

# The Physiology of the Senses

## Transformations For Perception and Action

### Lecture 12 – Memory

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#### ***A few definitions.***

**Memory:** information that is stored (e.g. the memory of grandmother) or the structure that stores this information ( e.g. the strength of synapses in a particular part of the brain )

**Learning:** the storage process (e.g. what mediates a change in synaptic strength)

**Remembering:** the retrieval of stored information

#### ***Types of Memory***

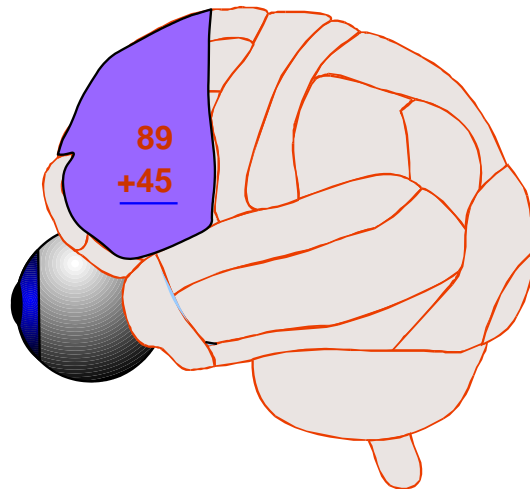
##### **1. Short term / Working memory**

A sort of scratch pad which allows for temporary storage of information.

Example 1: storing numbers when adding.

Example 2: storing words that one reads to form a meaning full sentence.

Example 3: spatial location of objects when you close your eyes and point to remembered objects. It involves the frontal lobe and has a very limited capacity (e.g. limited to about a 9 digit new #).



##### **2. Long Term**

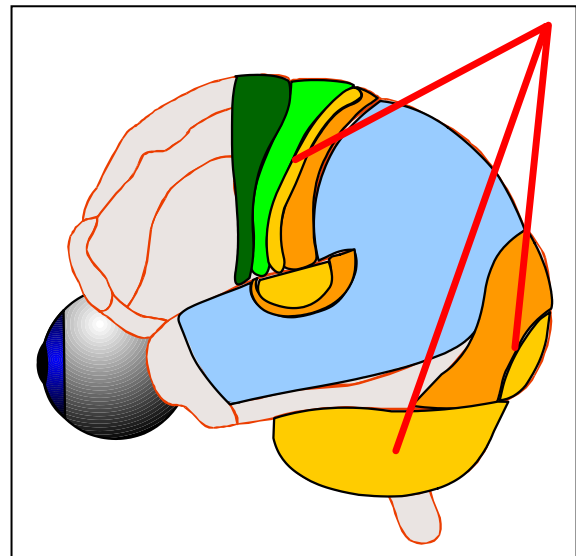
Two types of long term memory are procedural and declarative.

##### **2.1 Procedural (knowing how)**

Characteristics:

includes skills such as skiing

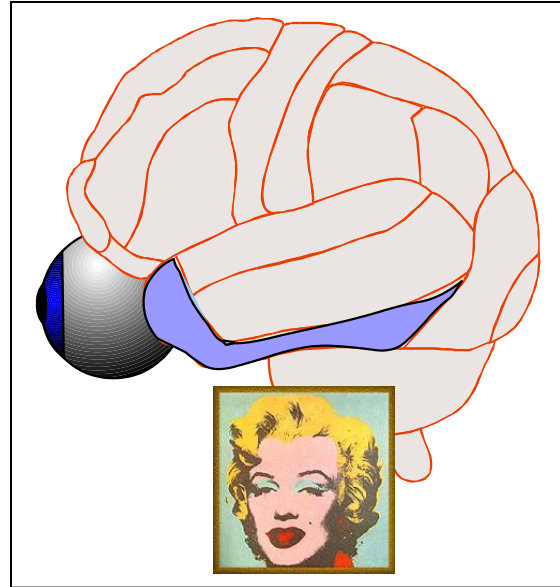
- established slowly by practice
- one is not conscious of remembering the skill
- starts to develop at birth
- is not affected in amnesia
- is coded and stored in much of the CNS, for example, the tuning of binocular V1 cells during the critical period for stereopsis and in the cerebellum and motor cortex for motor skills.



## 2.2 Declarative (knowing that)

Characteristics:

- representations of objects and events  
e.g. face of a friend
- involves associations e.g. name with face
- often established in one trial
- one is conscious of remembering
- starts only after the age of 2 yrs
- affected by amnesia
- learning involves the hippocampus in medial part of the inferior temporal lobe.
- memories are stored in all the association areas but in particular in the inferior temporal lobe.



Two types of declarative memory are semantic and episodic.

### 2.2.1 Semantic

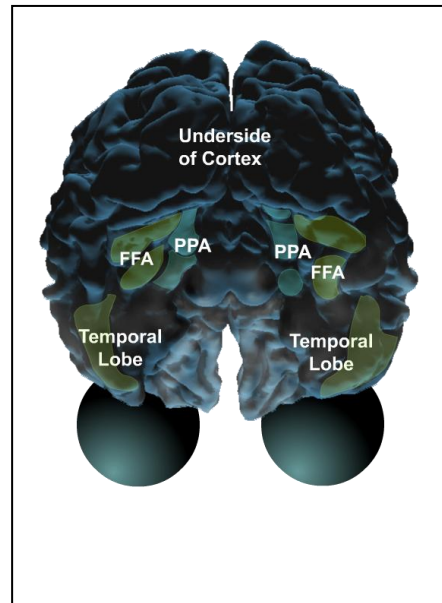
Characteristics:

- Remembering faces and places.
- Remembering facts and concepts.
- The visual aspects of familiar places are recognized and stored in the parahippocampal place area (PPA) in medial areas of the inferior temporal lobe.
- Those of familiar faces in the fusiform face area (FFA) in more lateral areas.

### 2.2.2 Episodic

Characteristics:

- Remembering particular objects and places in one's personal past.
- Episodic are composed of several semantic memories.
- Associating who and what with where and when.
- Examples:
  - In episodic memory one not only recognizes the person in the picture but also when the picture was taken. "We visited Paris when the kids were young".
  - The sequence of places one passes while walking across a city. The synthesis of such representations provides us with a map of the spatial layout of the city.



The areas activated by remembered objects are the same as those activated during the perception of these objects.

Different areas specialize in different categories of objects. We saw that the FFA is activated during face perception. After a lesion FFA, patients develop prosopagnosia.

## ***Working memory***

Working memory is subdivided into several compartments.

Three compartments are:

- Spatial Locations
- Words
- Visual Objects

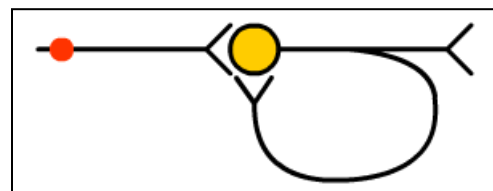
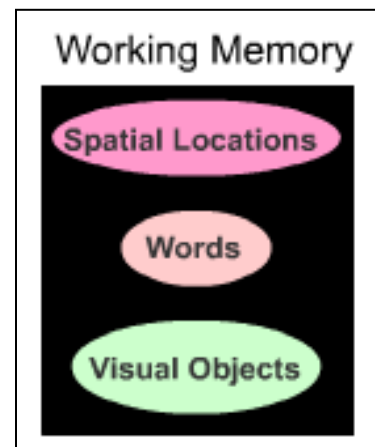
Each has its own separate limited capacity.

One compartment can be full and the others empty.

Visual working memory of objects is not stored in retinal coordinates, but perhaps in object centered coordinates.

Short term working memory involves reverberating circuits.

In such a circuit, activity continues long after input/sensation ends.



## ***Long Term Memory***

Long term memory involves semi permanent changes in synaptic strength between assemblies of neurons.

For example, rats raised in a rich environment have a thicker cortex with larger and more synapses.

In the case of procedural memory, the changes are produced gradually by repeated exposure to the stimulus.

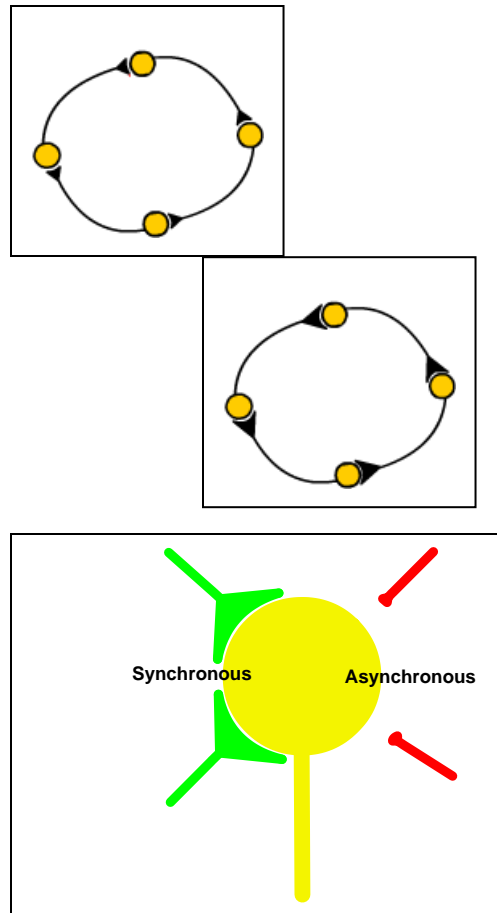
## ***Molecular basis of Long Term Memory***

The key in long term learning is the NMDA receptor which opens only when the cell is strongly depolarised.

If two synapses fire at the same time (synchronously) they produce a larger depolarization than if they fire at different times (asynchronously).

Cells that fire together wire together.

This is the basis for plasticity or learning throughout the CNS.



## ***Mechanisms of Learning Procedural Memories.***

You can be trained to produce blinks in response to a sound by classical conditioning.

One begins with a naive subject; one that does not blink in response to a flash of light or a sound.

The next thing needed is a good teacher: a stimulus that will always produce a blink.

A puff of air is a good teacher. A puff of air, through a strong synapse, always produces a blink.

This is called classical conditioning: the puff depolarises the blink cell. This strengthens the synapses from the paired sound's synapse.

That is, the puff of air teaches sound to produce a blink.

A similar strengthening and pruning of synapses is the basis of all forms of long term memories.

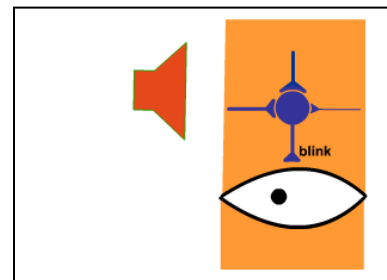
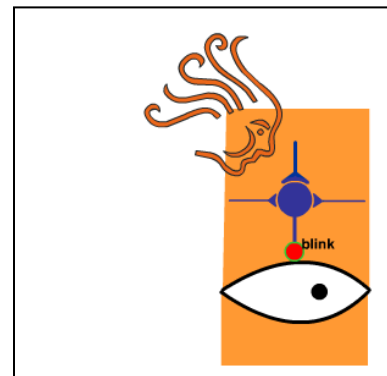
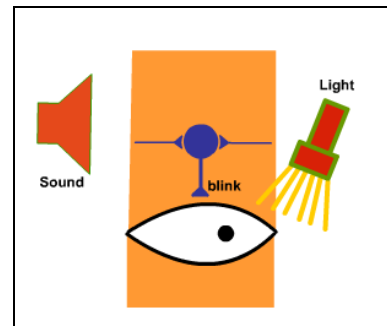
After conditioning, the synapse from the sound is strong and can produce a blink on its own.

That is, the blink becomes associated to sound but not to some other stimulus such as a light.

This conditioning also involves pruning of connections. While connections from sounds are strengthened, those from light are weakened.

This procedural type of memory involves the cerebellum.

A lesion of the deep cerebellar n. eliminates the learnt blink to a sound.



## Memory is consolidated over time

New memories are fragile.

If one learns a particular sequence of finger taps and soon after learns a second sequence, the skills (speed and accuracy) learnt in the first are disrupted.

Over a period of several hours memory undergoes consolidation, making it resistant to interference. Now learning a second sequence does not disrupt the skills learnt in the first.

Surprisingly after a memory has been consolidated, brief periods of rehearsal return the memory to a labile state.

Normally rehearsal further refines the learnt sequence. However this can also have negative consequences.

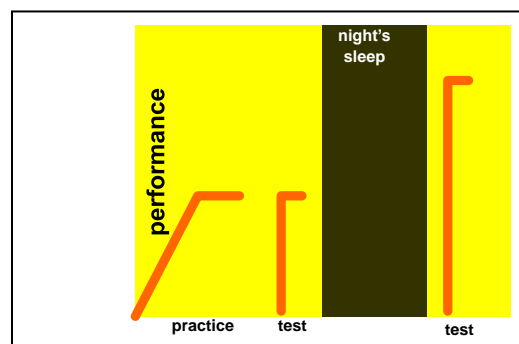
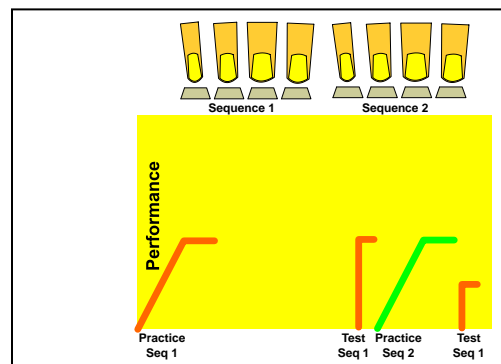
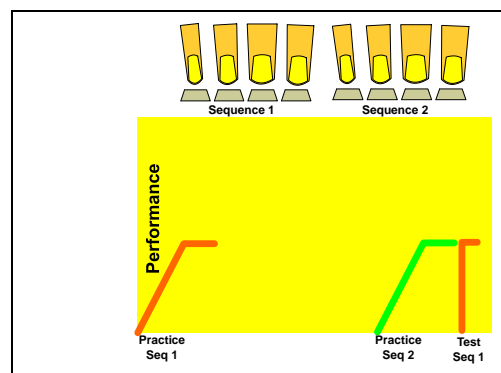
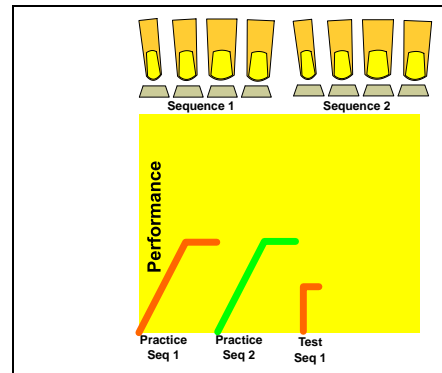
Here a brief re-test of sequence 1 makes it labile and now a practice of sequence 2 reduces one's skill in sequence 1.

The observation that practice makes old memories labile again may apply not only to procedural memories. Remembering episodes in our past makes them suggestive to change. Sometimes these suggestions can be incorrect and result in incorrect memories of our past. But making old memories labile through practice can be beneficial because it can make it easier to improve on what we have learnt. Presumably this also holds for all semantic and episodic declarative memories.

Memories improve during sleep.

The performance, of a learnt motor skill is enhanced after a night's sleep.

Debates continue as to which phases of sleep are most critical (e.g. REM vs. slow wave sleep).



## ***Where are these modifiable synapses located?***

Examples of three different skills.

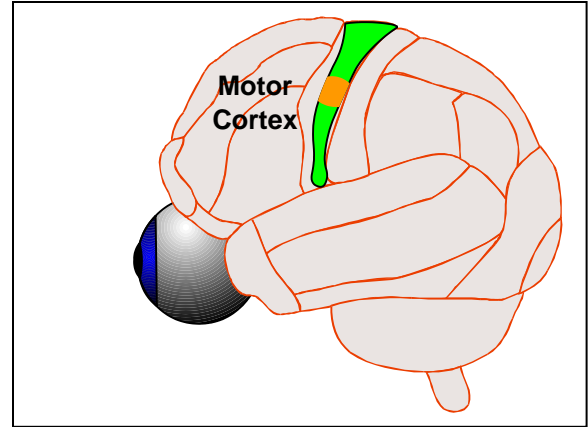
### **1. Motor Cortex.**

For motor skills, like a sequence of finger taps, the synapses undergoing plastic changes are distributed in various motor areas.

One key area is primary motor cortex.

After training, a larger area is activated in the hand area of motor cortex when the trained sequence is performed than for a naive sequence.

In violinists, who use their left hand for fingering, the hand area in the right motor cortex (the side controlling the left hand) becomes larger than that on the left.

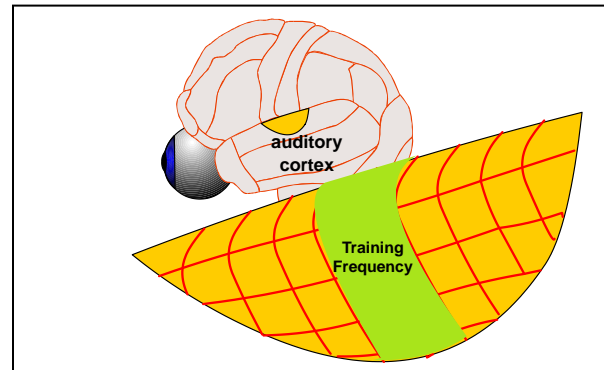


### **2. Auditory Cortex**

When trained to discriminate between slightly different frequencies of sound, around a mean frequency, one's ability to discriminate frequencies improves.

This improvement is specific for frequencies near the mean training frequency.

Training causes expansion of the region representing this frequency in the primary auditory cortex (A1).

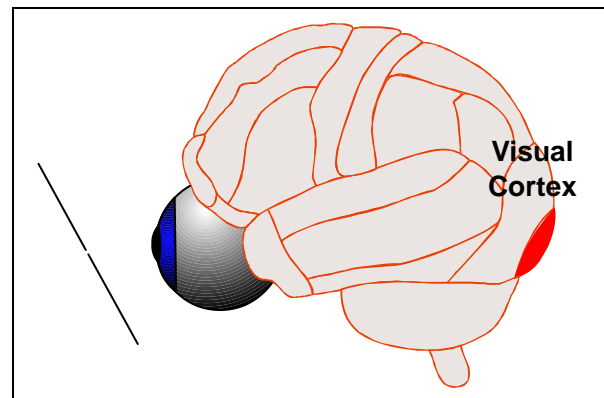


### **3. Visual Cortex**

You can also improve your vision by training. Your ability to detect a break in a line improves with practice.

This improvement is specific for the orientation that you trained for.

This improvement involves plasticity in primary visual cortex.



### **Take home message.**

Procedural memories continue to be consolidated, in the primary sensory and motor regions. Not all plasticity is lost after the critical period (there is hope for elderly pros).

## ***Brenda Milner's famous patient H.M.***

To relieve epilepsy, H. M.'s medial part of temporal lobe and hippocampus were removed bilaterally.

This had an unexpected effect on one type of memory.

### **Not affected by lesion.**

**Working:** e.g. remembers names for as long as not distracted.

**Old Procedural:** e.g. language normal

**New Procedural:** can learn new sports

**Old Declarative:** e.g. recognises his mother.

### **Affected by lesion.**

**New Declarative:** e.g. cannot remember new acquaintances

The lesion of the hippocampus produced anterograde amnesia.

## ***A model of declarative memory***

Consolidation of short term working memory into long term declarative memory involves the hippocampus.

Unlike procedural long term memory which require repetitive practice, declarative memory often requires only a single exposure.

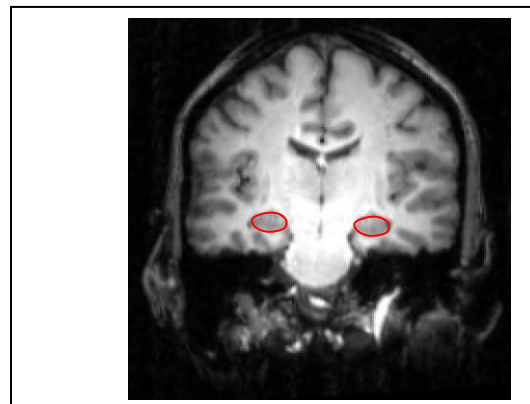
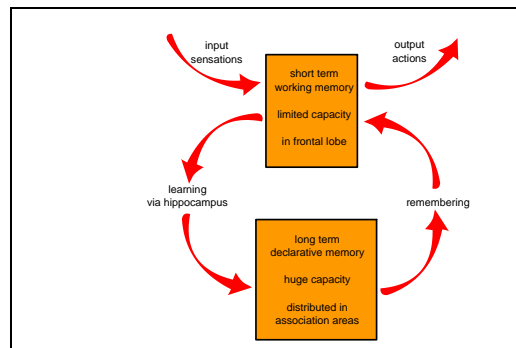
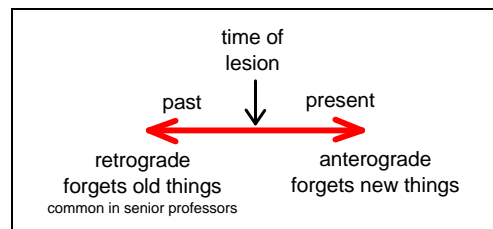
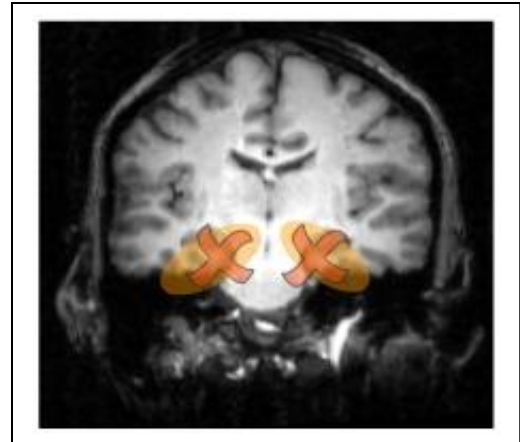
This is because the hippocampus is an excellent teacher.

The hippocampus is located in the medial part of the inferior temporal lobe.

It is a unique part of the cortex. Unlike other cortical areas, it continuously generates new neurons. New neurons also appear in the olfactory bulb (a smell cortical area). This is not a coincidence.

The hippocampus evolved from the olfactory bulb.

The hippocampus is well connected: an important attribute of a good teacher.





It receives input from all the association areas and sends signals back to them as well as other thus creating new associations..

## ***Encoding Declarative Memories***

The ventral stream

- 1) assembles visual features into an object,
- 2) encodes the object in an object centered reference frame, and
- 3) stores it temporally in working memory.

From working memory information is funnelled to the hippocampus.

The hippocampus in turn re-activates the areas coding the features of this object.

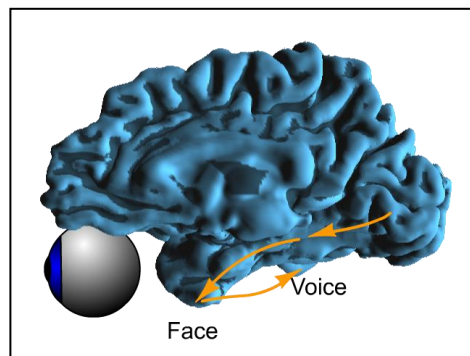
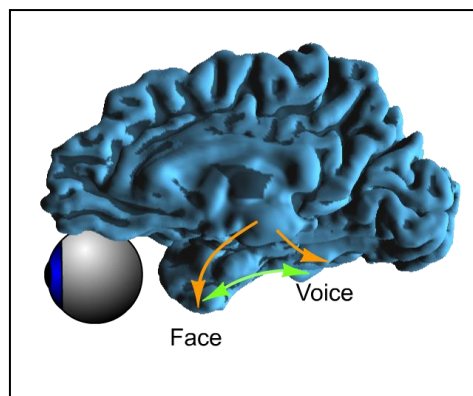
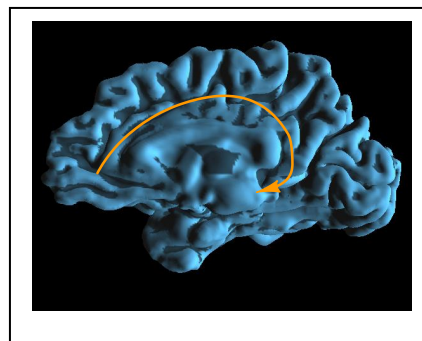
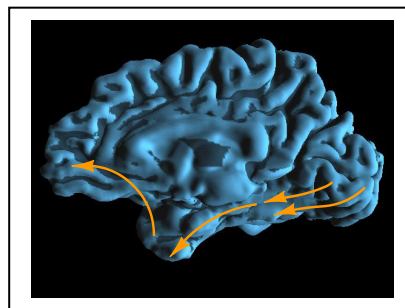
Features extracted by the different senses are associated (e.g. the sound of someone's voice with their visual features).

The hippocampus somehow binds together/associates features into a rich multi modal memory.

The memory is long term and requires the changes in the structure of synapses. These structural changes involve the expression of genes and the synthesis of proteins.

Patients like HM suggest that once these long term memory are formed, one can retrieve these memories into working memory without the hippocampus.

Or as the author Proust wrote that when he ate the cookie after dipping it in tea, the taste and smell of the cookie caused a flood of memories from the past.



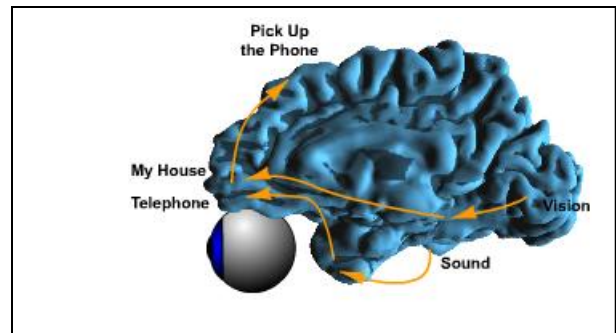
***Working memory in the frontal lobe is critical in decision making.***

Suppose the phone rings while you are **at home**.

The sound triggers one's long term memory of a phone.

Visual inputs are recognised by the parahippocampal place area as those of your house.

The frontal lobe with these working memories decides that the appropriate action in this context is to **pick up the phone**.

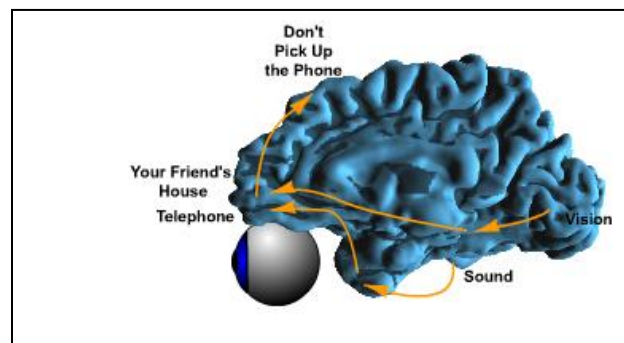


Suppose the phone rings while you are **at your friend's house**.

Again, the sound triggers one's long term memory of a phone.

Visual inputs are recognised by the parahippocampal place area as those of your friend's house.

The frontal lobe with these working memories decides that the appropriate action in this context is **not** to pick up the phone.



Working memory allows us to organize the things we remember.

This process is critical in decision making.

## ***Hippocampal Place Cells.***

A good example of associations formed by the hippocampus are those used to navigate to particular locations, like finding our way home.

For example in the rat, hippocampal cells, called Place Cells, fire when the rat senses that it is in a particular place. The place is associated by a particular combination of visual, auditory, somatosensory, and olfactory cues.

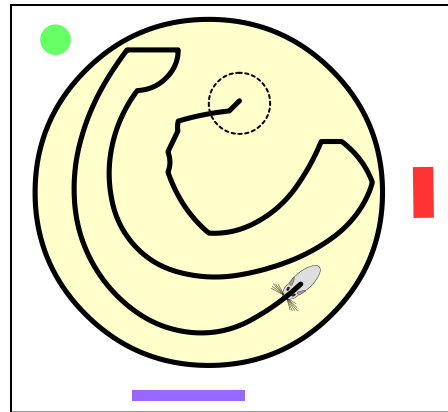
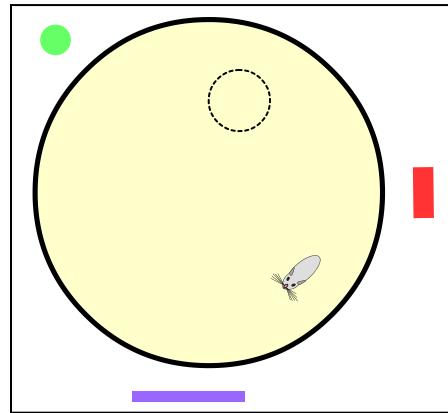
A useful tool used to examine spatial memories in the rat is the water maze. One takes a small pool and fills it with milky water. One then hides a platform just below the surface of the milky water. (The milky water hides the platform's location). Then one puts visual landmarks around the pool. Finally one drops a rat into the pool.

Rats are good swimmers but don't seem to enjoy it. Because of this, they hunt for the platform and tend to quickly find it.

Rats are also very good at remembering the location of the platform. Presumably they remember the platform location with respect to landmarks around the pool. When placed in the maze on the next day, the rat will swim directly for the platform.

Cells in the hippocampus, called Place Cells, code the allocentric locations of landmarks. For example, the cell illustrated here codes the location of the red block. Other place cells code the locations of the green sphere and the purple block. The platform location is coded by a particular pattern of firing rates of many place cells denoting the particular configuration of visual landmarks e.g. near the red block, somewhat near the green sphere, and far from the purple block.

A key step is that once the platform is reached, the hippocampus associates, elsewhere in the brain, this visual landmark configuration with the tactile sense of the platform. On subsequent days the rat can find the platform without the help of the hippocampus.



However if a rat with a lesioned hippocampus is placed in the water maze, it will not remember the location of the landmark. The rat will behave as if it had not seen the maze before. Like patient HM, the rat will remember locations learnt some time before the hippocampal lesion.

This suggested that the hippocampus is critical in forming long term memories of the associative spatial landmarks in brain areas that are outside the hippocampus.

### ***The amygdala is involved in learning emotional responses.***

The amygdala is essential for the acquisition and expression of conditioned emotional responses, such as a fear response to the sight of a lion.

During conditioning, the sound of a horn, (which is so loud that it startles you and elicits a sweating response) is paired with a blue square.

This pairing selectively strengthens the connections between the neurons detecting blue and those producing sweat (a bit more complicated than the one shown here).

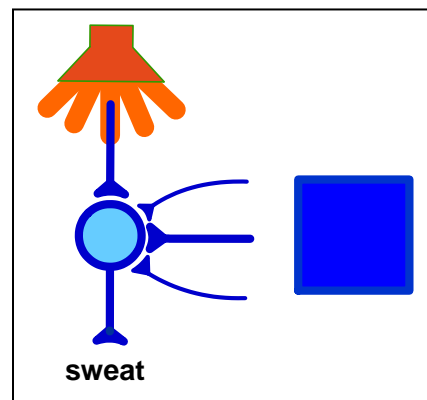
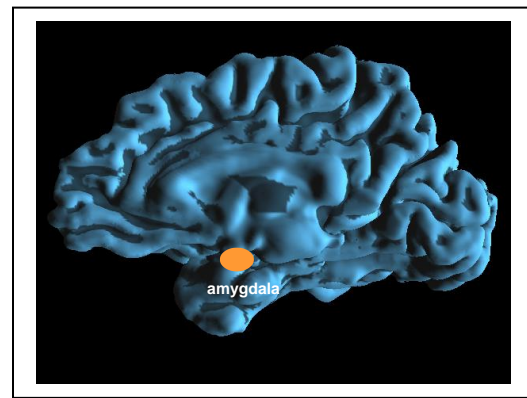
In normal subjects, after conditioning, a blue square will, on its own, elicit a sweat response and the subject will remember which stimulus was associated with the sound of the horn.

Patients with a lesion of the amygdala will not learn to produce a sweat response to the blue square.

Patients with a lesion of the hippocampus will not remember which color was associated with the horn but will sweat to the blue color.

Similar conditioning was seen when a small painful shock was applied to the skin. A more painful shock was associated with a blue color and a less painful with a green stimulus.

After 10 minutes of conditioning subjects felt a more painful stimulus after they are shown a blue color and a weaker after a



green color, even though the stimulus was the same.

A similar process may explain why a doctor in a white coat prescribing a drug to a patient can have placebo effects.

Summary: The Amygdala is required to consolidate the autonomic responses to a stimulus.

It also adds an emotional tone (e.g. fear or pleasure) to the memory of past events.

The amygdala is also involved (via the adrenal gland) with the release of stress related hormones (e.g. epinephrine).

## ***The amygdala is also involved face recognition.***

A 'glow' of recognition can occur without the conscious recognition of the person.

This 'glow' is accompanied by autonomic responses such as sweating. These responses can be entirely unconscious.

It is these autonomic responses that are form the basis of lie detector tests which measure the changes in skin conductance.

These two aspects of recognition are mediated by two parallel pathways:

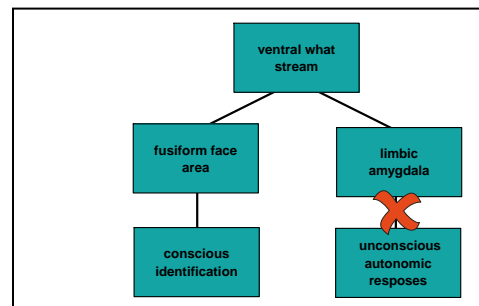
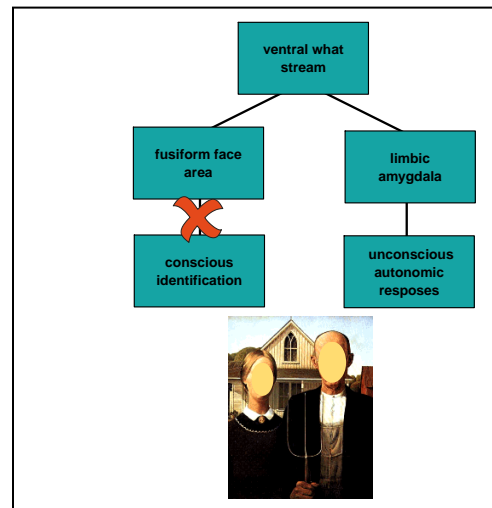
- A) the right inferior temporal cortex (fusiform face area).
- B) the limbic amygdala

A lesion of the fusiform face area produces a sense of familiarity without being able to identify who that person is (prosopagnosia).

A lesion of the amygdala produces the converse. The patient can identify who the person is but has no sense of familiarity.

One such young man, after a car accident which lesioned this pathway

- 1) could recognize his parents
- 2) felt that they had been replaced by aliens (i.e. no sense of familiarity)



## ***In Summary.***

It is remarkable that we can recognize a multitude of objects, each in a fraction of a second, with no apparent effort.

Each image activates millions of retinal ganglion cells. Although we typically see an object many times, we never see the same exact image on our retina twice.

Somehow for faces these neurons activate a similar group of neurons in FFA each time and this activation triggers recognition, presumably in the frontal lobes.

How? It is also remarkable that that is still a mystery!

