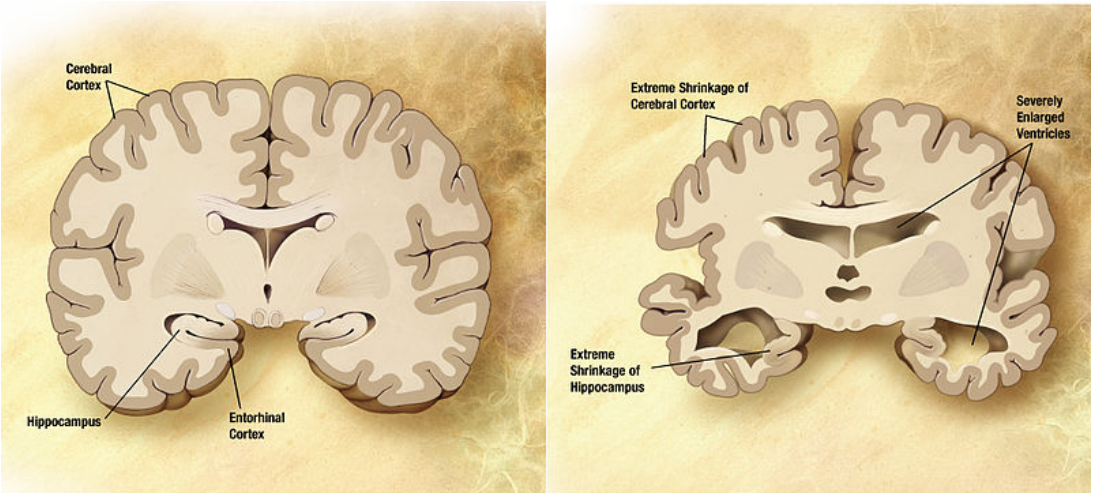


Image: Left: healthy brain; right: brain with Alzheimer. By Garrondo, License: Public domain

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Correct ansewers: 1C, 2 B, 3C

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