GETTING THE BIG PICTURE: HIGHER CORTICAL BRAIN FUNCTIONS

READING: Integration of sensory and motor function: The association areas of the cerebral cortex and the cognitive capabilities of the brain, Saper, Iversen, and Frackowiak, Chapter 19, *Principles of Neural Science*, 4'th edition.

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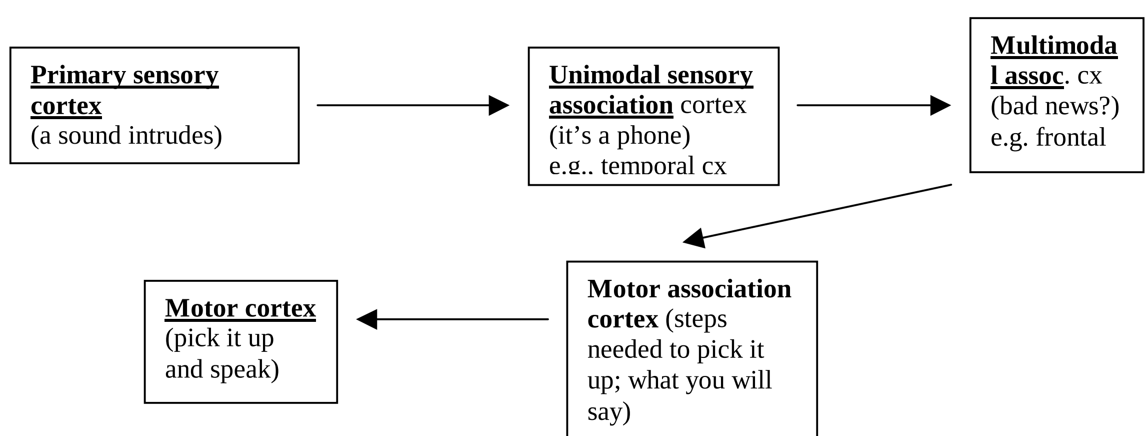
INTRODUCTION: The purpose of this lecture is to acquaint you with the organization of the structure and function of the neocortex as it relates to cognition.

For the most part, neuroscientists study in great detail the "small stories" of the brain, i.e., how a neurotransmitter is packaged, how ion channels within a neuron are structured and controlled, what the firing patterns of a group of clearly defined neurons are, why and when changes in transcription occur during development, etc. There is, however, a whole branch of neuroscience that tries to synthesize and understand the way that brain structure and functioning regulates cognition. This field is broadly defined as cognitive neuroscience. Cognitive neuroscience endeavors to understand how subcellular and cellular brain processes feedforward to ever larger groups of neurons which, in turn, allow us to think, be aware, and feel. *Cognitive neuroscience is a study of the neural mechanisms that control cognition and awareness.*

COGNITIVE PROCESSING GOES FROM THE SPECIFIC TO THE GENERAL

You wake up in the middle of the night hearing a sound. As you arouse to wakefulness, you become aware that the sound is a phone ringing. A moment of two later, your brain fully kicks into gear and you become aware that there could be some problem given that you are being called in the middle of the night, and you pick up the phone with some apprehension.



In the above example, the auditory cortex is activated when a sound reaches the auditory cortex (i.e., a type of **primary sensory cortex**) in Heschl's gyrus (after the brain was roused and alerted by subcortical systems). The slowly dawning awareness that the sound is a phone ringing comes from some preliminary processing of the sound in temporal cortex near the auditory cortex (this is an example **of unimodal sensory association** cortex). Finally comes the larger picture of awareness, that phone's ringing late in the night are unusual, often associated with bad news, and that there needs to be a response to the ringing (i.e., pick it up). The association of sound, a phone, night, fear, anxiety, and concern, and past memories of what a phone ringing at night means are all processed in **multimodal association cortex** (s).

Sensory Association Cortex

1. **Primary sensory cortex—**that part of the *neocortex* that processes the incoming sensory signal from subcortical structures.

2. **Unimodal sensory association areas—**that part of the brain that constructs the received sensory signal into a meaningful percept. The percept is constructed only in the one sensory domain that the primary sensory cortex perceives (i.e., sound, sight, sensation). For example, a sound is now perceived as a phone ringing, a shape the percept of a tree, a sensation from the fingertips as a keyboard, etc.

3. **Multimodal sensory association areas**—cognition is now integrated across domains and output is sent to the motor cortex. The sound of a car-horn and the sight of a car veering into your lane is linked to an emotional response of danger---your limbs are directed to steer away. The shape of a series of dark lines are connected to "phonemic" representations and semantic understanding and you read, with comprehension, a letter out-loud.

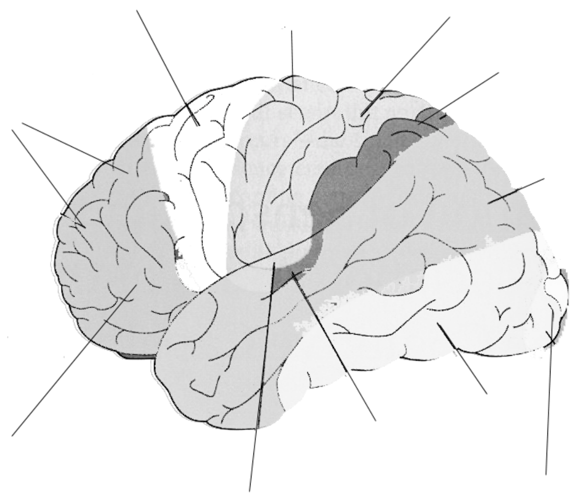
Motor association Cortex

1. **Motor association cortex—**motor plans for coordinated movements and the associated cognitive activities occurs here. Knowing how a hand would move to manipulate a hammer, for example, is the type of activity modulated by motor association cortex.

2. **Primary motor cortex—**executes the motor plans.

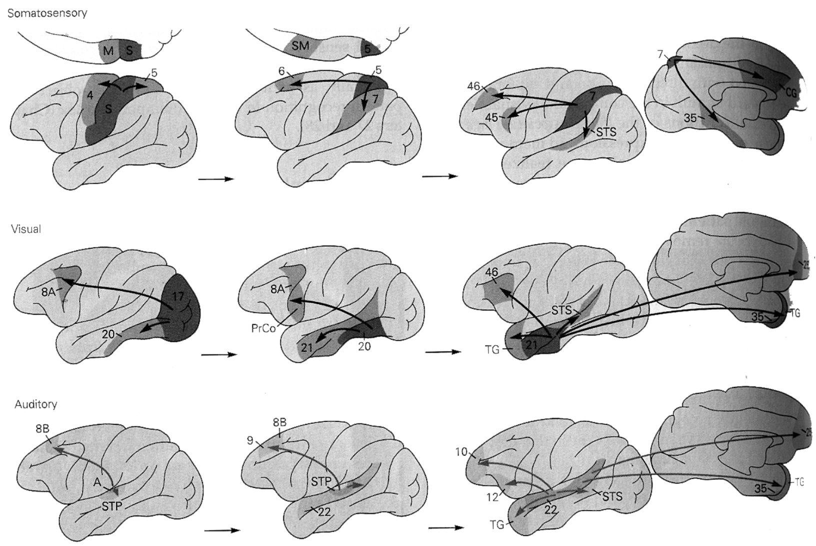
GENERAL RULE: Information flows from the primary cortex, to the unimodal association sensory cortex, to multimodal association sensory cortex, to motor association cortex, and then to motor cortex.

As shown in the figure and table, **primary sensory cortex** is found in the parietal occipital, and temporal cortex. **Unimodal sensory association** areas generally are in close opposition to the **primary sensory** cortex, and are found in the parietal (limb/body position, sensation, pain), temporal (also called Heschl's gyrus, sound) and occipital (also called the calcarine cortex, vision) cortex. **Multimodal sensory association** areas are found in the parietal/ temporal/ parietal junctions and frontal cortex. You should be able to identify all of the following structures on the figure of the brain.



Functional designation	**Lobe**	**Specific Location**
Primary sensory cortex		
Somatosensory	Parietal	Postcentral gyrus
Visual	Occipital	Banks of calcarine sulcus
Auditory	Temporal	Heschl's gyrus
Unimodal sensory association cx		
Somatosensory	Parietal	Posterior parietal
Visual	Occipitotemporal	Inferolateral surface of occipital and temporal lobes
Auditory	Temporal	Superior temporal gyrus
Multimodal sensory assoc cx		
Posterior (reading, writing, visuospatial localization, attention)	Parietotemporal	Junction between lobes
Anterior (motor planning, language production, judgement, etc)	Frontal	Prefrontal cortex (rostral to premotor areas on dorsal and lateral surfaces)
Limbic (emotion, memory)	Temporal, parietal, frontal	Cingulate gyrus, hippocampal formation, parahippocampal gyrus, amygdala, etc
Motor association cortex		
Premotor (motor preparation and programs)	Frontal	rostral to primary motor cortex
Primary motor cortex		
Motor cortex (movement of a joint along a vector)	Frontal	Precentral gyrus

Generally, after the primary sensation is processed, the organism ultimately generates a response if it is judged as "important" by limbic system input. In most organisms the "generated response" is motor activity (i.e. a lizard sees a fly, coordinates a motor response, and then jumps at it and eats it). This may take the form of flight, fight, seek a reward, avoid an aversive stimulus, mate, etc. Whatever the response, the general principal is that there is a higher level type of "reflex" arc that begins with a sensation and ultimately causes a motor response.



Injury to the primary sensory or unimodal association cortex

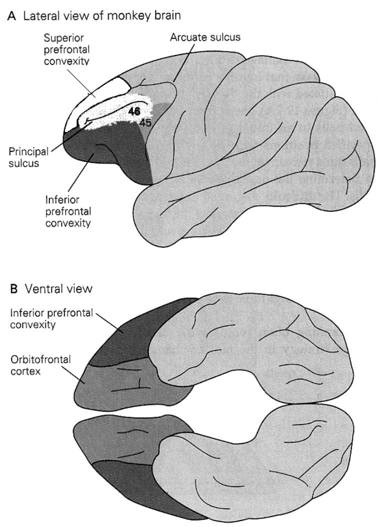
Injuries to these brain regions cause distinctive types of cognitive impairment. First, lesions to the primary sensory cortex cause a total and permanent loss of the ability to perceive the sense mediated by the cortex. Lesions of the calcarine sulcus cause blindness, to the auditory cortex deafness, and to the somatosensory cortex loss of touch and limb kinesis. When only one hemisphere of the brain is affected, then the loss most often is in the contralateral "organ".

On the other hand, loss of unimodal cortex often appears to cause similar deficits. For example, loss of areas 18/19 (unimodal cortex of the visual system) will cause the person to appear to be blind. However, that individual will retain all of the visual reflexes, such as blinking when hands are clapped in front of their face, etc., due to the fact that the primary sensory cortex is intact. This particular condition is referred to as psychic blindness.

MULTIMODAL ASSOCIATION SENSORY CORTEX

There are three areas of the brain defined as being multimodal association sensory cortex, including the anterior association cortex (e.g., prefrontal cortex), the posterior association cortex, and the limbic association area.

1) **Anterior sensory association area (prefrontal cortex)**. In the monkey and the human, the prefrontal cortex is typically divided into a dorsal, mesial, and orbital (ventral) region [note: in point of fact, the prefrontal cortex is anatomically and extremely complex region of brain that has many anatomically distinct regions and projections that are only grossly captured by these subdivisions]. In the monkey, the principal sulcus is the anatomical landmark that delineates these regions.

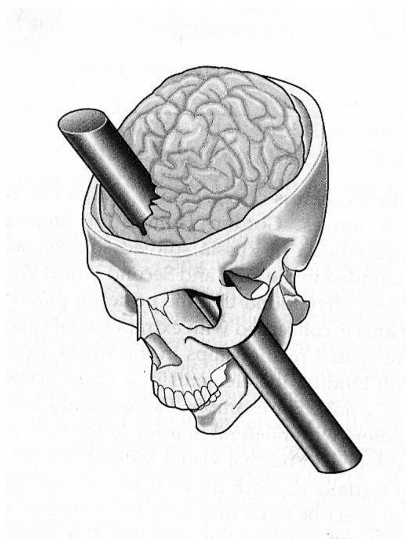


The prefrontal cortex (PFC) is the region of the brain that controls "executive functions". If you think of how an executive in a company does his/her job, motivating staff, coordinating activities, planning for the future, running multiple tasks simultaneously, organizing how the company is run, and generally "taking charge" of day-to-day operations of the company, you have a good idea of the role of the PFC. The PFC organizes, weighs future consequences of actions, problem solves, goal plans, and maintains social appropriateness matched to the situation at hand. These functions can be divided somewhat further by consideration of the various different PFC regions.

i) Dorsal prefrontal cortex: Particularly important in the organization of memory and other activities. Lesions of the dorsal PFC cause impairments of working memory. Working memory is "moment-to-moment" memory where attention and organization factors are key. Getting a phone number from the phone book and remembering the numbers in the correct order (while talking to you spouse about what movie they want to see) is an example of working memory. Going to the store to get several items, then forgetting what all of the items were when you get there (only to remember them on the drive home) is an example of working memory gone astray. In the monkey, the ability to do a delayed alternation task would be another example. Working memory normally "drops off" with aging, and is particularly susceptible to injuries that occur in the PFC.

ii) Mesial PFC: The initiation of motor movements, and the output region of motor planning regions. People with lesions here often can't initiate thoughts, actions or speech. An example of this will be shown on video of a Huntington's disease patient who cannot easily execute a complex motor pattern.

iii) Orbital/ventral PFC: Weighs future consequences of actions. The ability to inhibit socially inappropriate impulses, to follow social conventions, etc., are processed by this region. Phineas Gage's lesion was predominantly to this brain region, and his inability to be reliable, social, and responsible is attributable to his orbital PFC lesion.

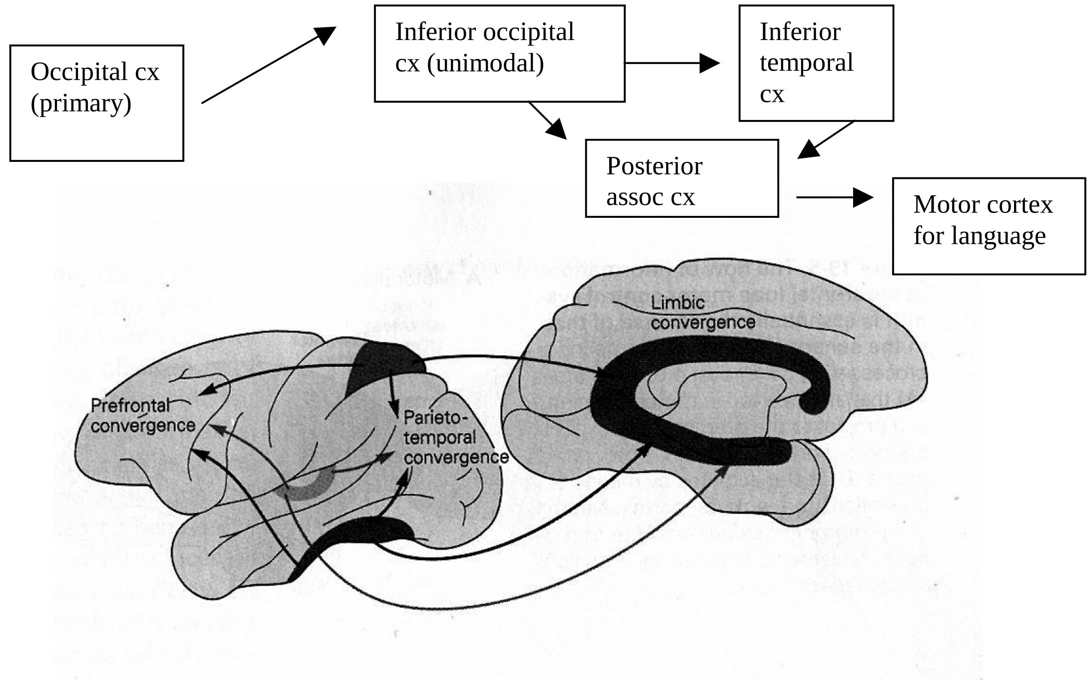


The above computer reconstruction shows the path of a railroad iron driven through the skull and brain of Phineas Gage. Gage went from a highly reliable family man and foreman on the railroad to a wild, erratically behaving man with disinhibited sexual behavior. The ability to be socially appropriate, to follow social rules, and to conform to social behaviors is controlled by the orbital PFC. Psychopathy has been suggested to result from dysfunctioning in this region of the frontal lobes.

2. Posterior association cortex:

This is found at the margin of the parietal, temporal, and occipital lobes. This brain region links information from several sensory modalities for perception and language. Injury may cause complex deficits in higher cortical functioning, such as agnosia (the inability to recognize familiar objects), aphasia (disorders of speech), visuoconstruction apraxia (disorders of drawing), dyscalculia (the ability to calculate), etc.

Depending on where the lesion in the posterior multimodal association cortex, a patient may have very different types of problems. In one case, they might be perfectly fluent but unable to recognize objects. In another, they might be perfectly fluent but be unable to read. In yet another, they might be unable to read, or write, or both.

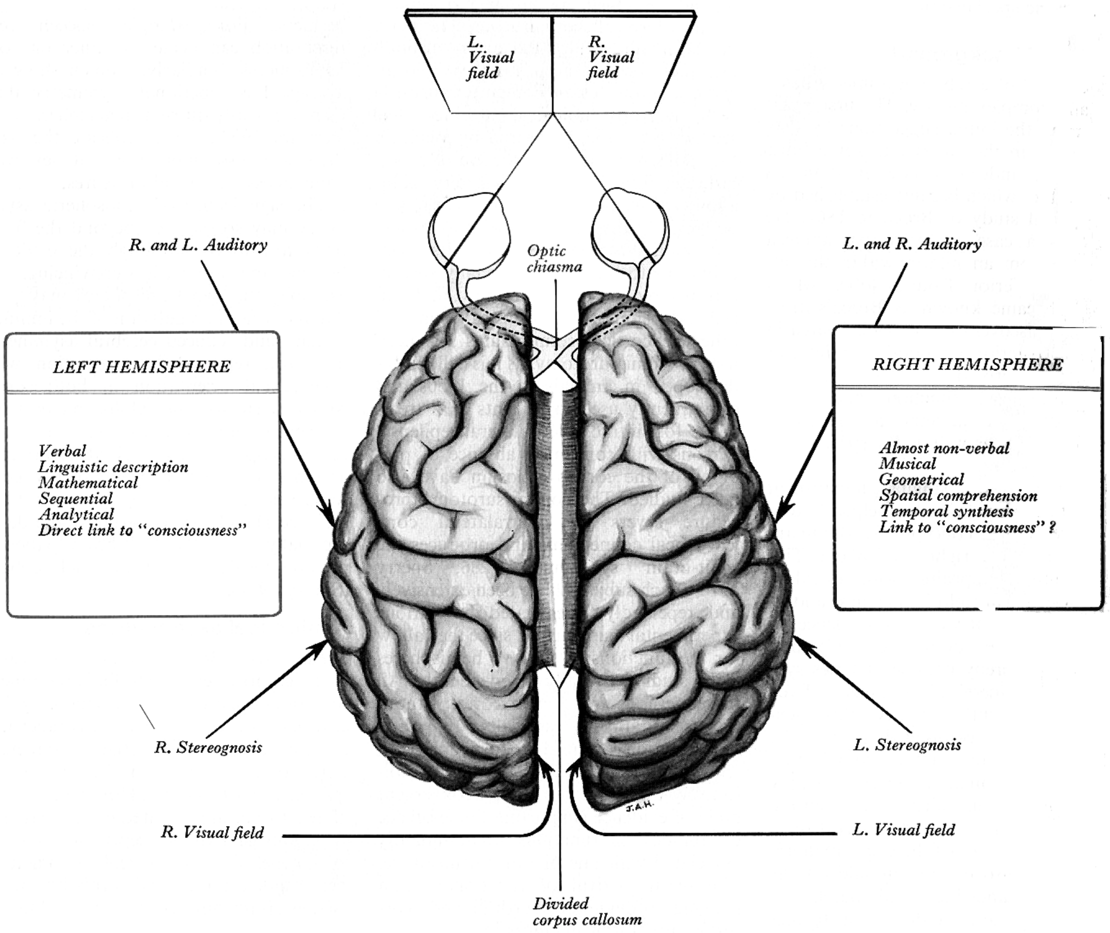


3. The limbic association cortex:

The limbic lobe is that tissue that, in a parasagittal cut, can be seen "circling" the inside layers of the neocortex and providing a "link" between neocortex and subcortical structures. Most prominent among these structures is the cingulate cortex. The limbic system is a more general term. The limbic system contains the limbic lobe plus all of the subcortical brain regions that project to, and receive projections from, the limbic lobe. Generally, the limbic system is the major regulator of emotion and motivated behavior in the brain. Systems that encode short-term memory (i.e., the hippocampus) are also contained in the limbic lobe.

ASYMMETRIES IN THE BRAIN:

When the left half of the brain is compared to the right half of the brain, they generally look quite similar on gross examination. Nonetheless, generally the left neocortex processes different information from the right neocortex. In most left and right handers, the left hemispheres processes language (i.e., is dominant for it). The right hemisphere can understand simple language but can "output" little to no information in the form of spoken language. The left hemisphere is also dominant for the control and perception of stimuli from the right half of the body, including touch, sensation, sight and hearing. Conversely, the right hemisphere is dominant for the processing of emotional content, visual-spatial analysis, and sensation and motor movements from the left half of space. These differences are summarized in the drawing below.


L. Visual field
R. Visual field
Optic chiasma
R. and L. Auditory
L. and R. Auditory
LEFT HEMISPHERE
Verbal
Linguistic description
Mathematical
Sequential
Analytical
Direct link to "consciousness"
RIGHT HEMISPHERE
Almost non-verbal
Musical
Geometrical
Spatial comprehension
Temporal synthesis
Link to "consciousness"?
R. Stereognosis
L. Stereognosis
R. Visual field
L. Visual field
Divided corpus callosum