Visual Object Recognition

Neurobiology 230 – Harvard / GSAS 78454

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Web site: http://tinyurl.com/vision-class

Dates: Mondays

Time: 3:30 – 5:30 PM

Location: Biolabs 1075
Correlations do not imply causation (Non Causa Pro Causa)

Some common logic errors:

“Smoking is correlated with alcoholism”

“Girls who watch soap operas are more likely to show eating disorders”

“Watching violence on TV is correlated with being violent in real life”

“Finns who speak the language of their Nordic neighbors are up to 25 percent less likely to fall ill than those who do not”

“The majority of children with autism are diagnosed between the ages of 18 months and three years old. That's also the same period of time when children receive a large number of immunizations. People see the correlation between receiving immunizations and the diagnosis of autism, and assume that that means that the immunizations cause autism.”
Neurons in visual area MT are sensitive to motion

MT (also known as V5) receives direct (magno) input from V1
MT neurons are sensitive to motion (and other properties, e.g. disparity)
Tuned to motion direction
Typical stimulus: random dots with a given degree of coherent motion

Salzmann et al 1990
Electrical stimulation in area MT, experiment design

10 uA biphasic pulses
200 Hz
0.2 msec
150 um clusters of similar preference
Stimulus placed in receptive field
Response indicated by saccades
Rewarded on correct responses

Salzma et al 1990
Electrical stimulation in area MT biases monkeys’ perception

Two example stimulation sites

Salzman et al. 1990
Electrical stimulation, population analysis

Salzman et al 1990
Before the removal was carried out, stimulation at points 5 and 7 produced the following experiential responses.

5. Patient did not reply.
5. Patient did not reply.
5. Repeated again. "People’s voices talking." When asked, he said he could not tell what they were saying. They seemed to be far away.
5. Stimulation without warning. He said, "Now I hear them." Then he added, "A little like in a dream."
7. "Like footsteps walking—on the radio."
7. Repeated. "Like company in the room."
7. Repeated. He explained "it was like being in a dance hall, like standing in the doorway—in a gymnasium—like at the Kenwood Highschool." He added, "If I wanted to go there it would be similar to what I heard just now."
7. Repeated. Patient said, "Yes, yes, yes." After withdrawal of the stimulus, he said it was "like a lady was talking to a child. It seemed like it was in a room, but it seemed as though it was by the ocean—at the seashore."
7. Repeated. "I tried to think." When asked whether he saw something or heard something, he said, "I saw and heard. It seemed familiar, as though I had been there."
5. Repeated (20 minutes after last stimulation at 5). "People's voices." When asked, he said, "Relatives, my mother." When asked if it was over, he said, "I do not know." When asked if he also realized he was in the operating room, he said "Yes." He explained it seemed like a dream.
5. Repeated. Patient said, "I am trying." After withdrawal of the electrode he said, "It seemed as if my niece and nephew were visiting at my home. It happened like that many times. They were getting ready to go home, putting their things on—their coats and hats." When asked where, he said, "In the dining room—the front room—they were moving about. There were three of them and my mother was talking to them. She was rushed—in a hurry. I could not see them clearly or hear them clearly."
Electrical stimulation in the human medial temporal lobe

**Table 1** Main symptoms evoked by rhinal cortices, amygdala, and hippocampus stimulation

<table>
<thead>
<tr>
<th>Induced symptoms</th>
<th>Rhinal cortices</th>
<th>Amygdala</th>
<th>Hippocampus</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>146</td>
<td>88</td>
<td>46</td>
</tr>
<tr>
<td>Experiential phenomena</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dèjà vu–dèjà vécu</td>
<td>16 (11)</td>
<td>2 (2.2)</td>
<td>1 (2.1)</td>
</tr>
<tr>
<td>Reminiscence of memory</td>
<td>5 (3.4)</td>
<td>1 (1.1)</td>
<td>0</td>
</tr>
<tr>
<td>Emotional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fear or anxiety</td>
<td>39 (26)</td>
<td>20 (22)</td>
<td>13 (28)</td>
</tr>
<tr>
<td>Viscero-sensitive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epigastric sensation or throat striction</td>
<td>13 (9)</td>
<td>12 (13)</td>
<td>10 (21)</td>
</tr>
<tr>
<td>Warming or cooling feeling</td>
<td>7 (4.8)</td>
<td>9 (10.1)</td>
<td>2 (4.3)</td>
</tr>
<tr>
<td>Speech disturbances</td>
<td>5 (3.4)</td>
<td>1 (1.1)</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>11 (7.5)</td>
<td>11 (12.5)</td>
<td>9 (19.5)</td>
</tr>
</tbody>
</table>

The results were obtained in 24 patients. The number (%) of stimulations that induced symptoms is indicated. Statistical analysis (comparison of the symptoms in the three regions) was done using chi-square analysis (or Fisher exact test indicated by *).

**Table 2** Comparison of entorhinal and perirhinal cortex stimulations

<table>
<thead>
<tr>
<th>Induced symptoms</th>
<th>Entorhinal</th>
<th>Perirhinal</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>83</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Experiential phenomena</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dèjà vu</td>
<td>14 (16.8)</td>
<td>2 (3.1)</td>
<td>0.008</td>
</tr>
<tr>
<td>Reminiscence of scenes</td>
<td>0</td>
<td>5 (7.9)</td>
<td>0.01 *</td>
</tr>
<tr>
<td>Emotional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fear or anxiety</td>
<td>29 (35)</td>
<td>10 (15.8)</td>
<td>0.01</td>
</tr>
<tr>
<td>Viscero-sensitive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epigastric sensation</td>
<td>13 (15.6)</td>
<td>0</td>
<td>0.0006 *</td>
</tr>
<tr>
<td>Feeling of warmth or cooling</td>
<td>6 (7.2)</td>
<td>1 (1.6)</td>
<td>0.11</td>
</tr>
<tr>
<td>Speech disturbances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blurred speech or reading arrest</td>
<td>1 (1.2)</td>
<td>4 (6.3)</td>
<td>0.16</td>
</tr>
<tr>
<td>Other</td>
<td>5 (6)</td>
<td>6 (9.5)</td>
<td>0.42</td>
</tr>
</tbody>
</table>

The results were obtained in 24 patients. The number (%) of stimulations that induced symptoms is indicated. Statistical analysis was done using chi-square analysis or Fisher exact test (*).
## Table 1. Responses of Patient 49 to Stimulation

<table>
<thead>
<tr>
<th>Site stimulated</th>
<th>No. of trains in sequence</th>
<th>Maximum pulses/s</th>
<th>Maximum current</th>
<th>Potential evoked?</th>
<th>After-discharge?</th>
<th>Déjà vu?</th>
<th>Hallucination?</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAm</td>
<td>8</td>
<td>60</td>
<td>6 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>LAHC</td>
<td>8</td>
<td>10</td>
<td>9 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LMHC</td>
<td>7</td>
<td>10</td>
<td>10 mA</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>LPHC</td>
<td>8</td>
<td>10</td>
<td>8 mA</td>
<td>-</td>
<td>DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LAHCG</td>
<td>8</td>
<td>10</td>
<td>6 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
<tr>
<td>LMHCG</td>
<td>9</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>-</td>
<td>D,D</td>
<td>-</td>
</tr>
<tr>
<td>LPHCG</td>
<td>8</td>
<td>10</td>
<td>6 x 1 mA</td>
<td>-</td>
<td>DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LMHC</td>
<td>1</td>
<td>10</td>
<td>10 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>M,M,M</td>
<td>-</td>
</tr>
<tr>
<td>RAHC</td>
<td>9</td>
<td>10</td>
<td>9 x 1 mA</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
<tr>
<td>RAHC</td>
<td>7</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RMHC</td>
<td>8</td>
<td>10</td>
<td>9 x 1 mA</td>
<td>-</td>
<td>1</td>
<td>M,M,M</td>
<td>-</td>
</tr>
<tr>
<td>RPHC</td>
<td>7</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAHCG</td>
<td>5</td>
<td>10</td>
<td>6 x 1 mA</td>
<td>1</td>
<td>1</td>
<td>M</td>
<td>-</td>
</tr>
<tr>
<td>RMHCG</td>
<td>7</td>
<td>10</td>
<td>9 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
<tr>
<td>RPHCG</td>
<td>7</td>
<td>10</td>
<td>7 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M<em>M</em></td>
</tr>
<tr>
<td>RUn</td>
<td>5</td>
<td>10</td>
<td>9 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M*</td>
</tr>
<tr>
<td>LMHCG</td>
<td>1</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>-</td>
<td>D</td>
<td>-</td>
</tr>
<tr>
<td>RAHCG</td>
<td>1</td>
<td>10</td>
<td>3 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
</tr>
</tbody>
</table>

### 2 weeks later

<table>
<thead>
<tr>
<th>Site stimulated</th>
<th>No. of trains in sequence</th>
<th>Maximum pulses/s</th>
<th>Maximum current</th>
<th>Potential evoked?</th>
<th>After-discharge?</th>
<th>Déjà vu?</th>
<th>Hallucination?</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAm</td>
<td>6</td>
<td>10</td>
<td>9 x 1 mA</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LAHC</td>
<td>10</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>-</td>
<td>DV,DV,DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LCG</td>
<td>8</td>
<td>10</td>
<td>7 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAHC</td>
<td>6</td>
<td>10</td>
<td>10 x 1 mA</td>
<td>-</td>
<td>DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAHCG</td>
<td>9</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>DV,DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RMHCG</td>
<td>9</td>
<td>10</td>
<td>6 x 1 mA</td>
<td>1</td>
<td>DV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RCG</td>
<td>7</td>
<td>10</td>
<td>6 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LOC</td>
<td>6</td>
<td>5</td>
<td>6 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAHC</td>
<td>2</td>
<td>10</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>DV</td>
<td>-</td>
<td>OH,U</td>
</tr>
<tr>
<td>LAN</td>
<td>6</td>
<td>5</td>
<td>8 x 1 mA</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LVA</td>
<td>5</td>
<td>5</td>
<td>7 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ROC</td>
<td>5</td>
<td>5</td>
<td>4 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RAN</td>
<td>5</td>
<td>5</td>
<td>5 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RVA</td>
<td>5</td>
<td>5</td>
<td>5 x 1 mA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Each row of this Table presents a sequence of stimulus trains applied to the same site. L = left; R = right; A = anterior; M = middle; P = posterior; Am = amygdala; HC = hippocampus; HCG = hippocampal gyrus; Un = uncus; CG = cingulate gyrus; OC = orbital cortex; AN = anterior thalamic nucleus; VA = ventral anterior thalamic nucleus. All mental phenomena indicated were obtained with the highest stimulation current used, or else were repeated with all higher current levels, unless marked by an asterisk. M = memory-like hallucination; D = dream-like hallucination.

Halgren et al 1978
Summary of electrical stimulation studies in the human brain

Table 1. Experiential Illusions and Hallucinations Observed with Stereotaxic Exploration of the Temporal Lobes

<table>
<thead>
<tr>
<th>Experience</th>
<th>No. of Observations</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual illusions</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Elementary visual hallucinations</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Complex visual hallucinations</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Auditory illusions</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elementary auditory hallucinations</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Complex auditory hallucinations</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Olfactory hallucinations</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Familiarity (déjà vu)</td>
<td>23</td>
<td>4</td>
</tr>
<tr>
<td>Unfamiliarity (jamais vu)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Memory recall</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Forced thinking</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Fear</td>
<td>&gt;49</td>
<td>7</td>
</tr>
<tr>
<td>Anger</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
</tr>
<tr>
<td>Irritation</td>
<td>&gt;3</td>
<td>1</td>
</tr>
<tr>
<td>Emotional distress</td>
<td>6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3</td>
</tr>
<tr>
<td>Far-away feeling</td>
<td>&gt;3</td>
<td>1</td>
</tr>
<tr>
<td>Feeling of someone being nearby</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pleasant emotion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sexual emotion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thirst</td>
<td>10&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2</td>
</tr>
<tr>
<td>Hunger</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Feeling of bodily distortion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Strange, indescribable</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>feeling (mental)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floating sensation</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

<sup>a</sup>All induced by electrical stimulation.
<sup>b</sup>Angry mood and facial expression, no aggression.
<sup>c</sup>In 1 instance, may have been caused by strong nausea.
<sup>d</sup>Nine of the 10 observations were in 1 patient.

Table 3. Complex Visual Hallucinations (5 Patients)

<table>
<thead>
<tr>
<th>Means of Elicitation</th>
<th>Amygdala</th>
<th>Hippocampus</th>
<th>Parahippocampal Gyrus</th>
<th>Limbic Diffuse</th>
<th>Temporal Neocortex</th>
<th>Limbic and Temporal Neocortex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deep</td>
<td>Deep</td>
<td>Deep</td>
<td>Deep</td>
<td>Deep and Superficial</td>
<td>Deep and Superficial</td>
</tr>
<tr>
<td>Initial seizure or afterdischarge</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Secondary spread</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Stimulation site</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Without afterdischarge</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*All induced by electrical stimulation.

Fig 6. Temporal lobe structures from which experiential responses were elicited by electrical stimulation with and without afterdischarge.
Electrical stimulation in early occipital cortex produces topographically-organized phosphenes

Text-fig. 1. The arrangement of cortical electrodes. Each is connected to the receiver that has the same number in Text-fig. 2. The thirty-nine electrodes that have given phosphenes are shown as filled squares. Of these thirty-nine, five ceased after some months to give phosphenes. It will be seen that the numbering of the electrodes is regular except for the displacement of 47 and the omission of 48. The heavy line shows the conjectured position of the calcarine fissure in relation to the electrodes.

Text-fig. 3. The positions of phosphenes in the visual field, excluding high-threshold phosphenes. The symbols used indicate very roughly the size and shape of the phosphenes. Four phosphenes that are not shown in the figure are as follows. Electrode 25 gave a single point phosphen not far from that of electrode 26; it failed before it had been properly plotted. Electrode 43 gave, and still gives, a single point phosphen that coincides with the middle one of the three given by electrode 45. Electrodes 65 and 71 give large cloud-like phosphenes containing many faint points, wholly below the horizontal meridian and ranging between 3° and 15° from the point of regard.

Brindley et al 1968
Electrical stimulation can induce color perception

1 subject
1 electrode

300 ms stimulating current, 200 Hz biphasic

Reported percept: “blue, purple color, like aluminum foil when it burns”

Near the center of gaze but not localizable to a small area

Increasing electrical stimulation to 1 second prolonged the percept but did not change its quality

Murphey et al. Current Biology. 2008
Electrical stimulation can induce color perception

Figure 3. Response of the Implanted Electrode to Visual Stimulation
(A) Average evoked response to presentation of a blue stimulus. The stimulus is shown at the top of the plot; a blue square on a gray background was presented for 125 ms and was then replaced with a baseline display. In the plot, the heavy trace is the mean response; the gray-shaded area is the 95% confidence interval. The blue-shaded rectangle shows the stimulus duration. The dashed lines show the time interval used to calculate the response power.
(B) Power of the response to different colors. Each symbol represents the response to a color square of the same color as the symbol (stimulus configuration shown in [A]). The x axis is dimensionless L - M cone contrast, the y axis is S - (L + M) cone contrast, and the z axis is the root-mean-square response power. The best-fit plane is shown in gray.
(C) Power of the response to blue stimuli with increasing luminance contrast. Each symbol represents the average response (bars represent 95% confidence interval) to a stimulus of the same color as the symbol.
(D) Power of the response to achromatic stimuli with increasing luminance contrast. Each symbol shows the luminance of the stimulus, except for the rightmost (white) symbol, shown with a black outline for visibility.

Figure 4. Receptive Field of the Implanted Electrode
(A) The visual stimulus used for receptive field mapping. Blue squares were presented in 121 visual field locations (white dashed lines, not present on actual display, show all possible locations). The subject performed a detection task on foveally presented letters to ensure fixation.
(B) The power of the evoked electrical response from the electrode for stimuli presented at each visual field location, interpolated to account for overlap between adjacent stimuli. Color indicates strength of the response. White crosshairs show the horizontal and vertical meridia for reference.
Electrical stimulation in face areas distorts face perception

Electrical stimulation in face areas distorts face perception

Towards prosthetic devices for the visually impaired
Using light to modulate neural activity in cortex with high specificity


Boyden-Desimone
Comments and open questions in electrical stimulation studies

- What exactly happens in the brain upon electrical stimulation?

- How specific are the effects of electrical stimulation?

- How many neurons are stimulated?

- How does this number depend on the intensity, electrode diameter, pulse type?

- Say that 5000 neurons fire in one direction and another 5000 neurons fire in another direction. Stimulation gives some average.

- May be dependent on topography (and therefore reflect more about topography than computation). “Elections analogy”: Force 20,000 people in Florida to vote, then average results.

- What types of neurons are being stimulated?

- How can we distinguish direct versus indirect effects?

- What type of evidence would convince us of a causal relationship between neuronal activity and perception?
Further reading

Original articles cited in class (see lecture notes for complete list)