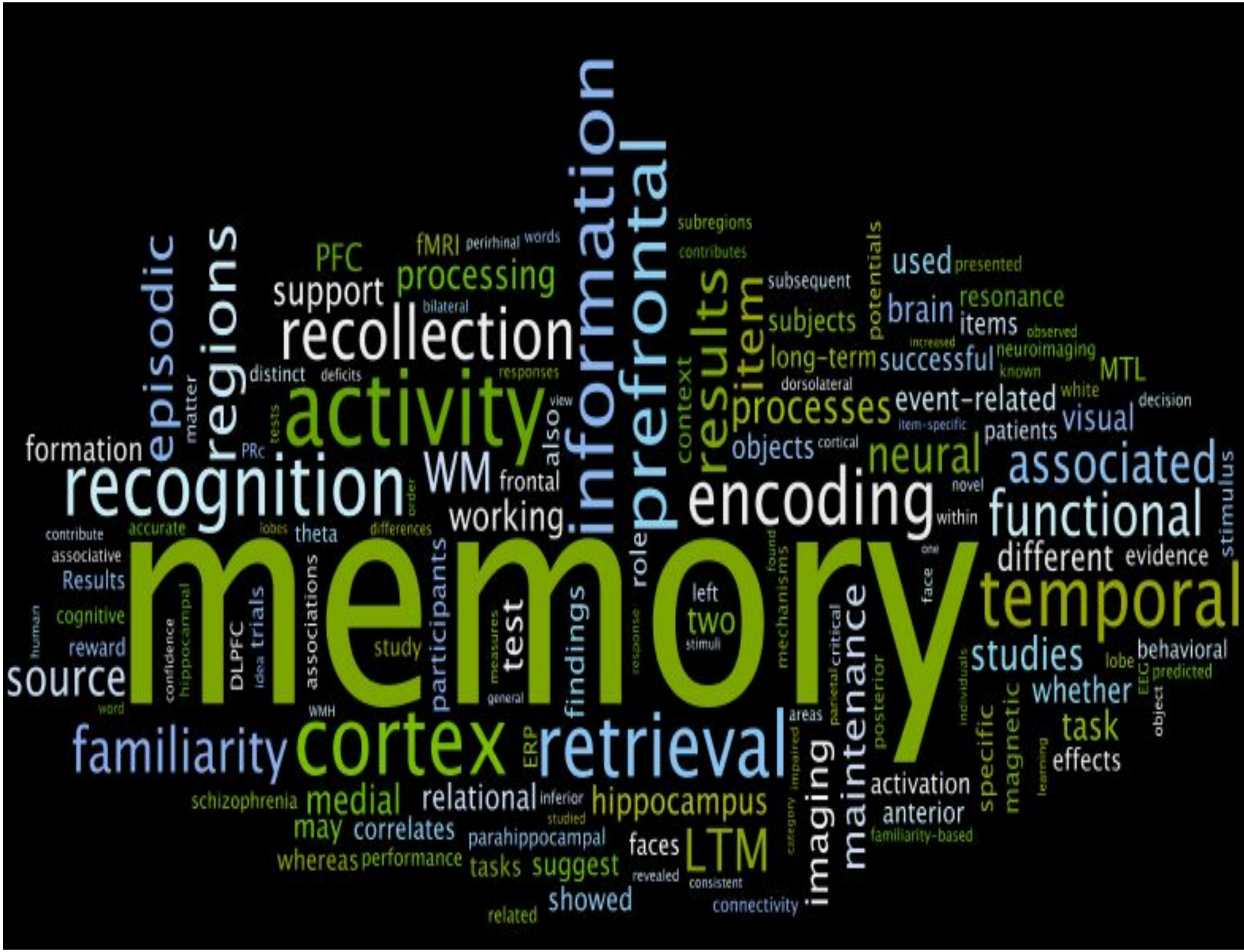
Neuropsychology of Memory



memory
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information
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revealed
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connectivity

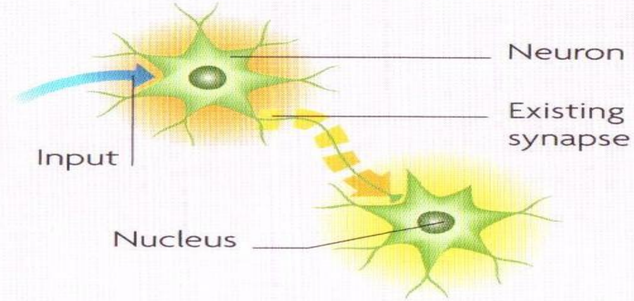
Memory FAQ:

- Where in the brain is memory?
- Is there a common neural substrate for all kinds of memory?
- What is the reason of “old timer’s disease”?
- Why should infants suffer amnesia for some things and not others?
- Do we store memories without any changes?
- Can we recall everything we had experienced?
- How much can memory hold?

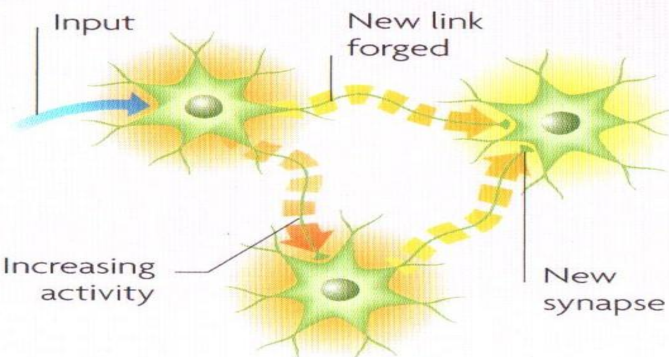
The brain has 100 trillion connections joining billions of neurons and each junction has the potential to be part of a memory.

FORMING MEMORIES

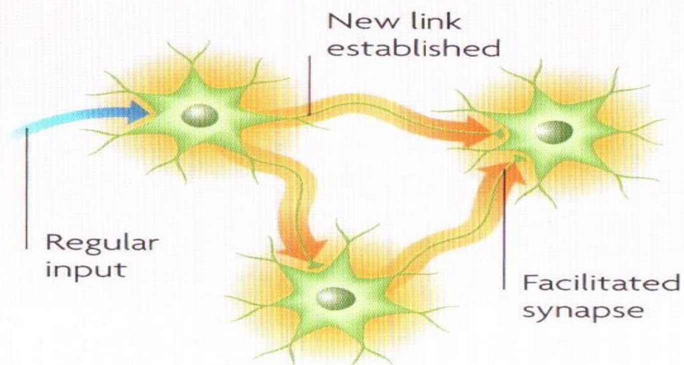
The initial perception of an experience is generated by a subset of neurons firing together. Synchronous firing makes the neurons involved more inclined to fire together again in the future, a tendency known as "potentiation," which recreates the original experience. If the same neurons fire together often, they eventually become permanently sensitized to each other, so that if one fires, the others do as well. This is known as "long-term potentiation."



1 INPUT
An external stimulus triggers two neurons to fire simultaneously. In future, if one fires, the other is likely to fire, too.



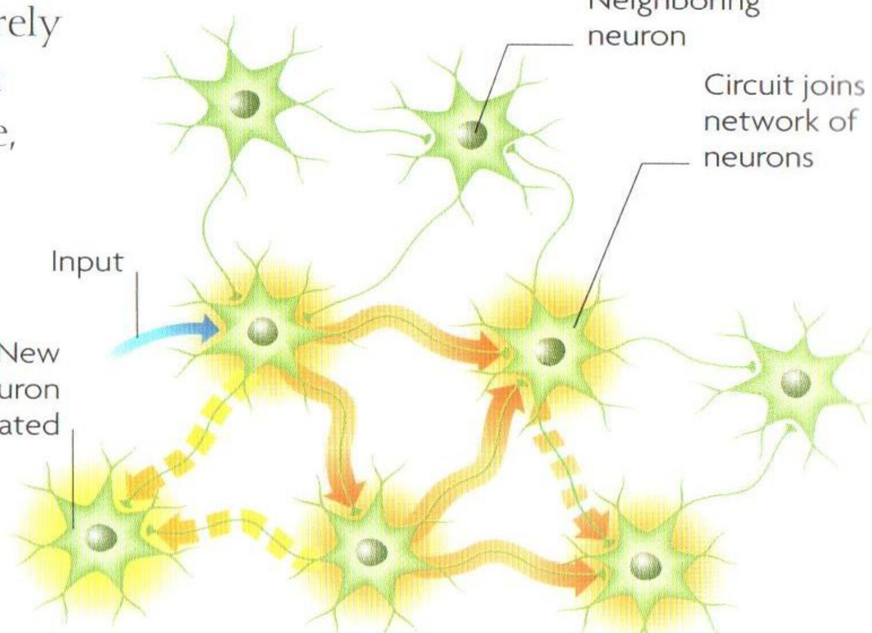
2 CIRCUIT FORMATION
A third neuron fires. One of the initial pair is stimulated to fire with it, triggering the second, so the three become linked.



3 INCREASING ACTIVITY
The three neurons are now sensitized to one another, so that if one fires, the other two are likely to fire as well.

DISTRIBUTED MEMORIES

Our memories are distributed throughout the brain, so even if one part of an experience is lost, many others will remain. One benefit of such a distributed storage system is that it makes long-term memories more or less indestructible. If they were held in a single brain area, damage to that place–for example, from a stroke or head injury–would eradicate the memory completely. As it is, brain trauma and degeneration may nibble away at memories but rarely destroy them entirely. You may lose a person's name, for example, but not the memory of their face.



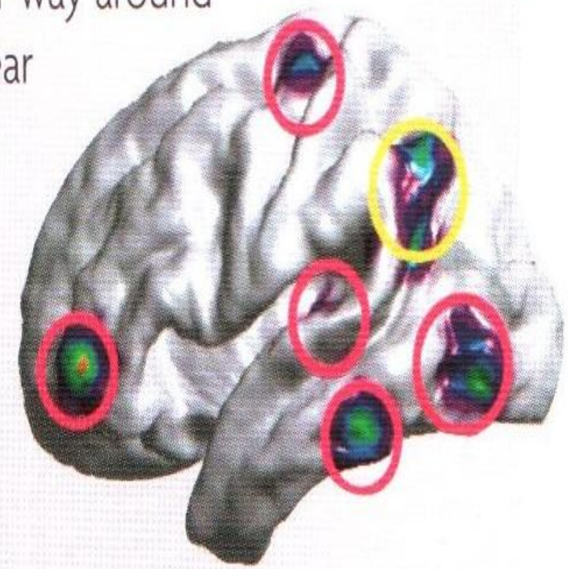
EXPANDING WEB
The memory web spreads through the brain as existing neurons make connections with new neurons by firing together.

LEARNING IS GOOD FOR YOU

Learning involves making new connections between clusters of neurons in different parts of the brain. This builds up the brain, making it fitter. For example, practicing spatial skills such as finding your way around a city has been shown to increase the size of the rear hippocampus. The more connections you create, the better you can use what you learn and the longer it takes you to forget it.

ENLARGED AREAS

This image shows areas to do with implicit learning (red) and explicit skills (yellow) that have grown denser with practice.



MEMORY PROCESS

The process of memory formation has several natural stages, from the initial selection and retention of information to recollection and, sometimes, eventual change or loss of the memory. Each stage has particular characteristics—and things that can go wrong.

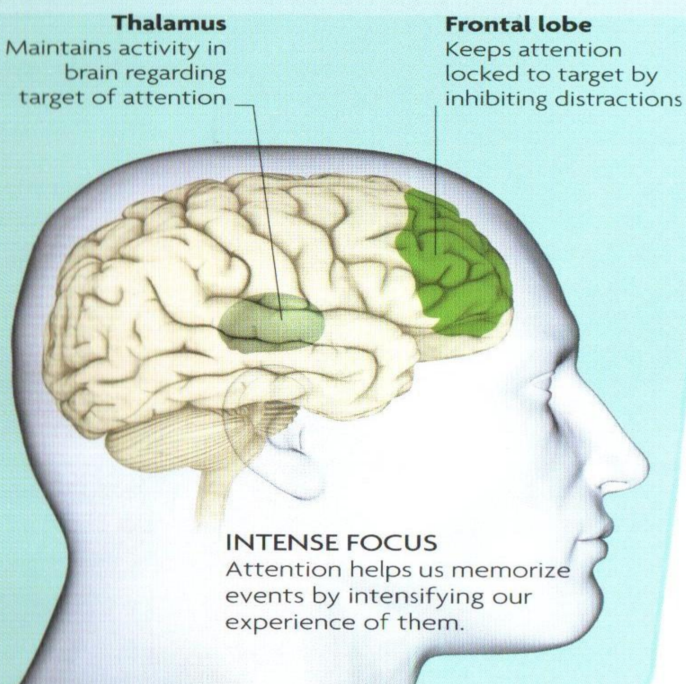
STAGE	WHAT'S MEANT TO HAPPEN	WHAT CAN GO WRONG
Selection	The brain is designed to store information that will be useful at a later date and allow the rest to pass by unnoted.	Important events are neglected or irrelevant ones retrieved. You might fail to recall a person's name, but remember the mole on their nose.
Lay-down	Experience selected for memorizing is stored so that it is associated with relevant pre-existing memories and retained for an appropriate period.	Information may be "mis-filed," with faulty links between items. Or new items are not laid down, so it is hard to learn or to retain new memories.
Recollection	Current events should stimulate the recollection of appropriate memories—i.e. information that can guide future actions.	Current events fail to prompt useful memories, such as words, names, events—you know the information is there but you cannot grasp it.
Change	Each time a memory is recalled it is altered slightly to accommodate new information.	Alteration may create false memories.
Forgetting	Items start to be forgotten as soon as they have been registered, unless they are regularly refreshed. Unnecessary information is deleted.	Important or useful information is forgotten. Alternatively, unnecessary or even damaging memories are not.

Memory and Attention

0.2 seconds Attention

The brain can absorb only a finite amount of sensory input at any point. It can sample a little input about several events at once, or focus attention on one event and extract lots of information from that alone. Attention causes the neurons that register the event to fire more frequently. Such activity makes the experience more intense; it also increases the likelihood that the event will be encoded as a memory. This is because the more a neuron fires, the stronger connections it makes with other brain cells.

MEMORABLE EVENT
Zooming in on an event helps capture it as a memory, like a camera taking a snapshot.



INTENSE FOCUS
Attention helps us memorize events by intensifying our experience of them.

Memory and Emotion

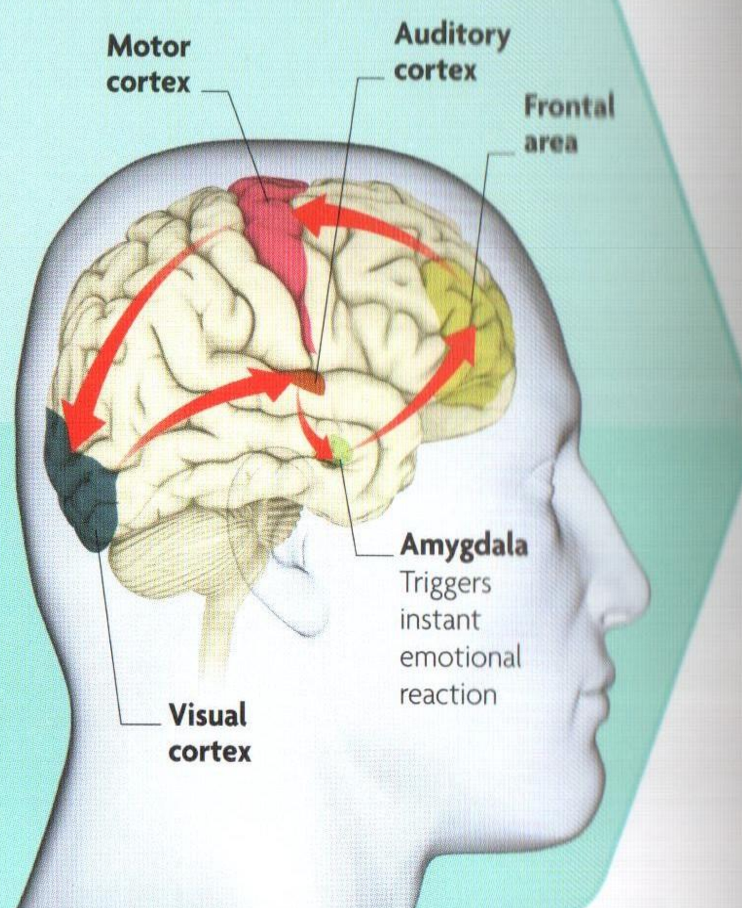
0.25 seconds Emotion

Intensely emotional experiences, such as the birth of a child, are more likely to be laid down in memory because emotion increases attention. The emotional information from a stimulus is processed initially along an unconscious pathway that leads to the amygdala; this can produce an emotional response even before the person knows what they are reacting to, as in the "fight or flight" response.

Some traumatic events may be permanently stored in the amygdala.

EMOTIONAL EVENTS
Personal interactions and other emotional events "grab" attention, so are more likely to be stored.

EMOTION PATHWAY
The amygdala helps keep an emotional experience "live" by replaying it in a loop, which begins the encoding of a memory.



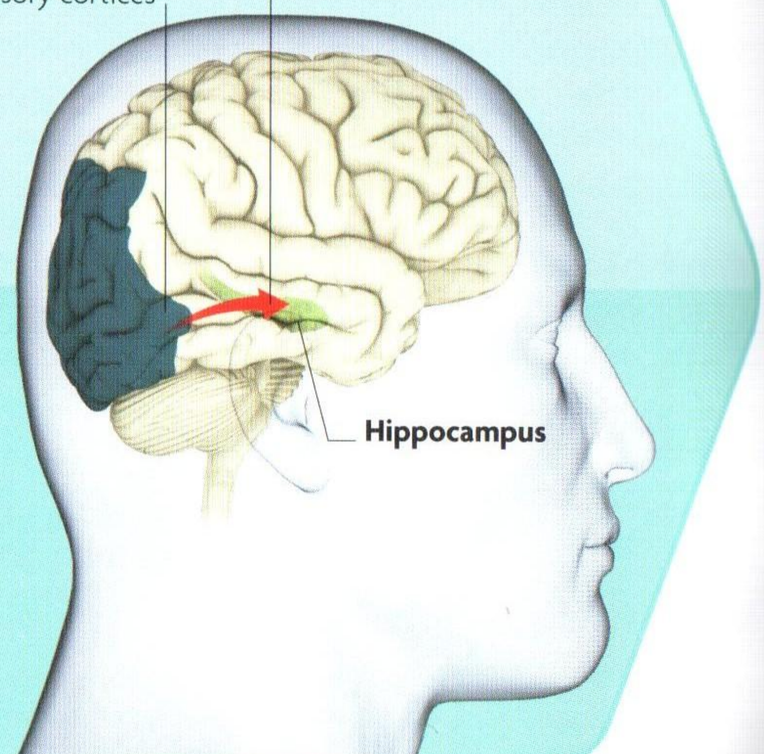
Memory and Sensations

0.2–0.5 seconds Sensation

Most memories derive from events that included sights, sounds, and other sensory experiences. The more intense the sensations, the more likely it is that the experience is remembered. The sensational parts of such "episodic" memories may later be forgotten, leaving only a residue of factual knowledge. For example, a person's first experience of seeing the Washington Monument may be reduced to the simple "fact" of what the tower looks like. When it is recalled, it triggers a ghost of a visual image, encoded in the sight area of the brain.

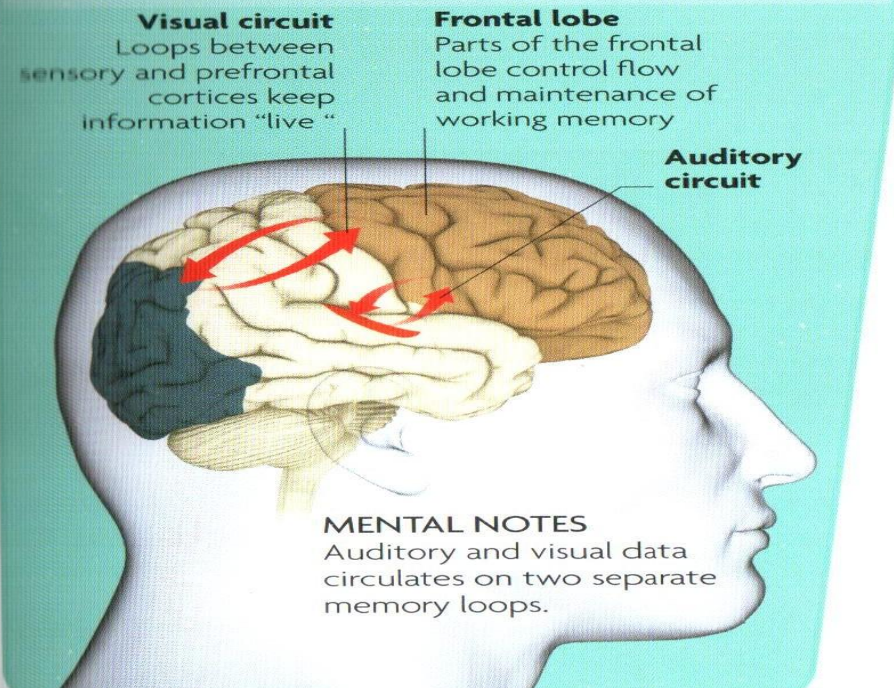
TASTE
Sensory perceptions, such as taste, sight, or smell, form the raw material of memories.

FORMING PERCEPTIONS
Sensations are combined in association areas, to form conscious perceptions.



0.5 seconds–10 minutes
Working memory

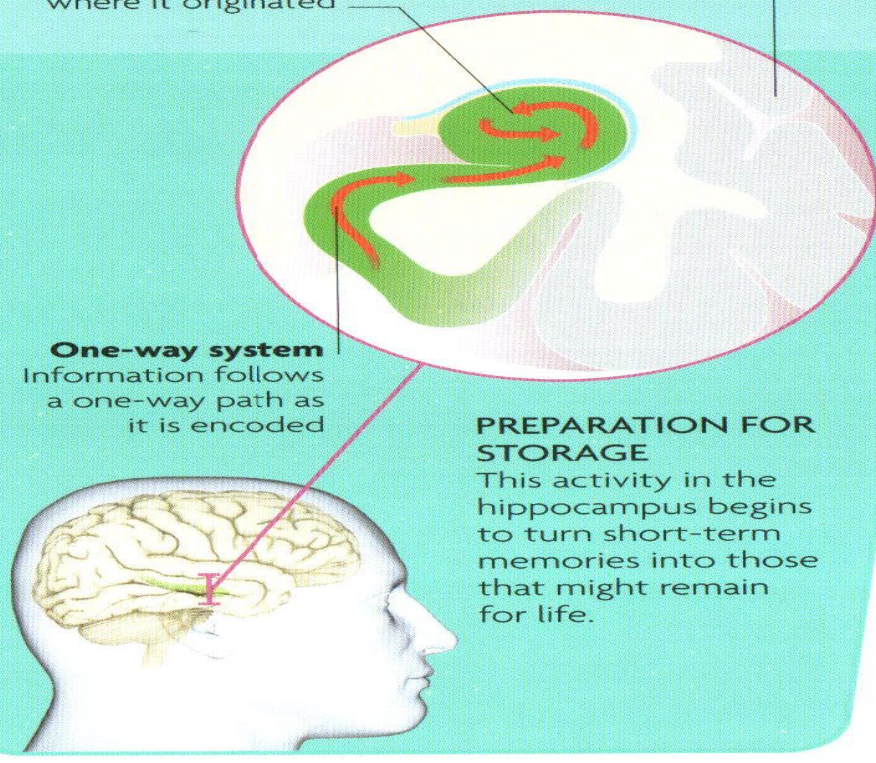
Short-term, or "working," memory is like text on a blackboard that is constantly refreshed. It begins with an experience, and continues as that experience is "held in mind" by repetition. A telephone number, for example, may be repeated for as long as it takes to dial. Working memory is thought to involve two neural circuits (see p.155), around which the information is kept alive for as long as it is needed. One circuit is for visual and spatial information, and the other for sound. The routes of the circuits encompass the sensory cortices, where the experience is registered, and the frontal lobes, where it is consciously noted. The flow of information into and around these circuits is controlled by neurons in the prefrontal cortex.



MENTAL NOTES
Auditory and visual data circulates on two separate memory loops.

10 minutes—2 years
Hippocampal processing

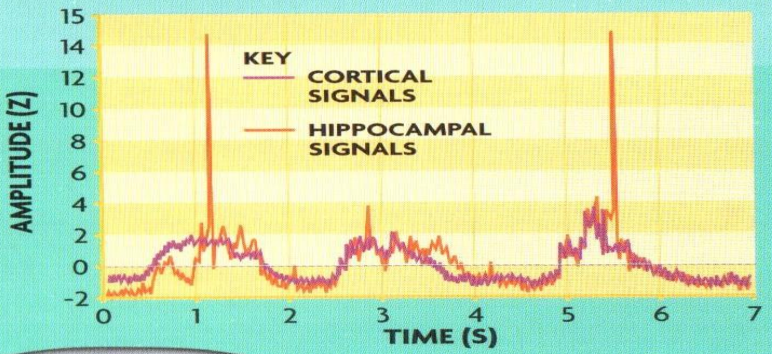
Particularly striking experiences "break out" from working memory and travel to the hippocampus, where they undergo further processing. They cause neural activity that loops around coiled layers of tissue; the hippocampal neurons start to encode this information permanently by a process called long-term potentiation (see p.156). The strongest information "plays back" to the parts of the brain that first registered it. A sight, for example, returns to the visual cortex, where it is replayed as an echo of the original event.

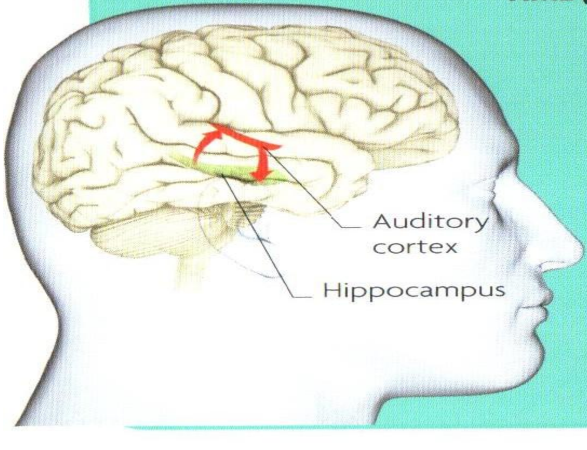


PREPARATION FOR STORAGE
This activity in the hippocampus begins to turn short-term memories into those that might remain for life.

2 years onward
Consolidation

It takes up to two years for a memory to become firmly consolidated in the brain, and even after that it may be altered or lost. During this time, the neural firing patterns that encode an experience are played back and forth between the hippocampus and the cortex. This prolonged, repetitive "dialogue" causes the pattern to be shifted from the hippocampus to the cortex; this may happen in order to free up hippocampal processing space for new information. The dialogue takes place largely during sleep. The "quiet" or slow-wave phase of sleep is thought to be more important to this process than rapid eye movement sleep (see p.184).





ECHOING SIGNALS
A hippocampal neuron (orange) talks to cells in the auditory cortex (purple), echoing their activity pattern. Hippocampal and cortical cells form almost identical copies of the same experience.

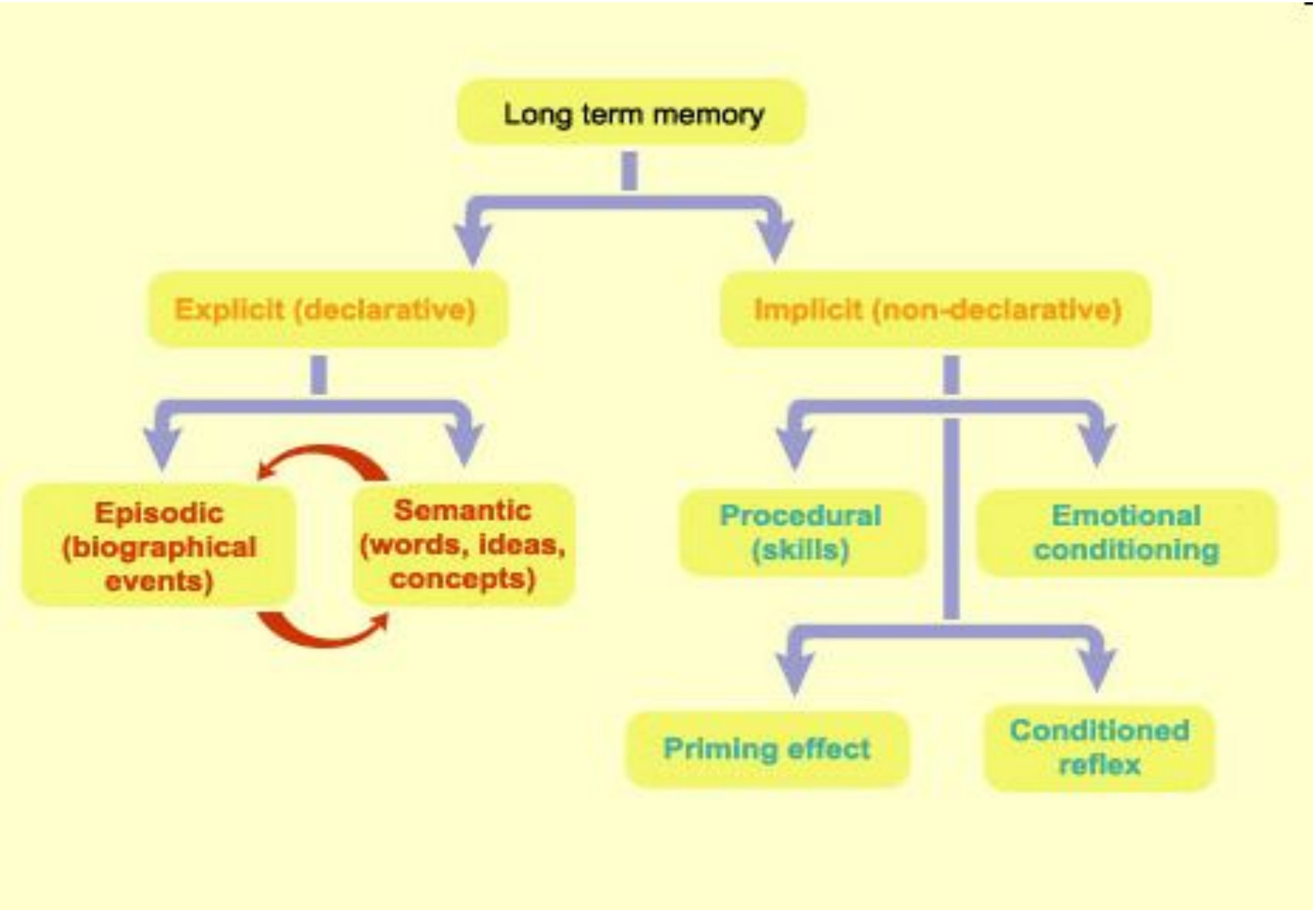
TABLE 18.6 Memory Mechanisms in the Time Domain and in the Spatial Domain

A. CELLULAR MECHANISMS INVOLVED AT DIFFERENT TIMES IN MEMORY STORAGE

SECONDS TO MINUTES	MINUTES TO HOURS	HOURS TO YEARS
Ongoing electrical activity of neurons; changes in intracellular Ca^{2+} and other ions; changes in second messenger systems	Protein phosphorylation and other covalent modifications; expression of immediate early genes	Additional changes in gene transcription and translation resulting in structural changes of proteins and neurons

B. ANATOMICAL STRUCTURES INVOLVED AT DIFFERENT TIMES IN STORAGE OF EXPLICIT MEMORIES

LESS THAN 1 SECOND ("ATTENTION" OR "REGISTRATION")	SECONDS TO MINUTES ("WORKING MEMORY")	MINUTES TO YEARS ("CONSOLIDATION")	YEARS
Brainstem–diencephalic activating systems; frontoparietal association networks; specific unimodal and heteromodal cortices	Frontal association cortex; specific uni-modal and heteromodal cortices	Medial temporal structures; medial diencephalic structures; specific unimodal and heteromodal cortices	Specific unimodal and heteromodal cortices


Long term memory
Explicit (declarative)
Implicit (non-declarative)
Episodic (biographical events)
Semantic (words, ideas, concepts)
Procedural (skills)
Emotional conditioning
Priming effect
Conditioned reflex

Two Kinds of Memory: Implicit and Explicit

- **Explicit memory** is the conscious, intentional recollection of previous experiences (To whom you have spoken since you woke up? Who is this celebrity on a photo? Where Paris is situated?)

- **Implicit memory** is an unconscious, nonintentional form of memory (an ability to use language, to ride a bicycle, to dance).

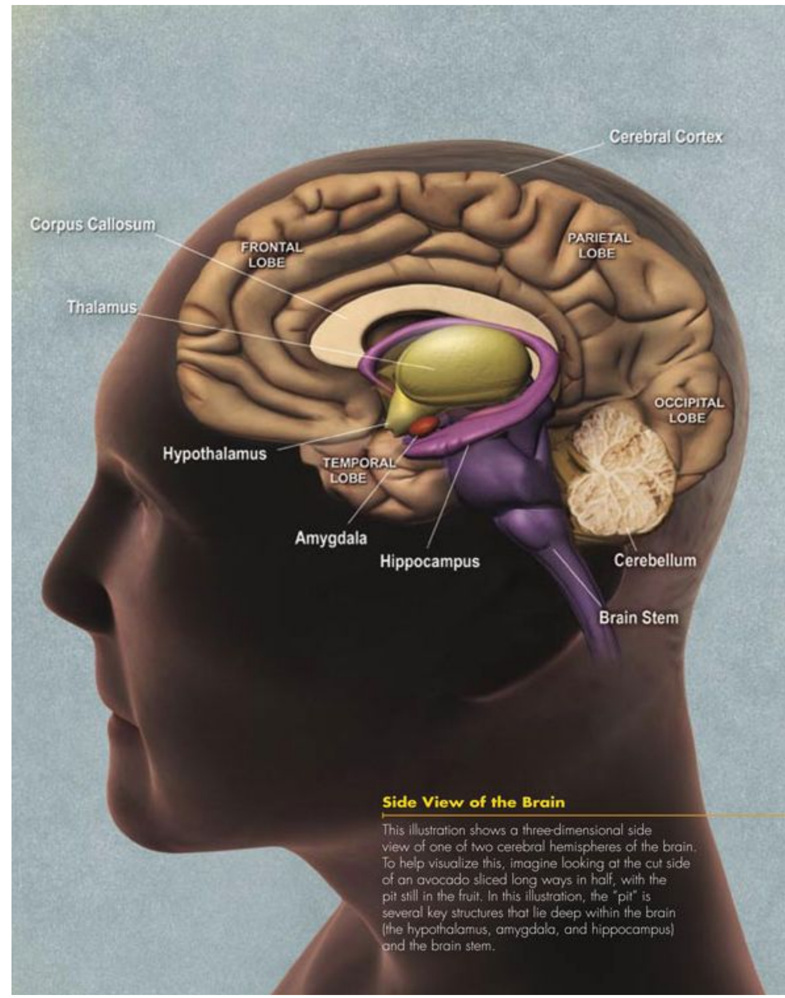
TABLE 1

Common Distinctions Between Implicit and Explicit Memory

Implicit memory	Explicit memory
early-maturing	late-maturing
nonepisodic	episodic (particular time/place)
without conscious awareness	with conscious awareness
general	specific
abstract	concrete
automatic	strategic
context-free	context-dependent
all-or-none	partial retrieval (decay effects)
perceptually weighted for form	weighted for function/meaning
incidental	intentional
nonassociative	associative

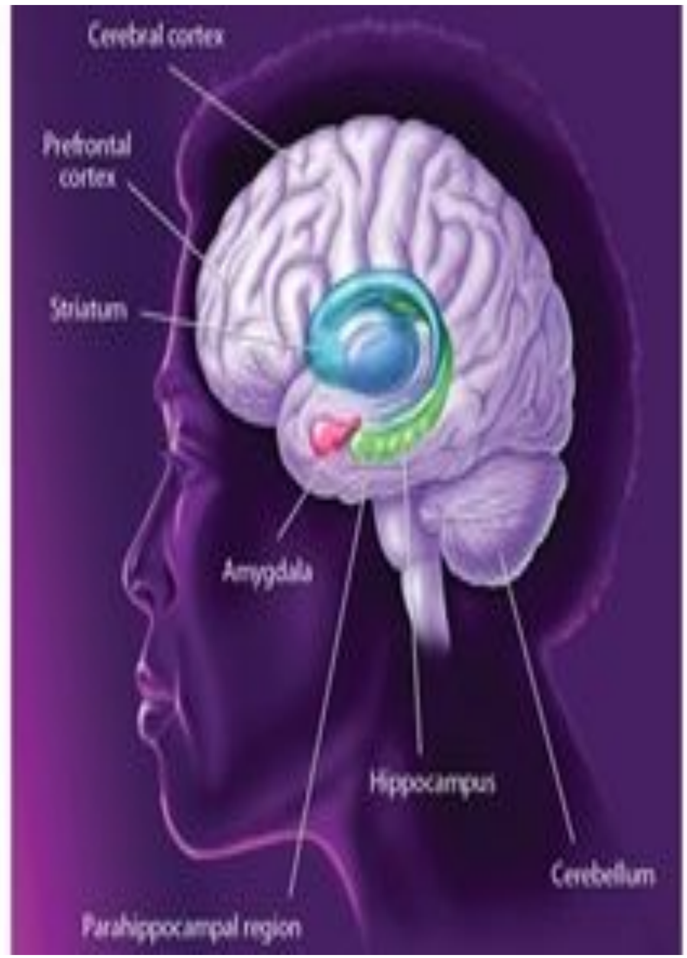
The neural basis of explicit memory

- The amygdala, the hippocampus, the rhinal cortexes in the temporal lobe, the prefrontal cortex which receive input from the neocortex and from brainstem systems.
- Key neurotransmitters: serotonin, acetylcholine, noradrenaline.

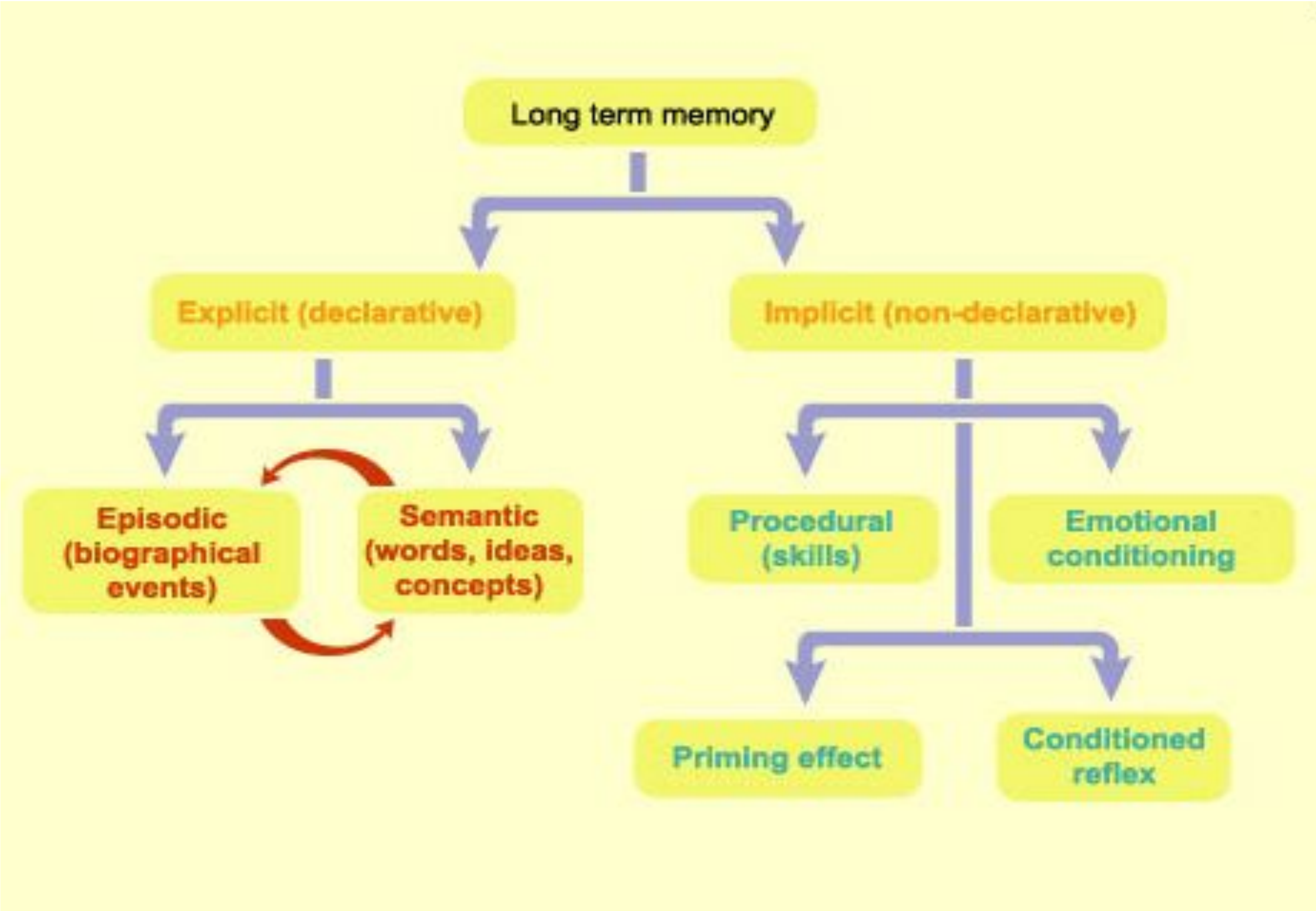


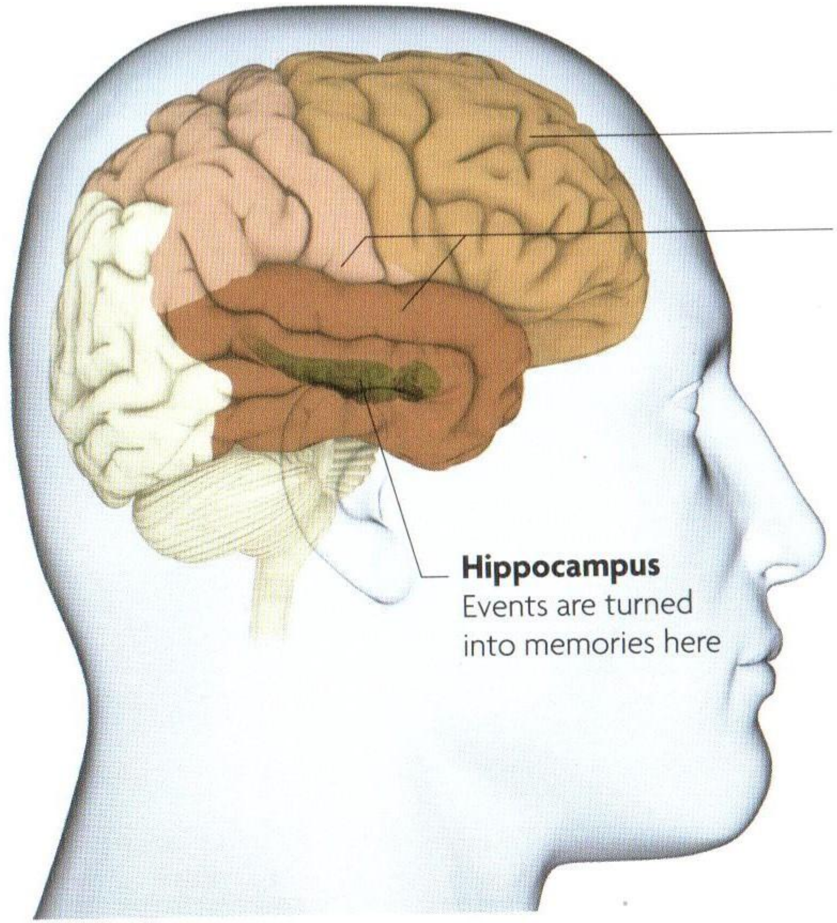
The neural basis of implicit memory

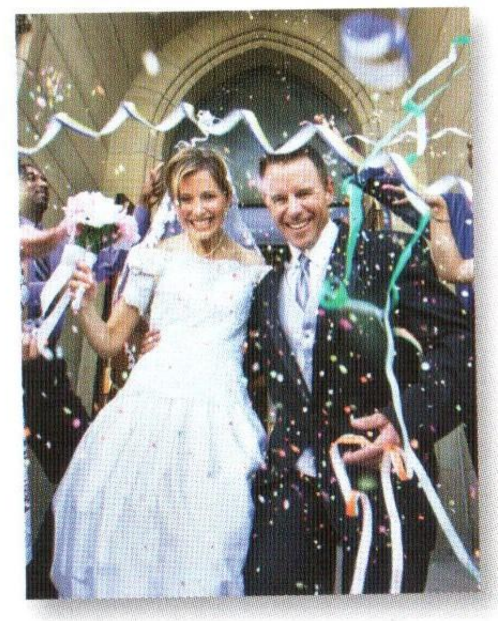
<u>Basal ganglia</u> (the caudate nucleus and putamen) which <u>receive</u> projections from substantia nigra (bottom-up) and all regions of the neocortex (top-down) and <u>sends</u> projections through the globus pallidus and ventral thalamus to the premotor cortex.



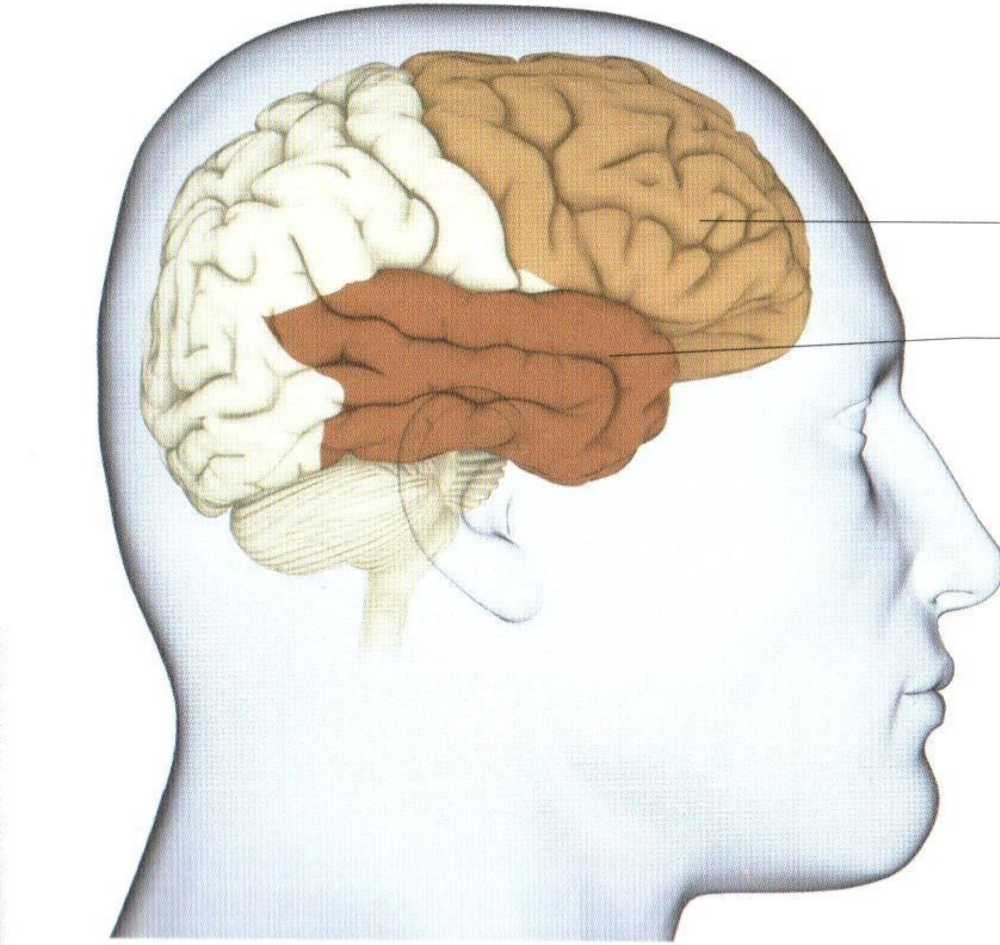
Key neurotransmitter: <u>dopamine</u>


Long term memory
Explicit (declarative)
Implicit (non-declarative)
Episodic (biographical events)
Semantic (words, ideas, concepts)
Procedural (skills)
Emotional conditioning
Priming effect
Conditioned reflex



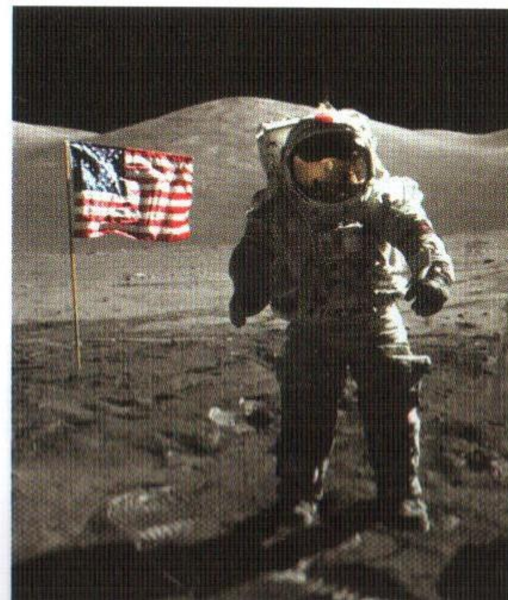


EPISODIC MEMORY
The parts of the brain involved in episodic memories depend on the content of the original experience. Highly visual experiences, for example, will activate visual areas of the brain, while remembering a person's voice will activate the auditory cortex.



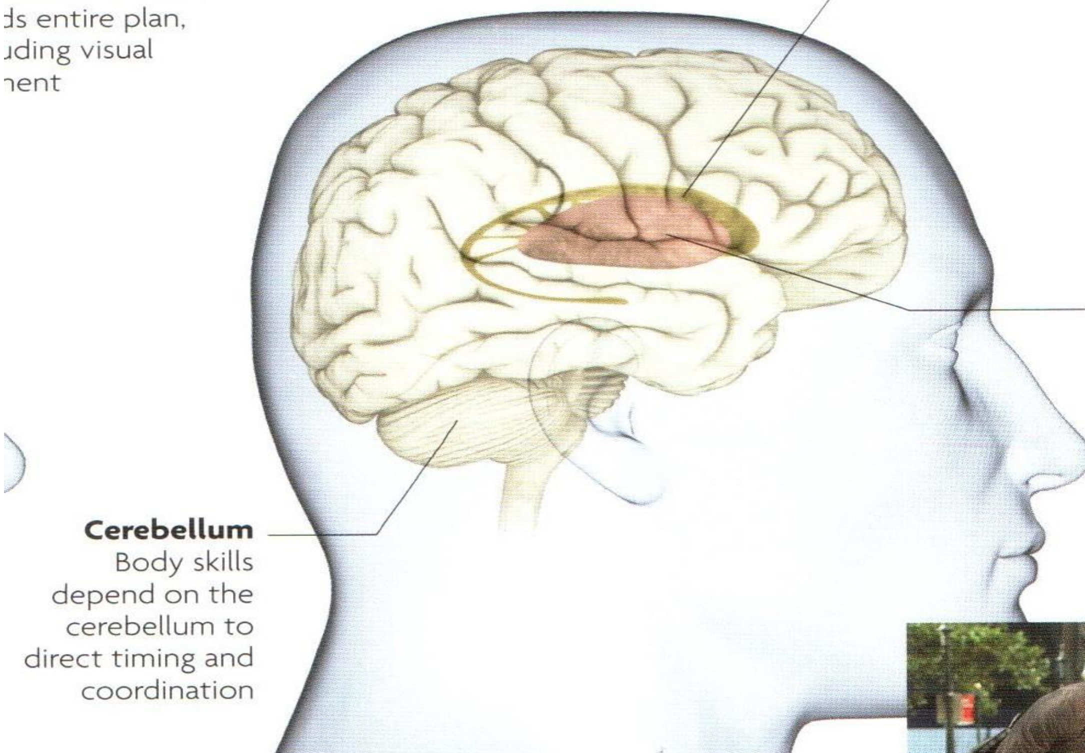
Frontal lobe
Semantic memories are activated by frontal lobe areas that draw on stored knowledge to guide current behavior

Temporal lobe
The temporal lobes encode factual information, and activity here is a marker of facts being recalled

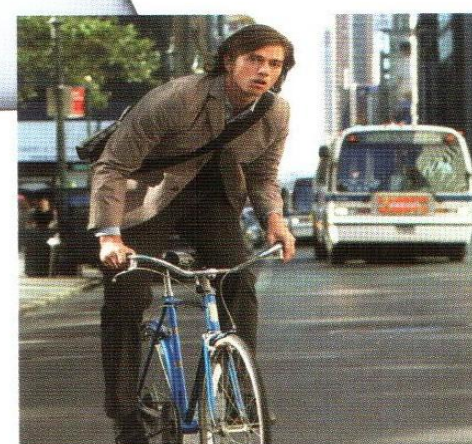


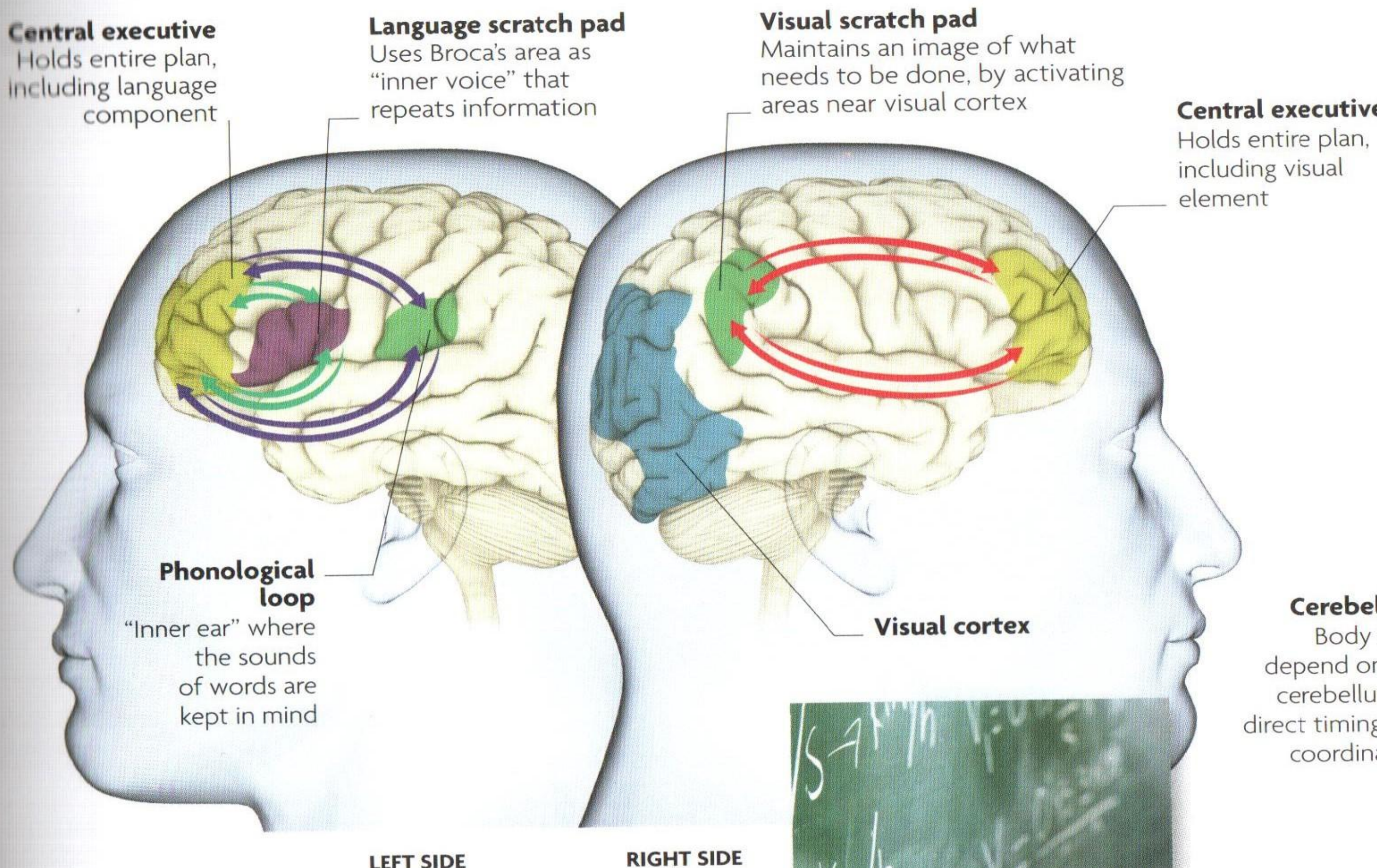
SEMANTIC MEMORY

Semantic memories are facts that may once have had a personal context but now stand as simple knowledge. The fact that a man once walked on the Moon, for example, may once have been part of your personal experience, but now it is just "knowledge."

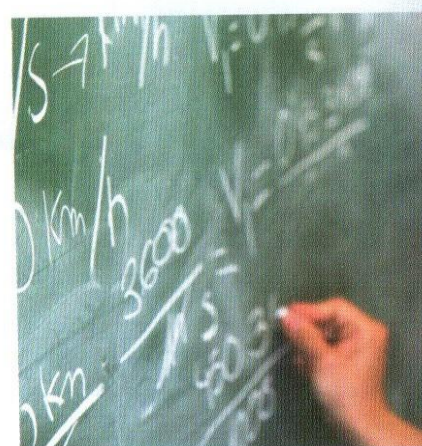


PROCEDURAL MEMORY
"Body" memories allow us to carry out ordinary motor actions automatically, once we have learned them. Such skills are stored in brain areas that lie beneath the cortex. They can be recalled to mind, but usually remain unconscious.



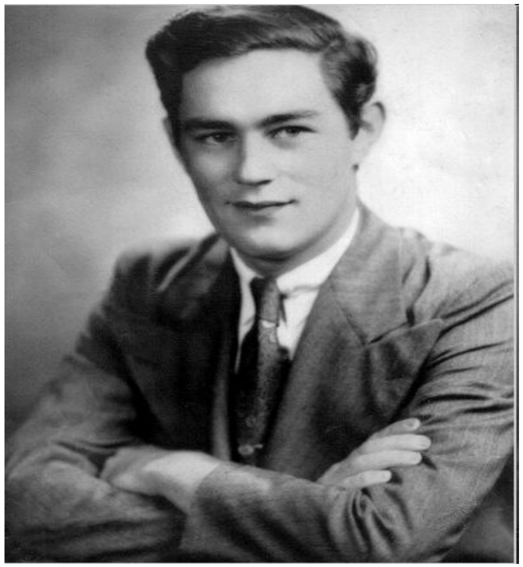


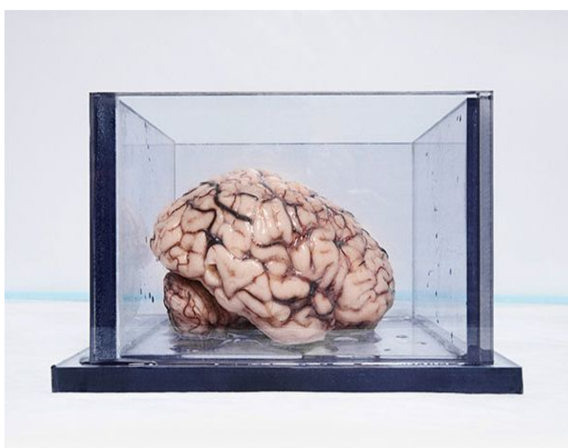
WORKING MEMORY
One part of the frontal lobes, the central executive, holds a plan of action while calling up items from the rest of the brain. There are also two neural loops, for visual data and for language; these act as scratch pads, temporarily holding data until it is erased by the next job.



Cerebellum
Body skills depend on the cerebellum to direct timing and coordination

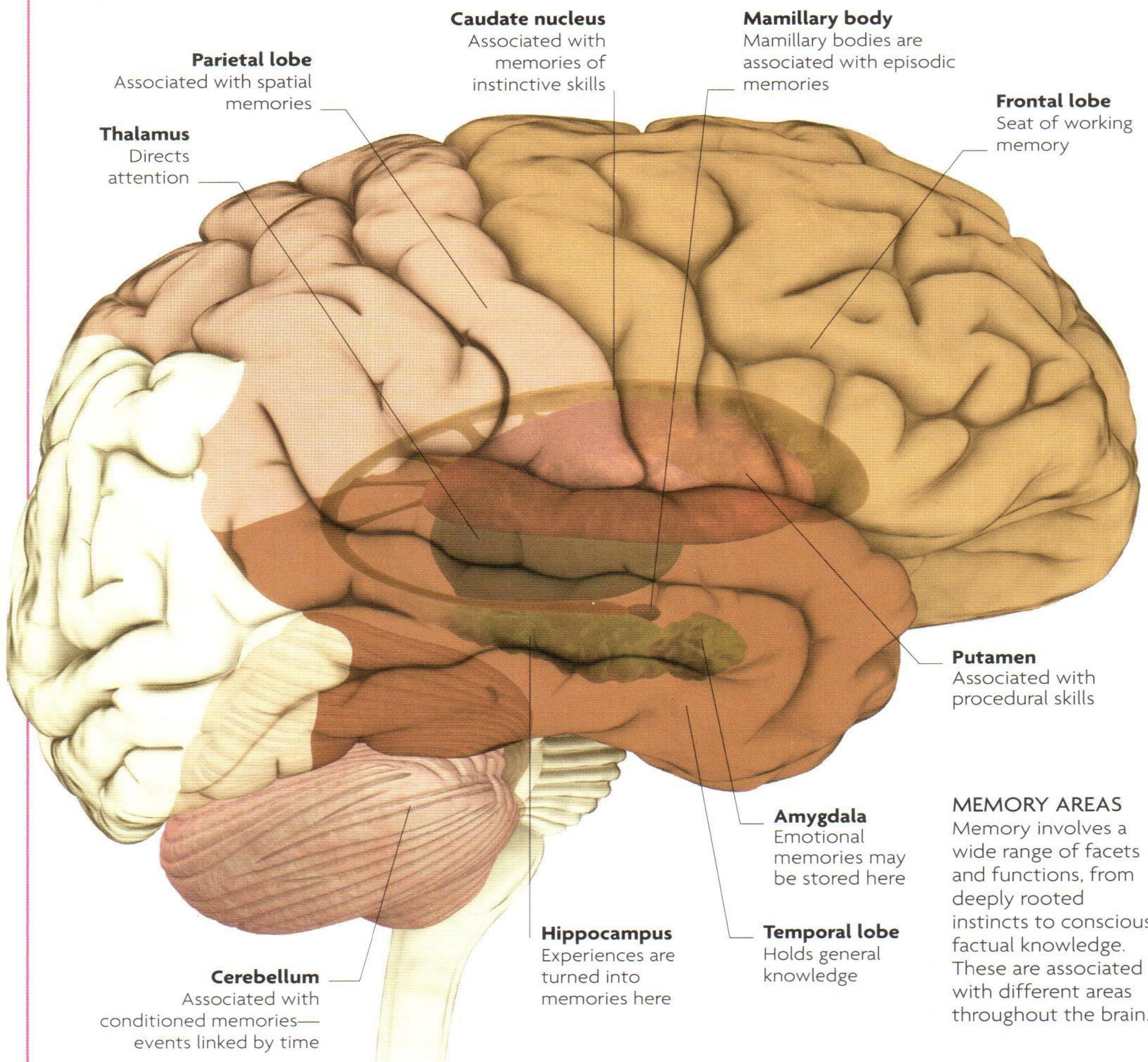
Amnesic Disorders





ANATOMICAL LESIONS USUALLY VISIBLE ON IMAGING STUDIES

- Bilateral medial temporal lesions
  - Surgery
  - Cerebral contusions
  - Infarct (posterior cerebral arteries)
  - Hippocampal sclerosis (usually with chronic epilepsy)
  - Herpes encephalitis
  - Paraneoplastic limbic encephalitis
  - Neoplasm
  - Inflammatory process, such as sarcoidosis
- Bilateral medial diencephalic lesions
  - Wernicke–Korsakoff syndrome
  - Infarct (thalamoperforator arteries)
  - Whipple's disease
  - Neoplasm
- Basal forebrain lesions
  - Anterior communicating artery aneurysmal rupture
  - Neoplasm
- Diffuse disorders
  - Multiple sclerosis
  - Numerous other diffuse cerebral disorders (additional deficits common)



Caudate nucleus
Associated with memories of instinctive skills
Mamillary body
Mamillary bodies are associated with episodic memories
Parietal lobe
Associated with spatial memories
Frontal lobe
Seat of working memory
Thalamus
Directs attention
Putamen
Associated with procedural skills
Amygdala
Emotional memories may be stored here
MEMORY AREAS
Memory involves a wide range of facets and functions, from deeply rooted instincts to conscious factual knowledge. These are associated with different areas throughout the brain.
Hippocampus
Experiences are turned into memories here
Temporal lobe
Holds general knowledge
Cerebellum
Associated with conditioned memories—events linked by time

(additional deficits common)

NO ANATOMICAL LESIONS VISIBLE ON CONVENTIONAL IMAGING[a]

- Seizures, including electroconvulsive therapy
- Concussion
- Ischemia (bilateral medial temporal or medial diencephalic structures)
- Diffuse cerebral anoxia
- Transient global amnesia
- Early Alzheimer's disease and other degenerative disorders
- Diffuse infectious or toxic/metabolic encephalopathies (additional deficits common), including those caused by medications such as benzodiazepines
- Psychogenic amnesia
  - Dissociative disorders
  - Repression
  - Conversion disorder
  - Malingering

“Normal” Memory Loss

- Infantile Amnesia
- During or shortly awakening from sleep
- Passage of time

Amnesia subtypes: bitemporal vs.diencephalic amnesia

- Bitemporal (global anterograde) amnesia (HM case) – mostly temporal lobe pathology.
- Diencephalic (Alcoholic Korsakoff disease) – thalamic, mammillary body lesion and frontal lobe damage: impairment in temporal order judgment, source monitoring (source amnesia), metamemory and feeling of knowing (estimation of one's own memory capabilities - FOK).

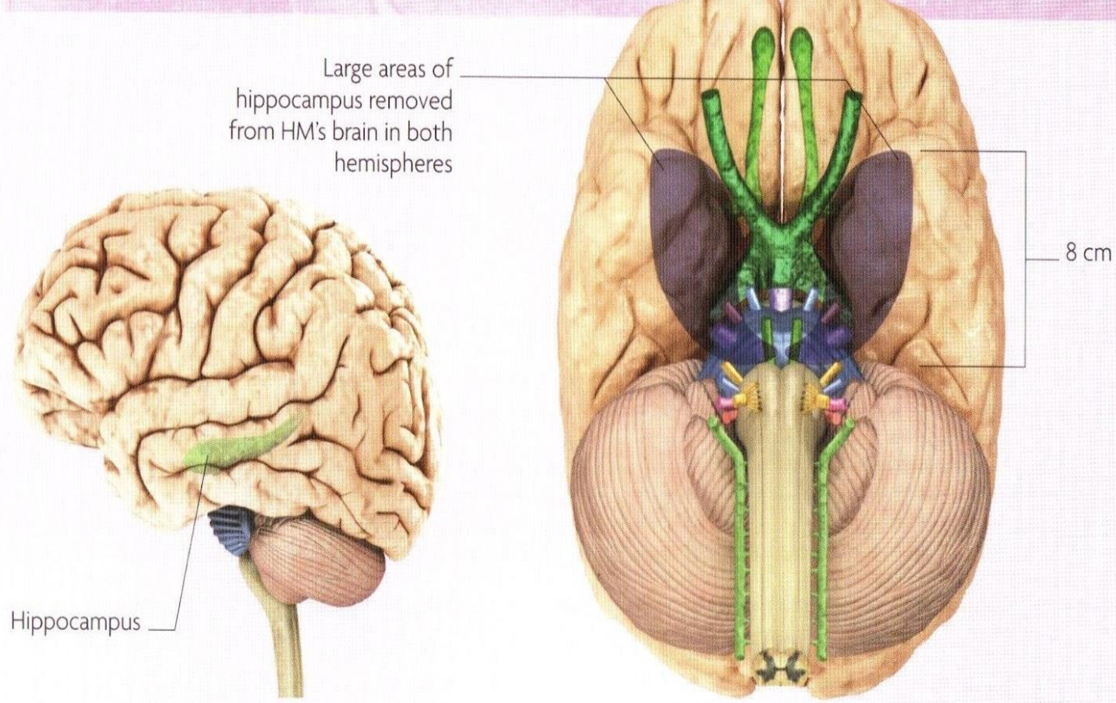
widely distributed areas of the brain.

INABILITY TO STORE

In 1953 surgery was performed on a patient known as HM to relieve the symptoms of severe epileptic seizures. The operation involved removing a large part of the hippocampus. This controlled the seizures, but it also produced a severe memory deficit. From the time HM woke up from the operation he was unable to lay down conscious memories. Day-to-day events remained in his mind for only a few seconds or minutes. When he met someone, even a person he had seen many times a day, year after year, he did not recognize them. HM believed himself to be a young man right into his eighties, because the years since his operation did not, effectively, exist for him. His case shows how essential the hippocampus is for memory storage.

THE MISSING PIECE

The hippocampus is embedded deep in the temporal lobes. Experiences "flow through it" constantly, and some of them are encoded in memory through a process of long-term potentiation. Thereafter, the hippocampus is involved in retrieving most types of memory.



SIDE VIEW

VIEW FROM BELOW

Transient global amnesia

- The onset of TGA is generally fairly rapid, and its duration varies but generally lasts between 2 to 8 hours.
- A person in a state of TGA exhibits no other signs of impaired cognitive functioning but recalls only the last few moments of consciousness plus deeply encoded facts of the individual’s past, such as his or her own name.
- Precipitating events: vigorous exercise (including sexual intercourse), swimming in cold water or enduring other temperature changes, and emotionally traumatic or stressful events.

Fugue state

A rare psychiatric disorder characterized by reversible amnesia for personal identity, including the memories, personality and other identifying characteristics of individuality

Memory Functions Spared in Amnesia

Preserved pre-illness memory

- Intact knowledge structure (context-free general knowlege)
- Motor and cognitive skills (playing piano, sports, using dictionary)
- Preferences (color, clothes, food, people, dangerous objects)

Preserved new learning capacities (mostly implicit)

- Skill learning (mirror drawing)
- Repetition priming (word-fragment completion task)

Classical conditioning

Electrophysiological responses