Visual Object Recognition
Computational Models and Neurophysiological Mechanisms
Neurobiology 130/230. Harvard College/GSAS 78454

Web site: http://tinyurl.com/visionclass
→ Class notes, Class slides, Readings Assignments

Location: Biolabs 2062

Time: Mondays 03:30 – 05:30

Lectures:

Faculty: Gabriel Kreiman and invited guests

TA: Yuchen Xiao

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Office Hours: After Class. Mon 05:30-06:30 or by appointment

Visual Object Recognition
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Class 1. Introduction to pattern recognition [Kreiman]
Class 2. Visual input. Natural image statistics. The retina. [Kreiman]
Class 3. Lesion and neurological studies of visual deficits in animals and humans. [Kreiman]
Class 4. Psychophysics of visual object recognition [Jiye Kim]
October 9: University Holiday
Class 5. Introduction to the thalamus and primary visual cortex [Camille Gomez-Laberge]
Class 6. Adventures into *terra incognita*. Neurophysiology beyond V1 [Frederico Azevedo]
Class 7. First steps into inferior temporal cortex [Carlos Ponce]
Class 8. From the highest echelons of visual processing to cognition [Leyla Isik]
Class 9. Correlation and causality. Electrical stimulation in visual cortex [Kreiman].
Class 10. Theoretical neuroscience. Computational models of neurons and neural networks. [Kreiman]
Class 11. Computer vision. Towards artificial intelligence systems for cognition [Bill Lotter]
Class 12. Vision and Language. [Andrei Barbu]
Class 13. **[Extra class]** Towards understanding subjective visual perception. Visual consciousness. [Kreiman]
FINAL EXAM

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.”

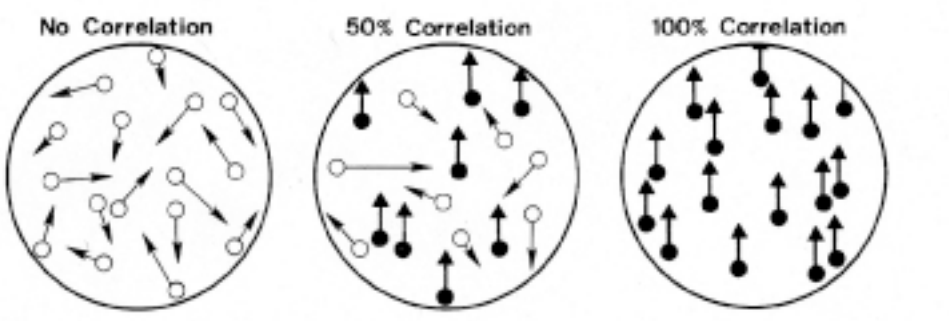
Neurons in visual area MT are sensitive to motion

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

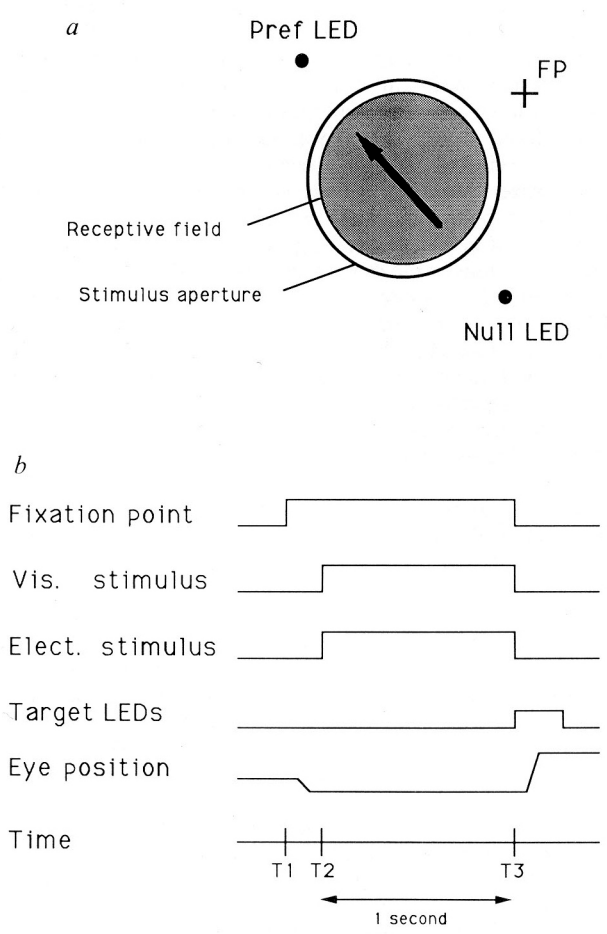
Typical stimulus: random dots with a given degree of coherent motion



No specially colored dots in the actual stimulus

Salzman et al 1990

Electrical stimulation in area MT, experiment design

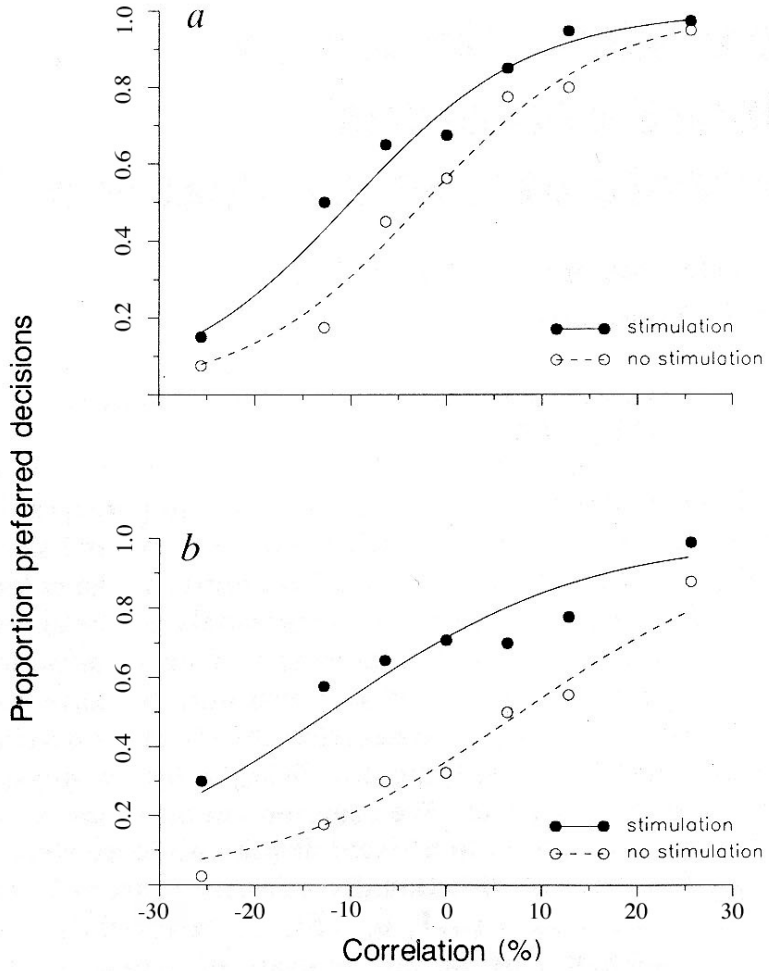


10 uA biphasic pulses
200 Hz
0.2 msec
150 um clusters of similar preference
Stimulus placed in receptive field
Response indicated by saccades
Rewarded on correct responses

Salzman et al 1990

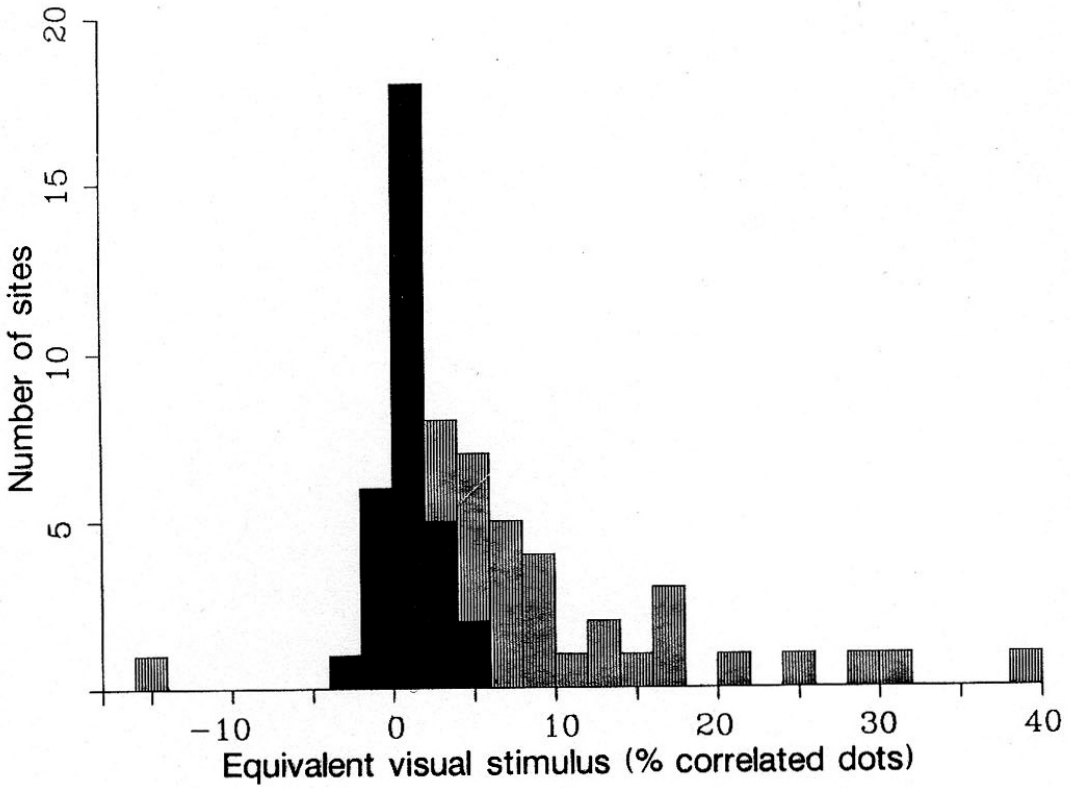
Electrical stimulation in area MT biases monkeys' perception

Two example stimulation sites



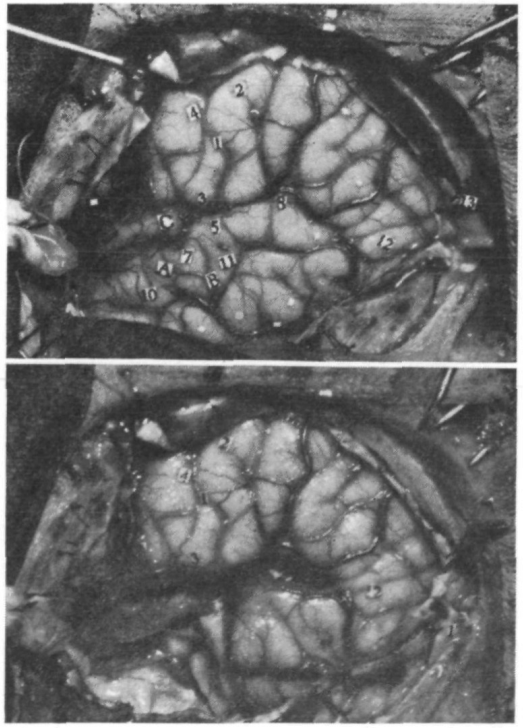
Salzman et al 1990

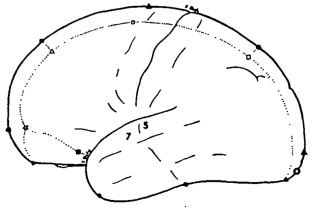
Electrical stimulation, population analysis



Salzman et al 1990

Electrical stimulation in the human brain





CASE 2.—R. B.

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

5. Patient did not reply.
5. Repeated. "Something."
5. Patient did not reply.
5. Repeated. "Something."
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."

Penfield & Perot. *The brain's record of auditory and visual experience. A final summary and discussion. Brain* (1963) **86**:595-696

Electrical stimulation in the human medial temporal lobe

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

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

The results were obtained in 24 patients. The number (%) of stimulations that induced symptoms is indicated. Statistical ana (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*

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

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 (*).

Bartolomei et al 2004

Electrical stimulation in the human medial temporal lobe

TABLE 1. RESPONSES OF PATIENT 49 TO STIMULATION

Site stimulated	*No. of trains in sequence*	*Maximum pulses/s*	*Maximum current*	*Potential evoked?*	*After-discharge?*	*Déjà vu?*	*Hallucination?*
LAm	8	10	6·4 mA	—	—	—	—
LAHC	8	10	9·0	↙	—	—	—
LMHC	7	10	10·0	↙	—	DV	—
LPHC	8	10	8·0	—	—	—	—
LAHCG	8	10	6·4	↙	—	—	M
LMHCG	9	10	8·6	↙	↙	—	D,D
LPHCG	8	10	6·8	↙	—	DV	—
LMHC	1	10	10·8	↙	—	—	—
RAm	9	10	9·0	↙	↙	—	M,M,M
RAHC	7	10	8·4	↙	—	—	—
RMHC	8	10	9·0	↙	—	—	M,M,M,M
RPHC	7	10	8·8	—	—	—	—
RAHCG	5	10	6·4	↙	↙	DV	M*
RMHCG	7	10	9·2	↙	—	—	M
RPHCG	7	10	7·8	↙	—	—	M*M*
RUn	5	1	9·4	↙	—	—	M*
LMHCG	1	10	8·0	↙	↙	—	D
RAHCG	1	10	3·4	↙	↙	—	M
			2 weeks later				
LAm	6	1	9·4	—	—	—	—
LAHC	10	10	8·0	↙	—	DV,DV,DV	—
LCG	8	10	7·4	—	—	—	—
RAm	6	10	10·4	↙	—	DV	—
RAHC	9	10	8·0	↙	↙	DV,DV	—
RMHCG	9	10	6·8	↙	↙	DV	—
RCG	7	10	6·0	—	—	—	—
LOC	6	5	6·6	—	—	—	—
RAHC	2	10	8·2	↙	↙	—	OH,U
LAN	6	5	8·8	—	—	—	—
LVA	5	5	7·2	—	—	—	—
ROC	5	5	4·4	—	—	—	—
RAN	5	5	5·8	—	—	—	—
RVA	5	5	5·0	—	—	—	—

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

Experience	No. of Observations	No. of Patients
Visual illusions	9	3
Elementary visual hallucinations (phosphenes)	15[a]	3
Complex visual hallucinations	18	5
Auditory illusions	0	0
Elementary auditory hallucinations	0	0
Complex auditory hallucinations	3	2
Olfactory hallucinations	2	1
Familiarity (déjà vu)	23	4
Unfamiliarity (jamais vu)	0	0
Memory recall	19	5
Forced thinking	10	2
Fear	>49	7
Anger	1[b]	1
Irritation	>3	1
Emotional distress (depression, guilt, etc)	6[c]	3
Far-away feeling	>3	1
Feeling of someone being nearby	1	1
Pleasant emotion	0	0
Sexual emotion	0	0
Thirst	10[d]	2
Hunger	0	0
Feeling of bodily distortion	2	1
Strange, indescribable feeling (mental)	2	2
Floating sensation (excitement? startle?)	7	1

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

Table 3. Complex Visual Hallucinations (5 Patients)

Means of Elicitation	Amygdala	Hippocampus	Parahippocampal Gyrus	Limbic Diffuse	Temporal Neocortex: Deep	Temporal Neocortex: Deep and Superficial	Limbic and Temporal Neocortex: Deep	Limbic and Temporal Neocortex: Deep and Superficial
Initial seizure or after-discharge	0	3	0	1	0	0	6	3
Secondary spread	1	0	1	0	0	2	0	0
Stimulation site								
Without afterdischarge	4	0	0	0	0	0	0	0
With afterdischarge	4	5	2	0	0	0	0	0

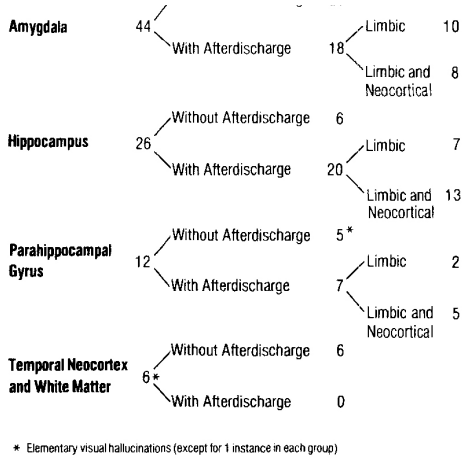
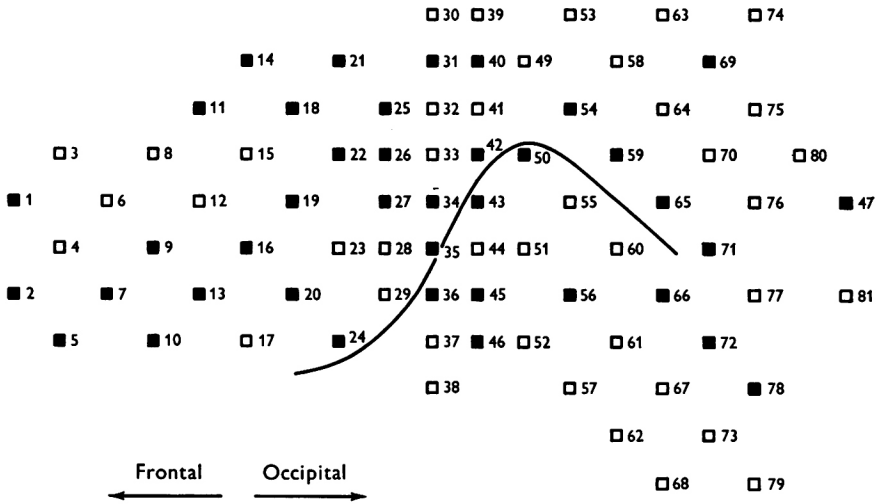


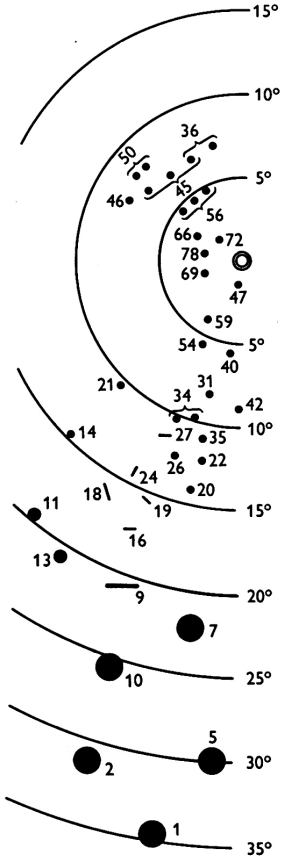
Fig 6. Temporal lobe structures from which experiential responses were elicited by electrical stimulation with and without afterdischarge.

Gloor et al 1982

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 phosphene not far from that of electrode 26; it failed before it had been properly plotted. Electrode 43 gave, and still gives, a single point phosphene 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

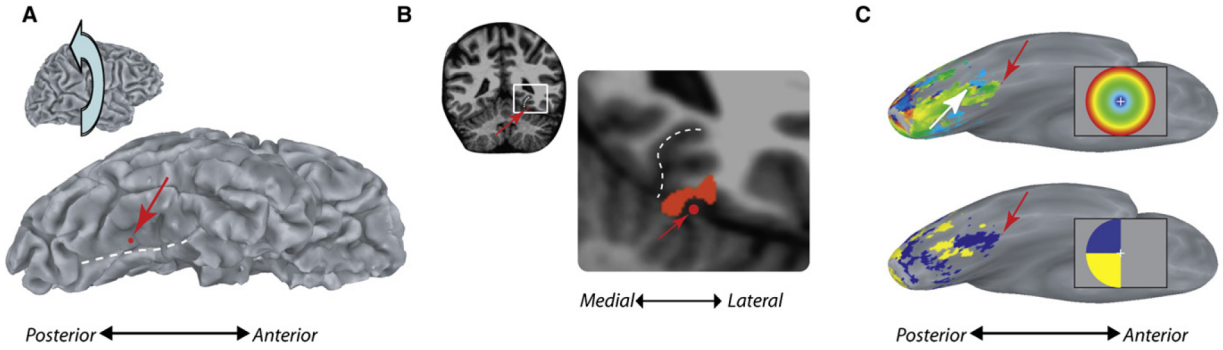
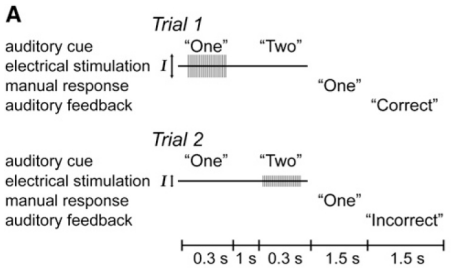


Figure 1. Location of the Implanted Electrode

(A) Lateral (top) and ventral (bottom) views of a cortical surface model of the subject's right hemisphere. The electrode, located on the fusiform gyrus, is shown as a red sphere (highlighted with a red arrow). The collateral sulcus is marked with a dashed white line.

(B) Coronal MR image in the plane of the electrode, shown as a red circle lateral to the collateral sulcus (dashed white line). Orange voxels showed a significant ($p < 0.01$) BOLD fMRI response to color stimuli.

(C) Ventral view of the subject's inflated right hemisphere. The top panel shows the results of eccentricity mapping (nodes are colored according to their preferred location in the visual field, inset). Blue nodes preferred foveal stimulation. The white arrow shows the location of the ventral foveal representation; the red colored nodes and red arrow indicate the location of the electrode. The bottom panel shows the results of polar angle mapping. Blue nodes responded to visual stimulation in the upper left quadrant, yellow nodes to visual stimulation in the lower left quadrant (inset).



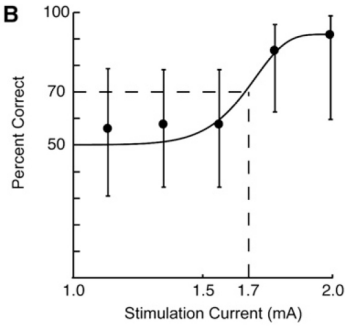


Figure 2. Stimulation of the Implanted Electrode

(A) The structure of each stimulation trial, shown for two sample trials. Each trial contained 200 Hz biphasic electrical stimulation delivered in one of two epochs. The subject attempted to detect the epoch in which the stimulation was delivered, responded with a button press after the completion of both epochs, and then received feedback. The amplitude of the stimulation current (I) varied from trial to trial. In these examples, the first trial contained high stimulation current, and the stimulation epoch was correctly detected. The second trial contained low stimulation current, and the stimulation epoch was not correctly detected.

(B) Psychometric function showing percent correct detection of stimulation epoch plotted against amplitude of stimulation current (I) for five different currents (error bars show 95% confidence intervals).

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

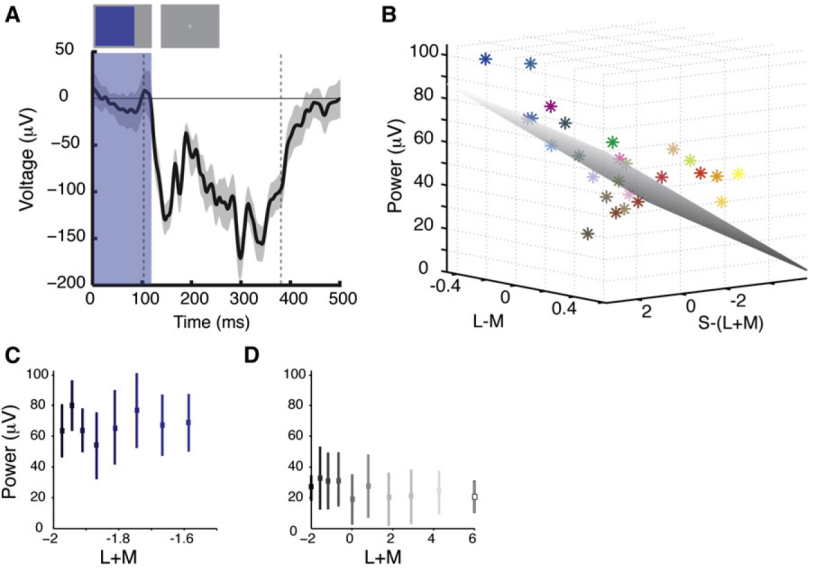


Figure 3. Response of the Implanted Electrode to Visual Stimulation

(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.

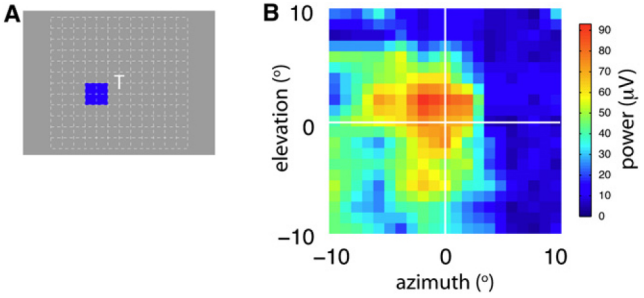


Figure 4. Receptive Field of the Implanted Electrode

(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.

Murphey et al. Current Biology 2008

Electrical stimulation in face areas distorts face perception

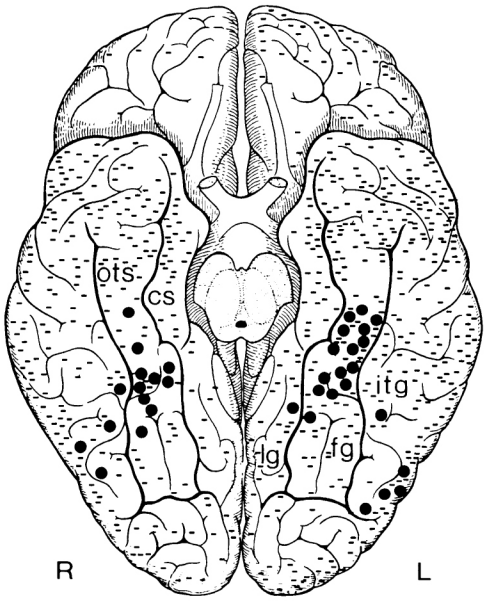


FIG. 3. Summary of locations from which a surface-negative potential (N200) was (●) and was not (– – –) recorded. The inferior view was made of a brain obtained at autopsy. Both hemispheres are shown as identical, but there is considerable variation in the morphology of this cortex. cs, collateral sulcus; fg, fusiform gyrus; itg, inferior temporal gyrus; lg, lingual gyrus; ots, occipitotemporal sulcus.

TABLE 2. *Results of cortical stimulation (10 mA) in patient RCN*

Electrodes	Location	Effect
LPTP 1–2	fg	No retinotopic effect; color perception normal; identification of famous faces normal
LPTP 2–3	fg	No retinotopic effect; color perception normal; unable to name Pres. Kennedy, hesitation in naming Benjamin Franklin; object naming normal
LPTP 3–4	fg, itg	No retinotopic effect; color perception normal; unable to name Michael Jackson; misnamed state governor as Pres. Bush; object naming normal
LPTP 4–5	itg	No retinotopic effect; color perception normal; stimulation terminated due to afterdischarge in EEG

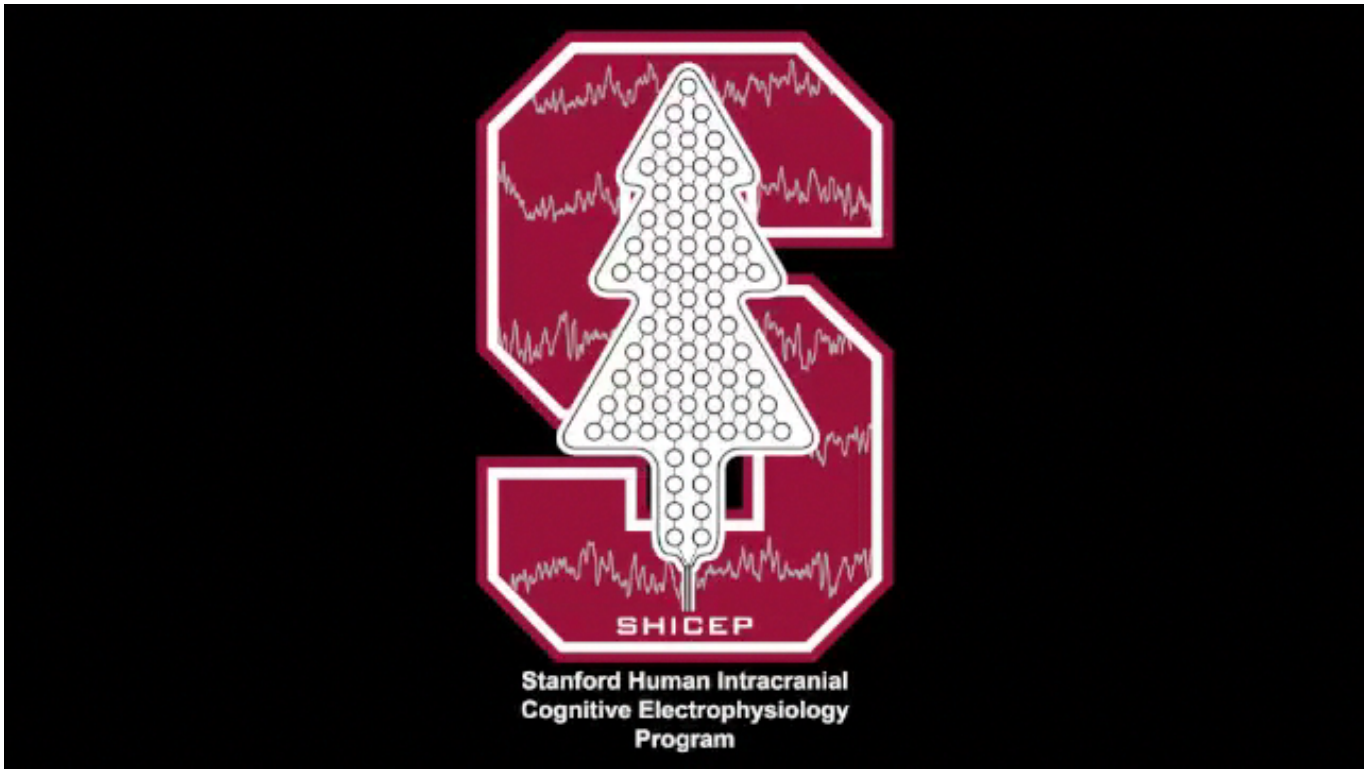
For electrode locations see Fig. 1, *D* and *E*. fg, fusiform gyrus; itg, inferior temporal gyrus; EEG, electroencephalogram.

location of discrete language-related regions (Ojemann et al. 1989).

N200 occurs ~100 ms after P100, the first prominent potential recorded from the posterior scalp and thought to be generated in occipital extrastriate cortex (Halliday and Michael 1970; Jeffreys and Axford 1972). In our recordings the faces were unfamiliar to patients, and no explicit identification or memory task was involved. N200 may thus re-

Allison, T., Ginter, H., McCarthy, G., Nobre, A. C., Puce, A., Luby, M., et al. (1994). Face recognition in human extrastriate cortex. Journal of Neurophysiology, 71(2), 821-825.

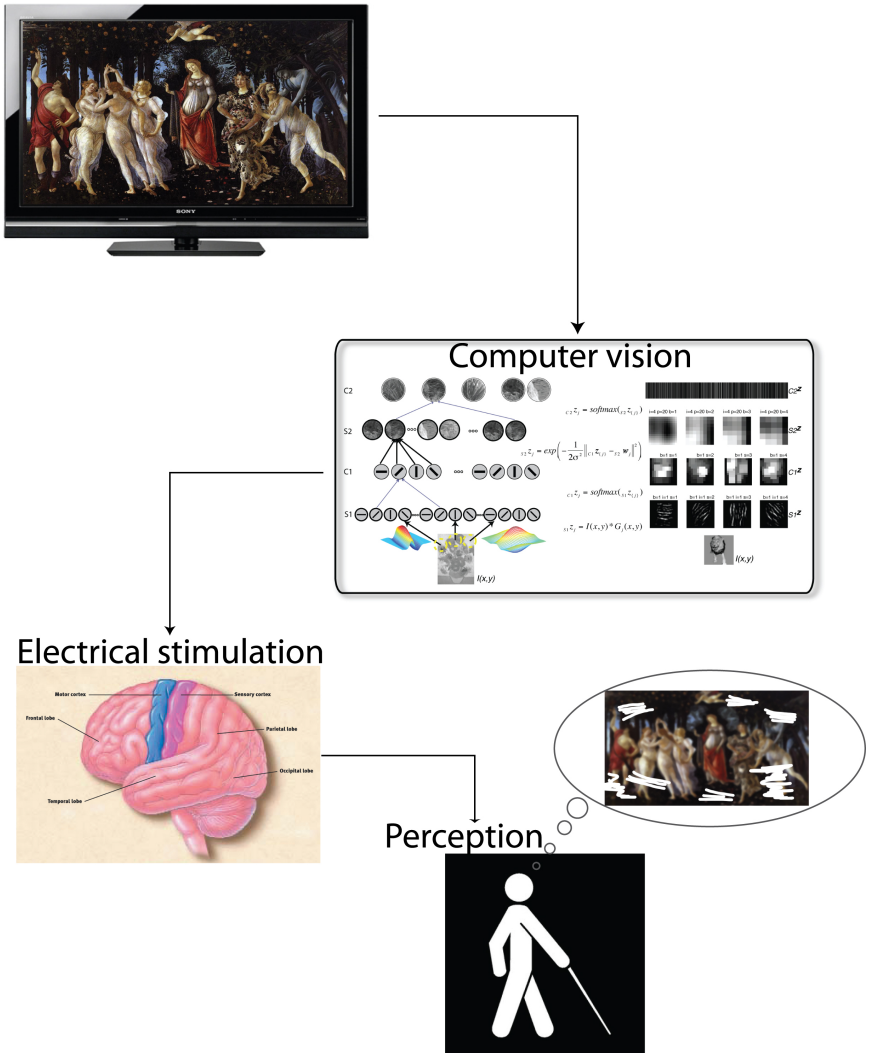
Electrical stimulation in face areas distorts face perception



LINK TO MOVIE

Parvizi, J., Jacques, C., Foster, B. L., Withoft, N., Rangarajan, V., Weiner, K. S., et al. (2012). Electrical stimulation of human fusiform face-selective regions distorts face perception. J Neurosci, 32(43), 14915-14920.

Towards prosthetic devices for the visually impaired



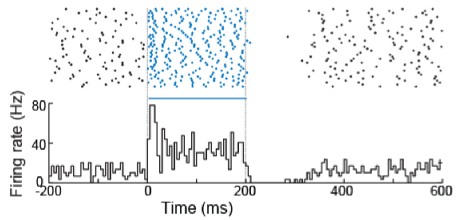
Using light to modulate neural activity in cortex with high specificity

activate

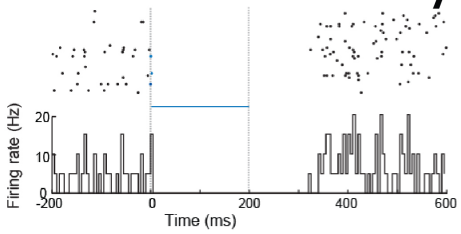
silence

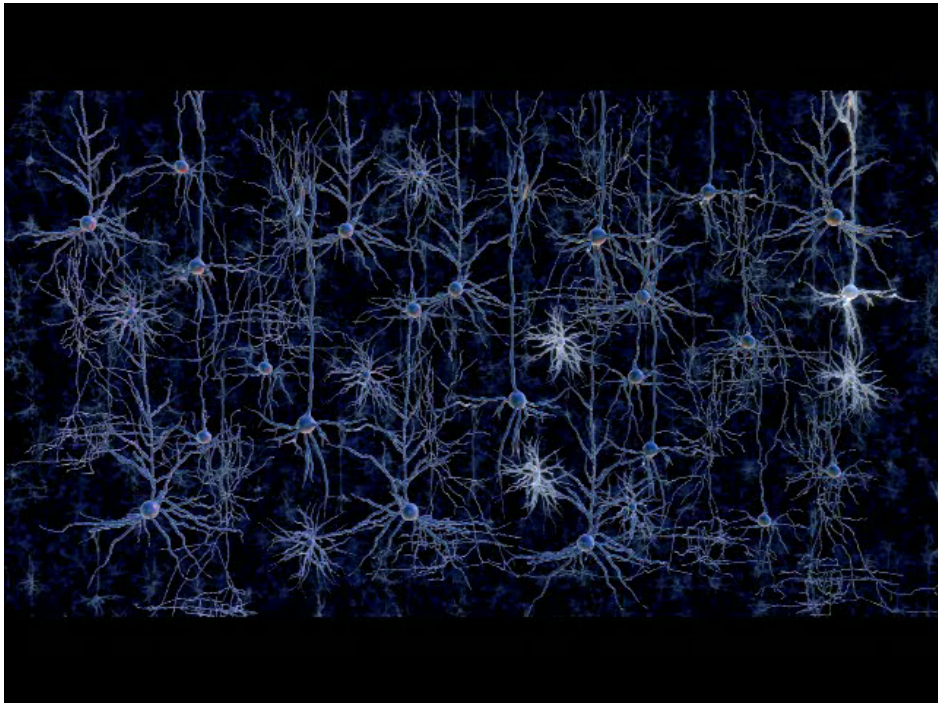
CHR2

200 ms light exposure



Arch-T





Boyden-Desimone

Hahn et al, Neuron 2009, Frontiers in Neuroscience 2011

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)

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- Bartolomei, F., Barbeau, E., Gavaret, M., Guye, M., McGonigal, A., Regis, J., et al. (2004). Cortical stimulation study of the role of rhinal cortex in deja vu and reminiscence of memories. Neurology, 63(5), 858-864.
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