Basic principles of attention and sensory decision-making, from sensory cortices to frontal areas
Organization and representation of goal-directed actions
Selection of potential actions
The ‘how’ (dorsal) pathway

• Do not mistake with the ‘where’ (old) pathway: SC and pulvinar
• Parietal cortex represents potential targets to reach with respect to body, and is involved in motor control (see Ramachandran, Balint’s syndrome)
The ‘how’ (dorsal) pathway

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• Lateral Intraparietal cortex (LIP):
  → highest-order area in the visual hierarchy of the dorsal stream
The ‘how’ (dorsal) pathway

- Do not mistake with the ‘where’ (old) pathway: SC and pulvinar

- **Parietal cortex** represents potential targets to reach with respect to body, and is involved in **motor control** (see Ramachandran, Balint’s syndrom)

- Lateral Intraparietal cortex (**LIP**):
  - highest-order area in the visual hierarchy of the dorsal stream
  - involved in gaze control, strongly connected with the frontal eye field (**FEF**) and superior colliculus (**SC**)

- Both LIP and FEF stimulation elicit **eye movement** (shorter delay for FEF [<20ms\(^*1\)], closer to motor output, than LIP [\(~40ms\(^*2\)]))
Defining PFC

- (Pre)frontal cortex comprises all the areas reciprocally connected with the mediodorsal (MD) thalamic nucleus
- Abundant dopamine innervation (contrary to parietal cx) $\rightarrow$ ADHDisorder

Preuss, 1995
Dissociation of functional roles of OFC and lPFC

- 2AFC attentional task
- Lesion of area 9 (lateral) or OFC
Dissociation of functional roles of OFC and lPFC

- 2AFC attentional task
- Lesion of area 9 (lateral) or OFC

- Lateral PFC controls **attentional shift** (Posner’s orienting attention)
- OFC deals with **mapping value to stimulus** (valence)/updating rule

Dias et al, 1996
Divisions of PFC

- **Medial and orbital frontal cx** (‘sensor’ PFC):
  - internal signals (from reward to emotions)

- **Lateral frontal cx** (‘doer’ PFC):
  - external signals (executive [top-down] attention, decision-making and cognitive planning)
Divisions of PFC

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- **Lateral** frontal cx ('doer’ PFC):
  - external signals (executive [top-down] attention, decision-making and cognitive planning)
  - largest growth in primates, and particularly humans (dotted region)

Preuss, 1995
Frontal cortex laminar organization

- With 5 layers, agranular cx is intermediary between neocx and allocx (hippocampus and piriform cx)

Zald, 2007
Defining PFC across species

Ventral (bottom) views

orbital PFC

Side view

Wise, 2008
Defining PFC across species

- Is mouse frontal cortex a replica-in-miniature of primate’s one?
- ? mouse mPFC ↔ primate dIPFC ?
Defining PFC across species

Passingham and Wise, 2012
Defining PFC across species

- Is mouse frontal cortex a replica-in-miniature of primate’s one?
- ? mouse mPFC ↔ primate dIPFC ?
  → MD reciprocal connections
  → widespread dopamine innervations

Sagittal views
medial PFC

Key:
- Allocortex
- Agranular cortex
- Dysgranular cortex
- Thin, lightly granular cortex
- 'Granular’, homotypical cortex

Wise, 2008
Defining PFC across species

- Is mouse frontal cortex a replica-in-miniature of primate’s one?
- ? mouse mPFC ↔ primate dIPFC ?
- cytoarchitecture do no suggest this view
- not completely supported by behavioral results in spatial delayed-response task
- still infra-, pre-limbic, agranular orbital and anterior cingulate are shared

Wise, 2008
# PFC nomenclature

<table>
<thead>
<tr>
<th>Species</th>
<th>Primates</th>
<th>Carnivores</th>
<th>Rodents</th>
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<tbody>
<tr>
<td>dlPFC</td>
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<td>mPFC</td>
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</tr>
<tr>
<td>OFC</td>
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<td>dlPFC</td>
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<table>
<thead>
<tr>
<th>Brodmann</th>
<th>Functional name</th>
<th>Other</th>
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<tbody>
<tr>
<td>8a</td>
<td>FEF</td>
<td>Prearcuate (monkey)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caudal lateral (humans)</td>
</tr>
<tr>
<td>46</td>
<td>Principal sulcus (monkey)</td>
<td>Middle frontal gyrus (humans)</td>
</tr>
</tbody>
</table>

Katsuki and Constantinidis, 2012
SENSORY DECISION-MAKING IN LIP
Selection of information and action in LIP

Snyder et al., 1997  Katsuki and Constantinidis, 2012
Selection of information and action in LIP

- RF are both sensory and motor-related.
- Tasks demanding **overt** attention make difficult to disentangle attention and motor action.

Gottlieb and Balan, 2010
Selection of information and action in LIP

- RF are both sensory and motor-related.
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Gottlieb and Balan, 2010
Selection of information and action in LIP

- In a conflict situation, LIP neurons **preferentially encode visual signals over motor decision**

→ Selected action can be contradicted or complemented in downstream areas

Gottlieb and Goldberg, 1999
Selection of information and action in LIP

- In a conflict situation, LIP neurons preferentially encode visual signals over motor decision
  → Selected action can be contradicted or complemented in downstream areas
- Only a few neurons coded gaze direction unambiguously

Gottlieb and Goldberg, 1999
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8-direction gaze task

Gottlieb and Balan, 2010
Selection of information and action in LIP

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Gold and Shadlen, 2007
RF are both sensory and motor-related.

Tasks demanding overt attention make difficult to disentangle attention and motor action.

Firing rate correlates with accumulation of sensory evidence.

→ LIP represents a final stage for the selection of specific courses of action, dynamically incorporating information (even at 0%!).

Gottlieb and Balan, 2010
Decision-related parietal activity in EEG

- EEG reflects a similar accumulation-to-thresholds dynamics than LIP neuronal pools

Kelly and O’Connell, 2013
Intracortical manipulation of accumulated information

Intracortical MT or LIP stimulation during motion presentation

Hanks and Shadlen, 2006
Gold and Shadlen, 2007
Intracortical manipulation of accumulated information

- Intracortical MT or LIP stimulation during motion presentation
- MT stimulation have much bigger effect

Hanks and Shadlen, 2006
Intracortical manipulation of accumulated information

- Intracortical MT or LIP stimulation during motion presentation
- MT stimulation have much bigger effect, in accordance to drift diffusion model

Gold and Shadlen, 2007
DECISION-MAKING IN PFC
PFC and decision-making

- Recordings in areas 8 (FEF) and 46

Kim and Shadlen, 1999
PFC and decision-making

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- Similar picture than in LIP
- **Competition** between different pools of neurons

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Kim and Shadlen, 1999
BOTTOM-UP AND TOP-DOWN ATTENTIONS

Parietal and frontal cortices
Rapid Plasticity in A1

Behavioral Paradigm

Parallel Auditory and Visual Tasks - Conditioned Avoidance

Tasks:
- Tone Detection
- Two-Tone Discrimination
- Click Rate Discrimination
- Click Rate Detection
- Light Discrimination

Time (1s intervals)

Symbols:
- TORC (Ref)
- Interrupted TORC
- Tone (Ref)
- Tone-in-TORC
- Steady Light
- Flashing Light

References:
A
B
C
D
E
Rapid Plasticity in A1

Ferret in Experimental Set-up

Quantifying Spectral Plasticity (i.e. Change in STRF shape)
**Tone Detection Task**

*Aversive*

![Graphs showing initial and detection STRF](image)

Systematic change at the target frequency across the A1 population

Fritz et al., 2003. Nature Neuroscience
dIPFC and adaptive behavioral gating

Fritz et al., 2010
dIPFC and adaptive behavioral gating

- Behavior-dependent task-relevant response in dIPFC

Fritz et al, 2010
dIPFC and adaptive behavioral gating
Top-down control

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- A1-FC LFP coherence reflects cross-area communication

Fritz et al, 2010
dIPFC and adaptive behavioral gating
Top-down control

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Control of attention through the brain network

Saliency map refers to the combination of bottom-up and top-down attentional effects to select salient stimuli.

**Bottom-up Control of Attention**
Attention is grabbed by salient stimuli that have high intrinsic value (such as a fast moving object).

Automatic highlighting of salient stimuli:
This is likely due to competitive interactions within a cortical region (see Figure 2) and flows in a bottom-up manner:

LIP → LPFC → FEF

**Top-down Control of Attention**
Attention is guided by internal values and goals, allowing one to select stimuli that are relevant to the current task.

Top-down signal originate in frontal cortex and flow towards posterior cortex:

FEF & LPFC → LIP → MT (Visual Area) → V4 → V2 → V1

Buschman and Miller, Science 2007
Saxlmann et al, Science 2007
Buffalo et al, PNAS 2010

Current Opinion in Neurobiology

Miller and Buschman, 2013
dPFC and PPC: who is doing what?

Take-home messages

• Both parietal and frontal cortices contain a mixture of sensory/cognitive/motor variables
• PFC can specifically gate its response to attended stimuli
• PFC integrates the ventral and dorsal stream (+ amygdala, hippocampus...), allowing even more flexibility
dPFC and PPC: who is doing what?

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➢ Role in learning, flexibility, distractor rejection...???