Cortical Integration

Learning Objectives:

A) Develop an appreciation for how visual information is processed in the primate brain beyond V1.

B) Understand the role in cognition of prefrontal cortex (PFC), particularly dorsolateral PFC.

C) Recognize the importance of corticocortical circuits for both A and B.

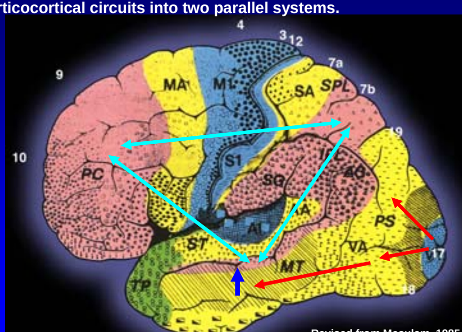
D) Understand why damage to high level visual association areas or prefrontal cortex leads to the observed deficits in humans.

Vision: An example of unimodal cortical integration.

Cognition and prefrontal cortex: An example of polymodal (some would say "supramodal") cortical integration.

The progressive integration of information into more complex images, thoughts, "rules", decisions, and commands is dependent on corticocortical connections.

Visual processing involves 25-30 cortical regions, linked through corticocortical circuits into two parallel systems.

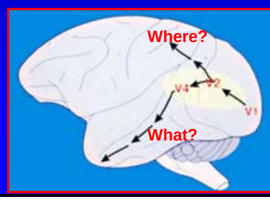


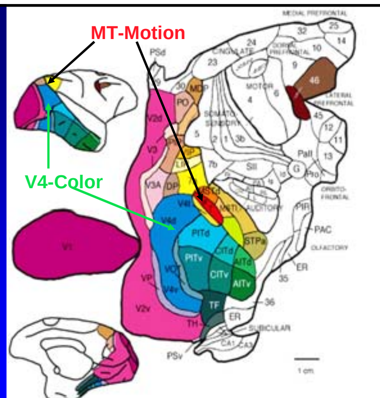
Cognition requires connections between polymodal areas, with convergence in prefrontal cortex.

Our knowledge of the organization of the visual system is based largely on studies of macaque monkeys.

Visual information arrives in V1, and remains segregated in two parallel systems with different functions.

Corticocortical connections link multiple visual areas.



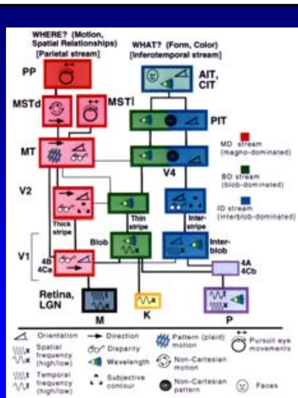


A "flat map" of visual cortex.

Each visual area has its own retinotopic map.

Felleman and Van Essen

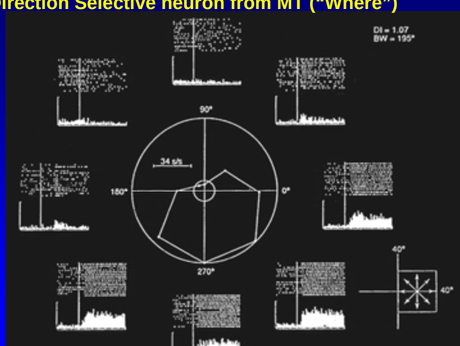
Electrophysiological studies in monkey visual areas reflect the existence of two streams and regional specialization within each stream.



There are preferred stimuli in each stream and each region, with increasing complexity further from V1

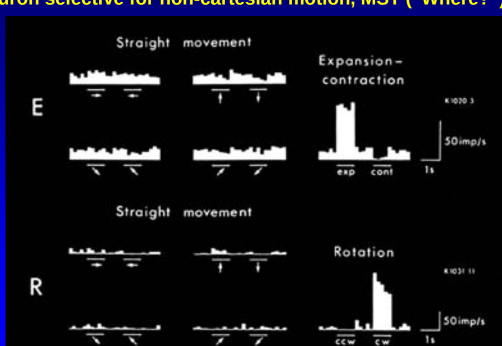
Van Essen and Gallant

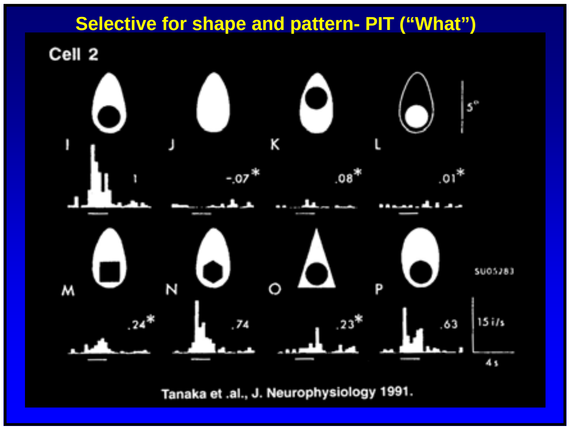
Direction Selective neuron from MT ("Where")

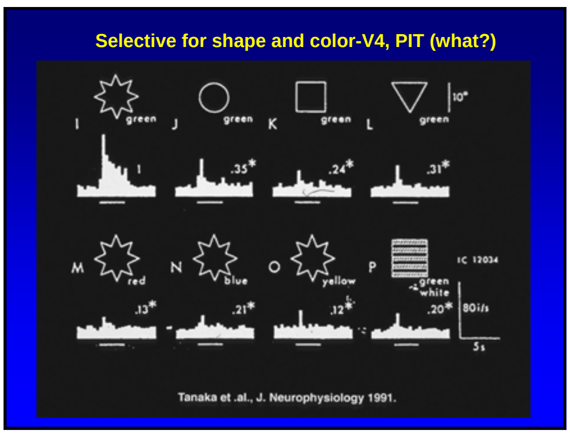


Colby et al

Neuron selective for non-cartesian motion, MST ("Where?")




Selective for shape and pattern- PIT (“What”)
Cell 2
I
J
K
L
1
-.07*
.08*
.01*
M
N
O
P
.24*
.74
.23*
.63
15 i/s
4 s
Tanaka et .al., J. Neurophysiology 1991.


Selective for shape and color-V4, PIT (what?)
green
green
green
green
I
J
K
L
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1
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.24*
.31*
M
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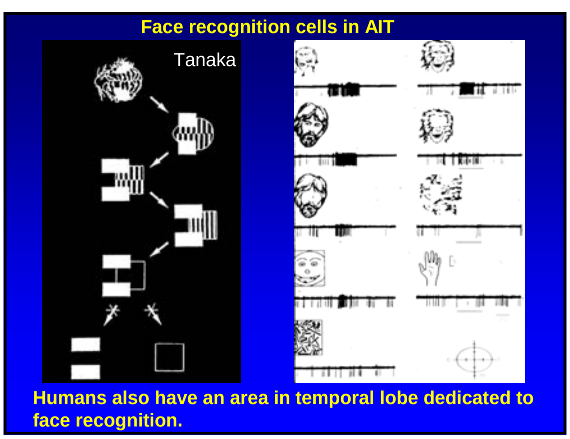
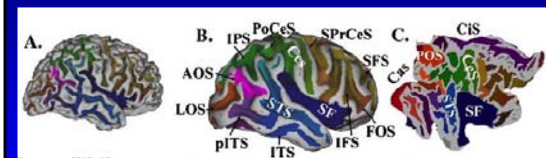
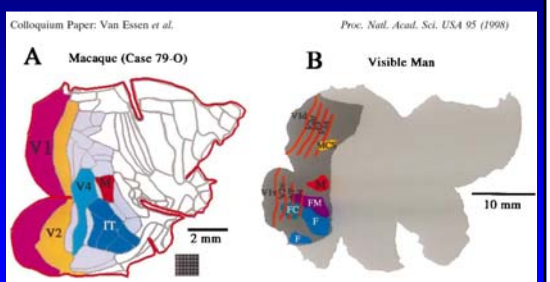
O
P
red
blue
yellow
green
white
.13*
.21*
.12*
.20*
80 i/s
5 s
Tanaka et .al., J. Neurophysiology 1991.


Face recognition cells in AIT
Tanaka
Humans also have an area in temporal lobe dedicated to face recognition.

Human Brain, with sulci designated by color (A) and expanded (B), with expanded version displayed as a flat map (C)



Flat maps of monkey and human neocortex, with key areas designated in monkey and some regional specialization of function shown for human.



F, form; C, color; M, motion; MCS, mixed functions

Disorders of higher cortical functions in humans: Vision

A) Disorders of pattern recognition

1. Visual Agnosia. Defined by Damasio as: "a disorder of higher behavior confined to the visual realm in which an alert, attentive, intelligent and non-aphasic patient with normal visual perception gives evidence of not knowing the meaning of those stimuli, that is, of not recognizing them."

2. Prosopagnosia. The inability to recognize previously known human faces or to learn new ones.

a) Generally they can perform complex perceptual tasks, and do not generally have visual spatial disturbances.

b) correlated with damage to the occipito-temporal region.

3. Visual object agnosia. In addition to prosopagnosia these patients have an inability to recognize even the generic class to which an object belongs (unable to know that a broom is a broom).

a) Comparable but more extensive damage than prosopagnosia to the ventral and medial parts of the occipito-temporal visual areas.

B) Disorders of spatial analysis

1. Balint's syndrome

a) Three major components: 1) Optic ataxia (impairment of target pointing under visual guidance. 2) Ocular ataxia (inability to shift gaze at will toward new visual stimuli). 3) Simultanagnosia (perception and recognition of only parts of the visual field.

b) Balint's syndrome is strongly related to bilateral damage of the occipito-parietal region.

Visual defects from localized damage in human neocortex reflect the existence of the occipito-temporal ("what") vs. occipital-parietal ("where") specializations of function characterized in monkeys.

Prefrontal Cortex and Cognition

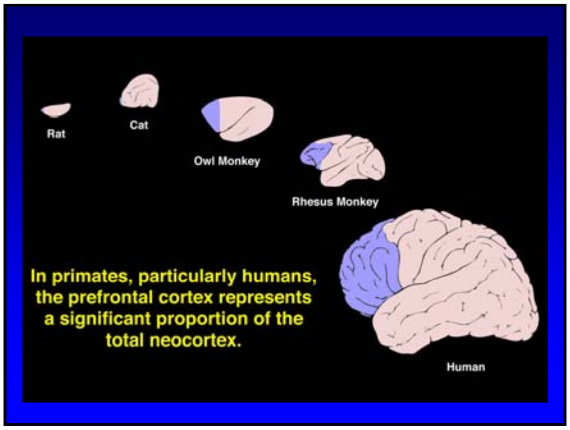
Prefrontal Cortex (dorsolateral) subserves functions such as:

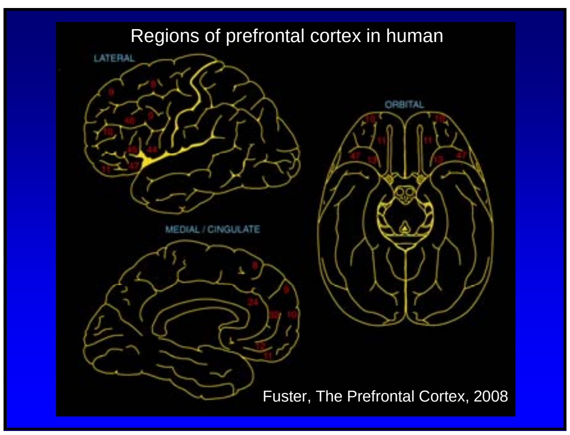
- **Working Memory**
- **Planning**
- **Temporal Structuring of Behavior**
- **"Top-Down" cognitive control, i.e., forming rules**
- **Modifying the rules**
- **Response inhibition**

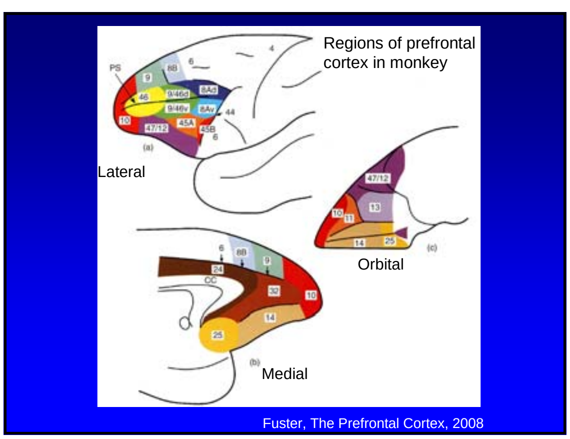
Patricia Goldman-Rakic: "Prefrontal cortex is necessary for regulating behavior guided by representations or internalized models of reality and is not required for behavior guided by external stimuli in the outside world."

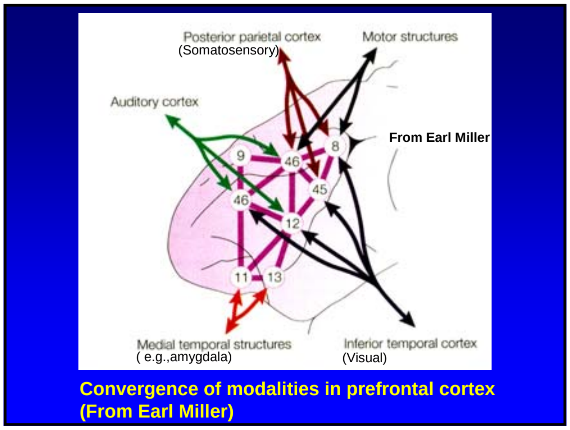
Earl K. Miller: "Nearly all intended behavior is learned and so depends on a cognitive system that can acquire and implement the 'rules of the game' needed to achieve a given goal in a given situation…the prefrontal cortex is central to this process."

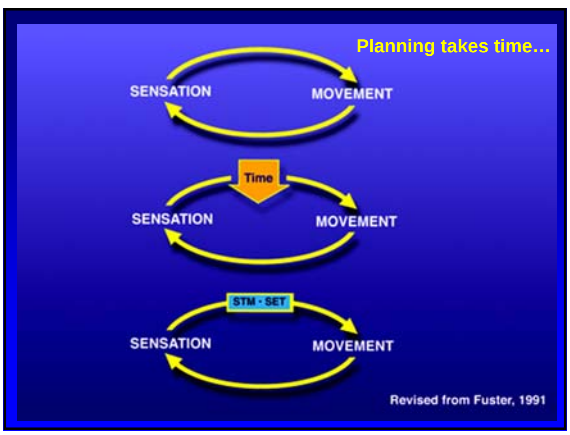
Joaquin M. Fuster: Prefrontal cortex coordinates cognitive functions in the "temporal organization of behavior; that is, in the formation of coherent behavioral sequences toward the attainment of goals."

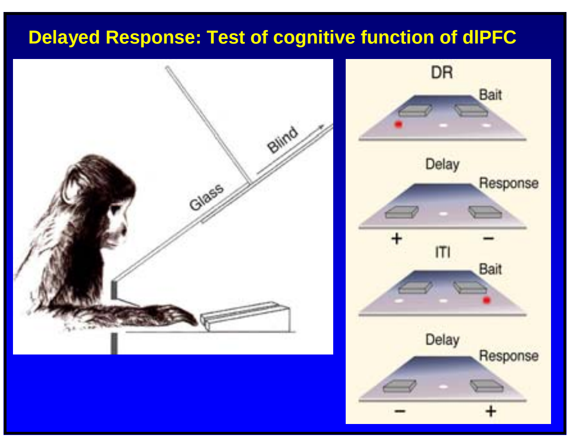

Rat
Cat
Owl Monkey
Rhesus Monkey
In primates, particularly humans, the prefrontal cortex represents a significant proportion of the total neocortex.
Human


Regions of prefrontal cortex in human
LATERAL
ORBITAL
MEDIAL / CINGULATE
Fuster, The Prefrontal Cortex, 2008

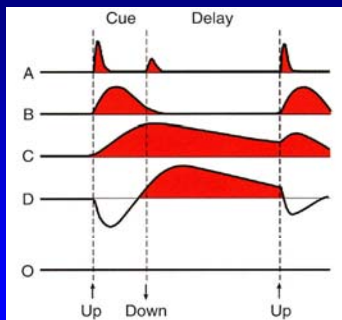

Regions of prefrontal cortex in monkey
Lateral
Orbital
Medial
Fuster, The Prefrontal Cortex, 2008


Posterior parietal cortex
(Somatosensory)
Motor structures
Auditory cortex
From Earl Miller
9
46
8
45
46
12
11
13
Medial temporal structures
(e.g.,amygdala)
Inferior temporal cortex
(Visual)
Convergence of modalities in prefrontal cortex
(From Earl Miller)


Planning takes time…
SENSATION
MOVEMENT
Time
SENSATION
MOVEMENT
STM - SET
SENSATION
MOVEMENT
Revised from Fuster, 1991

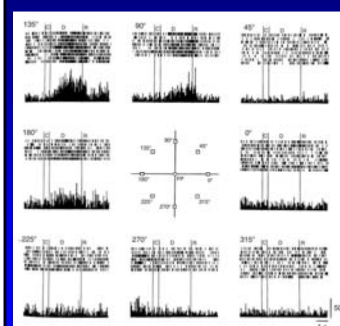

Delayed Response: Test of cognitive function of dlPFC
Blind
Glass
DR
Bait
Delay
Response
+
−
ITI
Bait
Delay
Response
−
+

Different patterns of neuronal responses during Delayed Response task. Note neurons that fire only during delay (D)



Fuster, The Prefrontal Cortex, 2008

Properties of Neurons in Prefrontal Cortex (Goldman-Rakic et al.) "Thinking is in the delay"



Delayed Response-spatial: Animal trained to fixate on FP. Stimulus flashes at specified angle from FP. Animal waits until FP goes off, then does a saccade to where stimulus had been.

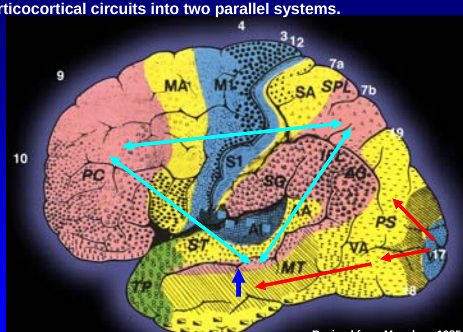
Key Characteristics of these neurons:

1) Active during delay

2) Spatially-selective(others are object-sensitive)

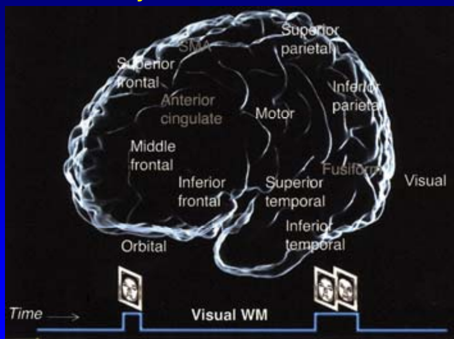
3) Resistant to distraction

Visual processing involves 25-30 cortical regions, linked through corticocortical circuits into two parallel systems.



Cognition requires connections between polymodal areas, with convergence in prefrontal cortex.

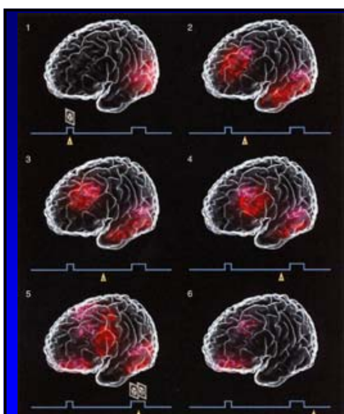
Delay tasks in humans with fMRI



Fuster, The Prefrontal Cortex, 2008

In the following examples, the primary locus of activity shifts with time as the cognitive demands evolve. Watch for the following patterns:

1) Visual stimulus (cue) activates visual cortex.
2) Early in delay (i.e., WM) dorsal PFC and posterior association region simultaneously active
3) The region of posterior association active depends on nature of modality (e.g., "what" vs. "where")
4) Late delay (Prep. Set), frontal activity moves to premotor in preparation for response
5) Motor cortex is active during choice and response



Delay task in humans with fMRI

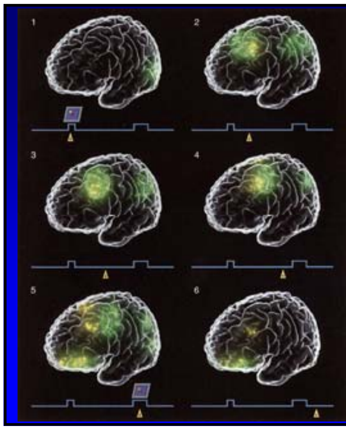
1) Visual stimulus- (form, face), activity in visual cortex during cue

2) During delay (WM), inferior temporal ("what" stream) and PFC simultaneously active

3&4) Late delay phase (Prep. Set), frontal locus moves into premotor

5) during choice (response) motor cortex active as well.

Fuster, The Prefrontal Cortex, 2008



Delay task in humans with fMRI

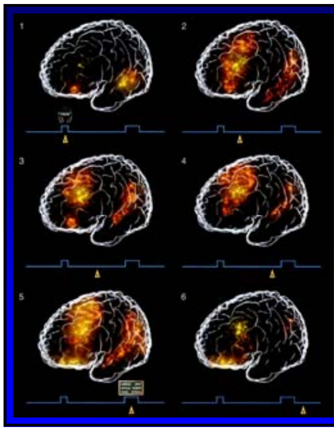
1) Visual stimulus-spatial (as with monkey), activity in visual cortex during cue

2) During delay (WM), inf parietal (“where” stream) and PFC simultaneously active

3&4) Late delay phase (Prep. Set), moving into premotor

5) during response, motor active as well

Fuster, The Prefrontal Cortex, 2008



Delay task in humans with fMRI

1) Auditory stimulus-word delivered through earphones. Auditory active

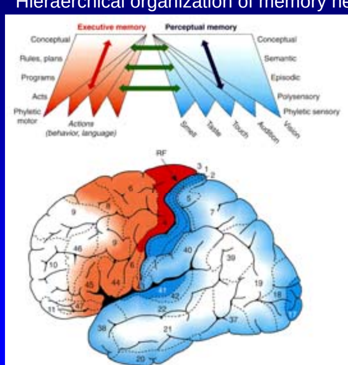
2&3) WM: Auditory assoc. and language areas posterior, dorsal PFC in frontal.

4) Late delay (Prep. Set) frontal locus moves caudally into premotor

5) During response, motor engaged and visual, since choice is presented visually

Fuster, The Prefrontal Cortex, 2008

Hieraerchical organization of memory networks



In the simplest terms, caudal to Central Sulcus is sensory/preceptual and rostral to CS is executive/motor.

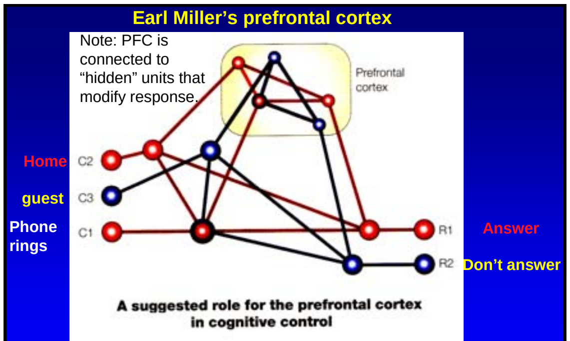
Lighter shades represent higher level perceptual and executive functions.

Bidirectional arrows represent perceptual corticocortical circuits (blue), executive CC circuits (red), and reciprocal projections across perceptual and executive domains (green)

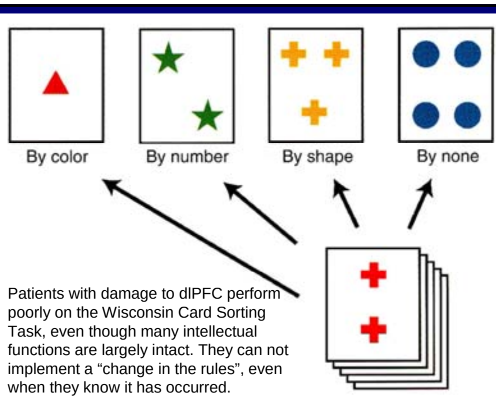
Fuster, The Prefrontal Cortex, 2008

Prefrontal cortex learns the rules for goal-directed behavior, and just as importantly, processes changes in the rules.

Earl Miller's prefrontal cortex



Prefrontal cortex is central to cognitive control: i.e, acquiring, implementing, and modifying the "rules of the game". As stated by Miller: "PFC engenders flexibility…dynamically selects among existing pathways."



Patients with damage to dlPFC perform poorly on the Wisconsin Card Sorting Task, even though many intellectual functions are largely intact. They can not implement a "change in the rules", even when they know it has occurred.

Cognitive Impairment Associated with Prefrontal Cortex Damage

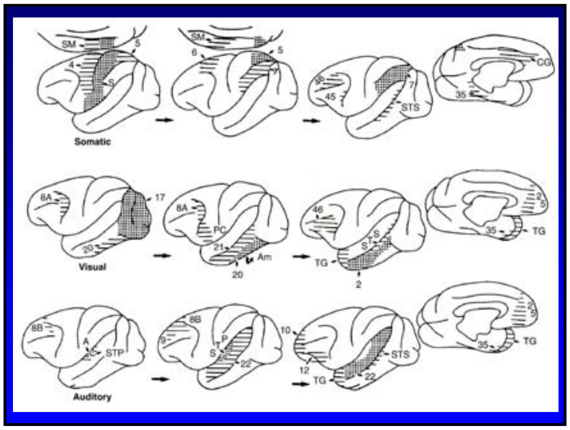
- Working memory deficits
- Problem solving deficits
- Impaired temporal order judgments
- Poor planning
- Impaired decision making
- Dysexecutive Syndrome/Impaired executive function
- Difficulty attending to a task
- Enhanced sensitivity to interference/distraction
- Perseveration
- Impulsivity/disinhibition

Take Home Messages:

A) Visual processing in the primate brain requires dozens of interactive cortical regions. There are two distinct but linked parallel streams- the "what" and "where" systems, and both reflect hierarchical processing with increasingly complex responses.

B) The prefrontal cortex receives highly processed input from virtually all major association regions and is capable of the highest level of cognitive functions, such as preparing a response, learning the rules, and changing the rules.

C) Complex and highly ordered systems of corticocortical circuits are required for A and B, above. Such circuits are particularly well-developed in humans, and their demise in disorders such as Alzheimer's Disease leads to dementia.


SM
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Somatic
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8B
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STS
CG
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Visual
8A
PC
21
20
Am
46
TG
2
35
TG
8B
A
STP
Auditory
8B
9
22
10
12
TG
22
STS
35
TG