Cognitive Neuroscience
Exploring Brain/Behavior relations

- Neuroscience
- Cognitive Neuroscience
- Psychology
- Computational Sciences / Artificial intelligence
Franz Joseph Gall & J. C. Spurzheim – localization of different psychological functions to different regions of the cerebral cortex (late 1700’s – early 1800’s)
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- phrenology
The brain hypothesis: functional specialization or distribution?

1810
Brain Hypothesis

- Mass action (Lashley, 1930s) and aggregate field theories

Flourens (1794-1867)
Older Methods

• Cognitive Psychology
  – Behavior is the basic unit of study
  – Phenomena must be well characterized
Cognitive Psychology

• Has benefited as a science by the development of a circumscribed set of methods and techniques
• Basic methods have yielded a number of phenomena in need of explanation
Measurement of Human Performance in Information Processing Tasks

Basic Units of measurement:
- Reaction time
- Accuracy

- Much work has been done to establish the validity and reliability of these measurements
The Posner Task

Results demonstrate that multiple representations are activated by a single stimulus
The Word Superiority Effect

A target letter can be identified more quickly when it is imbedded in a word than when it appears among a random letter string.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Stimulus</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word</td>
<td>RACK</td>
<td>90%</td>
</tr>
<tr>
<td>Nonsense string</td>
<td>KARC</td>
<td>80%</td>
</tr>
<tr>
<td>X's</td>
<td>XAXX</td>
<td>80%</td>
</tr>
</tbody>
</table>
The Sternberg Task

- RT increases monotonically with increasing memory set-size
- Similar RT slopes for both “yes” and “no” responses
Implications of Sternberg Task Results

• Memory retrieval is a serial comparison process between items in memory and those in the world
• Each comparison takes a fixed amount of time
• Mental operations can be quantified in terms of the amount of time they take
The Stroop Effect

- Subjects take longer to name a color word (e.g., red) when it is printed in a color that does not match the word.

<table>
<thead>
<tr>
<th>Color matches word</th>
<th>Random colors</th>
<th>Color doesn't match word</th>
</tr>
</thead>
<tbody>
<tr>
<td>RED</td>
<td>XXXXX</td>
<td>GREEN</td>
</tr>
<tr>
<td>GREEN</td>
<td>XXXXX</td>
<td>BLUE</td>
</tr>
<tr>
<td>RED</td>
<td>XXXXX</td>
<td>RED</td>
</tr>
<tr>
<td>BLUE</td>
<td>XXXXX</td>
<td>BLUE</td>
</tr>
<tr>
<td>BLUE</td>
<td>XXXXX</td>
<td>GREEN</td>
</tr>
<tr>
<td>GREEN</td>
<td>XXXXX</td>
<td>RED</td>
</tr>
<tr>
<td>BLUE</td>
<td>XXXXX</td>
<td>GREEN</td>
</tr>
<tr>
<td>RED</td>
<td>XXXXX</td>
<td>BLUE</td>
</tr>
</tbody>
</table>

Green, I mean red.
Implications of the Stroop Effect

- Multiple representations
- “Privileged access” of some representations over others
Older Methods

• Neuropsychology

*The study of cognitive deficits following brain damage*
Older Methods

- Neuropsychology

*The “lesion method”*

The role of a missing brain region may be inferred from what the patient cannot do after it is removed.
The Lesion Method

• Laid the empirical foundation for modern cognitive neuroscience
  – Broca: Left hemisphere language dominance
The Lesion Method

• Logic is based on a localizationist perspective

• Does not take into account the adaptive “parallel” nature of brain function
Neuropsychology Methods

- Basic question: Is brain region X important for Task A?
Single Dissociation

<table>
<thead>
<tr>
<th>Task A (recency memory)</th>
<th>Task B (familiarity memory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients w/ lesion to region X</td>
<td></td>
</tr>
<tr>
<td>92%</td>
<td>70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
</tr>
</tbody>
</table>

1 Patient group, 1 Control group
Two tasks,
Difference between groups only occurs in Task B
Inference Problems with Single Dissociations

- Both tasks assumed to be equally sensitive to group differences

- Single dissociation may result from general effects of trauma, not specific effect of lesion
**Double Dissociation**

<table>
<thead>
<tr>
<th>Patients w/lesion to region X (temporal lobe)</th>
<th>Task A (recency memory)</th>
<th>Task B (familiarity memory)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92%</td>
<td>70%</td>
</tr>
<tr>
<td>Patients w/lesion to region Y (frontal lobe)</td>
<td>64%</td>
<td>89%</td>
</tr>
<tr>
<td>Controls</td>
<td>90%</td>
<td>94%</td>
</tr>
</tbody>
</table>

2 Patient groups
1 Control group
Patient groups differ on task affected, control group unaffected
Representations in CNS

Different functions are represented in different brain regions.
Gross Anatomy: Anatomical division

4 lobes

- Frontal lobe
- Parietal lobe
- Temporal lobe
- Occipital lobe

Central sulcus
Parieto-occipital sulcus
Pre-occipital notch
Functional Divisions of the Cerebral Cortex

1. SENSORY CORTECES

a. Motor Areas of the Frontal Lobe

b. Somatosensory Areas of the Parietal Lobe

c. Visual Processing Areas of Occipital Lobe

d. Auditory Processing Areas of the Temporal Lobe
a. Motor Areas of the Frontal Lobe
b. Somatosensory Areas of the Parietal Lobe
c. Visual Processing Areas of Occipital Lobe
d. Auditory Processing Areas of the Temporal Lobe
The Emergence of Cognitive Neuroscience

• Fueled by the development of powerful new imaging instruments and techniques
• Formulation of questions based on discoveries with older, more established methods
• Relies critically on converging operations between new methods and older established methods
Cognitive Neuroscience Methods
The major methods

- Single-unit recording
- Lesion studies
- Transcranial magnetic stimulation (TMS)
- Neurosurgery-related methods
  - Direct cortical stimulation
  - Split-brain
  - WADA
- Functional imaging
  - Electromagnetic: EEG, MEG
  - Hemodynamic: PET, fMRI
Single unit recording

• Used extensively in animal studies
• A microelectrode is inserted into brain tissue and recordings of action potentials can be made from nearby neurons, ideally a single neuron.
  – Recordings are typically extracellular
• The animal can then be presented with various sensory stimuli, or trained to perform some task, and the effects on neural activity can be monitored
• Advantages: great spatial and temporal resolution
• Disadvantages: sampling only a very small fraction of a functional neural system
Transcranial Magnetic Stimulation

• A method for producing temporary focal brain “lesion” (disruption), via stimulation with a strong magnetic field.

• With milder fields, can produce “excitation” or facilitation effects.
Transcranial Magnetic Stimulation

- Coil placed over target brain region
- Cognitive failures recorded
TMS - Virtual lesions

The magnetic fields used in TMS are produced by passing current through a hand-held coil, whose shape determines the properties and size of the field. The coil is driven by a machine which switches the large current necessary in a very precise and controlled way, at rates up to 50 cycles per second in rTMS. Small induced currents can then make brain areas below the coil more or less active, depending on the settings used.
Previous studies have demonstrated suppression of visual perception with TMS over the occipital cortex (letter detection, trigram recognition).
Neurosurgery Methods

• Direct cortical stimulation
  – Delivery of a small electric current directly on the cortical surface
  – Causes temporary disruption or facilitation of function in cortex being stimulated
  – Used clinically to map function, so that critical regions can be avoided during tissue resection
  – Can be done intra-operatively, or more commonly now, via chronically implanted electrode grids
MAPPING THE SPEECH AREAS
CASE C. H. Color photograph of the left hemisphere as exposed at operation. Application of electrode at points 26, 27 and 28 produced aphasic interference with speech. See page 111 for case description and Figure VII-5 for labelled drawing of brain.
Neurosurgery methods (con’t)

• Split-brain
  – Sectioning of corpus callosum as a treatment for medically intractable epilepsy
  – Can study the separate contributions of the left and right hemispheres to various abilities/tasks
Neurosurgery methods (con’t)

- WADA procedure
  - Injection of sodium amytal (a barbituate), into one and then the other carotid artery temporarily (5-10min) puts half the brain to sleep allowing neurologists to assess function in the awake hemisphere
Neurosurgery methods (con’t)

• General considerations
  – Advantages: better experimental control in some situations, e.g., temporary lesions can be very focal and reversible
  – Disadvantages: all subjects in these subjects are undergoing these procedures because they have a neurological disorder, therefore it is not clear how generalizable the results are.
Functional imaging

• Electroencephalography (EEG)
  – Scalp electrodes measure the summed electrical activity of large populations of synchronously active neurons
  – Can look at the changes in this signal as a function of mental activity
    • Changes in synchrony of different populations of neurons
    • Changes in morphology of EEG signals that are time-locked to an event (e.g., a perceptual stimulus), this is called event-related potentials (ERPs)
Functional imaging

• Magnetoencephalography (MEG)
  – Measures magnetic fields associated with large populations of synchronously active neurons
  – Can measure synchrony or event-related changes in the signal like EEG
Functional imaging

• Electromagnetic techniques -- general considerations
  – Very good temporal resolution (milliseconds)
  – Generally poor spatial resolution (roughly on the order of the size of a cerebral lobe)
  – For simple sensory or motor events resolution can be better (closer to 1 cm), particularly for MEG
Functional imaging

• Positron emission tomography (PET)
  – Involves injection of radio-label oxygen or glucose into the blood stream, and measures the location in the brain that this material accumulates
  – Good spatial resolution (~1cm)
  – Poor temporal resolution (~1 min at best)
Positron Emission Tomography

- Subjects injected with radioactive isotop
- Measures local changes in blood flow that are linked to neural activity
- Neural activity $\Rightarrow$ increased metabolic demand $\Rightarrow$ local increase in blood flow of the active region}

Capitalizes on blood-flow or “hemodynamic” properties of brain
Example of a PET Experiment

• Petersen, Fox, Posner, Mintun & Raichle (1988) PET using radioactive O$^2$-tracer
• Wanted to understand brain bases of word processing
• Subjects performed several tasks
  – Looking at words
  – Listening to words
  – Saying words aloud
    • either read or heard
  – Thinking of words
    • word association task (apple-orange, sleep-bed)
Example Results

- looking at words
- listening to words
- speaking words
- thinking about words
Functional imaging

- Functional magnetic resonance imaging (fMRI)
  - Like PET, fMRI measures regional changes in blood flow, but does it very differently
  - As blood flow increases, so does the oxygen concentration in the blood. MRI is sensitive to these O2 concentration changes
  - Excellent spatial resolution (3-6mm), relatively poor temporal resolution (on the order of seconds)
Structural MRI

- Takes advantage of the fact that different types of tissue produce different radio-frequency (RF) pulses
• Takes advantage of the fact that neural activity is followed by blood flow in a highly predictable manner
• Altered blood flow alters RF signal from active brain regions
Functional MRI

- Permits examination of brain regions that become active during cognitive performance

\[ \text{cognitive task} \quad \rightarrow \quad \text{baseline} \]

*Facilitates comparison of brain activity in younger and older*
fMRI vs. PET

- BOTH: blood flow to brain provides the signals detected
  - when resting neurons become active, blood flow to them increases
- fMRI - detects changes in oxygen levels, which rise in nearby blood vessels when they are at rest
- PET - relies on increased delivery of injected radioactive water, which diffuses out of the vessels to reach rest of brain.
Some methods have better spatial resolution;

Some have better temporal resolution;

Some have functional resolution.