NST II Psychology  
NST II Neuroscience (Module 5)

Brain Mechanisms of Memory and Cognition – 6

The prefrontal cortex

Rudolf Cardinal
Department of Experimental Psychology

Monday 13, 20, 27 Jan; 3, 10, 24 Feb 2003; 10 am
Physiology Main Lecture Theatre
Chess and morality

Bergman (1957): ‘Det Sjunde Inseglet’ (The Seventh Seal)
The prefrontal cortex

von Hagens (1996–): ‘Bodyworlds’
The prefrontal cortex across species

Fuster (1997)
Lateral PFC regions

SP = sulcus principalis
As = arcuate sulcus
PC = precentral sulcus
CS = central sulcus

SFS = superior frontal sulcus
IFS = inferior frontal sulcus
Medial and orbital PFC regions

Monkey medial

Monkey orbital

Human medial

Human orbital
Connections of PFC subregions differ. Example: striatal loops.
Frontal lobe lesions in humans

Poor judgement
Poor planning
Poor decision-making
Lack of initiative

Disturbed attention
Increased distractibility
Perseveration

Disinhibition (inc. socially and emotionally)

Release of primitive reflexes

Disordered ‘executive function’
Impaired ‘higher cognitive processing’
Dorsolateral prefrontal cortex
Raven’s *Progressive Matrices* — geometric analogy

Penrose & Raven (1936); Raven (1938); Prabharakan et al. (1997) — DLPFC activation
The Tower of Hanoi

Invented by Edouard Lucas (1883); activates PFC (Morris et al. 1993; Baker et al. 1996)

“Legend says that at the beginning of time the priests in a Hindu temple were given a stack of 64 gold disks, each one a little smaller than the one beneath it. Their assignment was to transfer the 64 disks from one of the three poles to another, with one important proviso — a large disk could never be placed on top of a smaller one. The priests worked very efficiently, day and night. When they finished their work, the myth said, the temple would crumble into dust and the world would vanish.”

(At one move per second, and $2^{64}–1$ moves, this task would take 580 billion years.)
Grant & Berg (1948); impaired after DLPFC lesions (Milner, 1963)
Memory encoding and retrieval (1)

‘Hemispheric asymmetric in encoding and retrieval’ (HERA) model.

Passive perception is a typical control for ‘encoding’.

Tulving et al. (1994); Nyberg et al. (1996; 1998)
Fig. 1 Frontal cortical activation peaks from multiple neuroimaging studies of episodic memory encoding. Significant frontal activation peaks from studies involving intentional encoding of verbal and non-verbal information.
Encoding material activates different regions of the PFC depending on the material encoded.

Kelley et al. (1998)
Delayed response task (1)

Friedman & Goldman-Rakic (1988); task originally by Hunter (1913)
FIG. 5.9. Activity of a prefrontal unit during five delayed-response trials. In each trial, a horizontal bar marks the cue period and an arrow the end of the delay (i.e., the presentation of the choice stimuli). Note the activation of the cell during the delay: over 30 sec in the upper three trials, 60 sec in the lower two trials. (From Fuster and Alexander, 1971, with permission.)

Fuster & Alexander (1971)
Delayed response task (3)

Fuster & Alexander (1970); Fuster (1995)
Self-ordered monitoring tasks

Petrides & Milner (1982); Petrides (1996)

A

No effect of DLPFC lesion.

DLPFC lesions impair monkeys.

Recognition

Monitoring

Choose novel object.

Choose object not previously chosen.

B

Pick one of the six stimuli; turn to the next card; pick another stimulus (until all six have been selected).

DLPFC lesions impair humans.

Petrides & Milner (1982); Petrides (1996)
Working memory: PFC maintains posterior cortex activity?

Two-colour DMTS

Four-colour DMTS


Fuster & Alexander (1970); Fuster (1995)
Attentional set and set-shifting

(b) Simple discrimination

(c) Simple reversal

(d) Compound discrimination

(e) Intra-dimensional shift (IDS)

(f) Distractor probe test

(g) Extra-dimensional shift (EDS)

from Crofts et al. (2001)
Extradimensional set shifts impaired by DLPFC lesions

Open = sham-operated controls.
Hatched = DLPFC lesion (area 9).
Filled = OFC lesion.

Dias et al. (1996)
Extradimensional set shifts impaired by parietal lesions in rats

Table 1. Example of a possible combination of stimulus pairs for a rat shifting from digging medium to odor as the relevant dimension

<table>
<thead>
<tr>
<th>Discrimination</th>
<th>Dimensions</th>
<th>Exemplar combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relevant</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>SD</td>
<td>Medium</td>
<td>Odor</td>
</tr>
<tr>
<td>CD</td>
<td>Medium</td>
<td>Odor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDS</td>
<td>Medium</td>
<td>Odor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reversal</td>
<td>Medium</td>
<td>Odor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDS</td>
<td>Odor</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Half of the rats switched from medium to odor, and half switched from odor to medium. The correct exemplar is shown in bold and can be paired with either exemplar from the irrelevant dimension. In the IDS and EDS, the stimuli were novel exemplars of each dimension.

Table 2. Stimulus pairs used

<table>
<thead>
<tr>
<th>Odor pairs</th>
<th>Medium pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jasmine versus vanilla</td>
<td>Foam rubber versus plastic beads</td>
</tr>
<tr>
<td>Mulberry versus patchouli</td>
<td>Gravel versus BBs</td>
</tr>
<tr>
<td>Cinnamon versus gardenia</td>
<td>Pine shavings versus shredded manila folders</td>
</tr>
</tbody>
</table>

The exemplars within a dimension were always used in pairs. That is, for example, whenever jasmine appeared as one odor within a discrimination, the other odor was vanilla. No two rats within the same group received the same combinations, but the lesion and control groups were matched. The order of presentation of exemplars and the combination of exemplars into positive (+) and negative (−) stimuli were determined by a pseudorandom series generated before testing.

Fox et al. (2003)
Neuropsychiatric links: schizophrenia? (1)

• Some symptoms of schizophrenia are successfully treated by antipsychotics; their efficacy correlates with their potency as dopamine D2 receptor antagonists. The PFC is regulated by dopamine (directly and at the level of the striatum via corticostriatal loops).

• Schizophrenics may be impaired on the Wisconsin Card Sorting Task (Goldberg et al. 1987) and spatial working memory tasks (Park & Holzman, 1992). DLPFC blood flow doesn’t increase normally when schizophrenics perform the WCST (Weinberger et al., 1992) — but note controversy.

• Schizophrenia has a strong genetic component (e.g. MZ twin concordance 45–50%; DZ twin concordance 5–15%). Asymptomatic relatives of schizophrenics are impaired on spatial working memory tasks (Park & Holzman, 1995).

• Are hallucinations a deficit in perceiving internally-generated auditory and visual images as self-generated? Imagery uses many of the same cortical regions as perception (Farah, 2000).

• Schizophrenics are impaired at perceiving whether images of moving hands are their own hand or somebody else’s (Franck et al., 2001).

• Lesions of the DLPFC in rats (prelimbic cortex) impair their ability to perceive that their actions cause a certain outcome.
Neuropsychiatric links: schizophrenia? (2)

sham-operated rats

Test of action–outcome contingency knowledge

prelimbic (~ DLPFC)-lesioned rats

Balleine & Dickinson (1998)
Inhibition: a central function of the PFC?

1. Go trials are more frequent than stop trials.
2. The median reaction time on go trials is calculated.
3. The time between the go and stop stimuli is adjusted until $p(\text{successful inhibition on stop trials}) = 0.5$. This means that the effects of the stop signal are fast enough to cancel 50% of initiated responses, i.e. the stop signal influences responding on average at the same time as the go signal.
4. The stop signal reaction time (SSRT) is then calculated as the time between the onset of the stop signal and the median response time on go trials.

Stop tasks activate the right inferior frontal gyrus in humans.
Right inferior frontal gyrus lesions increase the SSRT in humans (Aron et al. 2003).
Anterior cingulate cortex
Cingulate cortex

(The numbers don’t mean anything!)
Sexual stimuli activate the ACC

Childress et al. (1999); see also Garavan et al. (2000)
Cocaine addicts watching a cocaine video; activations correlated with subjective reports of craving

Cue-induced cocaine craving activates the ACC and OFC

medial temporal lobe — amygdala

OFC

ACC

Childress et al. (2000)
Errors in responding produce an EEG signal localized to ACC

Electrical studies of error-related negativity (ERN). (a) Scalp distribution of the ERN (the purple area shows the centre of scalp negativity). (b) Responses that are in error produce an ERN.

from Bush (2000)
The Stroop test

<table>
<thead>
<tr>
<th>congruent</th>
<th>neutral</th>
<th>incongruent</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue</td>
<td>willow</td>
<td>red</td>
</tr>
<tr>
<td>yellow</td>
<td>trek</td>
<td>green</td>
</tr>
<tr>
<td>red</td>
<td>prefect</td>
<td>blue</td>
</tr>
<tr>
<td>green</td>
<td>felicitous</td>
<td>yellow</td>
</tr>
<tr>
<td>blue</td>
<td>destructive</td>
<td>blue</td>
</tr>
<tr>
<td>green</td>
<td>milk</td>
<td>green</td>
</tr>
<tr>
<td>yellow</td>
<td>bore</td>
<td>yellow</td>
</tr>
<tr>
<td>red</td>
<td>selection</td>
<td>yellow</td>
</tr>
<tr>
<td>yellow</td>
<td>karyotype</td>
<td>blue</td>
</tr>
</tbody>
</table>

*Stroop (1935)*
The Stroop test activates the ACC

from Bush (2000)

The Counting Stroop: count the number of words present.
ACC hyperactivity in depression

from Drevets (2000)
Orbitofrontal cortex
Orbitofrontal damage: the case of Phineas Gage

Harlow (1848; 1868); Damasio et al. (1994)
Orbitofrontal damage: the case of Phineas Gage
Orbitofrontal damage: the case of Phineas Gage

Earl Miller (a prefrontal cortex researcher) with the tamping iron
Bechara et al. (1994)
Anticipatory SCRs precedes knowledge

Bechara et al. (1997); normals and patients with ventromedial PFC (OFC) damage
“He chose poorly.”

Spielberg (1989): ‘Indiana Jones and the Last Crusade’
OFC and amygdala lesions on the Iowa gambling task (1)

Bechara et al. (1999)
OFC and amygdala lesions on the Iowa gambling task (2)

Bechara et al. (1999)
OFC and amygdala lesions on the Iowa gambling task (3)

Bechara et al. (1999)
Choosing between small/likely and large/unlikely rewards


orbitomedial (11)

orbitolateral (10)

inferior convexity (47)
Another gambling task...
OFC lesions: wrong, slow, but not ‘risk-taking’

Rogers et al. (1999) Neuropsychopharm.
OFC neurons reverse rapidly during reversal-learning tasks

Rolls et al. (1996)
Reversal learning impaired by OFC lesions in marmosets

Open = sham-operated controls.
Hatched = DLPFC lesion (area 9).
Filled = OFC lesion.

Dias et al. (1996)
OFC lesions can induce impulsive choice in rats

Mobini et al. (2002)
OFC dysfunction in criminal psychopathy?

Mitchell et al. (2002) matched control prisoners (matched for age and performance on Raven’s matrices) with psychopathic prisoners and observed differences in their performance on gambling tasks. The graphs show a decrease in high-risk selection over blocks for both groups, with control prisoners showing a statistically significant decrease compared to psychopathic prisoners. The error bars indicate variability in the data, with the control group showing less variability in their performance than the psychopathic group, particularly in the Response Reversal task where psychopathic prisoners made significantly more errors than control prisoners.