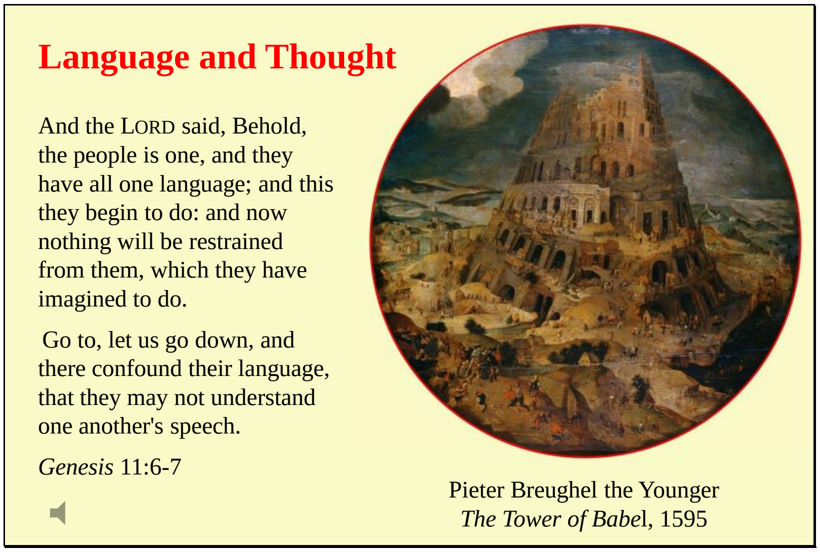
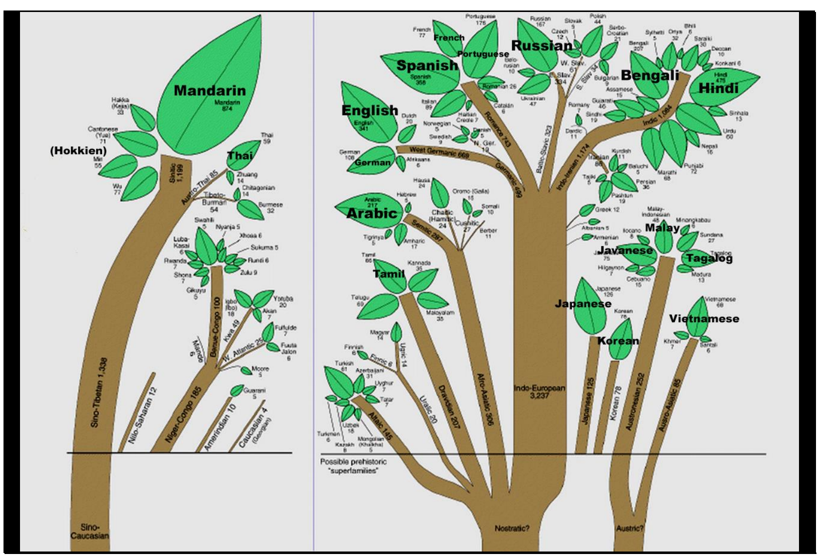


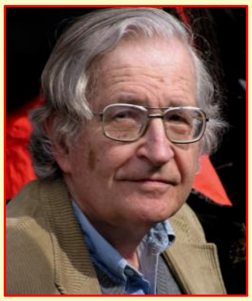
We begin our last sessions with the story of the Tower of Babel.
A rather vindictive deity, worried about the achievements of humanity, decides to “confound their language.”
The tower is unfinished; the people are scattered.



The story in Genesis is myth. Nevertheless, human beings have many different languages.
In this diagram the size of the leaves varies with the number of people with that language as a mother tongue.
There are some major branches – Sino-Tibetan and Indo European are the two largest.
Some languages such as Japanese and Korean have little apparent relation to other languages.

This is the final session of our course.
We have covered the basic anatomy and physiology of the brain and its neurons. We have considered how we move and how we experience the world. We have thought about how the human brain is conscious, and discussed two aspects of our consciousness – memory and emotion. Today, we shall consider the special processes that make our consciousness specifically human: language and thought.

The first half of this presentation will deal with language and its disorders. After the interval we shall talk about the frontal lobes and how they contribute to human intelligence.



Noam Chomsky (1928-)

Syntax and Semantics

Although animals can use symbols, they cannot manipulate these symbols as a language. This ability evolved with *Homo sapiens* about 200,000 years ago.

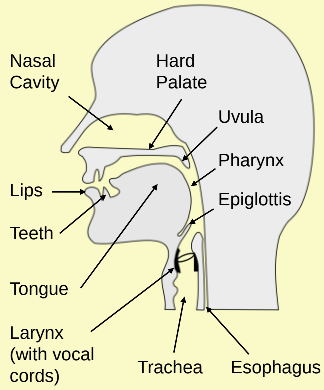
Nim Chimpsky (1973-2000)

Language uses rules to put sounds, words, and sentences together to convey meaning. Different languages use different rules but all human languages can be translated into each other.

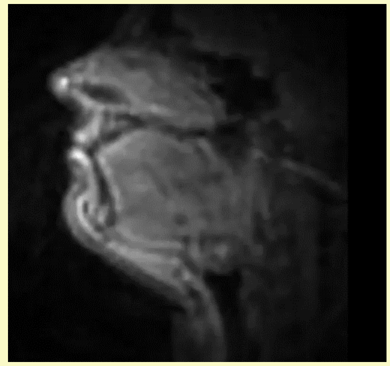
Noam Chomsky is the linguist who established our modern approach to language. His major idea was the “universal grammar” – every human being is endowed with a brain module that allows us to speak in sentences. The sounds and the words may differ among languages, but the sentence structure remains essentially the same.

Nim Chimpsky was a chimpanzee who was raised like a human child by a surrogate family. He learned to use signs but never showed any evidence of using grammar. The movie *Project Nim* considered his life.

Human Vocal Tract



During speech the vocal cords vibrate and the tongue moves rapidly to alter the resonance chambers of the mouth and throat:

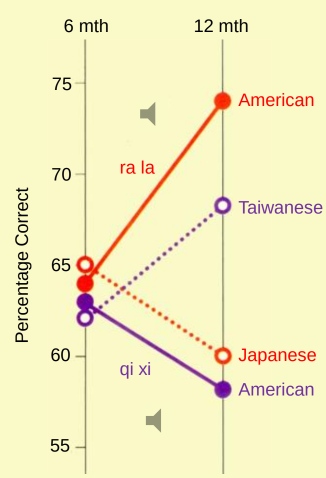


Speech is special. The human vocal tract is specially designed by evolution so that we can make all sorts of complex sounds.
The major differences between human beings and other primates is the descent of the larynx – this allows us to have a large resonance space in the throat (pharynx) as well as in the mouth. Another evolutionary development was the extremely high mobility of the tongue.
The resonances within the mouth and the pharynx gives us vowels. Stopping the flow of air at the teeth, lips or palate causes specific vowels
The MRI video at the right (about grandfather) shows how the lips, tongue, soft palate, and throat move during speech.

Video (by Jangwon Kim) is available at
https://www.youtube.com/watch?v=-kHtGlhPs3Y

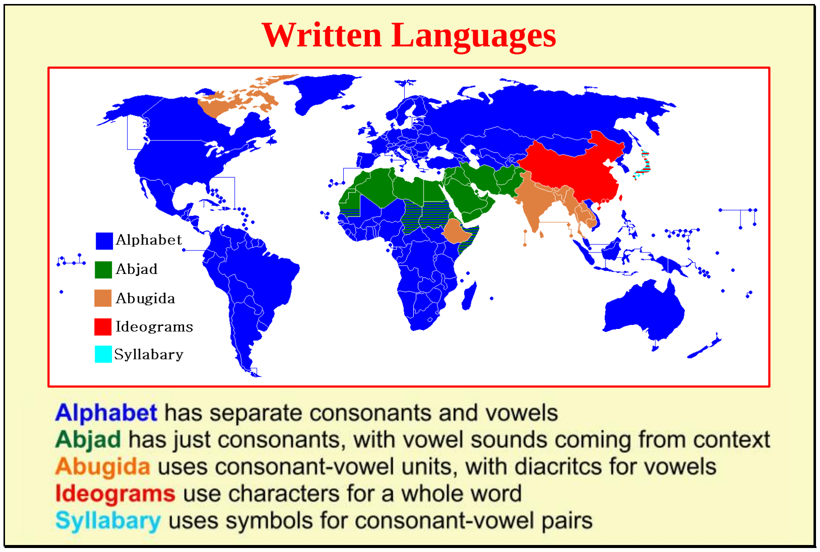
Speech Sounds

The various human languages use several hundred different "phonemes." Each language uses between 25 and 50 phonemes. Babies learn to distinguish between the phonemes in the language they are exposed to but will not be able to distinguish between some phonemes in another language. Thus Japanese babies cannot tell the difference between the 'l' and 'r' that American babies recognize. And American babies cannot tell the difference between the 'q' and 'x' that Taiwanese babies recognize. (Kuhl, 2015)



You can tell the difference between the 'l' and 'r' sounds in 'rate' and 'late.' (red – compares Japanese and American babies)

Most of you will not be able to discriminate the ‘q’ and ‘x’ of Mandarin Chinese (purple – compares Taiwanese and American babies)



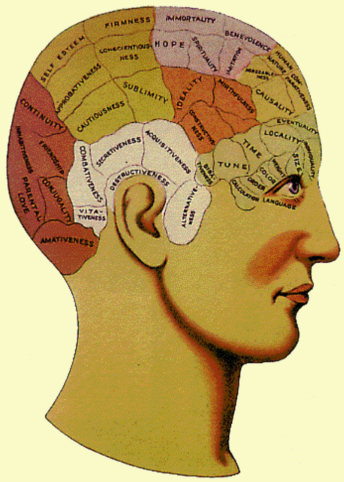
Written languages are almost as various as spoken languages. However, there are only five basic systems for writing.

English and many other languages use an alphabet with both consonants and vowels. The most common is the Latin alphabet. Some languages are strictly phonemic – the sound of a letter is always the same. Others, like English, are not.

Ancient Hebrew uses just consonants; modern Hebrew adds diacritics to show the vowels associated with the consonants.

Chinese uses ideograms. Words can be made up of a single ideogram or a combination of two or more ideograms. Each ideogram may be made up of simpler parts called radicals which can contribute to either the meaning or the sound of the ideogram

Japanese combines Chinese ideograms with two different sets of syllables: hirakana and katakana.



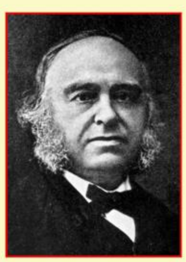
Localization of Function

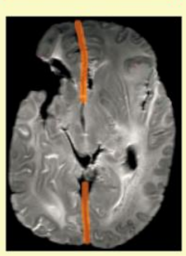
In the 19th Century, the phrenologists led by Franz Josef Gall (1758-1828) proposed that human abilities were localized to different regions of the brain.

Jean Pierre Flourens (1794-1867) showed that the cerebral hemispheres were necessary for intelligent behavior but he was unable to distinguish any focal areas within the hemispheres.

The controversy whether cognitive functions are localized or distributed in the brain continues to this day.

The discovery of how language is controlled in the brain is closely related to the idea that different functions are localized in different regions of the brain.
Phrenology was the study of the mind. It assumed that particular abilities would be localized in specific regions of the brain. If a particular ability were enhanced in a person, the regions of cerebral cortex related to that ability would be increased. Furthermore, the regions of the skull overlying the part of the cerebral cortex devoted to that ability would become prominent. Though the ideas of phrenology were totally illogical, some principles continue – that abilities might show some localization and that increased use of those functions increased the size of that region of the cortex.
The controversy between whether cognition is localized or distributed continues to this day. Some regions of the brain are essential to some functions, and without them these functions are not possible. However, the functions normally involve many other areas of the brain as well.



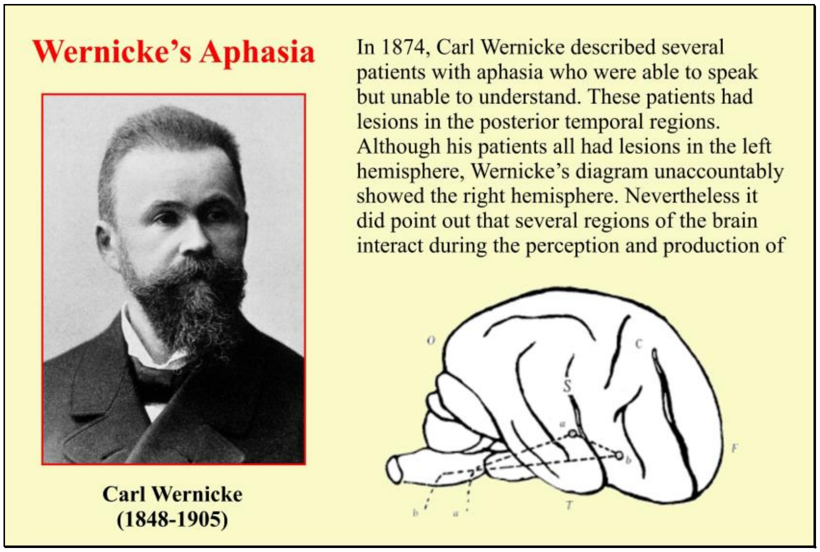


Localization of Speech

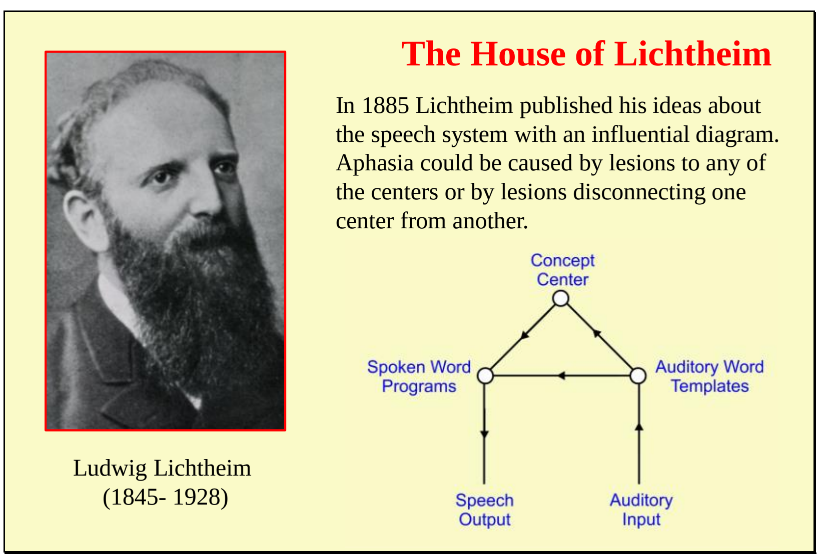
In 1861, Pierre Paul Broca (1824-1880) reported on the autopsy of Monsieur Leborgne, who had for many years been unable to speak. He had been known on the ward as "Tan" since that was the only sound he could make. The autopsy showed a focal lesion in the left inferior frontal region. The brain is preserved in the Musée Dupuytren in Paris.

Those believing in the localization of function received some clear support when physicians began to look at the brains of patients with aphasia.

Interestingly the brains of other patients with similar findings that Broca had studied had lesions to other areas of the left hemisphere. The lesions were all left frontal but some were higher up. The MRI at the lower left was taken from Leborgne’s preserved brain.

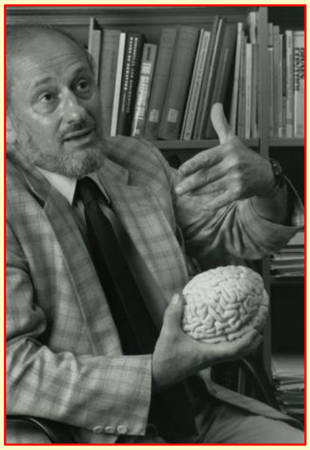


Wernicke suggested that the posterior temporal lobe was necessary for understanding speech and the inferior frontal lobe for producing speech. He did not pay attention to the fact that language defects involved the left hemisphere, and not the right.



The third main father of aphasiology was Ludwig Lichtheim.
His speech diagram looks like a house.

Disrupting the connection between auditory center and the speech center would prevent the simple rapid repetition of auditory input, even though the patient could understand and peak normally.



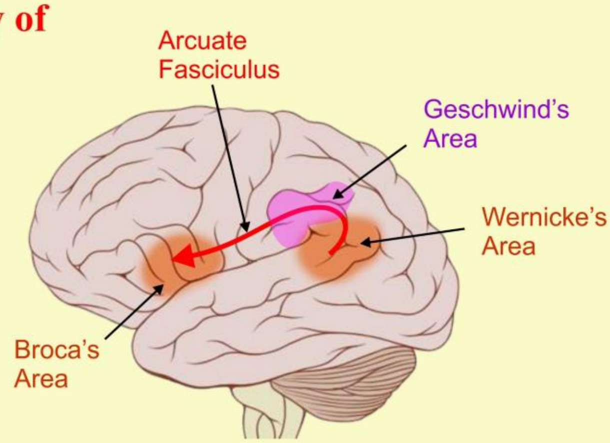
Norman Geschwind (1926-1984)

Disconnection Syndromes

Geschwind proposed that Lichtheim's concept center was located in the inferior parietal lobe, an area that was only fully developed in human beings. Lesions to the arcuate fasciculus could cause a "conduction aphasia" – patients had difficulty repeating phrases that were close to meaningless (such as "No ifs, ands, or buts"), although they could speak normally and could understand.

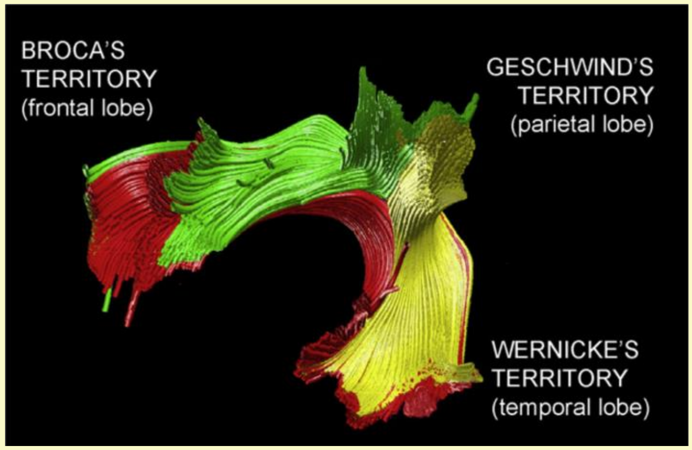
Norman Geschwind suggested an anatomical basis for the concept center, and proposed the idea of disconnection syndromes.
The prototype disconnection syndrome is conduction aphasia. A lesion to the arcuate fasciculus disconnect Wernicke's area from Broca's area.

Anatomy of Speech



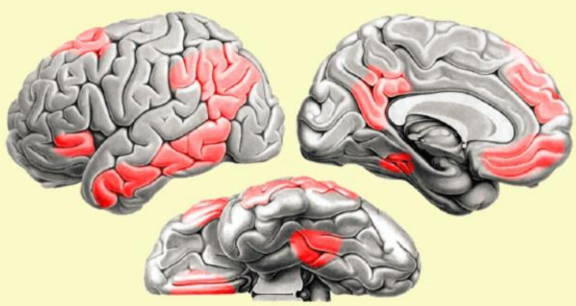
These are the main regions of the brain involved in speech and language in the classical (locationist) view.

Diffusion MRI: Arcuate Fasciculus



A special type of Magnetic Resonance Imaging is used to demonstrate the fibers within the white matter of the cerebral hemispheres.
This figure shows the arcuate fasciculus.

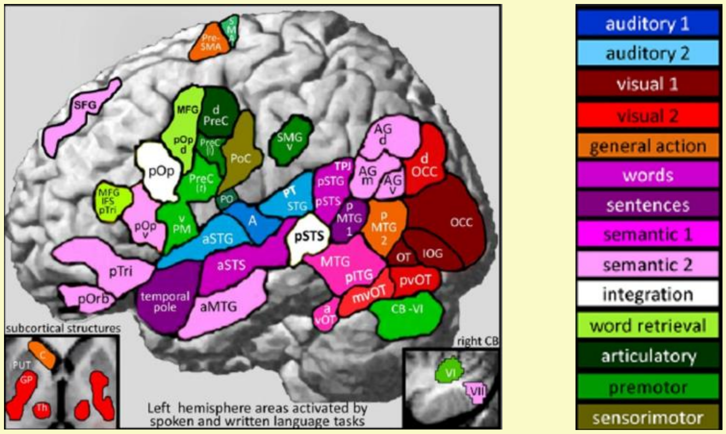
Semantic Memory



Recent studies using cerebral blood flow (e.g. Binder et al, 2009) have extended Geschwind's semantic area toward the middle temporal cortices. Damage to this area (by stroke or encephalitis) may significantly affect the memory for semantic concepts. The main clinical feature is "anomia" – the inability to find the word for an object or to say what it is used for. Sometimes the loss can be quite specific: the patient may be unable to recognize animals but can recognize tools, or vice versa.

Semantic memories – the facts that we have learned and consolidated – appear to be located in regions of the association cortex.
The main areas are the inferior parietal lobe (Geschwind's area) and the middle temporal gyrus.
The main symptom that follows lesions to these areas is anomia.
Other areas, particularly those in the frontal lobes, may be involved in searching or accessing semantic memories.

Blood Flow Studies of Human Language Processing

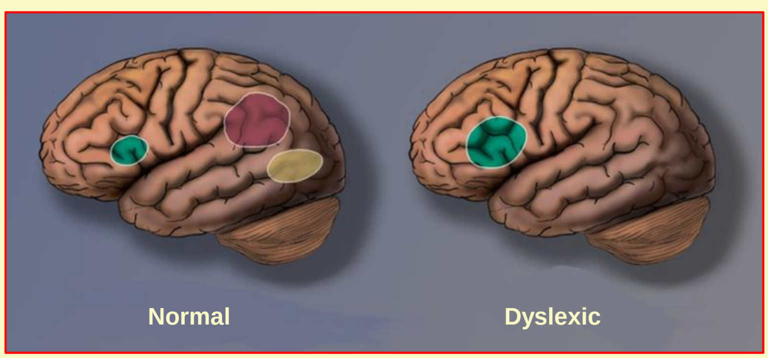


C. J. Price, *NeuroImage*, 2012

An abstract expressionist brain.
This figure is from a recent paper reviewing the cerebral blood flow studies over the last 20 years.Many different regions of the left hemisphere are involved in language processing.

We have just considered semantic memories - these are shown in the dark purple.
Light purple shows where syntax and semantics (grammar and meaning) come together.
Green is for articulation – the production of speech sounds.
Blue is auditory processing.
Red and brown are the areas for processing written language. These are disordered in dyslexia.

Dyslexia



Dyslexic children seem unable to process word forms (yellow) and meanings (pink). They activate the anterior word finding area (Broca's – green) more than normal children when trying to read words. (Shaywitz, 2005).

Dyslexia is an abnormality of processing written words and their meanings.
Two basic areas are affected – a word-form area in the temporo-occipital region, and a meaning area in the parieto-occipital region.

Dyslexic children often show increased activity in the left inferior frontal region. This may perhaps be related to the increased effort devoted to searching, when the word- and meaning-stores are noisy or empty.

Aphasia

Etiology: Aphasia can be caused by any process that damages the speech areas of the left (or dominant) hemisphere – trauma, tumor, degenerative disorders (particularly fronto-temporal dementia). However, aphasia most commonly occurs following a stroke.

Types: Aphasic stroke patients show the following types of aphasia: global – speech neither understood nor produced (30%), Broca's (15%), Wernicke's (15%), anomic (25%), others (15%).

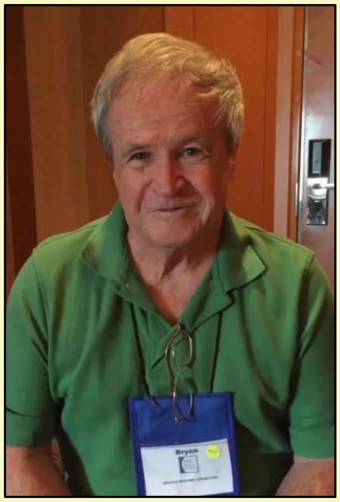
Prognosis: The more severe the initial symptoms, the worse the prognosis. However, all patients improve especially during the first year after the stroke. Global aphasia can progress to Wernicke's aphasia; Broca's aphasia tends to progresses to anomic aphasia. Fluent aphasias never become non-fluent.

Aphasia is a disorder of language.
It is almost always caused by damage to the left hemisphere (90+% of right-handed people and 70% of left-handed people).

Broca's Aphasia

Speech is very slow. Often the patient comes to a halt or can only make non-speech sounds like "um." There is great difficulty finding words. Writing is usually affected as well. Complete sentences are rare – the speech is like a telegram. The patient does not use grammatical features like the plural 's' or auxiliary verbs. Speech perception is good although the patient will not understand complicated grammatical structures (passives, etc.): "agrammatism." Patients are aware of their problems and sometimes very frustrated. There is almost always hemiparesis.

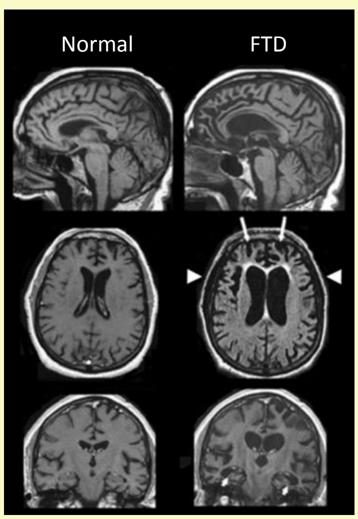
Full video is at
https://www.youtube.com/watch?v=khOP2a1zL9s



Wernicke's Aphasia

The speech is very fluent. However, the patient often makes mistakes, using the wrong word or changing the sounds in a word (paraphasias). Sometimes these paraphasias are so bad that the speech becomes gibberish or "jargon aphasia." The utterances are usually grammatically correct, but there is very little meaningful content to the speech. The patients have severe difficulty understanding questions. These patients tend to be unaware of their problems and have difficulty in understanding the need for therapy.

Note that he does not answer the questions posed to him. His speech is quite fluent – he is sometimes almost poetical in the way he repeats himself. He inadvertently repeats what the examiner says – there is no conduction aphasia.
Full video is at
https://www.youtube.com/watch?v=3oef68YabD0



Anomic Aphasia

Although the speech is fluent, the patient has difficulty finding words. Circumlocutions are common and both the patient and the listener become frustrated.

Testing involves (i) presenting the patient with an object (watch, pen, orange, etc.) and asking for its name, and (ii) asking the patient to give the meaning of a word, e.g., what is a knife?

As well as being caused by strokes, this type of aphasia is often seen in degenerative disorders such as frontotemporal dementia.

David Jane, *The Wall*, 2014. David has anomic aphasia and dyslexia after damage to the left temporal lobe from encephalitis in 1990.

David Jane was an artist who suffered severe damage to the left temporal lobe following Herpes encephalitis.
He was still able to paint after the encephalitis but has severe dyslexia.
This particular print gives the sense of what words look like in his consciousness.

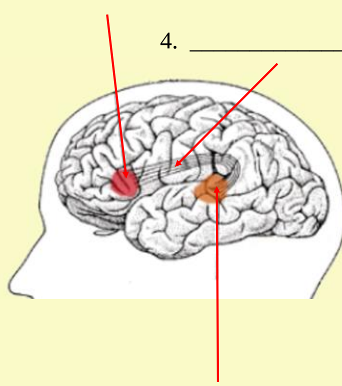
Quiz 8A

1. The most common type of aphasia seen immediately after a stroke is
A) Wernicke’s aphasia
B) Broca’s aphasia
C) Global aphasia
D) Anomic Aphasia

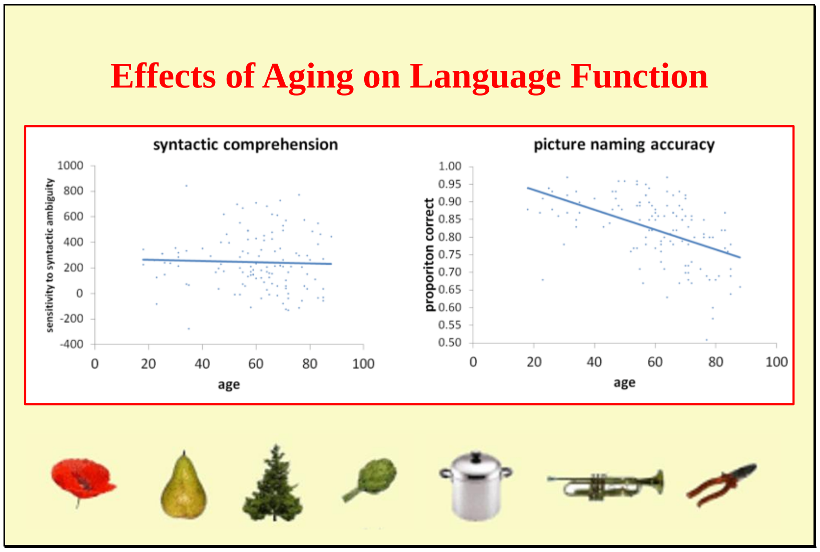
2. Anomic aphasia
A) does not occur in frontotemporal dementia
B) may evolve from Broca’s aphasia
C) can be treated with dopamine
D) is a symptom of normal aging

3. ________________

4. ________________



5. ________________



Some of you may have been worried about the question about anomic aphasia on the quiz. We all have difficulty finding words as we grow older – this is a mild form of anomic aphasia. Sometimes the words we are searching for are on the tip of the tongue – we might know the letter that the word starts with, we might know the word's rhythm but we just can't get the word. This is normal. It gets worse with age. It should not cause one to worry unless it becomes severe – unless you can't remember the names of 60% of pictured objects when you are 70 or 80.

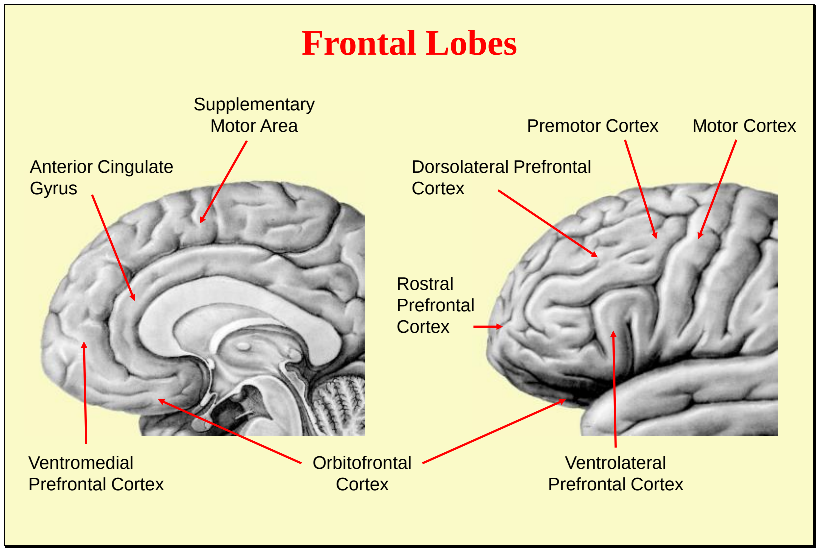
Frontotemporal Dementia

Anomic aphasia is only one part of the syndrome of fronto-temporal dementia (FTD).

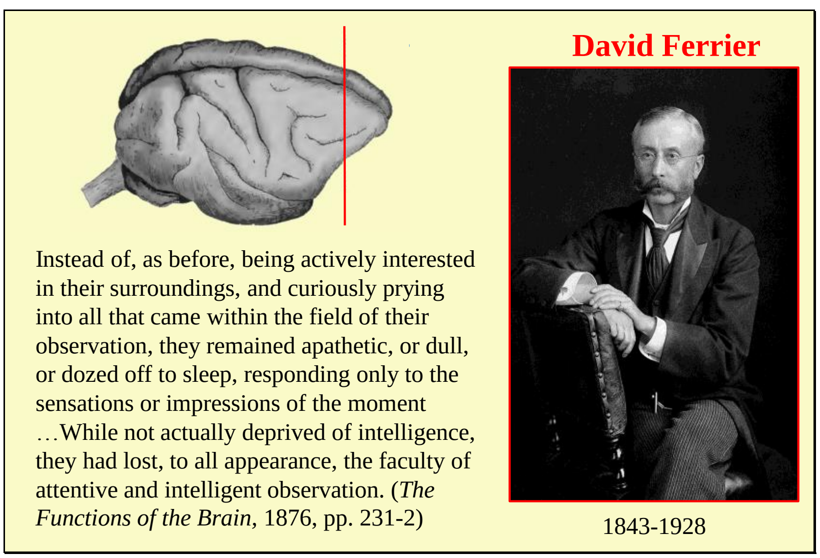
Patients with FTD present with behavior problems. If they are working, they make foolish decisions. Socially, they become quite "disinhibited." The patient may have bursts of impulsive or aggressive behavior. Often there is a general apathy.

One variant of this syndrome – Pick's disease shows abnormal tau-protein accumulations.

This is a patient with frontotemporal dementia. They typically have an anomic aphasia although this video does not show it. The other common findings are behavioral problems and apathy. This particular patient shows severe apathy. He does not remember his daughter's name, and has difficulty remembering his wife's.
https://www.youtube.com/watch?v=E09agP3swYs
There is a basic sadness to "Bye-bye blackbird."



The apathy of frontotemporal dementia is the result of degeneration in the frontal lobes.
There are many different regions in the frontal lobes and each controls its own set of processes.
The anterior cingulate, supplementary and premotor areas motivate, initiate and organize motor responses.
Medial and orbitofrontal cortex deal with emotions and morality.
Ventrolateral cortex is involved in accessing semantic memory.
The frontal pole is concerned with self and others.
They all act together to get things done. Without the frontal lobes we would just react – we would not initiate anything.

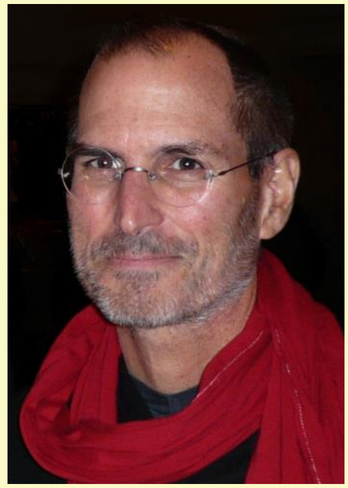


David Ferrier studied the effects of lesions to the anterior frontal lobes in dogs.

Frontal Lobe Functions

The prefrontal cortices, those regions of the brain anterior to the motor and premotor areas, are often considered the "executive" of the brain.

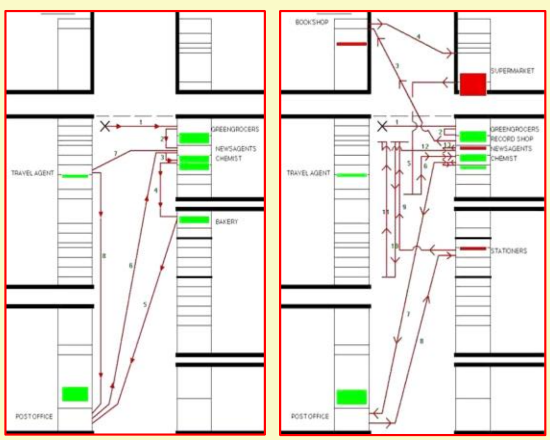
They are essential for ongoing **control** and **decision** processes. They channel our **motivations** into drives. They set **goals** and **monitor** whether these goals are being reached by present strategies. They make **inferences**, and **attend** to what is important. They consider the **future** implications of our actions. They maintain our **social** relations. They construct a **personality** and a life story.



Steve Jobs (1955-2011)

Without the anterior frontal regions we are like a business corporation without its CEO.
Lesions to these areas cause a loss of executive functions.
Steve Jobs was the quintessential CEO.

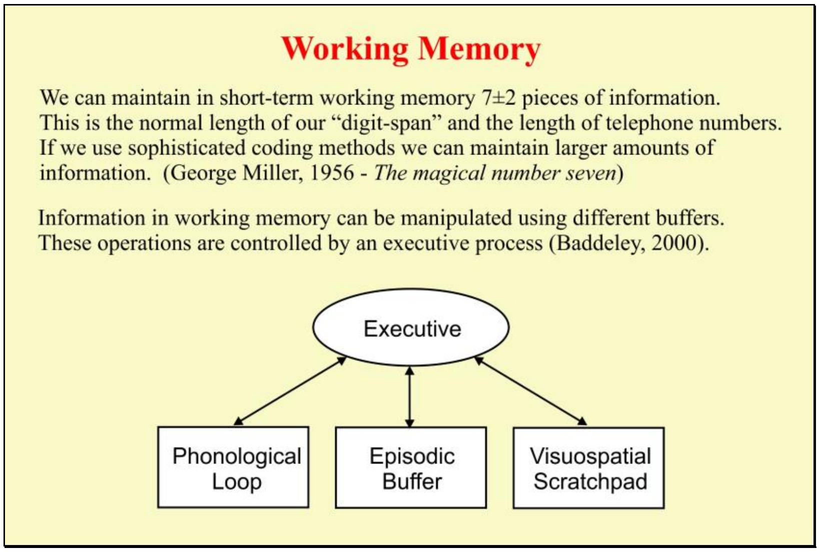
Planning/Strategy Deficits: Multiple Errands Test



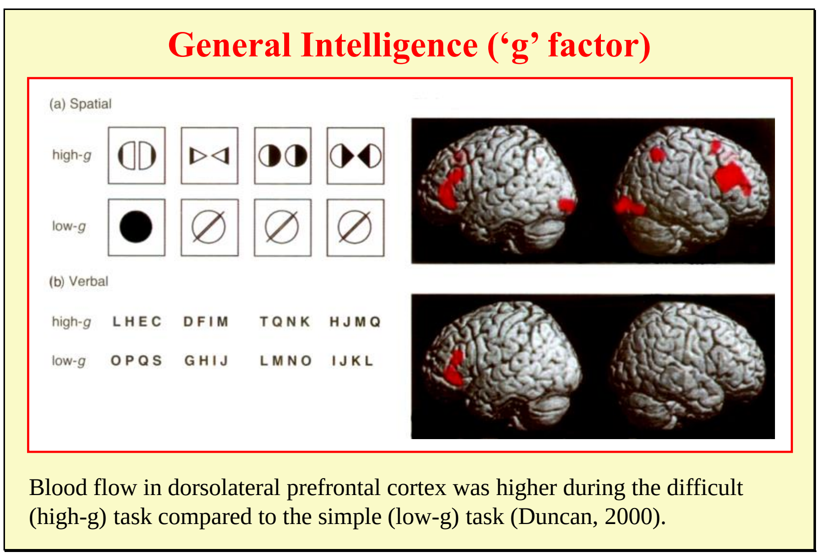
Normal Subject Frontal Damage

Patient must perform eleven tasks, such as buying a loaf of bread, buying a package of throat lozenges, finding out the exchange rate for the French franc, determining the price of a pound of tomatoes, etc., and then return to a particular place (e.g. post office) in 15 minutes.

Patients with lesions to the frontal lobes have difficulty setting up and following through on a strategy to get things done.
This can be tested in real life by giving the patient multiple errands to run. This was done by Tim Shallice and Paul Burgess.
A patient with a frontal lesion forgets what he is supposed to be doing, back-tracks, goes to one place several times, etc.

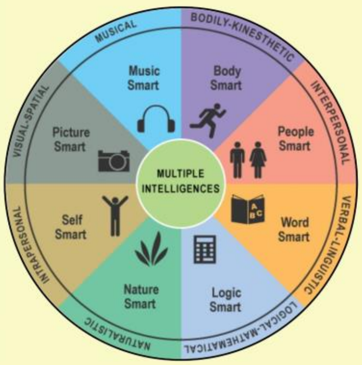


This is a slide from last week – working memory.
Setting up strategies and figuring out what to do involves working memory. Although some of the buffers used to store information or programs are in sensory cortex, the executive that keeps them operating is mainly located in the dorsolateral frontal lobes.



The intelligence quotient can be examined using various tests. In these examples you have to choose the example that does not fit with the others.
In the spatial high g example the third diagram is odd – the two halves are not mirror images.
The verbal high-g is very difficult. The letters are separated by an increasing or decreasing number of other letters. Third is odd – separation is always 2.
One area of the brain that is active during all these tests is the dorsolateral prefrontal cortex.
The activity increases as the test-question becomes harder.

Multiple Intelligences



In 1983, Howard Gardner in the book *Frames of Mind* argued for the existence of multiple intelligences, as opposed to a single general factor. He proposed that education should be adjusted to these innate abilities.

Most psychometricians and psychologists do not agree with this fractionation of intelligence, and it has no clear experimental support.

However, it has intuitive appeal – we all know people who are talented in one particular way. Whether these differences come from innate abilities or learning remains unknown.

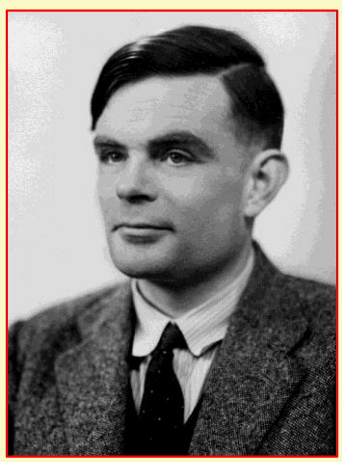
Howard Gardner has suggested that there are multiple intelligences.
The general factor may be related to the dorsolateral prefrontal cortex, and the different types of intelligence may be related to how that region interacts with other more specialized regions of cortex.

Artificial Intelligence

In 1950, Turing suggested that computers would soon intelligent behavior. He proposed a test: a human interrogator (or jury) would not be able to distinguish the computer from another human being, after a brief conversation.

In 1991, Hugh Loebner, an American inventor, established prizes for the first computers to pass the Turing test. None has yet won the silver (text only) or gold (audio and visual) prize.

Many computers now use programs based on neural principles (neural nets) to perform intelligently.

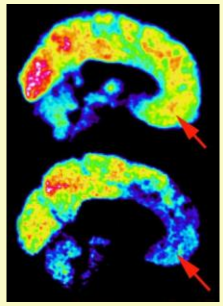


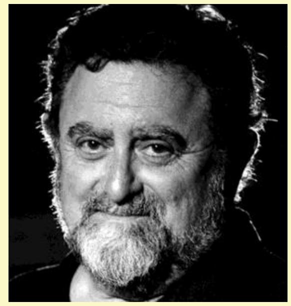
Alan Turing (1912-1954)

Computers can do many things much better than human beings.
However, they cannot yet act sufficiently like a human being that we cannot recognize the difference.

Psychopathy

Superficial charm
Grandiosity
Pathological lying
Lack of remorse or guilt
Lack of empathy
Irresponsible
Impulsive, fearless
Sensation-seeking
Promiscuous



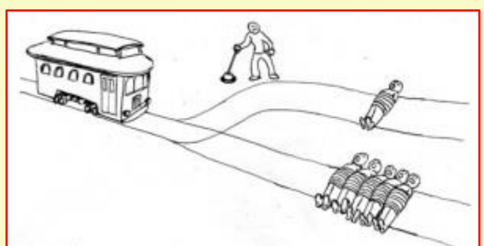


Most patients with Antisocial Personality Disorder show abnormalities in the **orbitofrontal cortex**, the **amygdala** and the **superior temporal gyrus**. There is also evidence that the brain’s **serotonin** system is abnormal, perhaps because of a genetic defect in the enzyme that metabolizes this transmitter. Some normal people may show many of the syndrome’s characteristics, and be quite successful – James Fallon is Professor of Anatomy at UC Irvine.

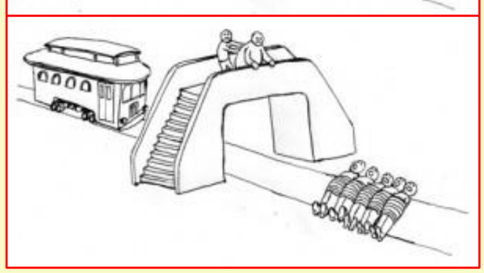
The orbitofrontal regions of the frontal cortex are involved in emotions and morality. Psychopaths often show abnormalities in these areas.
The upper scan is from a normal subject and the lower scan is from James Fallon. He found out that his own scan was indistinguishable from that scans of patients with antisocial personality disorder. He wrote a book about this in 2013 – *The Psychopath Inside.* He has also given TED talks on these ideas.
Several people have suggested that the psychopathic trait may help one succeed in competitive professions – running Apple, teaching anatomy. Provided it is properly controlled.

Moral Dilemmas

Trolley Problem

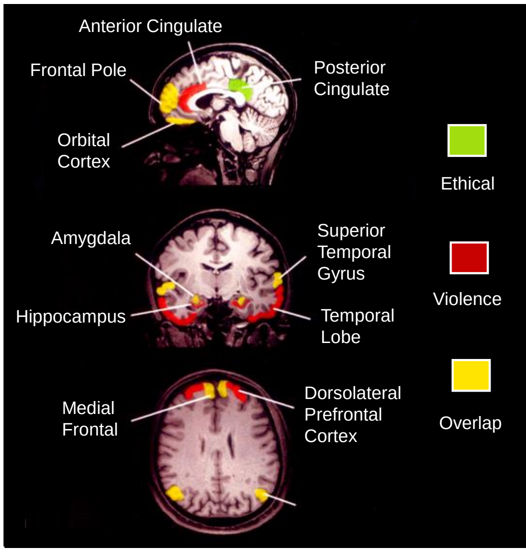


Footbridge Problem



These hypothetical problems have been used to evaluate what happens in the brain when one makes moral decisions.
Most people would change the switch so that one person rather than five are killed by the runaway trolley.
However, most people would not push the fat man off the footbridge to accomplish the same end-result.

And if the switch problem is recast as the transplant surgeon who wishes to take five different organs from a single healthy person to save the lives of five separate patients (each with a single-organ failure), no one would agree.
Figuring out what to do in these situations involves activity in many regions of the brain – particularly the anterior frontal lobes and the amygdala.



Moral Brain

When solving moral dilemmas, such as the Trolley Problem, many different regions of the brain are activated (green and yellow).

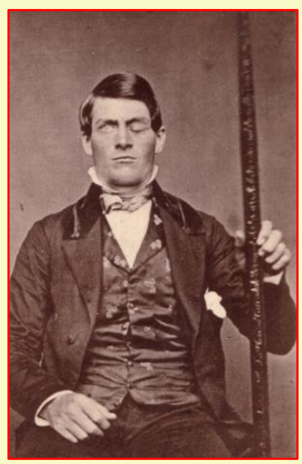
The areas of the brain found to be abnormal in violent offenders overlap extensively with these (red and yellow)

The areas used to figure out moral problems in normal brains overlap extensively with the areas that are abnormal in violent offenders.

The Myth of Phineas Gage

In 1848, Phineas Gage, a foreman on a railway construction gang, inserted gunpowder and fuse into a drill hole, probably forgot to use some covering sand, and then tamped the gunpowder with a metal rod. The powder exploded sending the tamping iron through his skull. After prolonged treatment by Dr. John Harlow, he appeared "quite recovered"

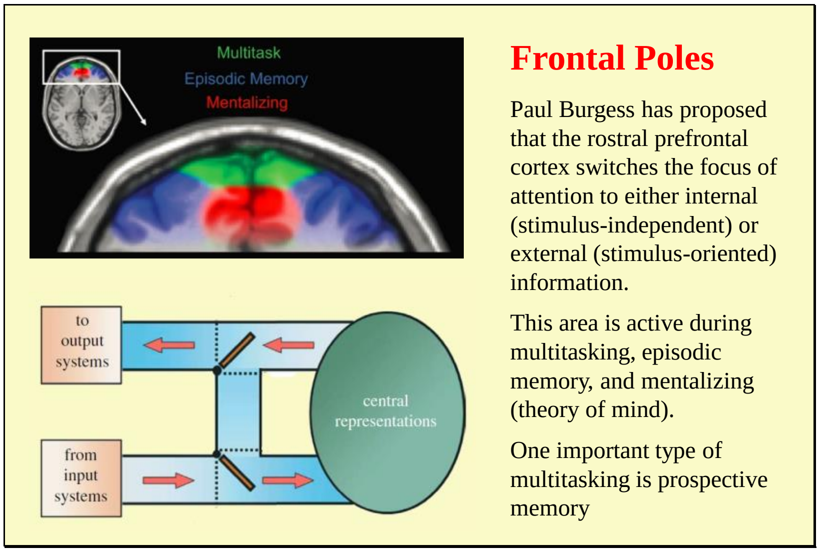
Harlow's 1868 report, suggested that the accident had drastically changed his personality – he was "no longer Gage." However, recent research has found that he was a conscientious worker until his death.



Phineas P. Gage (1823-1860)

Phineas Gage is probably the second most famous patient in the history of neuropsychology. (HM is the most famous)

Most studies have suggested that his brain damage indicated how the frontal lobes were involved in personality.
However, recent evidence has suggested that he actually did not change that much. His history therefore indicates the resilience of the brain (or the person) rather than its weakness.



Remember how we discussed the theory of mind in the session on consciousness. Areas of the anterior frontal lobe were involved when thinking about the self or about the minds of others ("mentalizing" in this diagram).
Thinking about the self is a stimulus-independent process.

Prospective memory is remembering to do something in the future. This is something that we have trouble with as we grow older.

It is probably similar to doing multiple tasks at the same time. While we are doing other things we must maintain in working memory an idea of what we have to do later.

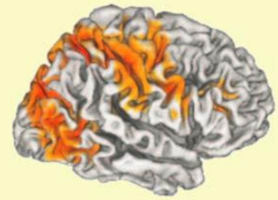
Attention Networks

Lesion studies have shown that

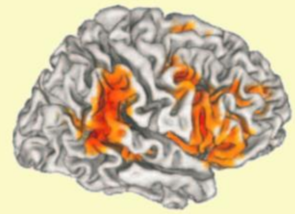
(i) the right parietal area is important for the spatial allocation of attention.
(ii) The anterior frontal lobes are essential to energization, task-setting and monitoring.

Blood flow studies (right) have identified two different networks that are active during attention – one goal-directed and one stimulus-oriented (Corbetta and Shulman, 2002)

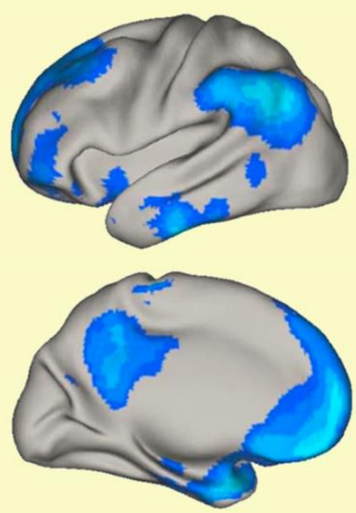
Dorsal Attention System (Goal-Driven)



Ventral Attention System (Stimulus Driven)



Attention is one of the major functions of the frontal lobe.
However attention is not localized in the frontal regions. Rather it involves interactions with other areas of the brain, most importantly the right parietal region which controls the spatial allocation of attention.
Two different attention-circuits occur – one directed to getting something done, and one directed to finding something out.



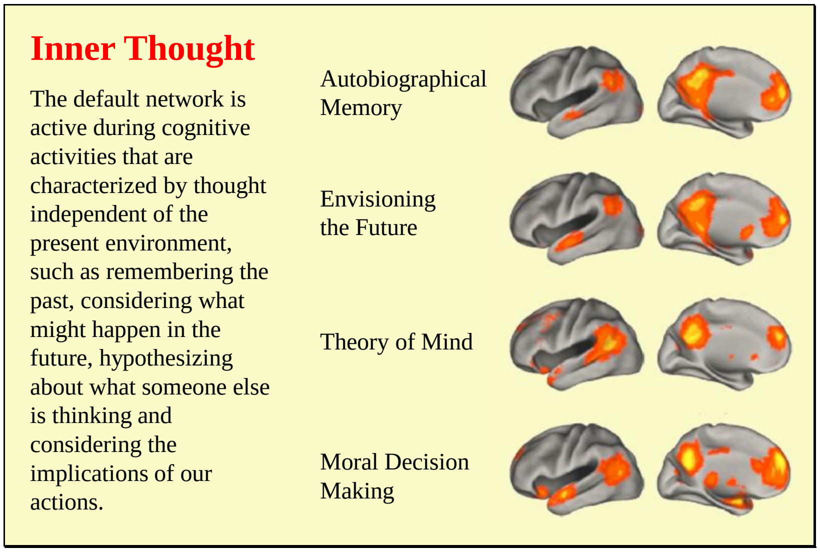
Default Network

Randy Buckner and his colleagues originally identified a set of brain regions that were active when the brain was at rest and deactivated during the performance of a specific task:

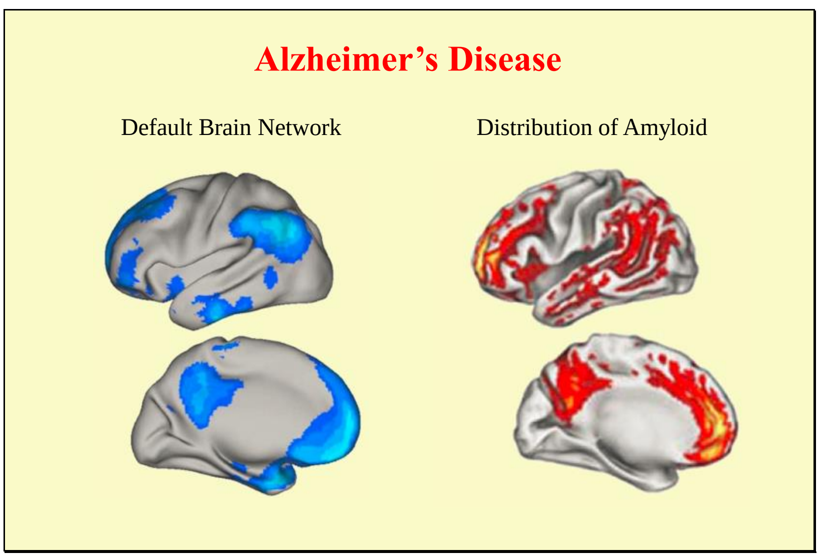
- Ventromedial prefrontal cortex
- Posterior cingulate
- Inferior parietal lobule
- Lateral temporal cortex
- Dorsomedial prefrontal cortex
- Hippocampus

These areas were also shown to be actively interconnected. They form one of the brains main networks.

This is the brain during the state of mind that we often call “revery” or daydreaming.

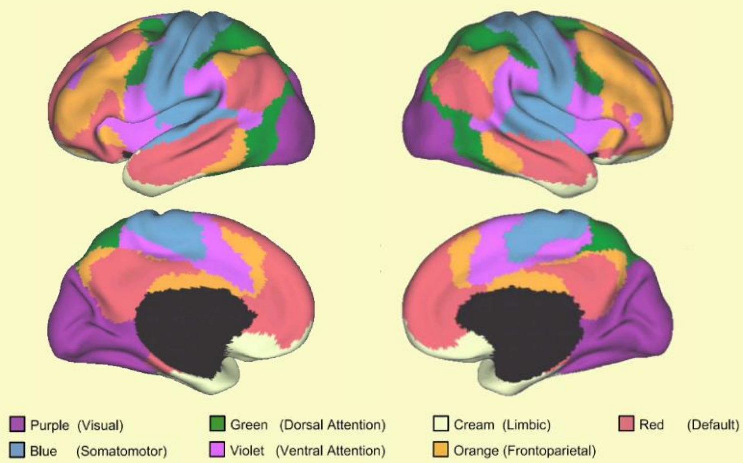


Inner thought of various kinds involves the default network – those areas of the brain that are active when we are not doing something else.



Interestingly, the distribution of amyloid deposits in Alzheimer’s Disease is similar to the default network.
This is different from the distribution of neurofibrillary tangles, which are most prominent in the medial temporal regions.
Why is not known. Perhaps the default network is the most active of our brain networks.

Brain Networks



Recent MRI studies of the brain have noted multiple different brain networks.
These may represent the modes of thought. Sometimes we are seeing the world, sometimes operating our bodies, sometimes paying attention, sometimes remembering, sometimes planning, sometimes doing nothing.

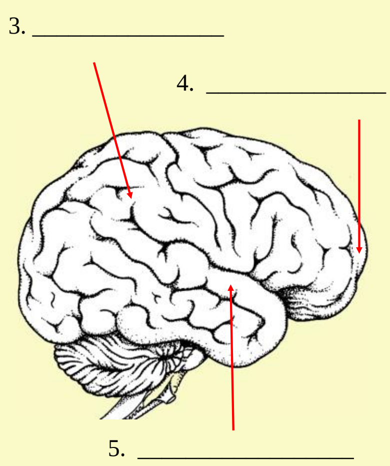
Quiz 8B

1. Which brain region is part of the "default network"

A) Precentral Gyrus
B) Calcarine Fissure
C) Inferior Parietal Lobule
D) Supplementary Motor Area

2. Which symptom is **un**common in Frontotemporal Dementia:

A) Wernicke's aphasia
B) behavioral problems
C) apathy
D) anomia



Jackson Pollock, Convergence, 1952

This is one of Jackson Pollock's abstract paintings. Everything is related; everything overlaps; nothing is just in one place; nothing is simple. Like the networks of the human brain.

The course is finished. I have probably told you much more than you will remember. Nevertheless, I hope that some of it has made sense and helped you to understand how the brain works.

Eat well, exercise, keep thinking, learn new things, talk to one another – these are the ways to keep the brain healthy. Most important is to keep thinking.

As Emily Dickinson said "The brain is wider than the sky."
The conscious brain is as complex as the universe that it tries to comprehend.

The Brain—is wider than the Sky—
For—put them side by side—
The one the other will include
With ease—and You—beside—

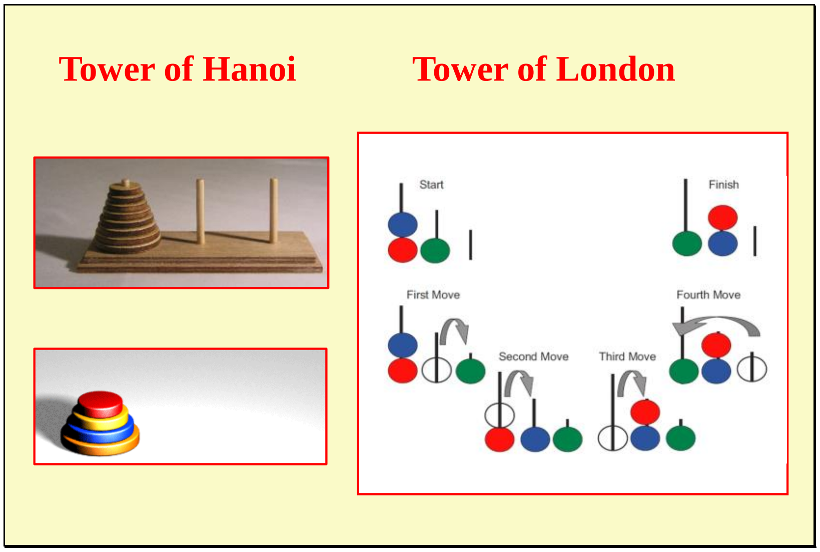
The Brain is deeper than the sea—
For—hold them—Blue to Blue—
The one the other will absorb—
As Sponges—Buckets—do—

The Brain is just the weight of God—
For—Lift them—Pound for Pound—
And they will differ—if they do—
As Syllable from Sound—

Emily Dickinson, 1863

Slide 51

Slide 52



The Tower of Hanoi is a game that requires setting up strategies and keeping the goal in mind. Tim Shallice invented a variant game – the Tower of London. The rules are simpler and the endpoint can be varied.

Slide 53

Fractionation of Frontal Function

Rather than considering the prefrontal lobes as a general purpose computer that is used on demand for performing tasks, some scientists have proposed that different regions of the prefrontal cortex subserve different functions.

Don Stuss and his colleagues at the Baycrest Centre have identified three separate functions:

1. **Energization** – implemented by the medial frontal lobes
2. **Task setting** – disrupted by lesions to the left frontal cortex.
3. **Monitoring** – associated with the right inferior frontal lobe.

One simple task that can dissociate these function is **tapping** at a regular rate – once every 1.5 seconds.

Patients with medial lesions cannot maintain their timing – they start out well but then deteriorate. Patients with right frontal lesions are much more variable than either normal subjects or patients with other frontal lesions – they have difficulty monitoring their performance.

In the tapping task, you are given six timed tones to get you going.