

PL3249 — MEMORY

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1 INTRODUCTION

Lecture 1
11th January 2022

The course aims to provide answers to the following questions:

- How does the brain support memory?
- Which parts of the brain are involved in memory?
- What do they do?

To study how the brain supports the mind, we can look out for **differences** and **changes** in terms of an individual's behaviour and brain. For example, we can consider if there are different behavioural outcomes and mental processes between people with good memory versus people with bad memory, and if different brain regions or neural processes are involved between these individuals. We can also consider if there are any changes in terms of mental representations and processes before and after learning, and/or changes to brain regions and neural processes.

1.1 *The Human Brain (Recap)*

The human brain consists of 4 lobes – the **frontal lobe**, the **parietal lobe**, the **temporal lobe**, and the **occipital lobe**.

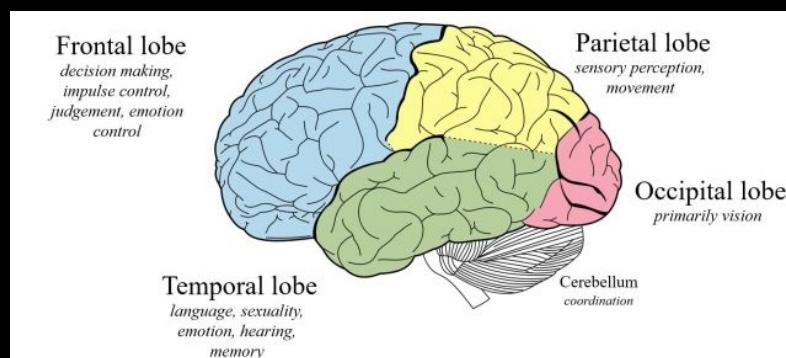


Figure 1: The cerebral cortex.

On the lateral surface of the brain, we are able to see numerous folds of the brain:

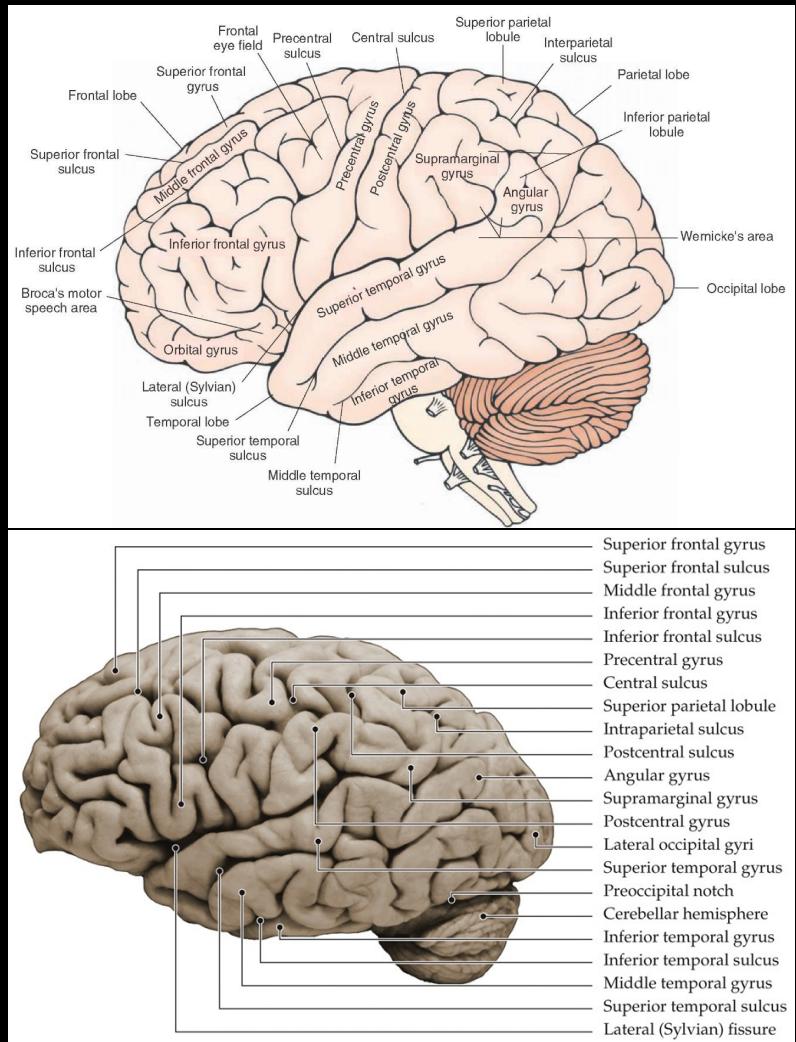


Figure 2: Lateral view of the human brain.

1.2 Methods

Changes and differences to the brain can occur **spatially** and **temporally**, and there are various methods in neuroscience to examine the space and time dimensions in the brain.

To answer the spatial question, some useful methods include:

- **Patient studies**

- Patients with lesions that result in *very specific impairments* (i.e., only a single mental operation is impaired, e.g., in H.M.) give invaluable insight into the neural structures that may support certain cognitive functions.

- These studies provide a starting point for other forms of investigation.
- However, lesions that people suffer tend to be fairly idiosyncratic, nor do they respect anatomical boundaries (i.e., two individuals with the same mental impairment may suffer from lesions in very different brain regions).
- **Animal models**
 - This is one way to tackle the limitation of patient studies, since animals can be lesioned very specifically, so researchers can be confident about where a lesion is. Animal models can be created via:
 - * Lesioning (e.g., by cutting, burning, or injecting toxins)
 - * Genetic manipulation (e.g., knockout mice)
 - This can allow for testing of hypotheses regarding a specific brain structure, e.g. by removing a brain structure and seeing if the predicted cognitive deficit occurs.
 - However, animal brains are not entirely identical to human brains.

- **Functional magnetic resonance imaging (fMRI)**

- fMRI *infers* activity from blood flow.
 - * Areas that work more require more oxygen, which is carried by RBC (i.e., haemoglobin).
 - * Blood with lots of oxygen has different magnetic properties from deoxygenated blood.
 - * fMRI is able to pick out these magnetic differences and inform us where RBCs are more concentrated, i.e., it looks out for blood oxygen level dependent (BOLD) differences.
- However, fMRI depends on the *haemodynamic response*, which takes a few seconds; on the other hand, mental processes only take milliseconds. Therefore, fMRI does not have good temporal resolution.

Other methods are used for measuring temporal differences and changes in the brain, including:

- **Event-related potentials (ERPs)**
 - Since neural signals are electrical in nature, we can track these electrical changes using recorders and amplifiers.
 - ERPs also provide us with some *very rough* spatial information, but its spatial resolution is generally poor.
 - * Recording of ERPs is done on the scalp, thus we are unable to determine the origin of the electrical signals (i.e., how far below the scalp are the signals originating from).
 - Refer to PL3232 for more details.

- Single/Invasive cell recording

face validity: whether the test appears (at face value) to measure what it claims to

- Single cell recordings are very **face valid** since they directly measure neural activity at the neuronal level; we can record neuronal activity to almost any stimulus.
- This informs us with regards to what neurons in a particular part of the brain are sensitive to.
- However, only a few sites can be measured at the same time → limited utility when accessing cognitive operations which involve multiple brain regions at the same time.

Figure 3 provides a comparative summary of the various methods in neuroscience.

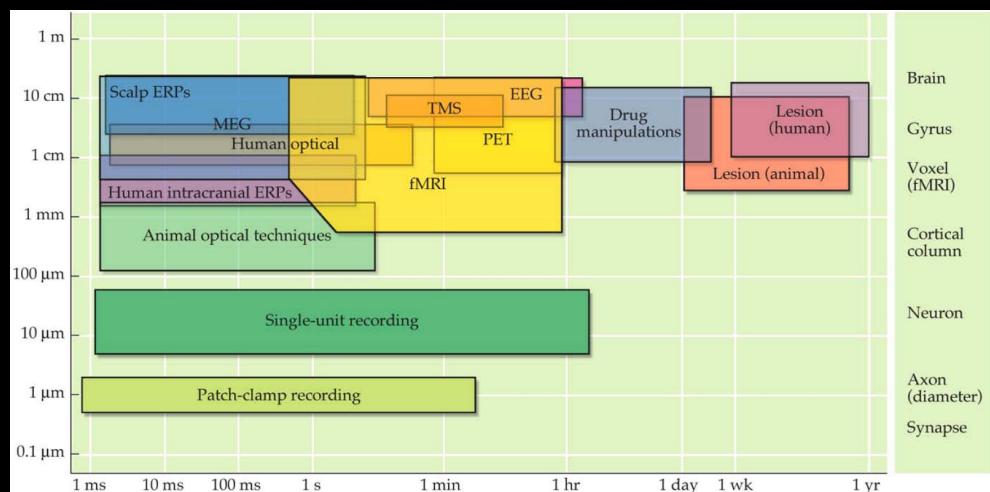


Figure 3: Summary of methods in neuroscience.

2 DECLARATIVE MEMORY IN HUMANS

Lecture 2
18th January 2022

Declarative memory refers to memory which we can express on our own volition. Some models (e.g., in Figure 4) suggest that declarative memory comprises of various subdivisions, including *episodic* and *semantic memory*.

In today's lecture, we will look into the case of H.M., one of the most famous neurological patients in the field of memory.

2.1 Primer on the hippocampus

The **hippocampus** is part of the limbic system, and it plays a vital role in regulating learning, memory encoding, memory consolidation, and spatial navigation.

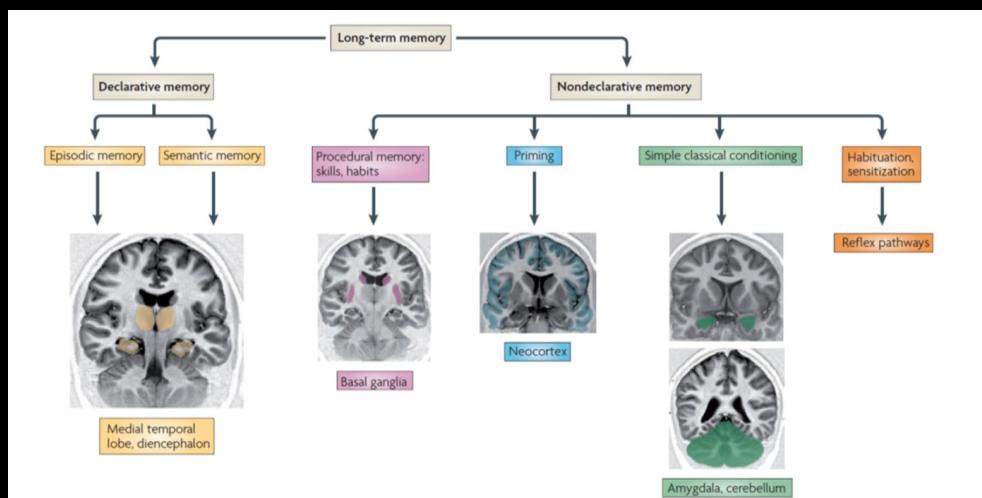


Figure 4: Henke's (2010) model for memory systems.

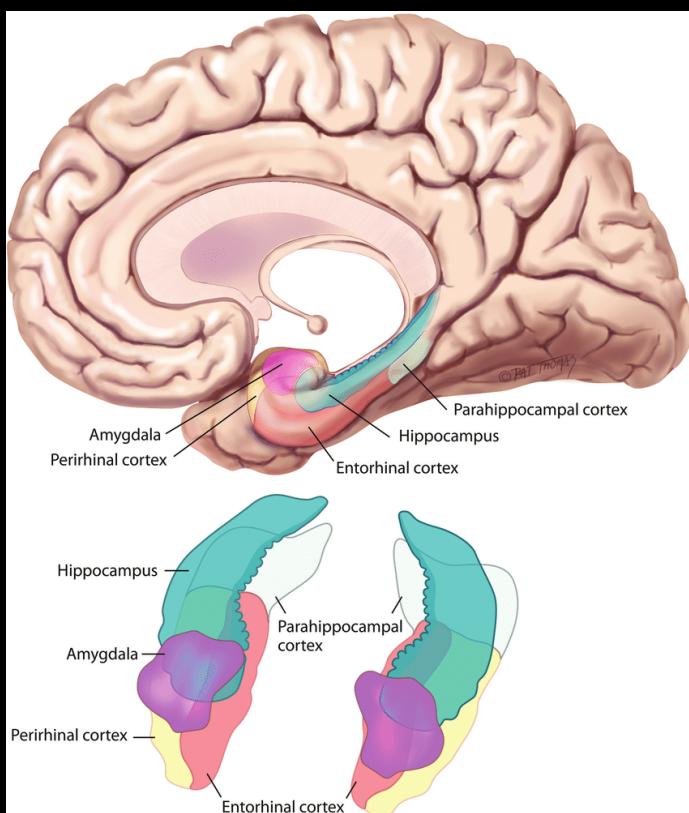


Figure 5: The medial temporal lobe consists of the hippocampal formation (blue-green) superiorly and the parahippocampal gyrus inferiorly. The entorhinal (brown) and perirhinal (yellow) cortices form the medial and lateral components, respectively, of the anterior portion of the parahippocampal gyrus, while the parahippocampal cortex (off-white) forms the posterior portion.

In fact, one might ask if the whole structure acts together, or if different parts of the hippocampus do different things? Additionally, if different parts do different things, how do these different parts interact with the rest of the brain?

Notice that the hippocampus is a spatially distributed structure. It is surrounded by many other subcortical structures, e.g., the amygdala and the thalamus.

Interestingly enough, it has been found that new cells can be generated in the human hippocampal formation (i.e., **neurogenesis**). Could this be a mechanism for the laying down of memories?

2.2 H.M.

H.M. started experiencing epileptic seizures at the age of 10 (as a result of getting knocked down by a bicycle when he was 7), and these seizures worsened over time. Since anticonvulsive medications did not bring about significant improvements to his condition, he was invited to an experimental surgery to remove his **medial temporal lobes**.

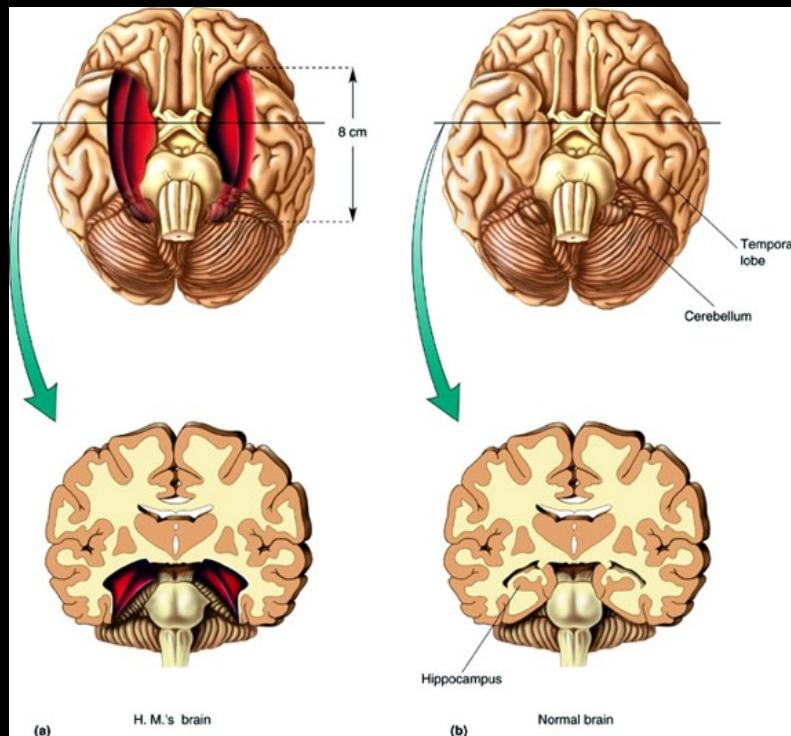


Figure 6: Areas removed from H.M.'s brain.

A lot of tissue was removed due to the difficulty to get to the medial temporal lobes in the brain, including:

- around two-thirds of the *rostral hippocampi*,
- the *amygdala*,
- the *parahippocampal cortex*, and

- the *piriform gyri*.

After the surgery, H.M.'s seizures were much more manageable, but it also left him with severe long-term memory deficits. However, he had intact perceptual, motor, and cognitive functions (i.e., it was a pure memory deficit). His mood, IQ, and linguistic abilities were also unaffected by the surgery.

His memory deficit was considered to be "global", since it was not specific to one modality or stimulus set. For example, he scored very poorly on tests that required him to recall pictures, and had trouble remembering number strings, drawings, songs, common objects, etc.

H.M.'s case suggests that the **medial temporal lobe** is likely to be involved with memory functions, since H.M. was specifically impaired on memory. There was further evidence supporting this conclusion, including (not limited to) the following studies:

- **Squire et al., 1992:** medial temporal lobe activation in PET
 - Subjects saw word stems, e.g., "SW__".
 - In the memory (experimental) condition, they were required to use the stems as cues to recall words that they had previously seen.
 - In the baseline (control) condition, they were asked to fill in the stems with whatever that came to mind. Furthermore, the stems could not be completed by the words presented earlier.
 - PET scans showed activation in the medial temporal lobe in participants in the memory condition.
- **Davachi et al., 2003:** using fMRI, it is shown that when people use cues to elicit memories, their medial temporal lobes will be activated.
- **Otten et al., 2001:** participants are asked to remember memories of a particular item; activation in the hippocampal region is detected only when the retrieval of long-term memories is successful.

H.M. was however still able to acquire *sensorimotor skills* (e.g., he showed improved performance over time on the mirror drawing test), and showed unimpaired performance on *priming tasks*. This suggests that the role of the **medial temporal lobe does not extend to all types of memory**. Clearly, some variants of memory are still preserved even when the medial temporal structures have been compromised.

Based on the following clues:

1. People with compromised medial temporal structures (e.g., hippocampus) have difficulty with *explicit memory tasks*.
2. The memory difficulty is *global*.

3. Their ability to learn implicitly/without any conscious intention is retained.

They seem to point towards the conclusion that the *medial temporal lobe* is involved in **declarative memory**.

2.3 Scoville, W. & Milner, B. (1957)

- Medial temporal lobe resections extensive enough to damage portions of the hippocampus and hippocampal gyrus bilaterally results in a clear and persistent disturbance of recent memory.
- However, hippocampal resection does not result in any deterioration in intellect or personality.
- The findings of the paper hint a special importance of the anterior hippocampus and hippocampal gyrus in the retention of new experience.
- There could be a positive relationship between the extent of destruction to the hippocampal complex, and the degree of memory impairment.

2.4 Eichenbaum, H. (2012)

The studies on H.M. generated 5 main findings:

1. Memory is a distinct psychological function.
 - Experiments on amnesiacs seem to point towards the conclusion that hippocampal information processing involves relating elements of an experience to one another, within the context of composing memories of the whole experience.
2. Amnesia spares short-term and working memory.
 - Neuropsychological assessments on H.M. showed fully intact memory for a normal amount of material over a brief period, typically until he was distracted by intervening mental activities.
 - Findings also showed that hippocampal memory processing that contributes to subsequent memories begins during the experiences that will become memories, and its involvement persists for some time.
3. Amnesia is an impairment of declarative (i.e., memory of facts and events) and episodic memory.
 - Findings have suggested that the core deficit in amnesia is a loss of the ability to relate distinct elements of memories, and distinct

memories to one another (i.e., **relational representation**), and consequently the ability to use the acquired memories inferentially in novel situations (i.e., **relational flexibility**).

- Amnesia is a relational processing deficit that begins at the outset of encoding, plays an important role in the organization of short-term and long-term storage, reflects the inherent relational organization of memories even without conscious awareness, and can be called upon in cognitive functions such as imagining future events.
- 4. The hippocampus is a core brain structure supporting memory.
 - The surrounding cortical areas interconnected with the hippocampus support distinct roles in memory.
 - The *perirhinal cortex* and *lateral entorhinal cortex* represent important objects, people, actions, and other specific events.
 - The *parahippocampal cortex* and *medial entorhinal cortex* represent the spatial environment in which important events occur, and may also represent the temporal context in which events occur.
 - The hippocampus integrates the “what” and “where” information into composite events, sequences event codes into representations of temporally extended experiences, and then compares and relates these individual event and episode representations to other memory representations.
 - Memory for items was predicted by activation of the perirhinal cortex, whereas memory for the associations was predicted by activation in the hippocampus.
- 5. The hippocampus supports the permanent consolidation of memories.

2.5 Gabrieli, J. D. E., et al. (1990)

Theoretical background:

- There are two kinds of priming:
 - **Activational priming:** dependent upon the activation of long-term memory representations, and intact in severely amnesic patients who established premorbidly the required memory representations.
 - **Episodic priming:** dependent upon the formation of new memory representations, or new associations, that are mediated (at least in part) by the same episodic memory processes that support recall and recognition.
- Intact priming of nonverbal material can be dissociated from impaired recognition memory of the same material.

- The preservation of pattern priming in H.M. reflects the separability of perceptual learning and recognition processes in the course of normal cognition.
- Such perceptual learning does not depend upon recall and recognition memory capacities.
- Extrastriate visual areas may be especially important in perceptual priming.
 - Extrastriate visual areas show selective activation in positron emission tomography (PET) studies when normal subjects perform a task thought to be sensitive to word form.
 - Single-cell recordings in monkeys have shown that neurons in the extrastriate visual cortex (V2), but not the primary striate visual cortex (V1), respond selectively to stimuli that humans perceive as contours (i.e., subjective continuities) despite no actual line being present.

1. What is the point of the experiment?

- To discover whether an amnesic patient could show normal priming with stimuli that were patterns.

2. What did the experiment do?

- Priming task: to determine whether there was a priming effect.
- Recognition task: to show that the amnesic patients truly have no declarative memory.
- Cued recall: was not further explored due to methodological issues (i.e., controls were not told to remember → patterns were not stored in their declarative memory).

3. What are the results?

- Controls had better performance on the recognition task, but there were no statistically significant differences on the priming task.
- H.M. actually scored higher on the priming task, which could be attributed to:
 - Statistical noise/variance.
 - (FFT) Neural plasticity (i.e., poorer declarative memory → better implicit memory)?

4. What do the results show?

- H.M.'s intact pattern priming cannot be classified satisfactorily as an example of either activational or episodic priming; it must be some form of unconscious priming.

5. What does this tell us?

- (Biological) We have separate brain systems, and each process is controlled by different systems.

-
- Specifically, the medial temporal lobe and the hippocampus are key features supporting declarative memory.
 - (Cognitive) Priming and recognition memory are distinct processes (i.e., declarative and nondeclarative memory).

3 DECLARATIVE MEMORY IN ANIMALS

Lecture 3
25th January 2022

In human patient studies, we saw that with hippocampal damage,

- sensory, motor, and cognitive processes are spared.
- short-term memory is intact.
- following short-term memory, memory declines very rapidly.
- memory deficit is global.
- graded retrograde amnesia results.

However, in patient studies, the lesions/ablations may extend beyond the boundaries of a given structure/landmark. Thus, studies using animal models were done in order to provide further evidence of the role of the hippocampus in declarative memory.

Several studies on monkeys revolved around delayed non-matching to sample (DNMS) tasks, where the monkey is presented with a sample stimulus. After a short delay, the sample stimulus is shown again along with a novel alternative, and the animal is rewarded for selecting the novel stimulus.

In general, monkeys with lesions were able to perform the task at short intervals, but not when the delay is long. This indicates that other psychological aspects such as perception, attention, and motor control cannot be problematic. Other studies have also found evidence of graded retrograde amnesia in monkeys.

3.1 *Relational Processing*

According to Cohen (1984), declarative memory:

- allows for a comparison and/or contrasting of distinct memories.
- enables the inferential use of memories in novel situations (i.e., comparing with procedural/habitual memories).

Additionally, Eichenbaum & Cohen also suggested that the hippocampal formation supports this relational representation. In their view, memory space

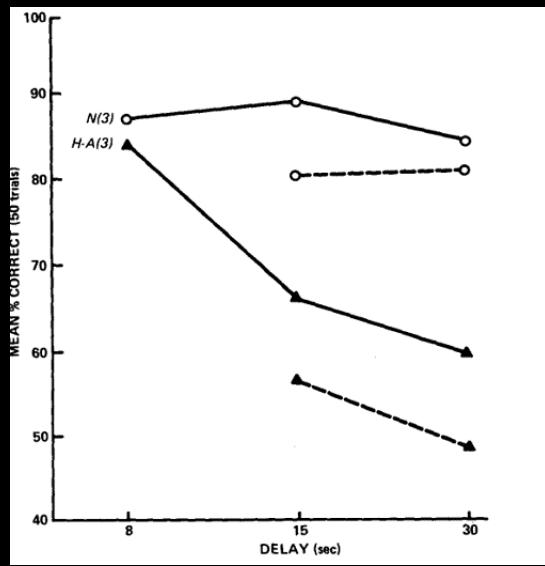


Figure 7: Results of the DNMS tasks. H – A indicates the performance of monkeys which had their hippocampus and amygdala removed, whereas N indicates the performance of the normal controls.

is essentially constructed by interleaving episodic memories into a semantic structure, thus enabling us to make sense of different episodes.

Based on these functions of declarative memory, we can operationalize and study declarative memory in animals by training animals on multiple distinct experiences, and observing whether these different experiences can be linked by memory to solve new problems.

- One such study is the Morris water maze (Morris et al., 1981), where rats are placed in a large pool of opaque water and are tasked to find a submerged platform.
 - After being trained to find the platform using spatial navigation strategies, they are placed in different (novel) start positions, where they have to navigate to the platform.
 - Normal rats are able to learn these strategies easily (by observing the relative positions of surrounding objects and/or synthesizing what they learn from one trial to the next), but rats with hippocampal lesions do not.
 - However, if the start point is always constant, the performance of rats with hippocampal lesions are relatively similar to that of normal rats.
 - This shows that hippocampal damage affects the ability to flexibly use memories to solve novel problems.
- Another study using odor paired associates further illustrated that rats with intact hippocampi show transitivity, but rats with lesions do not.

These evidence all point towards the idea that the hippocampus supports relational processing, and relational processing may support conscious declarative memory in humans.

3.2 *Hippocampal Cells*

O'Keefe & Dostrovsky (1971) found that hippocampal cells *fire selectively* to specific locations in the environment. Further research found that in fact,

- there are cells that code for specific episodes (i.e., fire differently to different trials, even when the location is same).
- there are cells that code for common details/elements between episodes.

3.3 *Chun, M. M., & Phelps, E. A. (1999)*

Theoretical background:

- When animal hippocampi are lesioned, they lose the ability of **relational processing** and **contextual learning**. In other words, they lose:
 - the contextual details linked to a particular piece of information (e.g., where, when, what), and
 - the relationships linked to a particular item (e.g., Y is a parent of X, Z is also a parent of X \implies Y is a spouse of Z).
 - When organisms are unable to perform relational processing, they are said to be doing **hyperspecific learning** (i.e., learning about an object without any regard of the surrounding context \rightarrow unable to generalize to similar contexts subsequently).
1. What is the point of the experiment?
 - To show whether (implicit) relational processing is present in amnesics.
 2. What did the experiment do?
 - A visual search task requiring participants to discriminate a 'T' from a set of randomly placed and rotated 'L's.
 - Some scenes were shown repeatedly; if participants had intact relational processing, their response time on that scene would be shorter relative to novel scenes.
 3. What are the results?
 - Contextual learning: there was evidence of contextual learning in the controls (i.e., faster response time on repeated scenes), but not in the amnesics.

- Procedural learning: there was evidence of procedural learning in both groups (i.e., performance increased over time across all scenes).
- A recognition task provided at the end further showed that the results of the experiment was purely due to implicit contextual learning, and not due to explicit memory.
 - Control subjects performed at chance in discriminating old displays (i.e., displays which were shown in the experiment) and novel displays.

4. What do the results show?

- Relational processing is also absent in amnesics.

5. What does this tell us?

- (Biological) The hippocampus is involved in relational processing in humans.
- (Cognitive) Declarative memory depends on relational processing.
 - No relational processing → no declarative memory.
 - All memories are relative (and linked) to each other.

NTS: conditioning = establishment of a link between memories?

4 KNOWLEDGE IN THE BRAIN

Lecture 4
8th February 2022

What we know and can actively recall must be stored somewhere in the brain.

- Based on studies of amnesic patients (e.g., H.M.), we know that the hippocampal formation is unlikely to be the only site of memory storage, since some memory of the past is still preserved.
- Experiments by Mummery et al. (2000), on the other hand, suggest that the cortex appears to be involved in the storage of memories.

Further experiments also suggested the hierarchical and distributed processing capabilities of the cortex.

- **Hierarchical processing:** the earlier a brain region is in the processing stream, the more basic the information that is processed by the region.
 - For example, the latter regions of the visual cortex process more complex features (e.g., motion, faces/objects), whereas the earlier regions process simpler features (e.g., color).

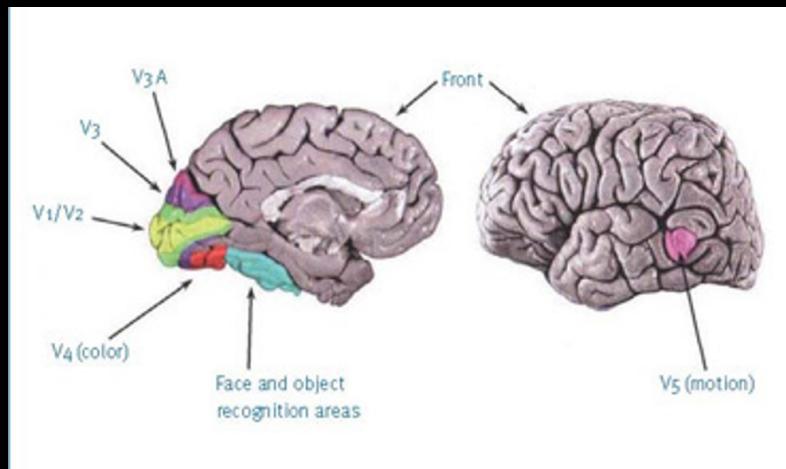


Figure 8: Illustration of hierarchical and distributed processing in the visual regions.

- **Distributed processing:** different things are processed in different parts of the brain.
 - In fact, areas of the cortex which are close to each other may be involved in fundamentally different things, which suggests that the processing of different stimuli occur in highly specific regions of the brain.
 - For example, neurons in the **middle temporal visual area (MT/V5)** is strongly activated when observing movement, and have a preference for directional movement.

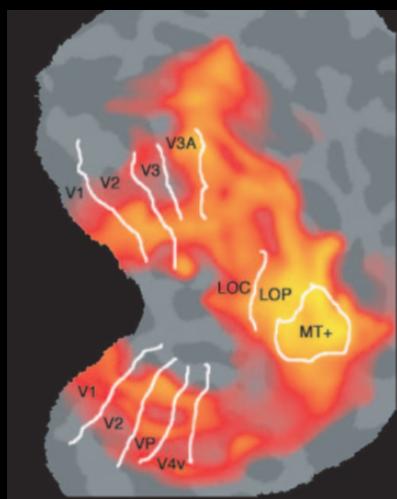


Figure 9: Activation of different brain regions when we see something that moves.

Cells in the MT also seem to have a preferred velocity.

- Other research has provided further evidence that distinct parts of

the ventral temporal cortex respond differently to different information categories.

- * Kanwisher et al. (1997) illustrated that there is a spot in the **fusiform cortex**, known as the **fusiform face area (FFA)**, which responds very strongly to faces. When stimulated, people would be able to “see” facial features.
- * Epstein & Kanwisher (1998) also showed the presence of a spot in the **parahippocampal cortex**, known as the **parahippocampal place area (PPA)**, which responds strongly to scenes but not to faces or objects.
- * In general, the **fusiform gyrus** (which contains both the FFA and the PPA) seems to be involved in processing complicated features.
- * In monkeys, neurons in the inferior temporal cortex seem to respond preferentially to facial stimuli.
- The recognition of tools and living organisms are also shown to be processed in different part of the brain.

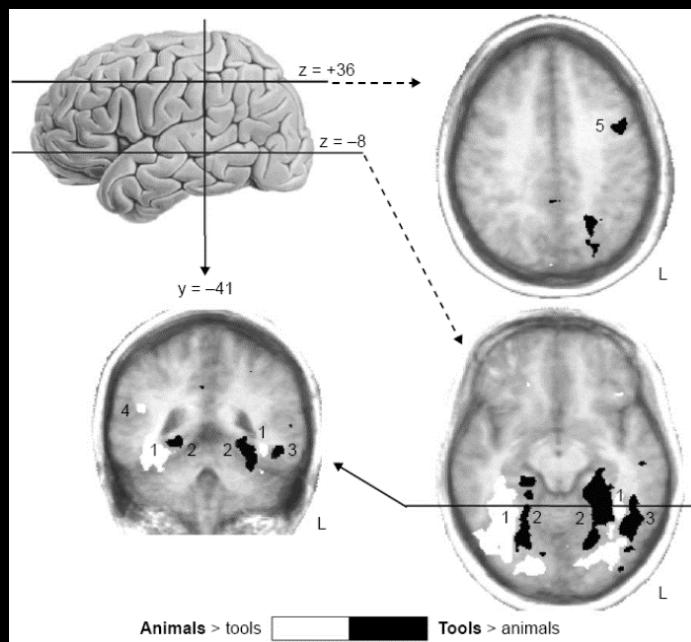


Figure 10: Diagram illustrating regions of the brain which are more strongly activated when tool/animal recognition takes place.

- * Damage to these areas leave victims with very specific semantic deficits.
- * For example, damage to the occipital/ventral temporal cortex results in deficits of animal recognition, but tool recognition is left intact.
- * (Speculative) This distinction between the two categories could be due to the need to process *fine visual details* when discrimi-

nating between living things (notice that the areas associated with knowledge of living things are nearer to the V1). On the other hand, the location of the memory of tools could be a result of tool-related memories being related to how we can or should use them (e.g., the premotor cortex is more strongly activated when tools are named).

However, the representation of an object is not completely discrete. In other words, not all the attributes of the object are held together.

- For example, people with face agnosia (i.e., prosopagnosia) are unable to recognize people via their faces, but could identify them via their sound or gait (i.e., manner of walking).
- Also, when some individuals are shown some common items, they may not be able to name the items (i.e., verbal identity is lost), but they are still able to withhold memories of the object form.

This suggests that:

- the way something is represented in the brain is widely distributed, and
- an entity generates a multiplicity of representations both within and across modalities.
 - thus, compromised representations in one modality do not affect the efficacy of other representations of the same entity.

The content of a memory can be stored distributedly because different parts of the cortex have different cells, which are able to store different types of information. This protects our brain from catastrophic shutdown (i.e., not all memories are lost when parts of the brain are damaged).

4.1 *Visual Processing Pathways*

It has been suggested that there are two streams/pathways in visual processing:

- the **dorsal (where) pathway**, and
- the **ventral (what) pathway**.

This has been shown by studies (e.g., by Pohl (1973)) which illustrated that when the temporal lobe of monkeys is ablated, they have a problem doing object discrimination; when the parietal lobe is ablated instead, monkeys have problems with tasks requiring spatial information.

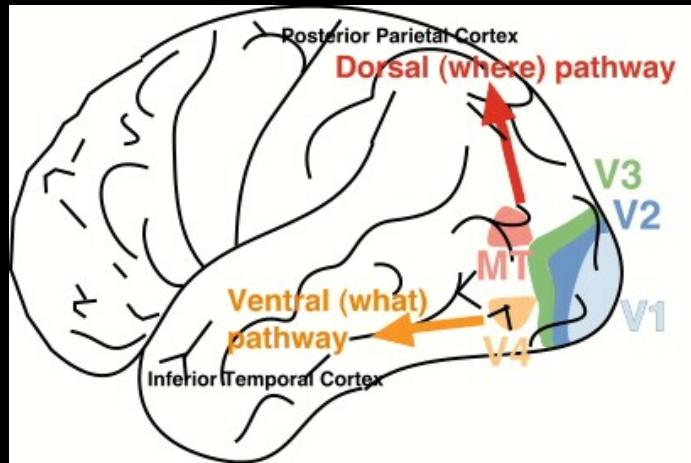


Figure 11: Pathways in visual processing.

4.2 Chao, L. L., et al. (1999)

Theoretical background:

- Before brain imaging technology was prevalent, our only clue as to how semantic knowledge is organized in the brain was the existence of highly specific disorders, e.g., *prosopagnosia* ad *ideational aphraxia* (i.e., loss of knowledge of tools).
- Usually, these disorders result in a loss of memory about either living or non-living things.

1. What is the point of the experiment?

- To further our knowledge/understanding of how semantic knowledge of different object categories are stored differentially (i.e., in different areas) within the cortex.
- Specifically, where and how is semantic knowledge of animals vs tools stored?

2. What did the experiment do?

- Participants' brains were scanned while carrying out 4 different tasks:
 - Viewing
 - Matching
 - Naming
 - Reading

This is because if only one task was done, it would be difficult to distinguish which of the activated areas are responsible for semantic knowledge, and which areas are responsible for the operation of the task.

- If certain brain areas show the same activation across multiple tasks, this would mean that it is highly likely that these brain areas are responsible for the one common element across all tasks (i.e., semantic knowledge).
- Researchers were interested to find out whether the pattern of activation would be different for viewing a picture, versus just the written name.
 - As a stimulus, a written word is very different from the picture of an object.
 - However, the semantic knowledge of the object is the same in both cases.

3. What are the results?

- General pattern: consistent differentiated patterns of activation for animals versus tools across all 4 tasks (i.e., it didn't matter whether stimuli were pictures or words).
- More specifically, in the:
 - **occipital lobe:**
 - * in both the **medial occipital region** and **inferior occipital gyrus**, animals produced more activation than tools.
 - **ventral temporal lobe/fusiform gyrus (FG):** responsible for processing 'object form'.
 - * **lateral FG:** animals > tools
 - * **medial FG:** tools > animals
 - **lateral temporal lobe:** responsible for processing 'object motion'.
 - * **superior temporal sulcus:** animals > tools (past research have suggested that this area is responsible for biological motion).
 - * **middle temporal gyrus:** tools > animals (past research have suggested that this area is responsible for non-biological motion).
- Differences were also found within living versus non-living objects:
 - animals and faces had similar areas of activation, but with some differences.
 - this was the same case for tools versus houses.
- The peak activation areas during the reading task are:
 - for animals: the **fusiform gyrus** (which is associated with 'object form').
 - for tools: the **middle temporal gyrus** (which is associated with 'non-biological motion').

4. What do the results show?

- Semantic knowledge for animals and tools is organized in different areas of the cortex.

- The fact that names (in the reading task) produce the same activation proves that these areas are responsible for **stored information about specific objects**, and not just **processing physical features** of the stimuli.
- Preferential activation for animals in the occipital lobe, the earlier part of the visual system, suggests that **visual details** may be more important for processing and identifying animals versus tools.
 - Tools only start to see preferential activation further forward in the brain/visual system (i.e., the temporal cortex).
 - Animals may be distinguished more by **form/visual detail**, while tools may be distinguished more by **associated motor movements**.

5. What does this tell us?

- (Biological) Different brain areas govern different categories of semantic knowledge.
 - This mirrors our sensory and motor systems in the brain.
 - e.g., the parts of the brain that are responsible for processing animal knowledge have a lot to do with the processing of visual information and object form, whereas the parts that are responsible for processing tools seem to have more to do with non-biological motion and motor movements.
- (Cognitive) This adds to the evidence that our semantic knowledge is organized into different separate categories.
 - The way that they are organized is strongly linked to the sensory modalities that these categories involve.

6. How is this knowledge useful?

- If we have a complete understanding of which parts of the brain is responsible for every kind of semantic knowledge, we can make predictions about what type of knowledge patients with brain lesions are going to use, and what kind of disorders would they develop.
- (FFT) If an individual loses information about animals, would it still be possible to teach this person about animals, by making them think of animals as tools?

5 SHORT TERM AND WORKING MEMORY

Lecture 5
15th February 2022

Previously, in delayed non-matching to sample tasks (refer to figure 7), we have seen that monkeys with hippocampal and amygdala lesions are still able to perform the task well with short delays. However, as the length of the delays increased, their performance dropped more significantly as compared

to the controls. This has illustrated that short-term memory is clearly distinct from long-term memory.

Modern views of short-term memories include:

- *Atkinson-Schiffрин memory model* (i.e., the classic view), which treats short-term memory simply as a short-term store (and equivalent to working memory).
- *Baddeley's model of working memory*, which treats short-term memories as something that can be operated upon by various cognitive processes.
- Computer models, which treat short-term memory as part of the long-term memory that is currently activated.

There has been evidence supporting all the above views (in fact, they are not entirely incompatible).

An example of an experimental setup that was used to study STM is the N-back task by Druzgal & D'Esposito (2001), where participants are shown a series of stimuli/frames, and had to press a button if the current stimulus is the same as a stimulus that was presented N frames ago.

- This task forces the updating of content in the STM, since there is a constant inflow of new information.
- Additionally, the bigger the value of N, the more information that is needed to be held in the STM.
- In their setup specifically, each frame contained a face (instead of characters or numbers). Note that:
 - the fusiform face area (FFA) is known to be the location in charge of processing facial information.
 - the fusiform object area (FOA) is known to process object information.

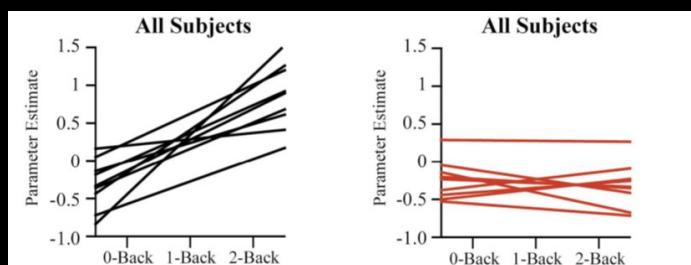


Figure 12: Activity in the FFA and FOA in the N-back tasks (Druzgal & D'Esposito, 2001).

Their results illustrated that activity in the FFA increases with (face) memory load, whereas activity in the FOA remained relatively constant over increasing

values of N. This shows that:

- brain regions are very specific in terms of information processing,
- the STM functions as a short-term store, and
- parts of the brain that are in charge of processing a stimuli are usually also in charge of storing memories related to the stimuli.

Further studies by Todd & Marois (2004) also showed that when the frames contained items instead of faces, as the number of items on a frame increases, the more activation there is in the FOA (since more information would have to be held in the STM).

There have also been studies investigating working memory as a part of the LTM that is currently activated. One such study was done by Wheeler et al. (2000), where subjects were presented either pictures or sounds, each of which was paired with a printed word, during a study phase. Subsequently, during the test phase (after approx. 2 days), the subjects were presented with a word and asked to recall if it was paired with a picture or a sound.

- When pictures were remembered, the visual cortex of participants were activated.
- On the other hand, when sounds were remembered, the auditory cortex of participants were activated.

This illustrates that whatever information that is stored in the LTM gets reactivated when there is a need to retrieve that particular piece of information for use. Even though the level of activation is lower (as compared to when processing information of the same modality), the regions activated are the same.

These results were supported by studies by O'Craven & Kanwisher (2000) and Ishai et al. (2002), which showed that there were different levels of activation in the FFA and PPA in perception and imagery tasks.

5.1 *Biological Location of the Central Executive*

Recall from Baddeley's model that the central executive coordinates the various components of STM. How do we identify the neural substrate of the executive that controls these operations?

One possibility is to look for areas that have activation profiles that scale with the amount of processing effort/load. This method has so far led to consistent results, especially with fMRI.

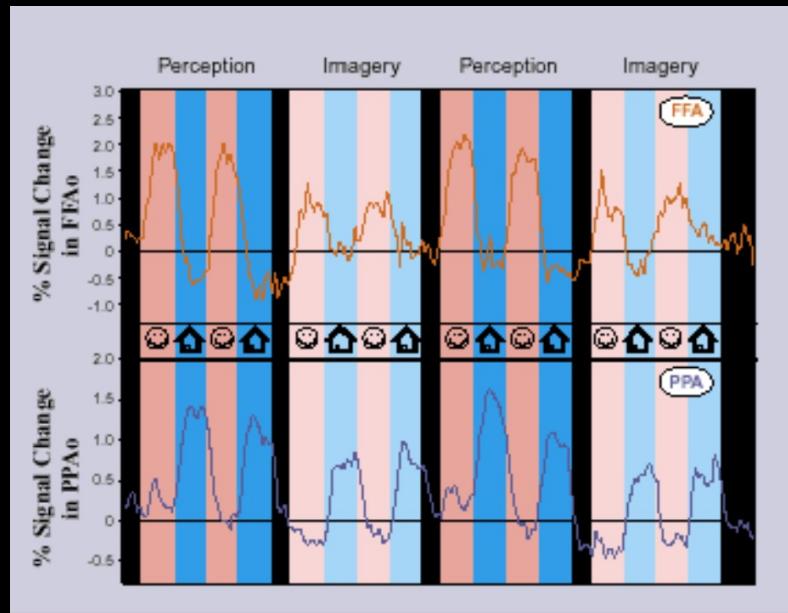


Figure 13: Activity in the FFA and PPA in perception and imagery tasks of faces and houses (O’Craven & Kanwisher, 2000).

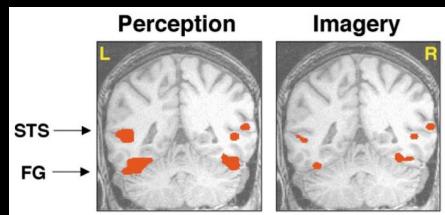


Figure 14: Activity in the superior temporal sulcus (STS) and fusiform gyrus (FG) in perception and imagery of famous faces (Ishai et al., 2002).

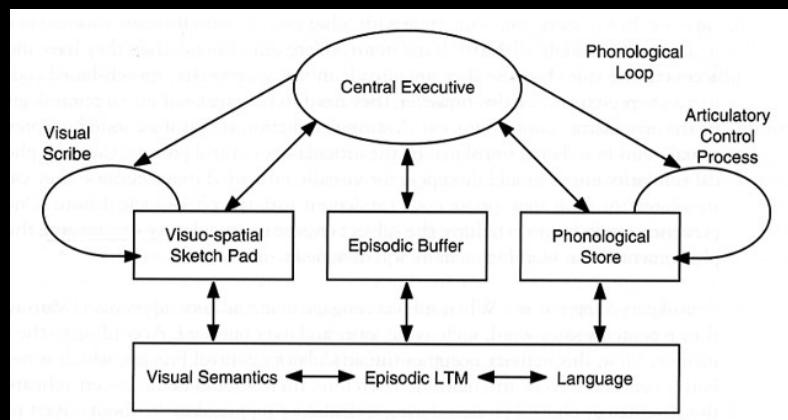


Figure 15: Baddeley’s model of working memory.

- Results from Cohen et al. (1997) suggest that the front of the brain (i.e., frontal lobe) seems to play the role of the central executive, since its activity increases when N (in the N-back tasks) increases.

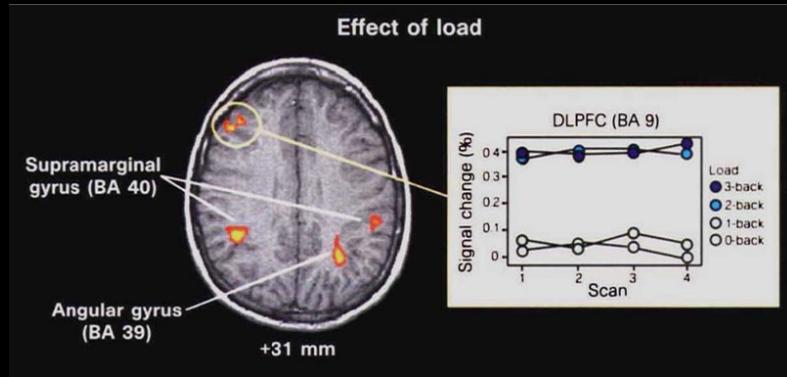


Figure 16: Brain activation during N-back tasks (Cohen et al., 1997).

- Furthermore, in tasks which require planning (e.g., Tower of Hanoi), the right **dorsolateral prefrontal cortex (DLPFC)** and the **parietal lobe** seem to show more activation as plans become more complicated/the task becomes harder.

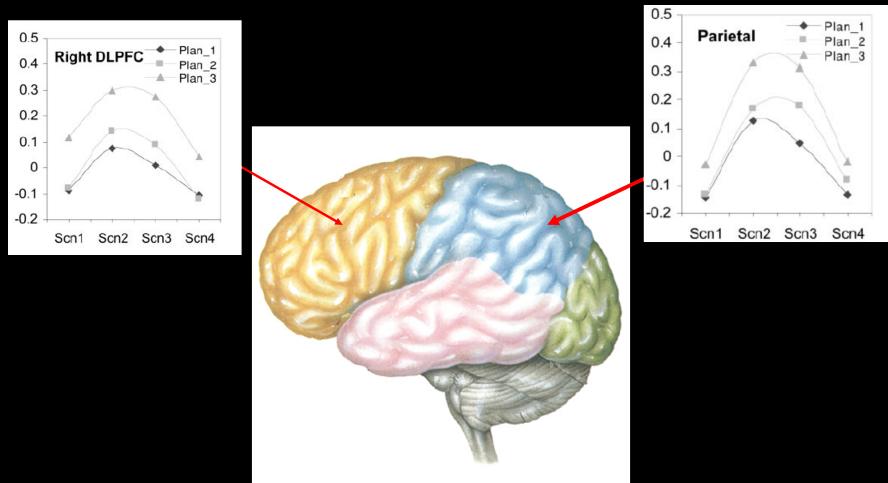


Figure 17: Brain activation during planning tasks (Fincham et al., 2002).

This is consistent with the observation that when the frontal lobe (and the parietal lobe) is impaired, one's executive functioning becomes affected.

- Additionally, Petrides (2000) has also showed in delayed non-matching to sample tasks using a variable-size stimulus set, that:
 - when the delay increased, the performance of monkeys with lesions in the **anterior inferotemporal (AIT) region** suffered more, as compared to controls.

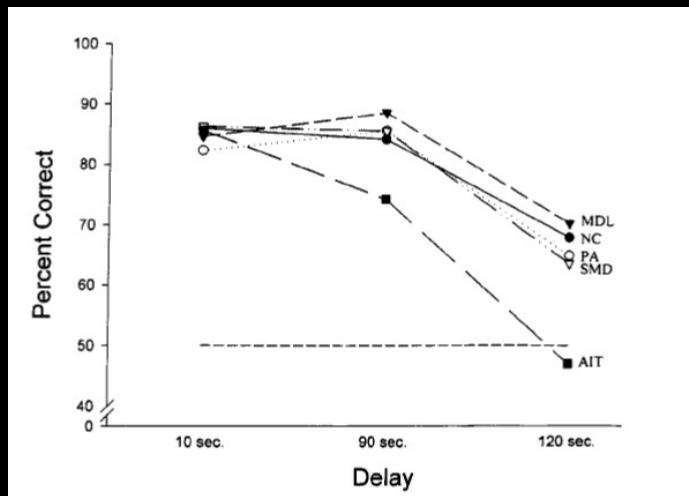


Figure 18: Performance on the DNMS as delay increases.

- when the size of the stimulus set increased, monkeys with **mid-dorsolateral (MDL)** and **dorsolateral prefrontal cortex (DLPFC)** lesions performed worse compared to controls (more stimuli → more comparisons to be made between training and test sets).
 - * This shows that the frontal areas are likely to be involved in executive processes.

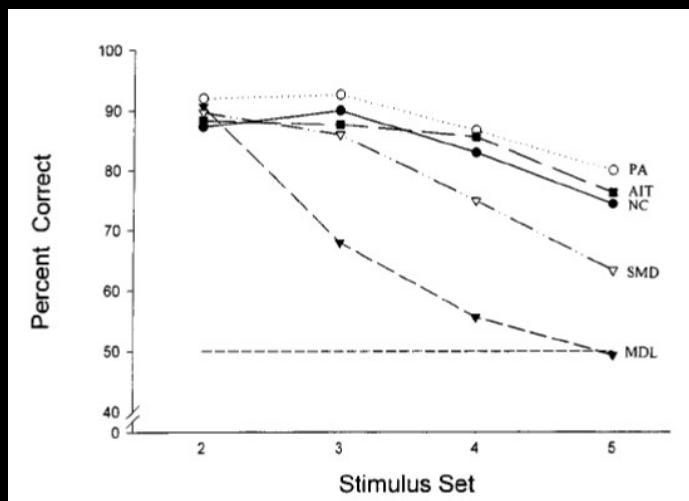


Figure 19: Performance on the DNMS as set size increases.

This shows that our ability to operate in an adaptive way is probably the outcome of the interaction of multiple areas (i.e., whole networks) in the brain, rather than due to localized actions within the brain.

5.2 Bor, D., et al. (2003)

Theoretical background:

- In general, working memory (WM) can be viewed as having two main roles: **storage** and **operation**.
- Here, we will assume that STM is equivalent to WM, and that STM consists of the part of memory that is currently activated.
- However, note that this does not imply that the STM is entirely part of the LTM; otherwise, we would not be able to learn new memories.

1. What is the point of the experiment?

- Past studies have provided evidence that the **dorsolateral pre-frontal cortex (DLPFC)** plays a role in WM operation (specifically, the organization of information in WM).
- However, these results were not conclusive because there is a confounding effect of *task difficulty* (which LPFC is also associated with).
- Therefore, the researchers required a task which becomes easier with more organization: i.e., chunking.
- By observing the effects of chunking on LPFC activity, the researchers wanted to show that:
 - (a) WM operation is associated with increased LPFC activity.
 - (b) LPFC plays a key role in WM operation.

2. What did the experiment do?

- fMRI was used to infer participants' brain activity while they memorized 2 types of spatial sequences: structured (e.g., regular shapes → conducive for chunking) and unstructured (e.g., shapeless forms).

3. What are the results?

- Participants in the structured condition had better **memory performance** and **reaction time**, which implies that they were able to apply chunking to make the sequences easier to remember.
- There was higher brain activity during encoding, and lower activity during maintenance during the structured condition.

4. What do the results show?

- The pattern of brain activation is indicative of the chunking process:
 - In the structured condition, more effort is put into *encoding* so that less effort is required to *Maintain* the information. Hence, the sequences were easier to remember, resulting in better task performance.

	ENCODING	DELAY (MAINTENANCE)	RESPONSE	TASK PERFORMANCE
STRUCTURED	More activity ↑	Less activity ↓		Better performance ↑
	LPFC* Inferior parietal* Fusiform gyrus	Parietal* Premotor*	N/A	
UNSTRUCTURED	Less activity ↓	More activity ↑		Worse performance ↓

*areas associated w/
 WM operation *areas associated w/
 WM storage

Figure 20: Pattern of brain activation observed across the encoding/training and test phases.

- In the unstructured condition, the brain couldn't encode much, so more effort was required to maintain the information.
- LPFC activity (which was higher during the encoding stage for structured sequences) is associated with WM operation (specifically, organization of material in the WM).
 - This idea was also supported by the control condition: when participants were asked to view structured sequences without using WM, significantly less LPFC activity was observed.

5. What does this tell us?

- (Biological)
 - The LPFC seems to play a key role in WM operation.
 - WM doesn't rely on only one brain area, but it is a function that arises from the interaction of many different brain areas.
 - * This is true in general for most behaviour and cognitive functions in humans.
- (Cognitive)
 - WM/STM is not just a short-term storage space for information; it also encompasses **cognitive operations** which can be applied to information for adaptive purposes (e.g., information organization, distractor suppression, etc.).
 - Putting more effort into the encoding of information can reduce maintenance demands, making things easier to remember.

6. How is this knowledge useful?

- When students apply better encoding strategies/spend more effort encoding information, less effort is required to maintain the same information, and better results ensue.

6 EXECUTIVE CONTROL

Lecture 6
8th March 2022

Executive functioning includes mental activity associated with the planning, initiation, and regulation of behaviour. Based on the generality of executive functioning, it is likely that it is associated with an area in the brain that performs very general functions (i.e., an area that is activated for almost every task).

To investigate which brain area(s) could be in charge of executive functioning, Duncan (2001, 2010) performed a meta-analysis on the parts of the brain that were activated when different tasks are carried out.

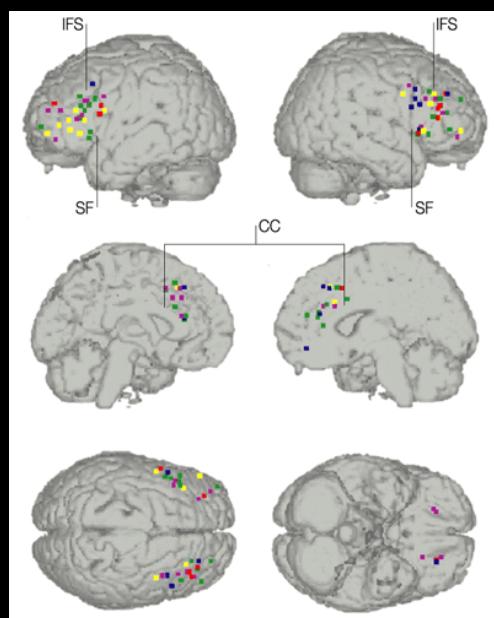


Figure 21: Brain activity as seen from a harder-easier (i.e., harder minus easier) contrast.

In figure 21,

- **red** dots indicate areas with differences in activity as *working memory delay* increases.
- **green** dots indicate activity differences w.r.t. response conflict (e.g., Stroop task).
- **blue** dots indicate activity differences w.r.t. perceptual difficulty.
- **yellow** dots indicate activity differences w.r.t. working memory load (i.e., the number of items that people have to hold on to).
- **pink** dots indicate activity differences w.r.t. task novelty.

We can observe that in general, the dots do not cluster together according

to colour; they seem to be fairly equally spread apart/jumbled up along the following areas:

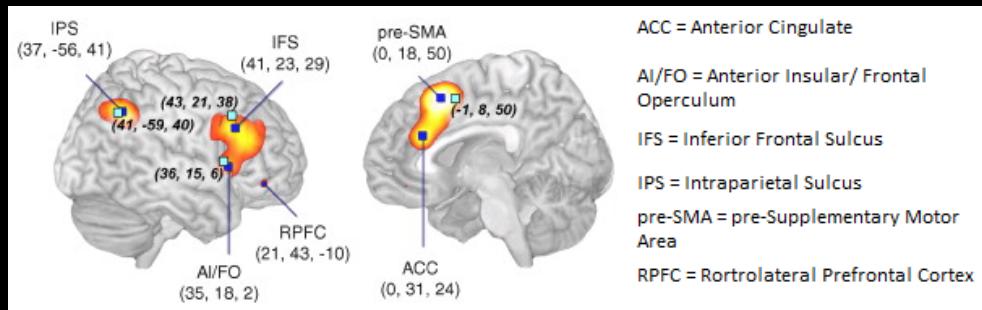


Figure 22: Brain areas which might be involved in executive functioning.

A plausible reason for the PFC being the neural substrate for the central executive could be due to it being **well connected**, either directly or disynaptically/indirectly with the rest of the brain. For instance, Selemon & Goldman-Rakic (1988) have shown that it is connected to areas of the brain providing:

- sensory inputs,
- motor outputs, and
- emotion areas.

Therefore, it has the ability to influence any of these aspects of our mental life. Further research by Gilbert & Li (2013) also yielded a map of synaptic connections across the human brain.

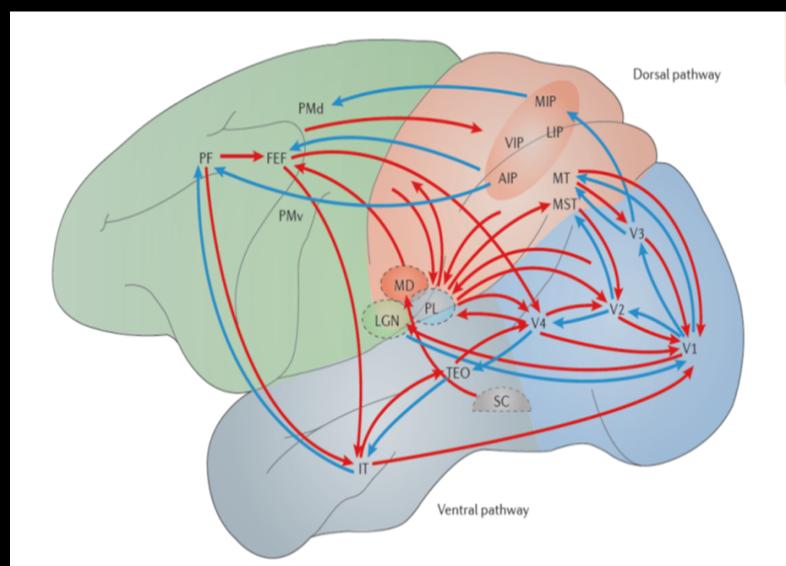


Figure 23: Synaptic connections across the brain.

Moore & Armstrong (2003) further illustrated that the PFC is in fact able to control and stimulate other sites of the brain.

- In their study, electrodes were implanted in the PFC and V4 of monkeys.
 - The electrode implanted in the PFC was a stimulating electrode, which fires electrical pulses to the frontal eye fields (FEF).
 - The electrode implanted in the V4 was a recording electrode.
- Subsequently, the monkey was presented with some visual object.
 - When the FEF was stimulated, activity in the V4 was detected to be higher than when no stimulation was performed.
 - This suggests that stimulating the effects of stimulating the PFC could be felt in other parts of the brain, even in distant sites.

6.1 Rule Encoding

Another study by Asaad et al. (2000) using single cell/electrophysiological recordings at the DLPFC of monkeys provided evidence for rule encoding in the brain.

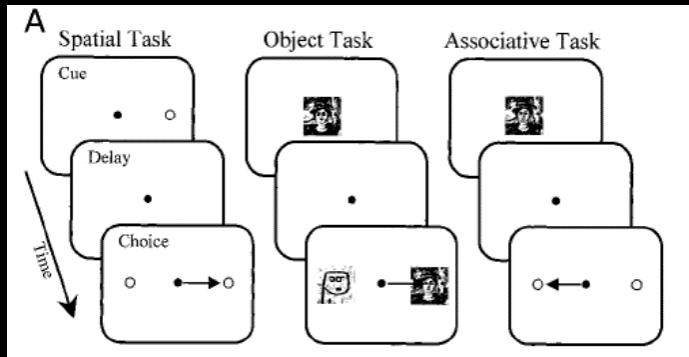


Figure 24: Asaad et al., 2000.

- In the experiment, monkeys were shown 3 frames (i.e., cue → delay → choice), and it had to keep their eyes fixated on the center dot during the delay frame.
- There were three conditions:
 - In the *spatial task*, the monkey had to make an eye movement/saccade to the position that was cued in the cue frame.
 - In the *object task*, the monkey had to make a saccade to the picture that was shown during the cue frame.
 - In the *associative task*, the monkey had to make a saccade to the location associated with the picture (this association was made known to the monkey).

- Since the associative task share the same stimuli with the object task, and the same response features with the spatial task, we could expect that some cells (which respond to a particular stimulus, e.g., faces) would respond regardless of the task.
 - However, it was found that neurons which showed stimulus-selectivity in the DLPFC interacted with task context; i.e., w.r.t. the same object, they showed greater response for a particular task over another.
 - This suggests that these cells encode something much more abstract: specifically, the interaction/relationship between the task and the object/stimuli.
 - Therefore, this tells us that the **task context/rules** are encoded in the **prefrontal cortex (PFC)**.

Yet another study investigating the role of the DLPFC was done by Freedman et al. (2001), where electrodes were implanted in the DLPFC of monkeys as well.

1. In this experiment, monkeys were first trained to distinguish between two categories: cats and dogs.
 - The researchers wanted to know whether the cells in the PFC can make a fine-grained distinction between cats and dogs.
2. Subsequently, 3D images comprising of a mixture of cat-dog features were shown to the monkeys.
 - Some cells were noted to be selective w.r.t. dogs (i.e., showing higher activation when images of dogs were shown).

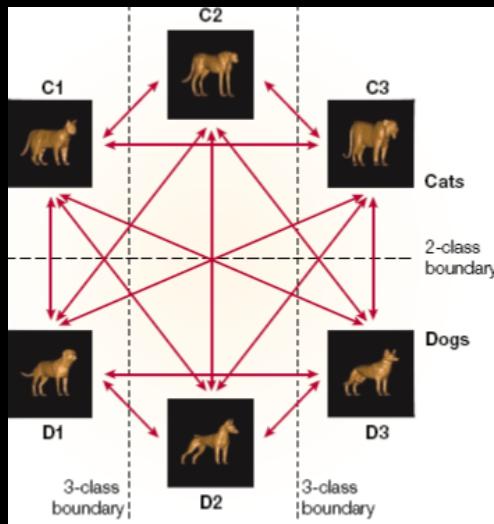


Figure 25: Pairs of animals used for the classification task in Freedman et al., 2001.

3. Afterwards, the monkeys were retrained to recognize pairs instead of the distinction between cats and dogs.

- After the training, it was seen that the cells now responded selectively to one pair or another, instead of selectively to dogs versus cats.
- This illustrated that the cells in the DLPFC changes what they do (i.e., their activity) based on what they were trained to do (e.g., rules of the task).
 - This is unlike cells in the visual areas, which always respond selectively to a certain stimulus (e.g., lines).
 - In other words, they are not stimulus-specific; rather, the rules of a task link a stimulus to a response by the cell.

Wallis et al. (2001) also attempted a study using a matching/non-matching rule. Specifically, after participants were shown a cue (i.e., an image), they had to choose either a matching image or a non-matching image after a delay (of around 1.5 seconds). Single cell recordings indicated that there was a difference in activity between the matching rule and the non-matching rule to the same object. This implies that the cells in the PFC do not only play the role of encoding task rules, they were able to use these rules as well.

6.2 Storage of Rules

Experiments employing the *Wisconsin Card Sorting Test* also helped to explain whether the PFC could store the rules for tasks over a period of time.

In the task, participants were tasked to sort a deck of cards based on some unknown sorting rule (e.g., by shape, number, or colour) which changes periodically, with an examiner informing whether the cards are being sorted correctly. On these tasks, patients with PFC damage tend to *perseverate* (i.e., they do not switch the underlying rule immediately) when told that the rule which they are employing is wrong.

6.3 Selectivity

One area of interest in executive functioning is the idea of **selectivity**, i.e., one's ability to monitor and control mental activity in order to behave in an adaptive manner. Thompson-Schill (1997) showed that the prefrontal cortex was also involved in selection; specifically, the PFC was more strongly activated when there were higher selection demands.

Rock & Gutman (1981) also illustrated in their experiment using overlapping items that items which were attended to are better retained in memory, as

compared to items which were not attended to.

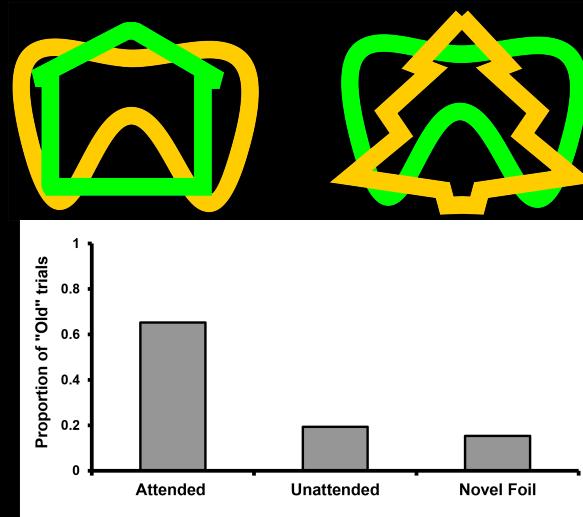


Figure 26: Rock & Gutman, 1981.

6.4 De Fockert, J. W., et al. (2001)

1. What is the point of the experiment?

- By definition, WM should have some effect on other domains (e.g., attention), because WM operation involves controlling how all the information in our mind is processed.
- The study attempts to investigate whether WM truly plays a role in visual selective attention.

2. What did the experiment do?

- The experimenters employed a multitasking paradigm, involving:
 - (Digit-span) working memory task: with low load (i.e., easy-to-remember sequences) and high load (e.g., numbers with random ordering) conditions.
 - Selective attention task: e.g., Stroop task.

3. What are the results?

- There was more distraction on the selective attention task when the working memory task required higher WM load.
- This could be inferred because:
 - reaction time was worse in the high load condition, especially when the face was incongruent to the name.
 - brain scans showed that there was higher brain activity (in the **fusiform gyrus** and **visual cortex**) for the distractor faces in the high load condition.

4. What do the results show?

- Working memory does play a role in visual selective attention.
- Specifically, high load → less available WM resources → less control over attention → reduced performance on the other task.

5. What does this tell us?

- (Biological) The frontal cortex is involved in central executive functioning (i.e., working memory operations).
- (Cognitive) Working memory (i.e., the central executive) is necessary to control how we direct attention to **task-relevant** information and stimuli.
 - This attentional control is what allows us to effectively complete different tasks.

6. How is this knowledge useful?

- Multitasking generally results in a deterioration of performance.
- Other things which affect WM capacity include rumination and sleep deprivation.

7 MEMORY CONSOLIDATION

Lecture 7
15th March 2022

From the Atkinson-Schiffrin model (1958) of memory, we know that there is supposed to be an intervening process between STM and LTM (i.e., **consolidation**). Based on studies into amnesics (e.g., H.M.), it seems to suggest that:

- the medial temporal lobe (which was impaired in H.M.) may be involved in memory consolidation.
- older memories may no longer require the intervention of the MTL/hippocampus.
 - This can be inferred from the case of H.M. (and other amnesics), who has graded retrograde amnesia (instead of total memory loss) despite having MTL lesions.

Later research by Rempel-Clower et al. (1996) found that **retrograde amnesia severity** was related to the **extensiveness of MTL damage**, based on analyses of postmortem sections of the brain.

An experiment was also conducted by the same researchers on several amnesics, requiring them to recall memories from the past. In line with the postmortem analyses, it was found that the extent of damage to the hippocampus was strongly correlated with the extent of retrograde amnesia, with patients having more severe lesions recalling a greater proportion of memories from the earlier decades.

Table 3. Summary of neuropsychological and neuropathological findings from four patients with bilateral damage to the hippocampal formation

	Anterograde amnesia	Retrograde amnesia	Damage to the hippocampal formation
RB	Moderate	Minimal	CA1 field
GD	Moderate	Minimal (?)	CA1 field
LM	Moderate	Extensive	CA1, CA2, CA3 fields, dentate gyrus, entorhinal cortex
WH	Severe	Extensive	CA1, CA2, CA3 fields, dentate gyrus, subiculum, entorhinal cortex

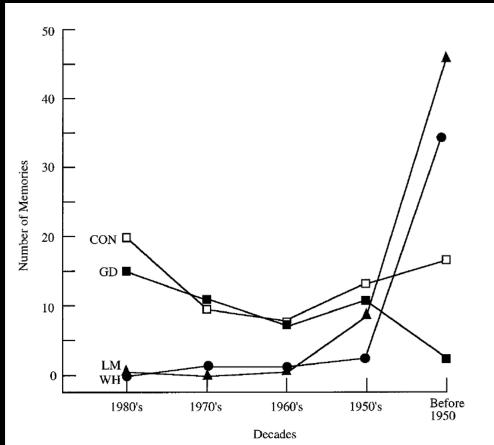


Figure 27: Graph showing the number of memories recalled for patients with different extents of hippocampal damage. The higher number of memories recalled by LM and WH (relative to the other amnesics) in the earlier decades could be due to the availability heuristic (i.e., they were more able to draw from memories which they are most familiar with).

Studies on other patients also demonstrated that graded retrograde amnesia is not restricted to a single domain. For example, amnesics also demonstrated graded retrograde amnesia for **spatial knowledge**, such as routes and layouts.

Similar results were seen on animal studies (e.g., on monkeys and rats), where it was shown that lesions made to the hippocampus (but not to the thalamus) resulted in graded retrograde amnesia. This illustrates that this pattern of memory consolidation is not peculiar to humans.

This evidence seems to suggest that over time, the hippocampus might become less involved with the memory; when this happens, the memory becomes **hippocampus-independent**. Therefore, only memories which still require the hippocampus are affected when the hippocampus is lesioned.

However, we still do not know how long does the process of memory consolidation take, nor do we know how long does it take for a memory to become completely independent of the hippocampus.

7.1 Relational Networks

McClelland formulated a distributed network/hierarchical model of memory, based on his ideas that the cortex identifies stimulus characteristics and sorts (incoming) information into these categories and subcategories.

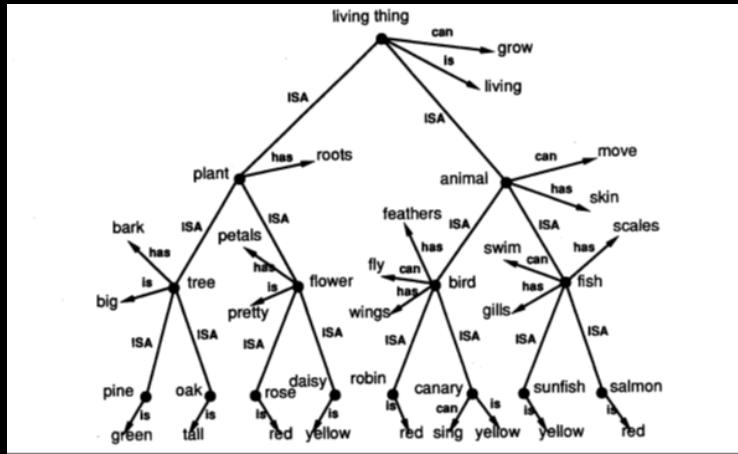


Figure 28: Example of a distributed network model for semantic organization in the brain.

Even though networks are able to learn things very easily, whenever a network absorbs new information, it tends to result in a cascading effect across the network. For example:

- Prior to learning about penguins, there may be an absence of links between the concepts “fish” and “birds”.
- However, after learning about penguins, which have the characteristics of both birds (i.e., wings) and fish (i.e., swimming), it would affect our organization of knowledge about other birds and fish.
 - As more is learnt about penguins, it becomes harder to make more accurate responses to other birds and fish.

This is particularly the case when the learning is intensive; in such cases, the system seems to try to learn one fact to the exclusion of everything else. This typically manifests as problems remembering older materials.

McClelland’s solution was to add a smaller network that would acquire new memories very quickly, and which would gradually feed new memories to the larger network (akin to the hippocampus). When learning is slow and progressive, prior knowledge is not affected too greatly, thus the error associated with the prior information held within the brain is maintained relatively stable.

Perhaps, the creation of long-term declarative memories is linked to relational processing. For example, perhaps one reason why the hippocampus seems to

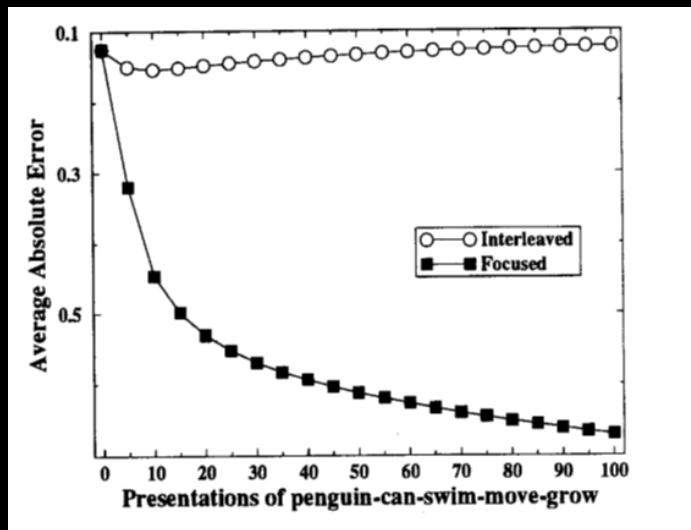


Figure 29: Graph depicting error associated with information on birds when different modes of learning penguins were applied.

be involved in the earliest stages of memory formation is because it may be able to create the relational links between episodes fastest. The connections between cells in these areas are greater than in the cortex, thus the relationships between things may be coded very quickly and efficiently, as compared to the time required for these connections to be represented in the cortex.

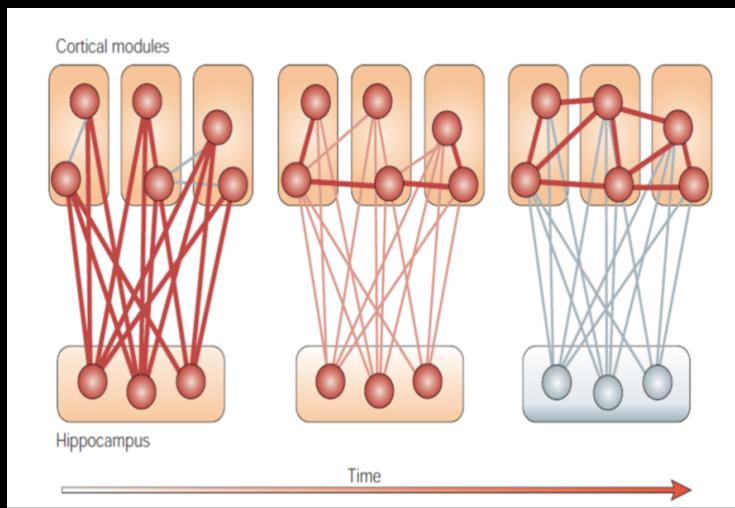


Figure 30: Illustration of memory consolidation. Initially, there are very sparse inter/cross-module connections. Over time, the memories are stored in the cortical modules (with stronger inter-module connections), but the connections between the modules and the hippocampus get pruned.

There are several biological processes which could support/speed up this process (e.g., sleep), but in general, the time taken for the process of consolidation is still unknown, and may be dependent on the nature of the memory.

7.2 Haist, F., et al. (2001)

Theoretical background:

- The ultimate goal of LTM is to establish direct links between representations within the cortex.
 - However, this cannot be immediately achieved, as changes in connectivity within the cortex are slow and gradual.
 - Therefore, the hippocampus acts as a mediator to achieve this consolidation, through a series of steps:
 1. First, it supports the link between the representations through itself.
 2. Over time, as a direct link forms within the cortex, the links between the hippocampus and the cortex gradually disappear.
 3. Eventually, a link is fully formed within the cortex, and the memory becomes **hippocampus-independent**.
 - Aside from consolidation theory, there is a competing theory known as **multiple memory trace theory (MMTT)**, which argues that:
 1. Similar to consolidation, the hippocampus initially supports the link between the representations through itself.
 2. However, when the direct links begin to form within the cortex, the links between the hippocampus and the cortex do not gradually vanish.
 3. Eventually, there would be two memory traces/links: one through the hippocampus, and one within the cortex.
 4. It is argued that they represent different types of memory: i.e., hippocampal damage will remove a memory's episodic trace, but not its semantic trace.
1. What is the point of the experiment?
- To determine the role of the hippocampus/MTL in LTM consolidation, and to explore which parts of the brain are involved in consolidation.
 - This is important to:
 - find evidence to support our current view of consolidation, and
 - to compare consolidation with other competing theories, e.g., **multiple memory trace theory (MMTT)**. Specifically, if:
 - * **consolidation theory** holds, then the hippocampus' role is **time-limited**, and recalling very old memories shouldn't trigger any hippocampal activation.

* MMTT holds, then the hippocampus' role is **time-invariant**, and recalling very old memories would still result in hippocampal activation.

2. What did the experiment do?

- Participants were asked to recognize famous faces from past decades.
- To control for media familiarity, they recruited participants who were media-savvy (i.e., confident that they could recognize famous people).

3. What are the results?

- There was a slight drop in activation within the hippocampus from the 90s to the 80s, but activity remained relatively stable afterwards.
 - This seems to imply that the hippocampus may only be involved in the first few years of a memory.
- Activation dropped much more significantly across the 90s to the 40s for the entorhinal cortex.
 - This implies that the entorhinal cortex may play a greater role in memory consolidation.

4. What do the results show?

- The hippocampus may only play a role in LTM consolidation in the first few years.
- This role is eventually passed on to the **entorhinal cortex** (which is located in the **parahippocampal gyrus**).
- The entorhinal cortex continues to support consolidation over a period of **decades** (at least for famous faces).
- The involvement of the entorhinal cortex could be necessary because:
 - The cortex has a large capacity, but is slow to form new connections. On the other hand, the hippocampus is fast to form new connections, but has limited capacity.
 - Therefore, the hippocampus may not be able to hold all the new connections that it forms while pending the establishment of direct links within the cortex.
 - Hence, the entorhinal cortex (with moderate capacity and connective flexibility) is suitable to help take over the hippocampus' role in consolidation, so that the hippocampus can focus on learning and encoding more connections/relationships.

5. What does this tell us?

- (Biological)
 - (a) The first short stage of consolidation involves the hippocampus.

- (b) The second, longer stage involves the parahippocampal gyrus, specifically the entorhinal cortex.
- (Cognitive) Long-term memory consolidation is a multi-stage process.

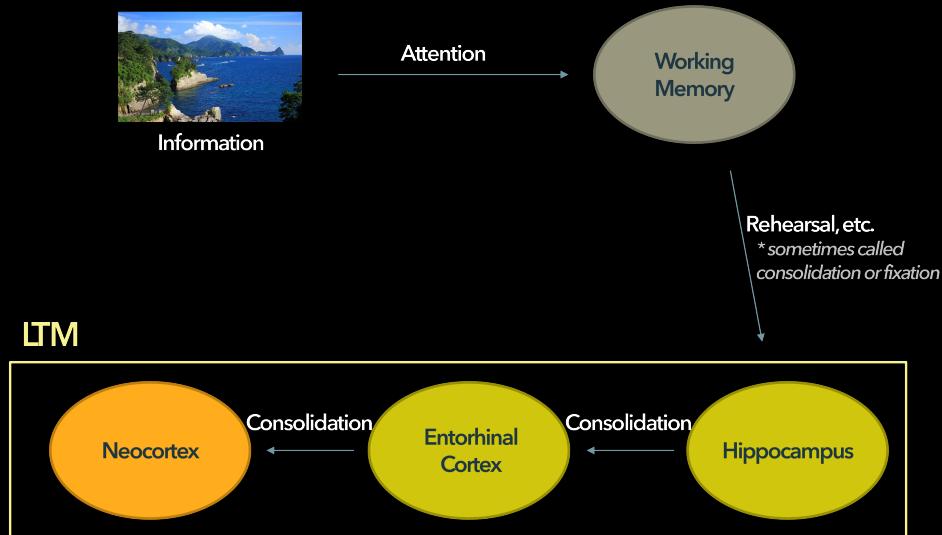


Figure 31: Life cycle of a memory (excluding sensory/intermediate memory).

8 NON-DECLARATIVE MEMORY

Lecture 8
22nd March 2022

Since H.M. was able to learn new procedural skills, this led to the idea that there could be multiple independent memory systems in the brain (specifically, MTL-independent memory systems). We know that procedural/sensorimotor memory is not declarative, since declarative memory is *flexible* (i.e., memory from one context could be generalized to/utilized in other situations), but procedural skills are generally not flexible.

Numerous studies have shown that priming and sensorimotor skills are spared in amnesics (e.g., on the mirror drawing test), but declarative memory is compromised heavily. However, do different types of non-declarative memories share the same neural substrate, or do they leverage on different brain regions?

8.1 Procedures

With regards to motor processing, past research has shown that the **basal ganglia** is one of the main structures that is involved. There are multiple structures inside the basal ganglia, including:

- **caudate nucleus**,

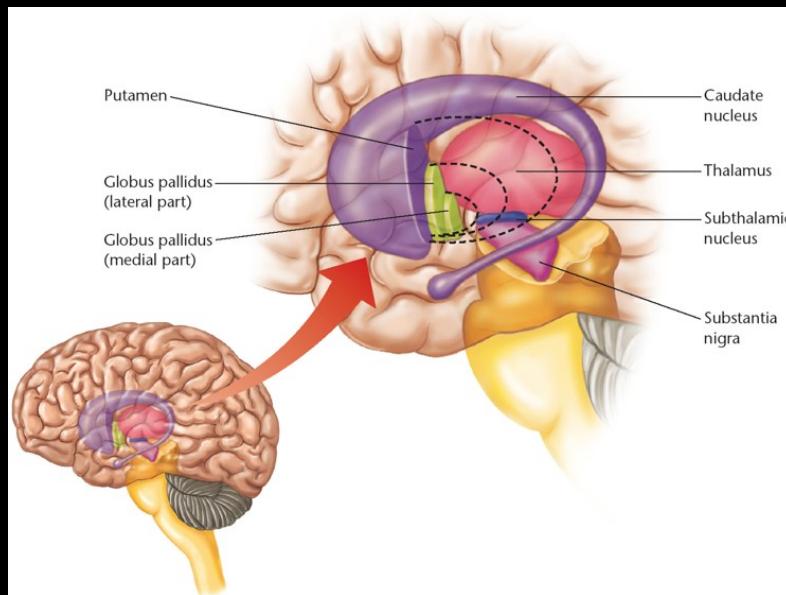


Figure 32: Components of the basal ganglia.

- **putamen**,
- **substantia nigra**,
- **globus pallidus** (lateral and medial parts),
- along with a few other structures.

While the thalamus is not part of the basal ganglia, it is its vicinity.

To make sense of how the basal ganglia is involved in motor processing, we could illustrate its connections with the motor cortex using a *wiring diagram*.

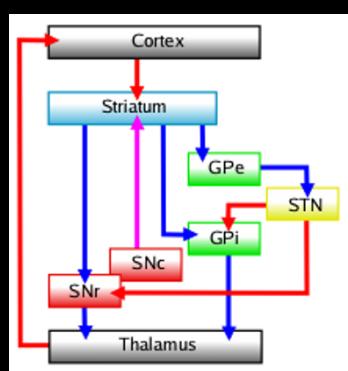


Figure 33: Wiring diagram illustrating the connections between the basal ganglia and the motor cortex (specifically, the premotor cortex). GPe refers to the lateral/external side of the global pallidus, whereas GPI refers to the medial/internal side of the global pallidus.

We know that the basal ganglia is linked to motor functioning because when it

is compromised, movement disorders result. For example, Parkinson's disease (characterized by uncontrollable tremors) results when there is significant cell death in the major output nuclei of the basal ganglia (i.e., the **substantia nigra**).

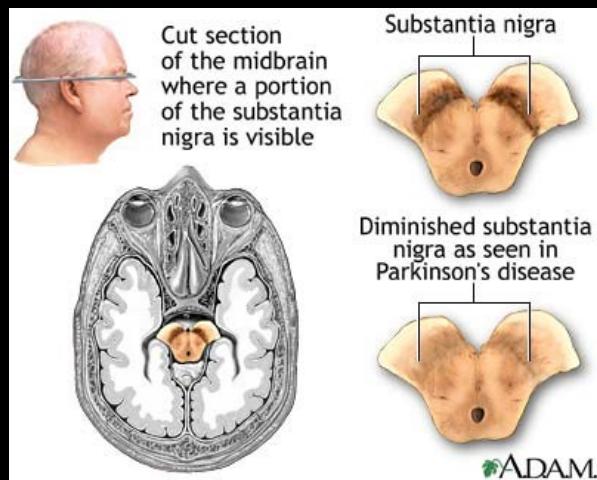


Figure 34: Compromisation of the basal ganglia in Parkinson's disease is characterized by diminished substantia nigra. Typically, there needs to be ~ 70% cell death in the substantia nigra before the symptoms of PD becomes obvious.

To examine the role of the basal ganglia in habit/procedural learning, Packard & McGaugh (1996) performed a study on rats.

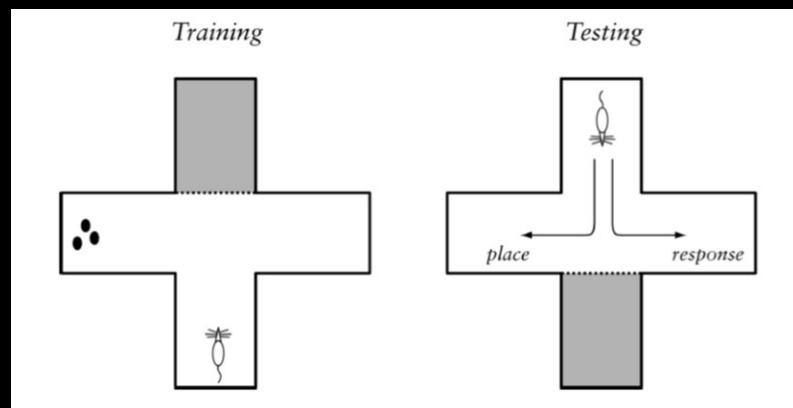


Figure 35: Experimental setup of Packard & McGaugh, 1996.

- In the training phase, rats were trained to move to the arm of the T-maze which has some reward. The object of the training is for the rat to be able to get to the location where the reward is.
- Some rats will then get an injection into the caudate nucleus, whereas some rats receive injections into the hippocampus. The injection received is either a saline solution (i.e., placebo/nothing should happen), or a

lidocaine solution (i.e., an anaesthetic which should result in the brain structure switching off).

- In the testing phase, the starting point of the rat is reversed (i.e., the rat starts in the arm opposite of that in the training phase). Here, the rat can employ two strategies:
 - *Place strategy*: going to the location where the food is actually located in (i.e., based on its mental map of the maze).
 - *Response strategy*: going to the location based on its habit/procedural memory.

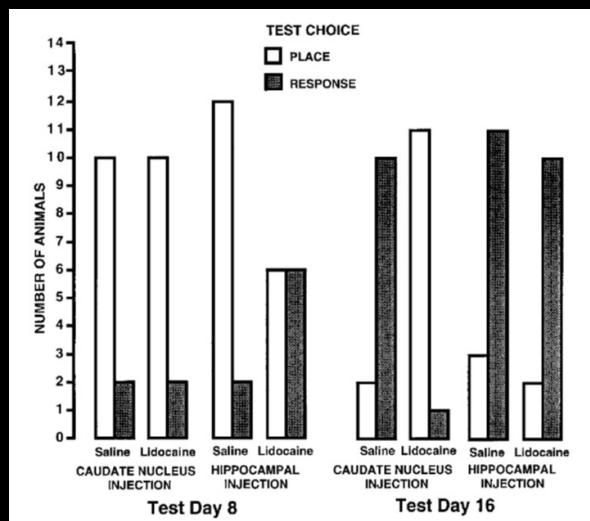


Figure 36: Results from Packard & McGaugh, 1996.

- When saline is injected into the caudate nucleus:
 - the vast majority of rats would use the place strategy before the habit is learnt; the exact same pattern is seen for rats with lidocaine injections into the caudate nucleus.
 - after several days of training (i.e., the habit should have been learnt), rats with saline injections adopted the response strategy instead, whereas rats with lidocaine injections stuck with the place strategy.
 - this suggests that switching off the caudate nucleus affects the rats' habitual/procedural memory.
- When saline is injected into the hippocampus:
 - the vast majority of rats would use the place strategy before the habit is learnt, but this was not observed for rats with lidocaine injections into the hippocampus (i.e., there was greater reliance on the response strategy).
 - this is because when the hippocampus is deactivated, the contextual information/relational processing ability of the rat is impaired, thus there is a greater reliance on procedural memory.

- after several days of training, the response strategy is more widely used in both conditions.

A further study by Knowlton et al. (1996) showed that habits can be cognitive, and not necessarily purely behavioural in nature.

- In a weather forecasting task, participants were tasked to predict either rain or shine based on a random combination of 4 cards. Each combination has a predefined probability of either rain or shine.
- Even though participants may not exactly know what the percentage is, or what the correct combination may be, most participants were able to achieve a higher percentage of correct responses as they gain more experience in the task (which illustrates a practice effect).
- However, participants with Parkinson's disease do not illustrate the practice effect, even though the performance of amnesics showed the same trend.
 - This suggests that participants with PD were not able to learn any "procedures".
 - This shows that the basal ganglia may be involved in general procedural memory (i.e., not just motor-based procedures), since declarative memory does not play any role in this experiment (as evidenced from the performance by the amnesics).

Therefore, this points towards the conclusion that the basal ganglia plays a general role in the *acquisition of skills or habits*.

8.2 Priming

priming: a change in the ability to identify or produce an item as a result of a specific prior encounter

On the other hand, **priming** has also been shown to be MTL/hippocampus-independent in studies on amnesics. Does priming involve the basal ganglia as well?

There are many different variants of priming (e.g., word/semantic priming, pattern priming, etc.), which may involve different stimuli. Across the various types of priming, it is clear that priming is an implicit process (i.e., we don't try to *demonstrate* priming); in fact, under the appropriate conditions, we have no control over priming. How, then, could the brain support such a process?

Research has shown that this depends on the **locus of the priming** (e.g., perceptual versus conceptual).

8.2.1 Perceptual Priming

Buckner et al. (1998) performed a study to investigate the neural basis of priming.

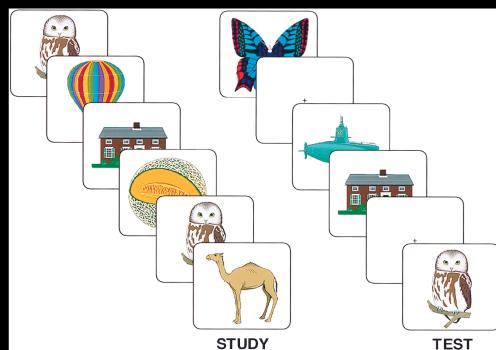


Figure 37: Buckner et al., 1998.

- During a study/training phase, participants were shown a series of images containing different objects.
- During the test phase, they were shown another series of images, and had to make a response to each picture.
 - For example, they may be asked to answer whether the item in the picture can move on its own.
 - Some items were presented in the study phase, whereas some items were not presented before.
- Brain activity was then tracked when the stimuli were presented in the test phase.
 - Analyses of brain activity indicated that the presentation of new items resulted in additional brain activity in the visual perceptual areas.
 - This suggests that there is less brain activation for items which have been primed/have been seen before.

Another study by Kourtzi et al. (2001) investigated the encoding of objects in the lateral occipital complex.

- Participants were shown different stimuli sequentially. The stimuli were categorized into 4 categories:
 - Identical: two completely identical objects at the same depth.
 - Same shape: same object, different depth.
 - Same depth: different object, same depth.
 - Completely different: different object, different depth.

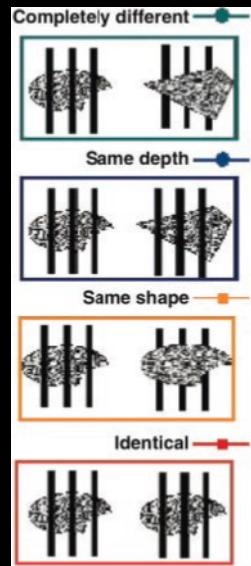


Figure 38: Stimuli by Kourtzi et al., 2001.

- Activity in the **lateral occipital complex** was tracked while participants were exposed to the stimuli.
 - Analyses showed that this part of the brain (i.e., which is part of the visual area) appears to be coding for objects but not depth, since more activation is observed when different objects are presented, but not when different depths were presented.

These studies gave rise to the important concept/neural effect known as **adaptation**, which could be what underlies **perceptual priming**.

8.2.2 Conceptual Priming

In addition to the perceptual areas highlighted in Buckner et al. (1998)'s study, it was also observed that there was increased activity in the **left DLPFC** when new images were shown to participants. This could be due to us not being able to stop the retrieval of semantic information related to the new object, even though it is not needed.

Notably, this observation (i.e., activation of left DLPFC when semantic information needs to be retrieved) has also been made in other studies. For example, research has shown that when the semantic meaning of 4 words (as compared to 2 words) needs to be retrieved, the DLPFC showed greater activity.

Therefore, it is hypothesized that **conceptual priming** may be related to a *reduction in left frontal activation* (specifically, where semantic retrieval occurs),

whereas **perceptual priming** may be related to a *reduction in posterior sites* (e.g., visual areas). Both priming are expected to illustrate the same pattern: i.e., new information would require greater brain activity than old information.

What might account for the reduction in activation in priming? There are two possibilities proposed by Henson (2003):

1. **Sharpening effect:** the reduction is caused by neurons “*falling out*” of the representation.

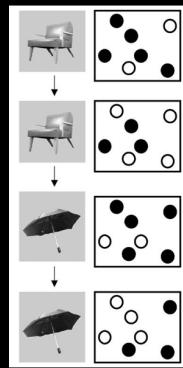


Figure 39: Neurons falling out of the representation over time.

- One reason may be that the neurons that fall out do not code for essential information.
- In other words, only the neurons that remain and continue to fire strongly are important to the representation.

2. **Lateral efficiency effect:** the same neurons remain firing, but at a *lower rate/less strongly*.

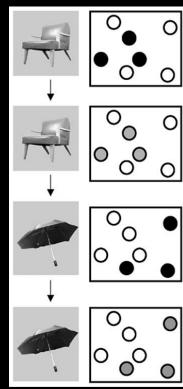


Figure 40: Neurons firing less strongly/rapidly over time.

- This could be because over time, neurons become more efficient at encoding/processing the same information.

8.3 Henson, R., et al. (2000)

Theoretical background:

- **Priming** is a behavioural effect defined by the increase in speed, bias, or accuracy of processing a specific stimulus due to prior exposure with it (or a related stimulus).
 - We know that priming is a neural effect as well, which manifests as **repetition suppression** in brain areas involved in the processing of the stimulus.
1. What is the point of the experiment?
 - To investigate whether stimulus familiarity affects the repetition suppression associated with priming.
 2. What did the experiment do?

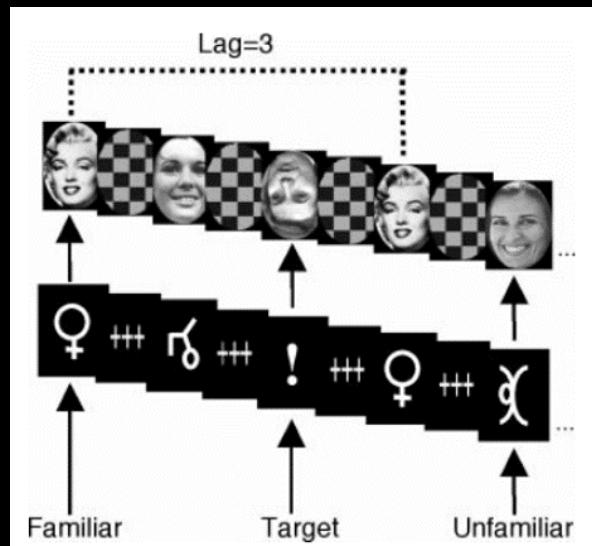


Figure 41: Setup of the experiment.

- Participants were asked to view familiar versus unfamiliar faces, and familiar versus unfamiliar symbols, while fMRI scans were conducted.
 - The *target* serves as an irrelevant task to make sure participants focus their attention on the relevant stimuli (i.e., the familiar/unfamiliar faces and symbols).
 - However, the behavioural effects of priming was not measured/ascertained in the study.
3. What are the results?
 - When familiar stimuli were primed, **repetition suppression** was evident in participants' **right fusiform region**.

- However, when unfamiliar stimuli were primed, **repetition enhancement** was observed instead in the same region.
- A **lag effect** was also observed, i.e., the longer the gap between repetitions of the prime, the smaller the suppression (or enhancement).

4. What do the results show?

- If a stimulus is familiar, repeated exposure leads to greater processing efficiency, and reduced brain activity in relevant areas.
- If a stimulus is unfamiliar, repeated exposure leads to a change in perception (typically recognition), and enhanced brain activity in relevant areas.
- However, both mechanisms still result in the behavioural effect of priming.

5. What does this tell us?

- (Biological)
 - Priming of familiar things usually involves reduced brain activity in the relevant brain areas.
 - Priming of unfamiliar things usually involves enhanced brain activity in the relevant brain areas.
 - However, by modifying the task (e.g., showing negative images preceded by positive images), we could reverse the pattern of brain activation between familiar and non-familiar stimuli. Thus, the familiarity of a stimulus is not the key; rather, brain activity is associated with whether the same processes (or new processes) are involved.
- (Cognitive) There are different kinds of priming.
 - Priming of familiar things usually involves the same cognitive processes becoming more efficient.
 - Priming of unfamiliar things usually involves the recruitment of additional cognitive processes (i.e., recognition).
- The effects of priming are temporary.

6. How is this knowledge useful?

- Ads: mere exposure to products can prime us towards purchasing them, especially in situations where we might not have strong preferences towards either option.
- Persuasion: priming can also be used to induce ideas in others.
- Education: priming of content before entering an exam hall.
- Subliminal priming: inclusion of extremely brief messages in advertisements or media.
- Experimental manipulation: priming can be used to induce temporary attitudes in participants, regardless of internal beliefs and values.

For example, if we prime a negative image with a positive image of the same famous person, the increased recognition of the negative image following priming results in more processes being recruited, thus repetition enhancement ensues.

9 EMOTIONAL MEMORY

Lecture 9
29th March 2022

The **amygdala** is a structure often linked to feelings and affect in humans. This is a very small yet dense structure, comprising of different nuclei, and positioned in front of the hippocampus. Even though it is small, its density enables it to influence different cognitive functions.

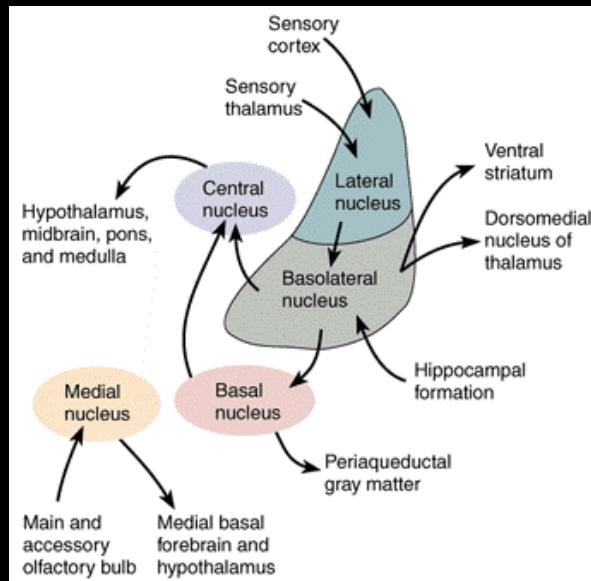


Figure 42: Structure of the amygdala.

Studies on monkeys with amygdala lesions illustrated the presence of *psychic blindness*: i.e., they approached objects which were supposed to initiate a fear response. Further studies showed that aside from fear, the amygdala seems to play a role in emotions in general.

For instance, in the case of H.M., even though there was no evidence of mood problems, he seemed unresponsive towards painful clinical conditions.

- Typically, when we are presented with an aversive stimulus, our skin conductance increases (partially due to sweating). However, this response was not observed in H.M. when electric shocks were applied to him.
- H.M. also had difficulty with pain discrimination. For example, he could not make the judgment that a stimulus was painful, regardless of how intense the stimulation was. This was not observed in other amnesics which did not have their amygdala removed, which suggests that this could be a result of the removal of his amygdala.

Adolphs et al. (1994) studied a patient, S.M., (not an amnesic) with **Urbach-Wiethe disease** (a disease which in some cases, results in the calcification of the amygdala, while leaving other brain regions untouched). The calcification

of the amygdala results in inhibited functioning in the brain area.

- S.M. was asked to classify a face (showing an emotional expression) with regards to different emotion categories.
- Relative to healthy controls, S.M. had difficulties differentiating whether each face demonstrated certain emotions.

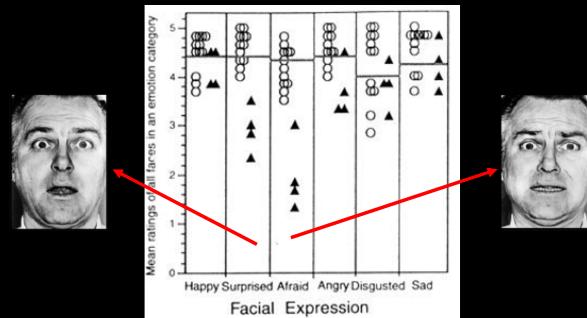


Figure 43: Examples of facial expressions presented to participants, along with their ratings. Black triangles on the chart indicate S.M.'s ratings.

- However, she was able to recognize familiar faces, which indicates that this was not a basic face perception or processing problem, nor was it a problem related to declarative memory.

9.1 Encoding of Emotional Memory

It has also been observed that in general, one tends to remember emotional information better than neutral information. One study looking into this effect was done by Cahill et al. (1996), utilizing PET scans of the brain.

- Participants were shown films with emotional content, as well as neutral films.
 - When the film that was being watched contained emotional content, the amygdala was activated more strongly (i.e., during encoding).
- Subsequently, films with emotional content were recalled better than neutral films.
 - For people whose amygdala activated more strongly, they remembered more memories.
 - On the other hand, when films did not consist of emotional content, amygdala activation was independent/uncorrelated with the ability to recall films.

in PET scans, a radioactive substance is injected into the bloodstream, and concentrations of the radioactive substance are subsequently analyzed

Another study by Hamann et al. (1999) also illustrated the correlation between amygdala activity and recall performance.

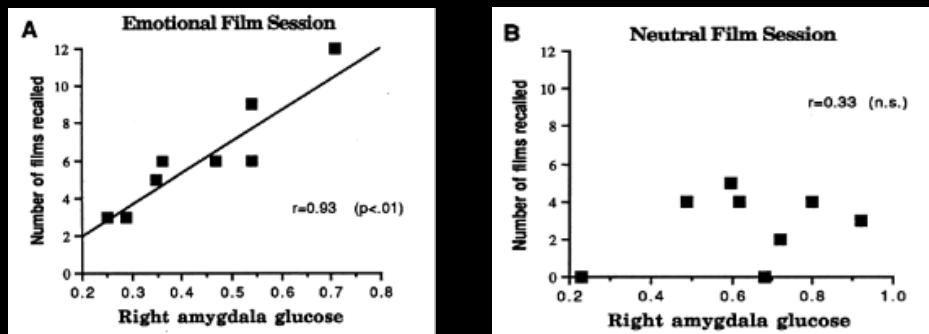


Figure 44: Recall performance at different levels of amygdala activation.

- Subjects were shown pictures which were either pleasant or aversive.
- Both the hippocampus and the amygdala were shown to respond during the encoding phase, and activity in the amygdala was associated with better performance on a memory task.

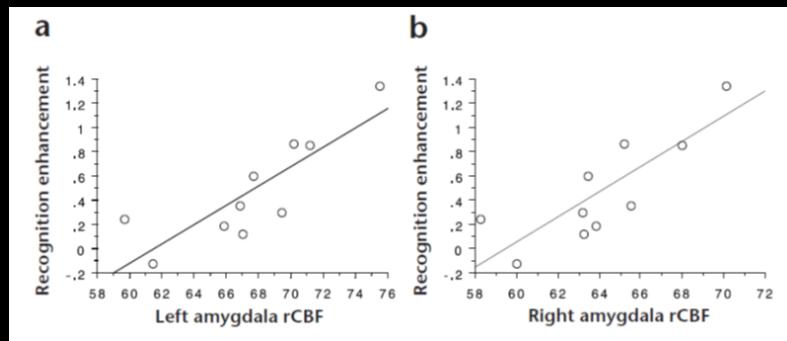


Figure 45: Correlation between amygdala activity and recall performance.

9.1.1 Dm Effect

Dm = difference due to memory

The **Dm effect**, also known as the **subsequent memory effect**, refers to the difference between remembered and forgotten items *at the point of encoding*.

Research by Dolcos & Cabeza (2002) illustrated that emotional pictures elicit the Dm effect earlier than neutral pictures.

- When a picture has emotional content, the Dm effect starts early and carries through time.
- When a picture is neutral, the Dm effect develops only in a later epoch.

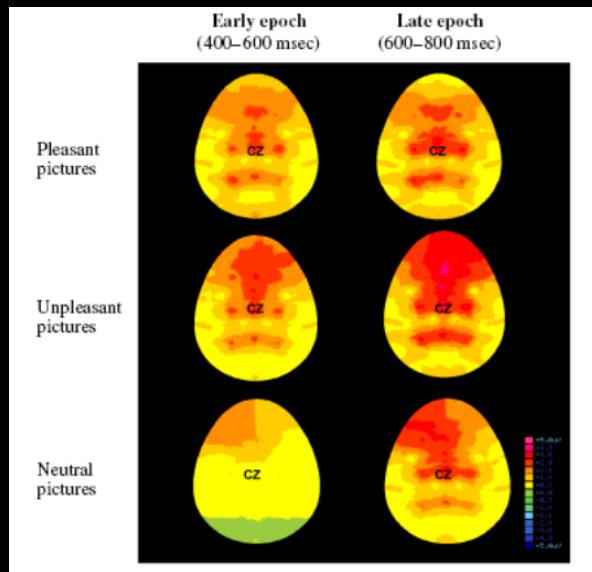


Figure 46: Chart showing the ERP heatmaps of the Dm effect on a recall task, with redder regions indicating the parts of the brain which are more active during the encoding of remembered items relative to forgotten items.

Using fMRI, Kensinger & Corkin (2004) also showed that the emotional Dm effect seems to be evident in both the hippocampus and the amygdala. This suggests that there is a qualitative difference between how neutral and emotional information are treated, which might have an effect on memory.

Could the amygdala be interacting with the MTL to give rise to the differences observed in emotional memory? A study by Dolcos et al. (2004) illustrated that this could be the case, where a correlation between amygdalar and MTL Dm was observed during the encoding of emotional pictures. However, this correlation was not observed in neutral/non-emotional pictures.

9.2 Retrieval of Emotional Memory

When we are trying to retrieve memories, if the memory has some emotional content, the difference between HITs and MISSes would be more significant and would involve the amygdala (in addition to the hippocampus and the entorhinal cortex). This indicates that the amygdala contributes to memory in some way by interacting with the memory structures, even though itself is not part of the memory system.

HIT: old items classified as old
MISS: old items classified as new

Past research has utilized a fear conditioning paradigm to illustrate the neural differences between emotional and neutral memory at retrieval time.

- Setup: a rat is placed inside a cage with metal wires as the floor.
 - Initially, a sound is presented but nothing else happens; in this

case, the blood pressure of the rats remain relatively stable, and there are no significant changes in their movement.

- Subsequently, the sound is paired with an electric current passing through the floor. This results in a huge cessation of movement, and their blood pressure would go up.
- If the rat has learnt to pair the sound with the electric shock, a fear response would be seen in the rat when the sound is presented next.
- To find out which brain structures are involved in fear conditioning, researchers examined whether conditioning could be carried out in rats with lesions to different brain structures.

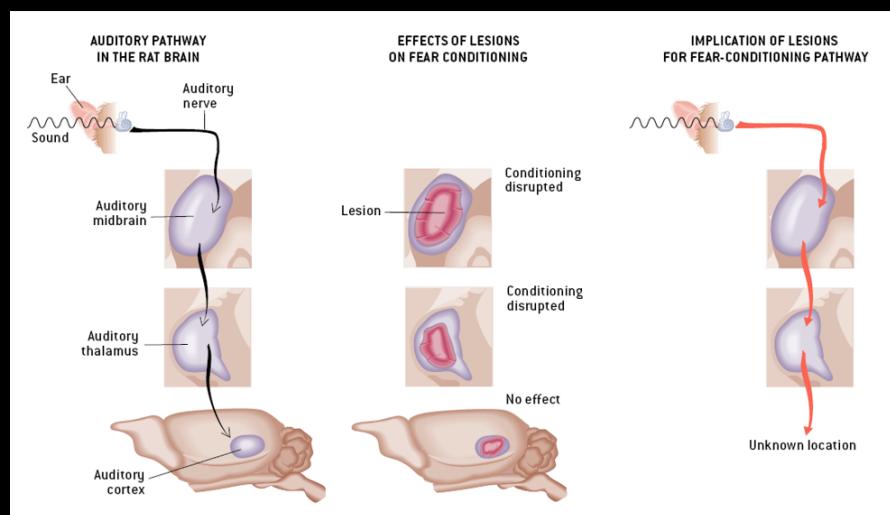


Figure 47: Effects of lesions on fear conditioning.

- When the **midbrain** and **thalamus** were lesioned, conditioning fails to take place, because presumably the sound signal cannot be heard, registered, or processed by rats.
- However, when the **auditory cortex** is lesioned, conditioning proceeds as normal.
 - * This indicates that there is a route from the auditory system which does not go through the cortex.
 - * Instead, some structure other than the cortex could be key in fear conditioning (perhaps, the amygdala?)

On a similar note, research by Le Doux (1994, 2002) showed that there are two distinct pathways from the visual system to the amygdala:

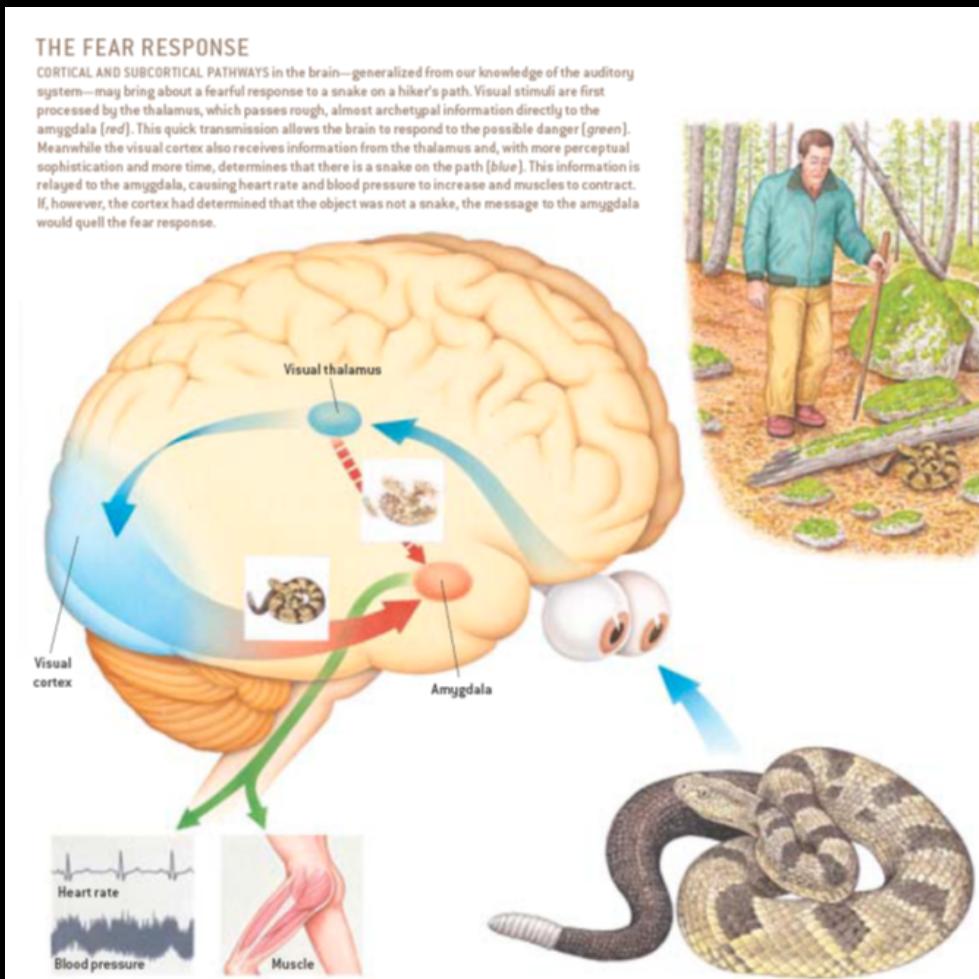


Figure 48: The visual pathways for fear conditioning.

- (faster) eyes → visual midbrain → thalamus → amygdala
- (slower) eyes → visual midbrain → thalamus → visual cortex → amygdala

When one of the pathways is impeded, the other pathway would still be active, thus enabling fear conditioning to still take place.

Just as the PFC and the BG, a large part of the ability of the amygdala to be involved in many processes (aside from memory) could be due to its extensive connections with the rest of the brain.

- Critically, it is strongly connected to the MTL, which enables the amygdala to play a role in memory.
- Additionally, the connection between the amygdala and the PFC could influence the functioning of the executive system, potentially causing stimuli with strong emotional content to affect our WM and attention.

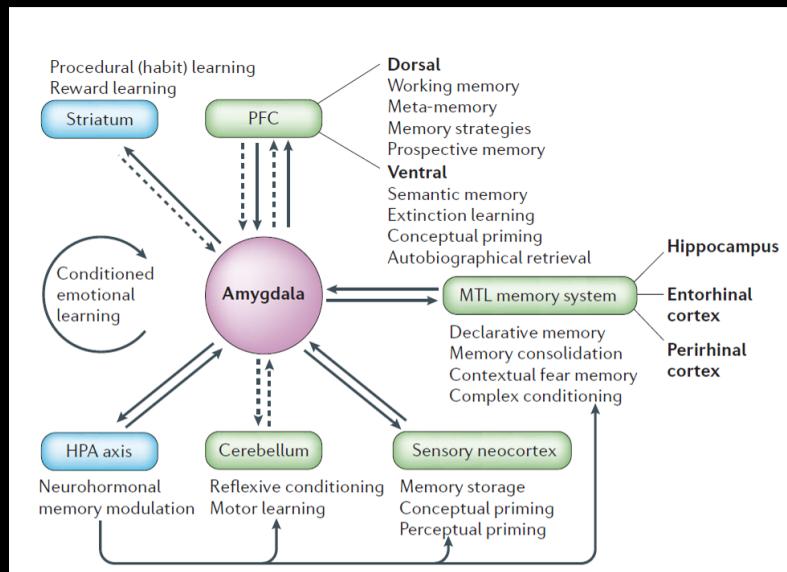


Figure 49: The amygdala and its connections.

Once again, this provides evidence that different parts of our brain need to interact with each other in order to produce our complex cognitive functions and behaviour.

9.3 Dolcos, F., et al. (2005)

Theoretical background:

- The **emotional enhancement effect** describes the situation where people tend to remember emotional events and stimuli better.
- This is due to enhanced **encoding** and **consolidation** for emotional information mainly in the hippocampus and **amygdala**.

1. What is the point of the experiment?

- To investigate whether brain activity differs between retrieval of emotional versus non-emotional information, and
- whether the **emotional enhancement effect** also involve differences in brain activity at retrieval.

2. What did the experiment do?

- Participants were shown images and had to respond to whether they remember, know/recognize, or have never seen the pictures before.
 - Remembering/Recollection and knowing/familiarity are distinct; the former is more associated with the vivid experiences of emotional memories.

3. What are the results?

- Between the emotional and non-emotional conditions, there was a statistically significant difference on recollection performance, but no significant difference on familiarity.
- Activity between emotional and non-emotional procedures were compared using the metric of **retrieval success (RS)**, defined as:

$$RS = \text{Activity for HITs} - \text{Activity for MISSES}$$

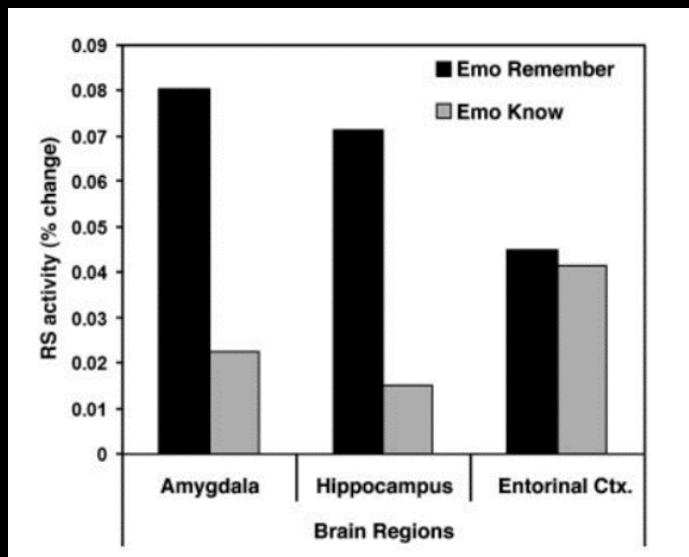


Figure 50: Retrieval success (RS) activity across different regions.

- There was enhanced brain activity for the **retrieval** of emotional memories in all 3 relevant areas.
- The amygdala and hippocampus mainly supported **recollection**, but the entorhinal cortex supported **recollection** and **familiarity** equally.

4. What do the results show?

- The emotional enhancement effect only applies to recollection, but not to familiarity.
- At retrieval, this effect manifests as increased brain activity for emotional memories in the amygdala, hippocampus, and entorhinal cortex.
- The amygdala and hippocampus play a bigger role in recollection compared to familiarity, but the entorhinal cortex supports both processes equally.

5. What does this tell us?

- (Biological) The emotion enhancement effect is supported by the amygdala and the MTL, particularly the hippocampus.

- (Cognitive)
 - Emotion is a powerful tool for recollection.
 - Mutual reinforcement:
 - * Emotions can serve as a retrieval cue that facilitates the retrieval of other contextual details of an event.
 - * However, recollecting an event and its details will likely increase the emotional arousal elicited by retrieval as well.
- This has been argued to be the process facilitating PTSD.

6. How is this knowledge useful?

- Interest: current emotion psychology treats interest as a positive emotion, which implies that our memory for information we are interested in should be enhanced.
- Hypercorrection effect: students who made a mistake on a question would remember the correct answer better than students who got it right in the first time.
 - Note that this effect is not present when we make mistakes which we don't care about; it only matters in important contexts.
 - Hence, a key driver of this effect could be an emotional enhancement effect due to the negative affective responses to mistakes on important tasks.

A STRUCTURE-FUNCTION MAPPINGS

1. Medial temporal lobe

- (a) Declarative/explicit and episodic memory.
- (b) Global memory (i.e., not specific to one modality or stimulus set).
- (c) Damage → graded retrograde (i.e., memories before the event) amnesia.
- (d) No relation with short-term memory.
- (e) No relation with implicit learning/memory.
- (f) No relation with sensory, motor, and cognitive processes.

2. Anterior inferotemporal (AIT) region

- Long-term declarative and episodic memories (?)

3. Hippocampus

- Declarative memory.
- Relational processing and contextual learning.
- Permanent consolidation of memories.
- Integrates the “what” and “where” information into composite events.

-
- Compares and relates individual event and episode representations to other memory representations.
 - There are cells which code for specific details/elements in the environment, and cells which fire selectively to specific episodes.
4. **Perirhinal cortex and lateral entorhinal cortex**
 - Memories of important objects/items, people, actions, and other specific events.
 5. **Parahippocampal cortex and medial entorhinal cortex**
 - Spatial and temporal context of events.
 6. **V2 (extrastriate visual cortex)**
 - Responds selectively to contours (i.e., subjective continuities).
 7. **V4**
 - Responds to color.
 8. **V5/MT (middle temporal visual area)**
 - Responds to motion/movement, especially directional movement.
 9. **Fusiform gyrus (contains FFA and PPA)**
 - Involved in processing complicated features, e.g., *object form*.
 10. **Fusiform face area (FFA)**
 - Responds very strongly to faces.
 - When stimulated, people are able to “see” facial features.
 11. **Fusiform object area (FOA)**
 - Responds strongly to objects.
 12. **Parahippocampal place area (PPA)**
 - Responds strongly to scenes (but not to faces or objects).
 13. **Occipital lobe (contains medial occipital region and inferior occipital gyrus)**
 - Responds more strongly to animals than to tools.
 14. **Lateral temporal lobe (contains STS and medial temporal gyrus)**
 - Responsible for processing *object motion*.
 15. **Superior temporal sulcus (STS)**
 - Responsible for biological motion.
 16. **Middle temporal gyrus**
 - Responsible for non-biological motion.
 17. **Frontal lobe (especially the dorsolateral prefrontal cortex, DLPFC)**
 - Seems to play the role of the central executive (cf. Baddeley’s model of working memory).

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