Forms of memory

Figure 8.9 The hypothesized structure of human memory diagramming the relationship among different forms of memory.
Different types of learning & memory rely on different brain structures

Explicit memory
- Medial temporal lobe; diencephalon
  - Facts (semantic)
  - Events (episodic)

Implicit memory
- Procedural memory: skills & habits (basal ganglia)
- Classical conditioning
- Skeletal musculature (cerebellum)
- Emotional Responses (amygdala)
- Priming (neocortex)
- Eyeblink conditioning in rabbit

Different types of learning and memory
Fig. 1. Memory consolidation phases. Studies of memory and neuroplasticity support Müller and Pilzecker’s hypothesis proposing that the consolidation of new memory into long-term memory is time dependent (1), but strongly suggest that short-term and different stages of long-term memory are not sequentially linked, as proposed by the dual-trace hypothesis (9). Evidence that drugs can selectively block either short-term (seconds to hours) or long-term memory (hours to months) suggests that time-dependent stages of memory are based on independent processes acting in parallel. Later stages of consolidation resulting in memory lasting a lifetime likely involve interaction of brain systems in reorganizing and stabilizing distributed connections.

McGaugh, 2000
Neuroscience of memory

• Karl Lashley (1950) searched for the *engram*, the physical location of a memory.

• He destroyed progressively larger areas of monkey brain tissue after training them on a task.

• The monkeys retained the memory, suggesting it was distributed to many parts of the brain, a principle known as *equipotentiality*.
Lashley’s Search for the Engram in the 1920s

Rats are trained to run through a maze without entering blind alleys.

After training, cortical lesions are made. Three different lesion locations are shown in red, blue, and yellow.

Errors are associated with the size rather than the locus of the lesion.
Forms of Long Term Memory

Declarative
- Semantic
- Episodic

Nondeclarative
- Nonassociative (sensitization and habituation)
- Procedural (Skill learning)
- Priming
- Simple Classical Conditioning
Neural substrates of long-term memory

• Semantic memory linked to the limbic cortex.
• Consolidation of episodic memory mediated by the hippocampus.
• Procedural memory function associated with basal ganglia and motor cortex.
The limbic system

- Major Components of the Limbic System
- Corpus callosum
- Limbic cortex
- Fornix
- Mammillary body
- Amygdala
- Hippocampus
- Hippocampus of right hemisphere (ghosted in)
- Cerebellum
The hippocampus

• This brain structure is responsible for *consolidation*, the transfer of information from STM to LTM.

• Damage to the hippocampus results in *anterograde amnesia*, an inability to retain new information subsequent to the damage. Example: The tragic case of H.M.

• This should be distinguished from *retrograde amnesia*, in which it is difficult to remember information learned prior to a traumatic incident.
Hippocampus
Hippocampal structure and function

Diagram showing the flow of information:
- Dentate gyrus to CA3 via mossy fibers
- CA3 to CA1 via Schaffer collaterals
- CA1 to Subicular complex
- Perforant path from Entorhinal cortex to Super and Deep layers
- Super layer connects to Cortical lobes (Olfactory, Frontal, Parietal, Temporal)
- Deep layer connects to Cortical lobes

Sensory information flow diagram
Basal Ganglia

- Can examine Parkinson’s & early Huntington’s Disease
- no apparent amnesia (declarative memory ok)

But implicit memory problems in “procedural memory”
- Perceptual-Motor Learning
- Habits
- Skills

Separate from motor disorders
Memory systems in Implicit Memory

• Not all implicit memory is independent of the hippocampus

• Not all implicit memory depends on the basal ganglia, e.g., emotional learning, priming, certain motor responses

• Cortical systems (e.g., priming)
• Amygdala (fear conditioning)
• Cerebellum (eyeblink conditioning)
…etc
Neural substrates of working memory

- Storage of verbal material: posterior parietal cortex in left hemisphere.
- Rehearsal of verbal material: prefrontal cortex.
- Storage of spatial information: posterior parietal cortex in right hemisphere.
- Maintenance of spatial information: dorsolateral prefrontal cortex.
Learning and memory

• *Learning* is a change in the nervous system caused by some event that in turn causes a change in behavior.

• Learning in a nervous system requires a change in the structure or biochemistry of a synapse, what is called *synaptic plasticity*.

• If a group of neurons is repeatedly activated, the synaptic connections between them will be strengthened. This circuit will then contain the new information.
Classical (Pavlovian) conditioning and memory

There are many different forms of classical conditioning and the responsible brain structure depends on the form.

Examples:

a) Pavlovian fear conditioning:

\[
\begin{align*}
\text{Tone} & \rightarrow \text{Shock} & \text{Then:} & \text{Tone} & \rightarrow \text{freeze} \\
(\text{CS}) & & (\text{US}) & & (\text{CS}) & & (\text{CR})
\end{align*}
\]

• Depends on the amygdala
• + the hippocampus with trace procedure
• + the hippocampus if the CS is a context

b) Eyeblink conditioning

\[
\begin{align*}
\text{Tone} & \rightarrow \text{puff of air to eye} & \text{Then:} & \text{Tone} & \rightarrow \text{eyeblink} \\
(\text{CS}) & & (\text{US}) & & (\text{CS}) & & (\text{CR})
\end{align*}
\]

• Depends on cerebellum
• + hippocampus with trace procedure
• Declarative knowledge of task always depends on hippocampus
Amygdala is a key structure in fear and anxiety.
Unconditioned Fear Circuit: Central Nucleus of the Amygdala and its Outputs
Unconditioned Fear Circuit: Central Nucleus of the Amygdala and its Outputs

Central nucleus outputs coordinate all of the defensive responses (learned and innate).

Source: Adapted from Davis, M., Trends in Pharmacological Sciences, 1992, 13, 35-41. Copyright © 2001 by Allyn & Bacon
Pavlovian fear conditioning is reducible to discrete mnemonic processes

Procedure: Tone – Shock Pairing

Conditional Stimulus, CS

Unconditional Stimulus, US
Unconditional Response, UR (Fear)
Pavlovian fear conditioning is reducible to discrete mnemonic processes

**Procedure:**
Tone – Shock Pairing

**Memory Process:**
Association

Tone Representation
Shock Representation
Pavlovian fear conditioning is reducible to discrete mnemonic processes

**Procedure:**

Tone – Shock Pairing

**Memory Process:**

Association

Tone Representation

Shock Representation

**Conditioned Response, CR:**

Tone

Tone Repr.

Shock Repr.
Pavlovian fear conditioning is reducible to discrete mnemonic processes

**Procedure:**
- Tone – Shock Pairing

**Memory Process:**
- Association
  - Tone Representation
  - Shock Representation

**Conditioned Response, CR:**
- Fear Responses
  - Freezing
  - Potentiated Startle
  - Blood Pressure
  - Flight
  - ...

- Tone
- Tone Repr.
- Shock Repr.
- Fear State
Basic model that has emerged for Pavlovian fear conditioning

The Probable Location of the Changes in Synaptic Strength Produced by the Classically Conditioned Emotional Response That Results from Pairing a Tone with a Foot Shock

Central nucleus = output of fear/unlearned fear
Basolateral/lateral nucleus = learned fear
Long Term Potentiation
Hebb’s postulate:
When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth processes or metabolic changes take place in one or both cells such that A's efficiency as one of the cells firing B, is increased.

The Organization of Behavior, 1949

“Fire together, wire together”
Formation of New Synapses Between Neurons Showing LTP

Electron microscopic examination of synapses before and after undergoing LTP. Hippocampal neurons showing increases in $\text{Ca}^{2+}$ also showed doubling of spines (From Toni et al., 1999).
Synaptic Changes that Could Support Memory

(a) Before learning

(b) After learning

(c) Interneuron modulation causes increased transmitter release

(d) More sensitive postsynaptic region

(e) Before learning

(f) After learning

New synapses formed

Shift in synaptic input
Hebb's (1949) Theory of Consolidation

1. Experience activates sensory pathways, which conduct neural impulses to the CNS.

2. **Short-Term Memory**: Hebb hypothesized that the short-term memory of each experience is stored by neural activity reverberating in closed-loop CNS circuits.

3. **Long-Term Memory**: Hebb hypothesized that reverberating activity, if maintained for a sufficiently long time, produces structural changes in synapses and that these changes facilitate subsequent transmission over the same pathways.

4. The changed pathways of transmission produced by synaptic facilitation can influence motor output and thus behavior.

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Amnesia Partial or total loss of memory, usually resulting from shock, psychological disturbance, brain injury, or illness.

Organic caused by shock, brain injury, illness
• hypoxic episode, herpes encephalitis
• epilepsy, brain injury, Alzheimer’s disease

Psychogenic caused by psychological trauma
• dissociative disorders
• psychogenic fugue
• multiple personality disorder
Amnesia

Amnesia can be **global** or **material-specific**

**Global** any kind of information is affected  
**Material-specific** certain kinds of material (e.g., faces)

Amnesia can be **anterograde** or **retrograde**

**Anterograde amnesia** inability to learn anything new since the time of the trauma (usually organic)

**Retrograde amnesia** loss of memory for events prior to the time of the trauma (psychogenic or organic)