9.13 The Human Brain Class 5

Survey of Methods in Cognitive Neuroscience,
& the Questions they answer,
applied to face perception (Part 2 of 2)

Outline:

A. Computational theory.
B. Behavior
C. fMRI
D. ERPs
E. MEG
F. Intracranial recording
G. Patients with focal brain damage
H. TMS
E. Electrical stimulation of the brain
Short quiz at 12:18.

Face Recognition: What we Want to Know

Key Questions about Face Recognition:

Last time, quick review

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level

2. What is the nature of the representations we humans extract form faces?

3. Is face perception a distinct system from the rest of vision/cognition?

4. How fast are faces detected and recognized?

5. How is face recognition implement in individual neurons/circuits?

6. What is the causal role of each brain region in face recognition?

Face Recognition: Review from Yesterday

Questions to ask at Marr's Computational Theory Level:

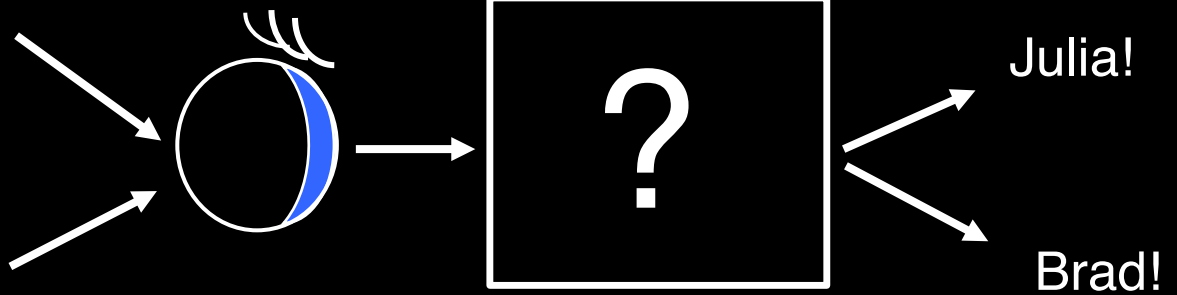
What is the problem to be solved?

What is the input? What is output?

How might you get from input to output?

✔ familiar

✗ unfamiliar



What goes on in here?

Big computational challenge: Each time we see a face it looks different in lighting, orientation, hair, mood, etc.

How do we do it? Our field has many methods to address this.

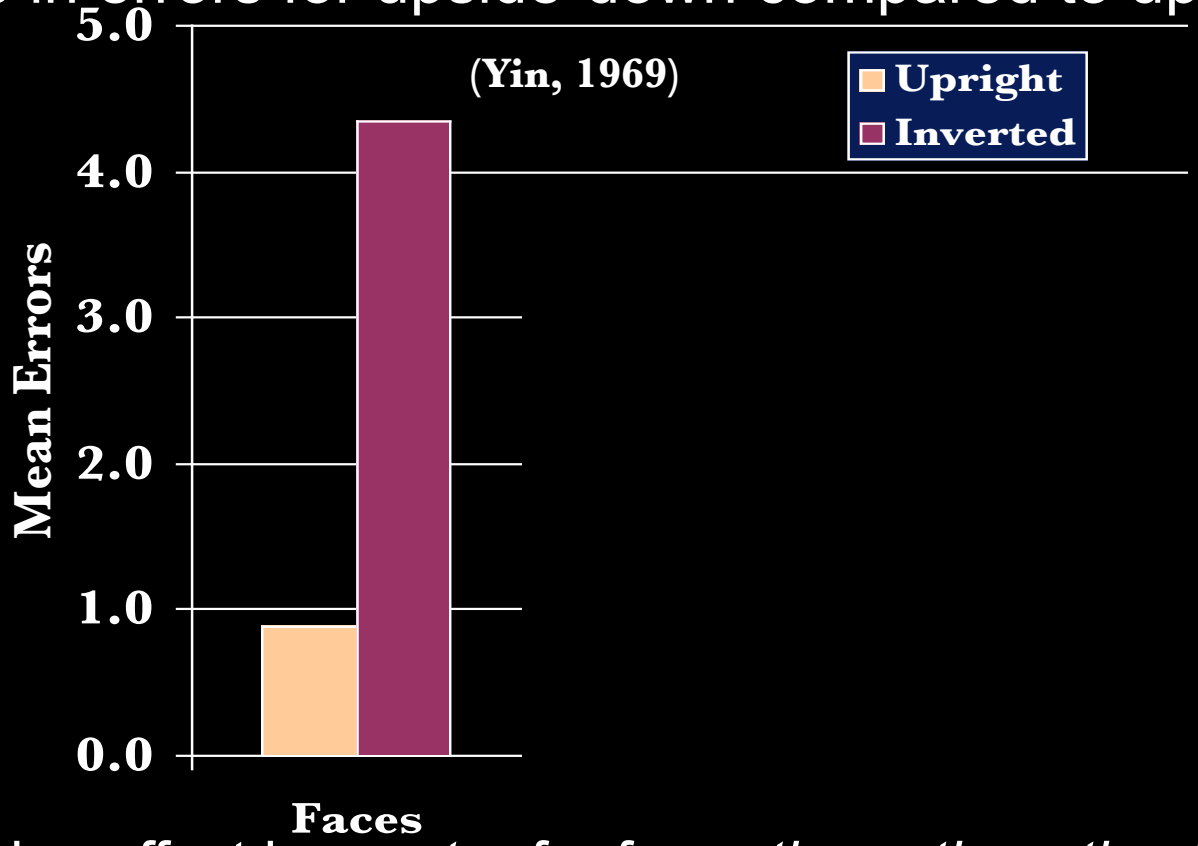
i) Behavior: We are bad @ extracting invariant representations of unfamiliar people

Another simple yet revealing behavioral finding...

A Very Low-Tech but Profound Discovery Made in a Ph.D. thesis this Department in 1969

The "face inversion effect":

An increase in errors for upside-down compared to upright stimuli



The Inversion effect is *greater for faces than other stimuli.*

Suggests face recognition may work differently from object rec.

Many different versions of the face inversion effect....

Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level
   major challenge: huge variation across images of a single face
2. What is the nature of the representations we humans extract form faces?
   not image invariant
   orientation specific
   insights from simple behavioral data
3. Is face perception a distinct system from the rest of vision/cognition?

4. How fast are faces detected and recognized?

5. How is face recognition implement in individual neurons/circuits?

6. What is the causal role of each brain region in face recognition?

Strengths and Weakness of Behavioral Methods

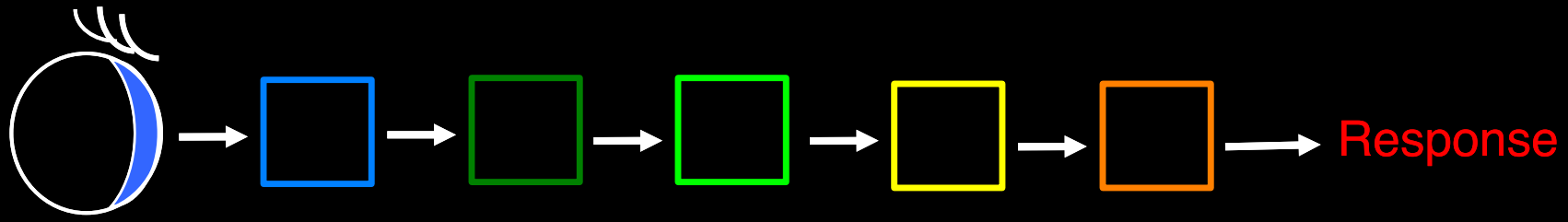
Strengths:

1. Good for characterizing internal representations.
   at least qualitatively
2. Good for dissociating distinct mental phenomena.
   e.g. face versus object processing
3. Cheap!

Weaknesses:

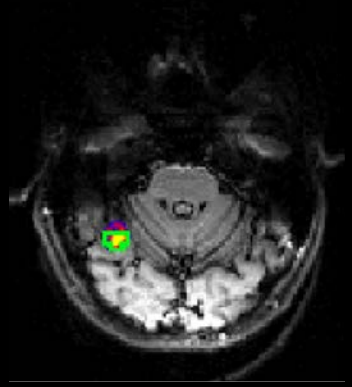
1. No relationship to the brain, at least not without further information

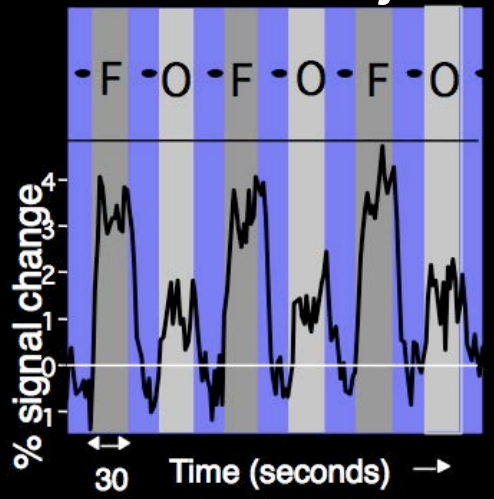
2. Data are sparse: all we have is the output of the final stage,
   but we would like to characterize each stage in the whole sequence of processing.
   Many ways to do this, but a particularly powerful one is fMRI…



Testing the Hypothesis: A Face Selective Region exists in the Brain.

1. Do we find a region w/ higher response to faces > objects? Yes!





Now think up alternative hypotheses: different accounts of this finding.

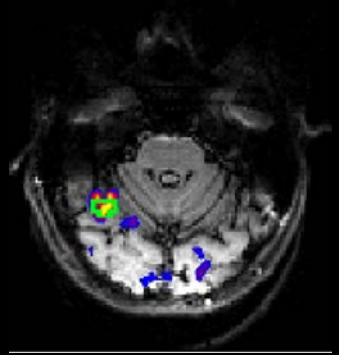
2. Test those alternative hypoths:

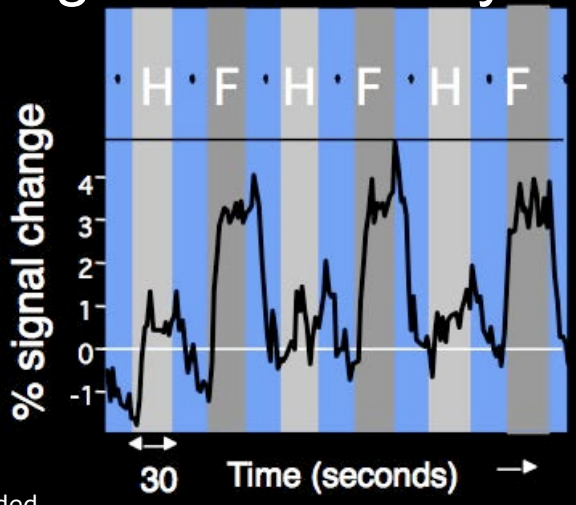
i) Use #1 as a "localizer" to find that region in each subject individually.

ii) Now measure the response of that region to new "conditions".

~~anything human?~~ ~~any body part?~~ ~~anything attended?~~ ~~anything curvy~~?

(1-back)

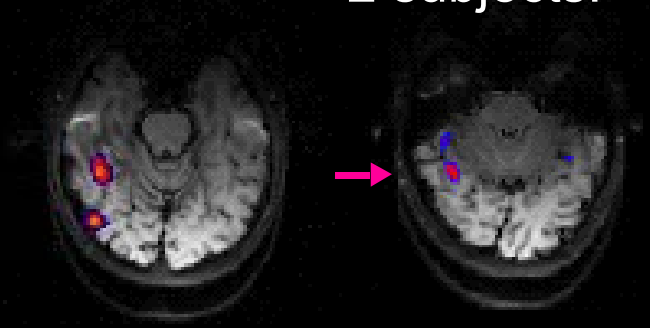




Have you nailed your hypothesis? Or are there still other alternative accounts?

Fusiform Face Area

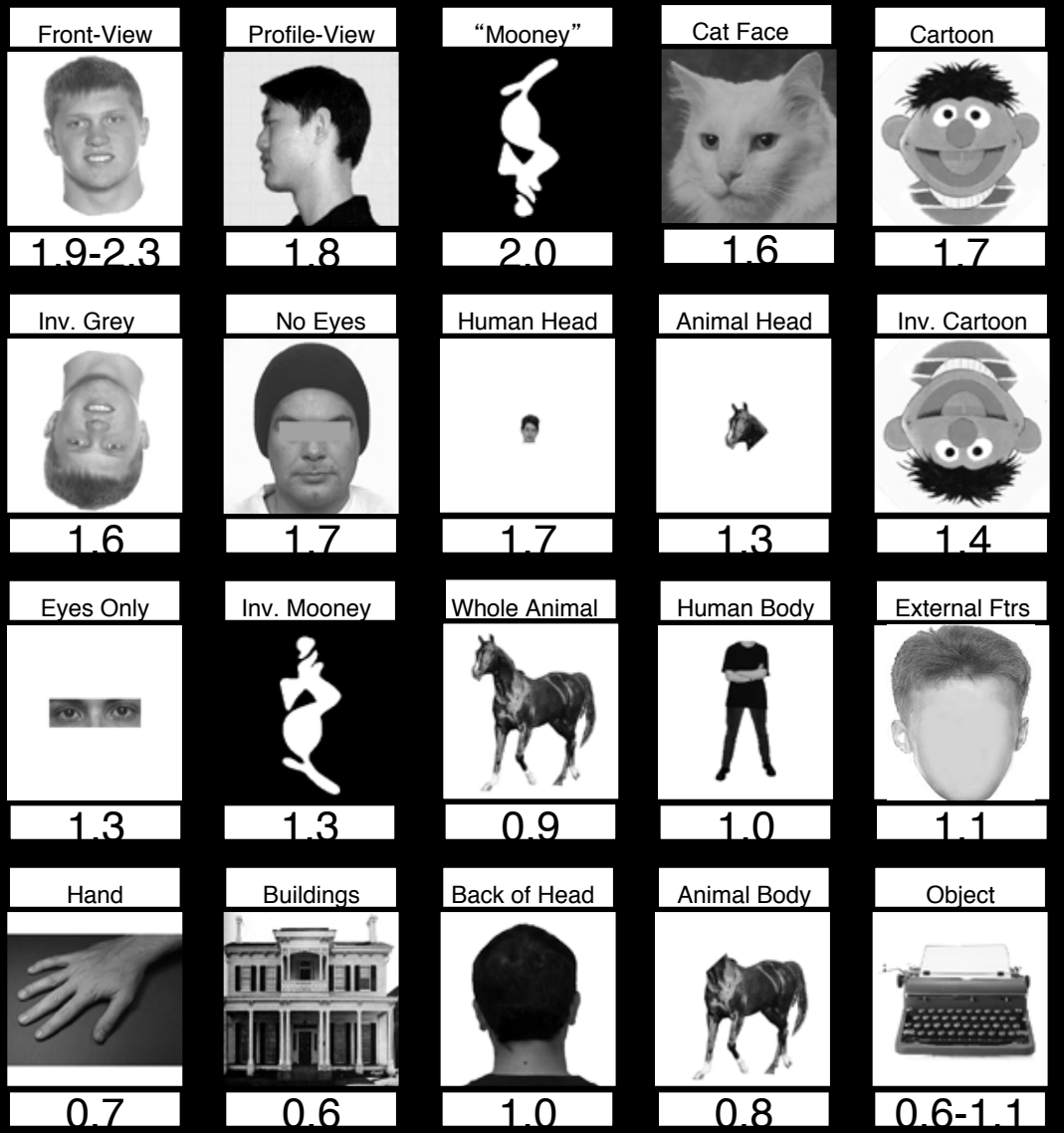
Faces > objects in 2 subjects:



This region is found in a similar location in ~ every normal subject.

Responds more to faces>
anything else yet tested.

Does this mean that
this region is innate?
this region is *necessary* for face recognition?
Does it tell us how face recognition *actually works*?



fMRI: Advantages & Disadvantages

Advantages:

- The best spatial resolution available for studies on normal subjects.
- Noninvasive.

Disadvantages:

- Can't tell if activity measured plays a causal role in cognition/behavior!
- The physiological basis of BOLD is unclear (synaptic activity vs spikes).
- Spatial resolution a ~1 mm at best (difficult to see cortical columns),
- Expensive (>$600/hour!).
- "Susceptibility artifact" due to magnetic inhomogeneities near ear canals and sinuses.
- Loud banging noise.
- Temporal resolution not on a par with visual information processing.

Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level
   Major challenge: huge variation across images of a single face
2. What is the nature of the representations we humans extract form faces?
   Not image invariant for unfamiliar faces.
   Orientation specific
3. Is face perception a distinct system from the rest of vision/cognition?
   Looks like it, from both behavior and fMRI, but we have not yet nailed the case.
   Think about why.
4. How *fast* are faces detected and recognized?
   can fMRI tell us this?
5. How is face recognition implement in individual neurons/circuits?

6. What is the causal role of each brain region in face recognition?

Electroencephalography (EEG)

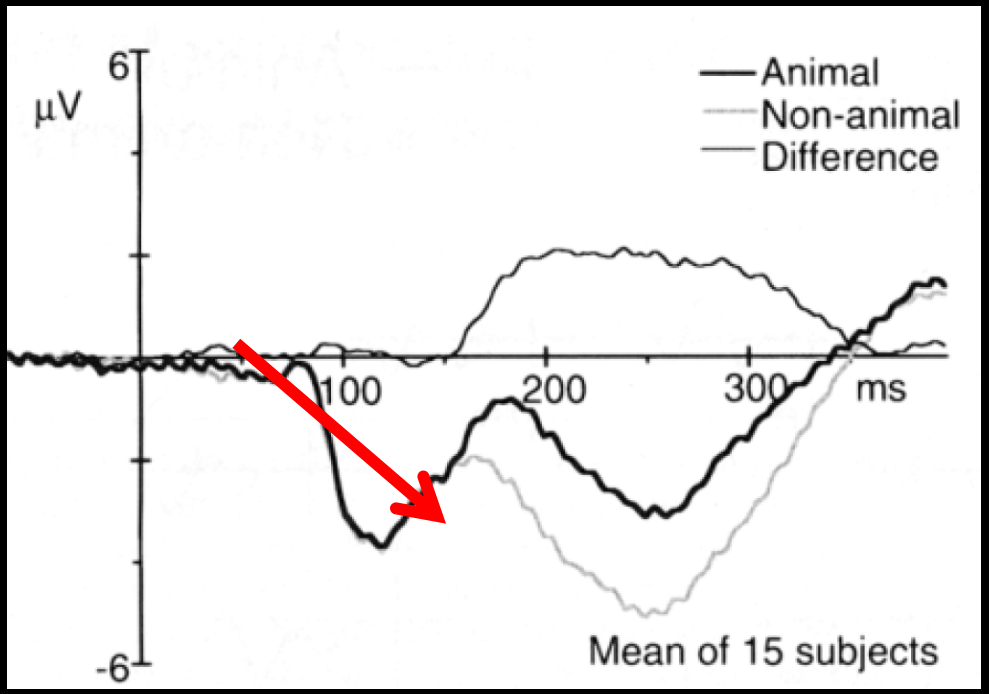
12-100+ scalp electrodes measure electrical response in brain, summing over LOTS of neurons.

- Poor spatial resolution.
- Old analogy: Like microphone on roof of football stadium: can tell when touchdown occurs, but that's all.
- This is changing…

Thorpe et al (1996) assigned reading:
How fast can we tell if image contains animal?
First: Why not just measure reaction time?

Average ERP responses over frontal electrodes over 15 subjects
for trials containing animals vs not:

So, how fast can people do this?
Is the animal detection finished by then?
Might it have started earlier?



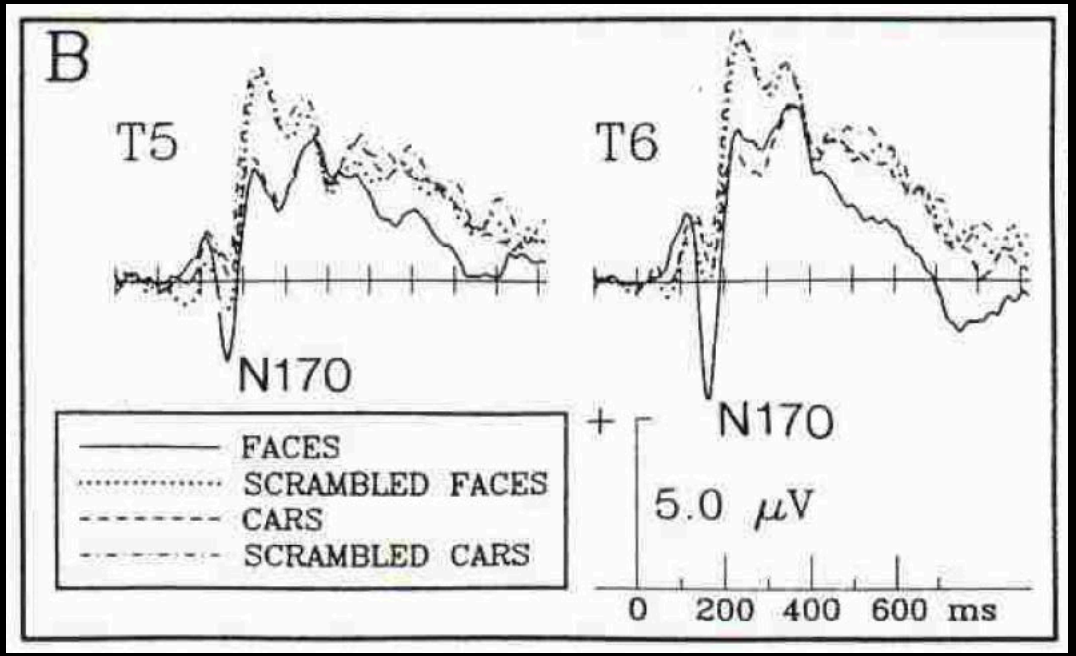
From S. Bentin, et al. Electrophysiological Studies of Face Perception in Humans. *J Cogn Neurosci 1996; 8 (6): 551 565*. doi: https://doi.org/10.1162/jocn.1996.8.6.551. License: CC BY.

Event-Related Potentials (ERPs)

Can ERPs answer any of our questions about face perception?

Yes!

A face-specific response can be detected at 170 ms after stimulus onset, showing



- more evidence that some brain mechanism is specific to faces
- faces are discriminated from nonfaces by 170 ms (fast).
- Does this signal come from the FFA?
- Can we do a little bit better localizing the source?

Magnetoencephalography (MEG)

300+ sensors arrayed around head. Measure magnetic fields produced by current in neurons. (right hand rule!)

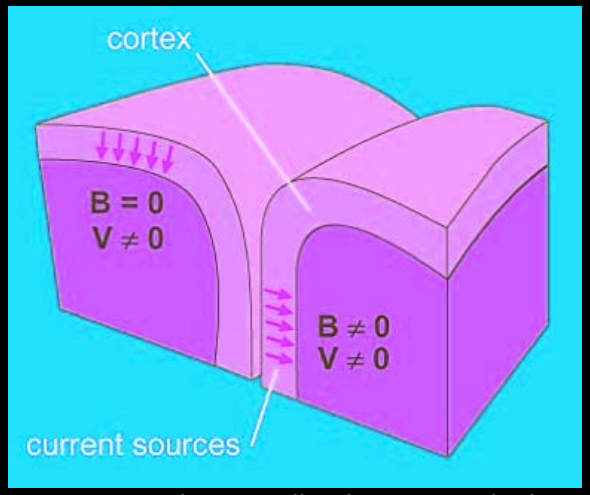


Figure © source unknown. All rights reserved. This content is excluded from our Creative Commons license. See https://ocw.mit.edu/fairuse for more information.

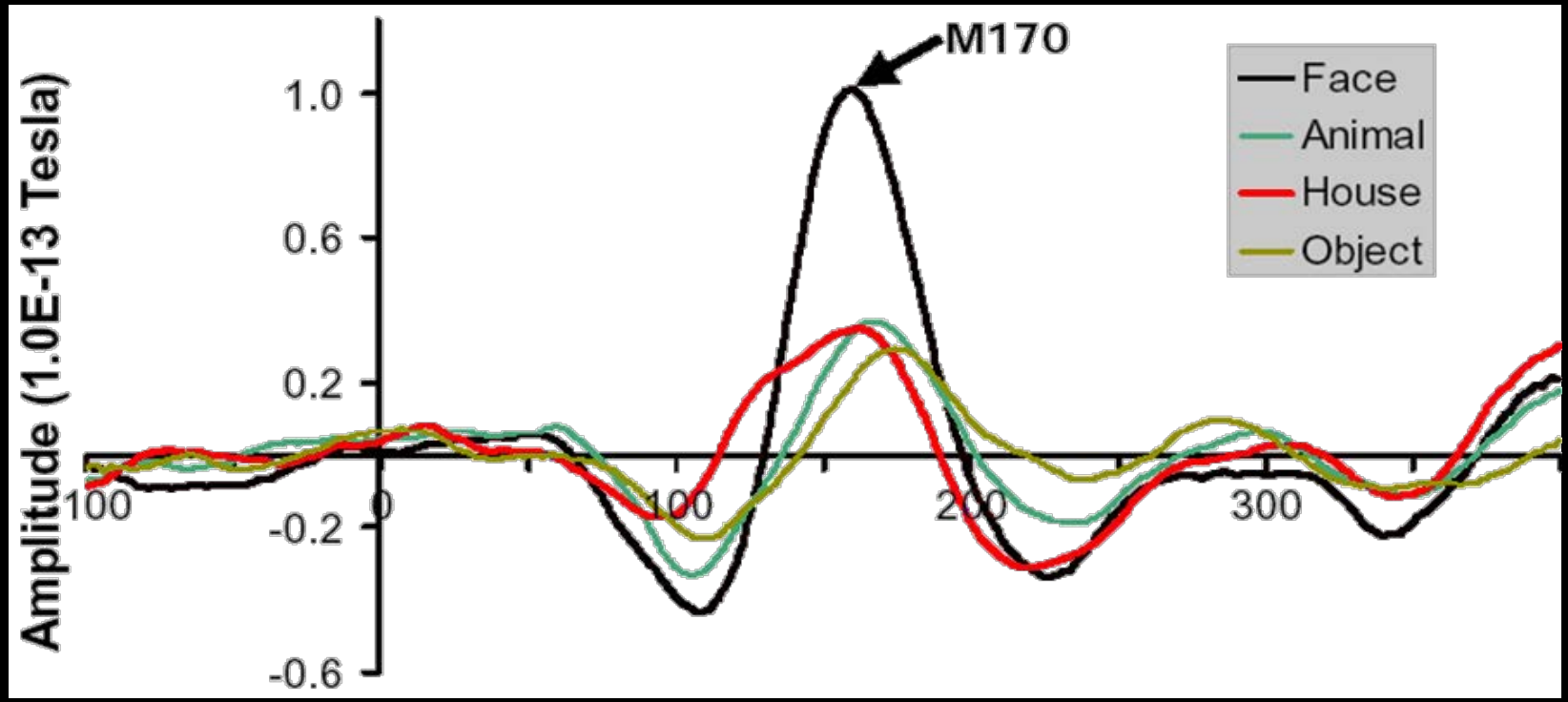
Photo of MEG setup at CBMM. This content is excluded from our Creative Commons license. See https://ocw.mit.edu/fairuse for more information.

- MEG primarily "sees" activity in brain's folds (sulci), not bumps (gyri).
- Fields ≅ 10^{-13}Tesla, ~ 10^{6} times weaker than earth's magnetic field.
- Need lots of shielding.
- Detectors = Superconducting Quantum Interference Devices (SQUIDs) cooled to -269 degrees with liquid helium.

Can MEG Tell us anything about Face Perception?

Yes!

A face-selective “M170” occurs over occipitotemporal sensors 170 ms after stimulus onset.



- Shows that face detection occurs quickly. (what about recognition?)
- Implicates specialized cortical machinery for doing it.

EEG & MEG

Advantages:

- Noninvasive
- Excellent temporal resolution.

[Why would we care about time?]

- The methods described so far rely on finding specific selective responses.

But new ML methods can ~ “decode” from ERP and MEG responses what the person saw/thought.

This works surprisingly well.

Opening up lots of research possibilities.

More on that later.

Disadvantages:

- Lousy spatial resolution. Ill-posed “inverse problem”.

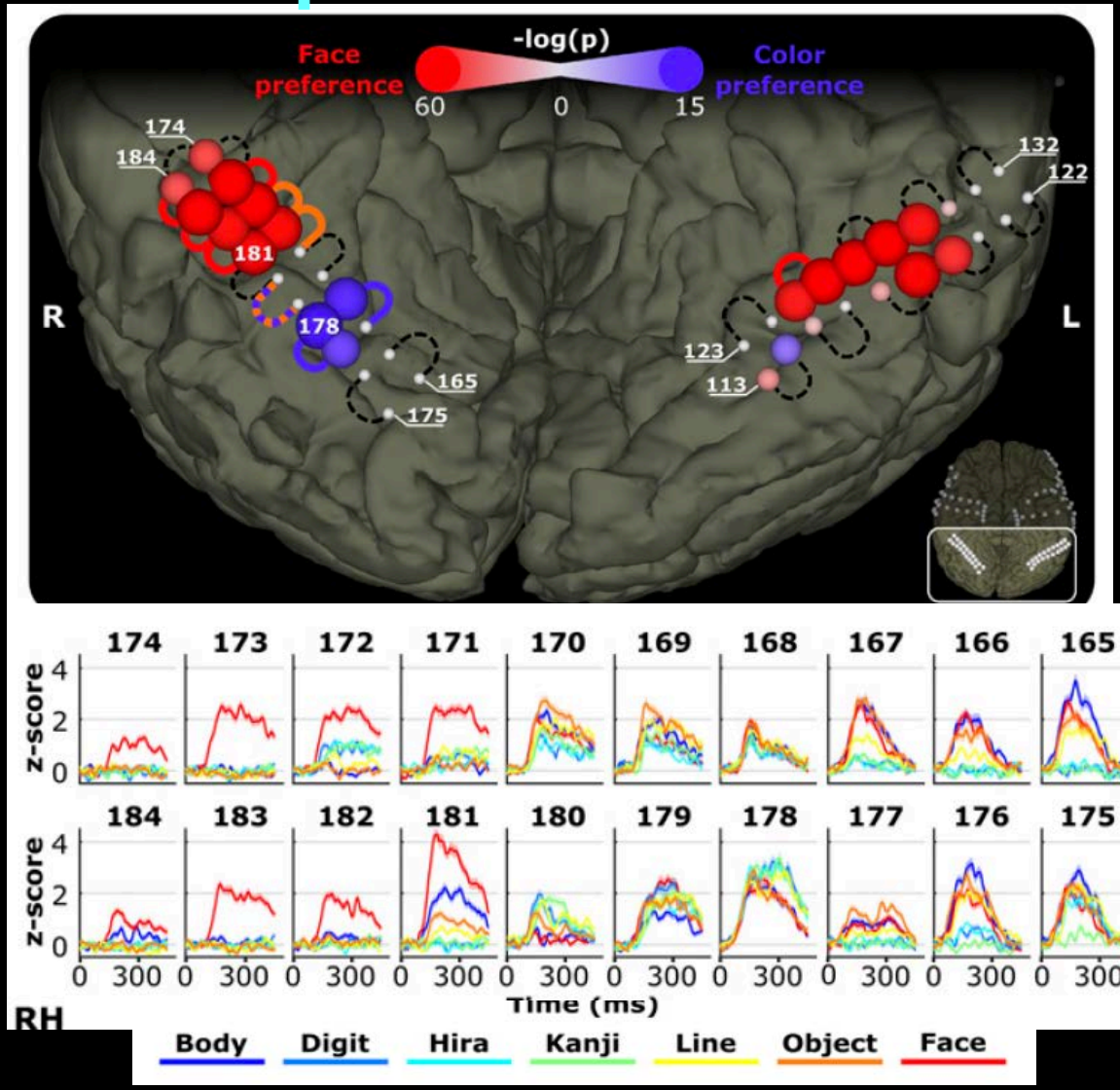
What are we gonna do about that?

Intracranial Recording: The One Method with High Spatial *and* Temporal Resolution

Neurosurgery patients with electrodes on the surface of the brain.

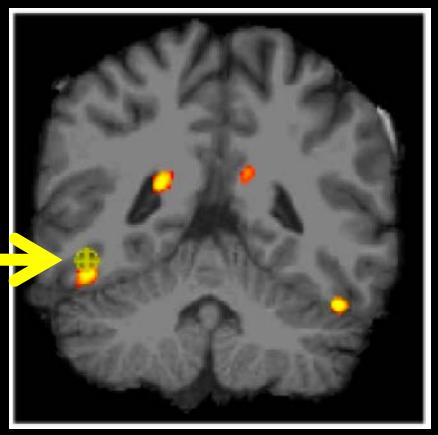
Wow.
Small (2-mm) patches of cortex respond *exclusively* to faces starting around 150 ms.

Still, that is LOTs of neurons.
Can we record from *individual neurons in humans*?

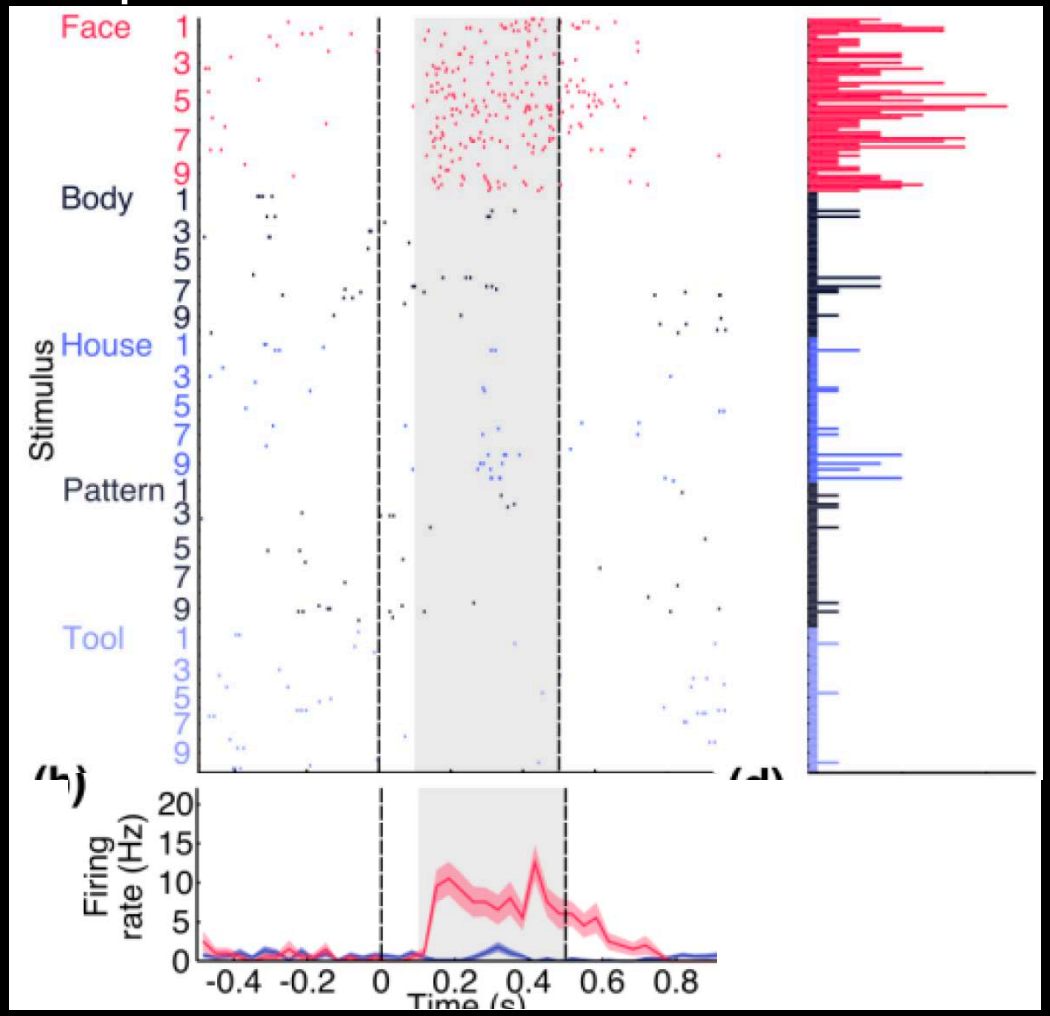


Intracranial Recording: Individual Neurons in the human FFA

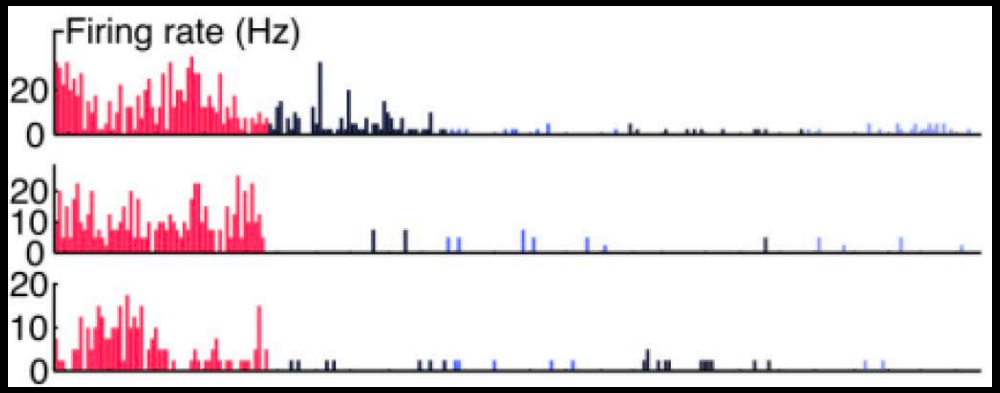
Location of electrode with μwires that can record individual neurons



Response of individual neuron:



Three more FFA neurons:



FFA neurons are selective for faces.
Can they distinguish different faces?
Does this tell us how face perception works?

Intracranial Recording

Advantages:

- The only method in humans w/ high spatial *and* temporal resolution

Disadvantages:

- Invasive; Only possible in patients with neurological problems.
- Data are rare and hard to control.
- Can't tell if activity measured plays a causal role in cognition/behavior!

that won't do!

causality is the essence of scientific understanding

what are we gonna do?

to test the causal role of region X in behavior we need to *mess with X!*

that is, disrupt X, and see what happens to behavior

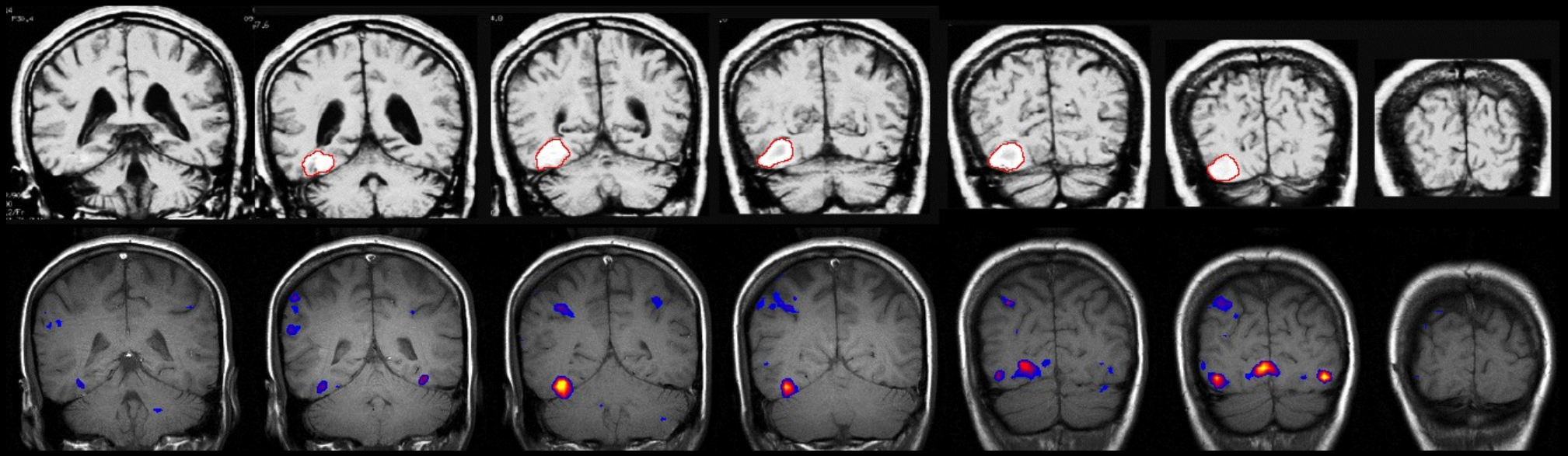
Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level
   Major challenge: huge variation across images of a single face
2. What is the nature of the representations we humans extract form faces?
   Not image invariant for unfamiliar faces.
   Orientation specific
3. Is face perception a distinct system from the rest of vision/cognition?
   Looks like it, from both behavior and fMRI, but we have not yet nailed the case.
   Think about why.
4. How *fast* are faces detected and recognized?
   Face detection begins by 170 ms, maybe earlier.
   Face recognition we don't yet know. Stay tuned.
   Does this tell us what kinds of computations are involved? Not really yet but…
5. What is the causal role of each brain region in face recognition?
   How might we tell?
6. How is face recognition implement in individual neurons/circuits?

Evidence from Patients with Focal Brain Damage

↓ This patient, who is apparently missing an FFA: ↓



↑NK's FFA↑

Cannot recognize faces!

Source: Wada Y, Yamamoto T. *J Neurology, Neurosurgery & Psych* 2001;71:254 257.

Crucially, this patient is *completely normal at recognizing objects!*

This suggests that:
FFA is critical for face recognition *but not for object recognition.*

More generally…..

Wada & Yamamoto, 2001

Double Dissociation

Prosopagnosia

- Impairs face discrimination & recognition, not face detection
  voice recognition, naming from description of profession intact
- In rare cases where lesion is small, deficit can be very specific,
  leaving object recognition intact.
- Does this prove we have special brain machinery for face recognition?

The Opposite Syndrome

- Patient CK (Moscovitch et al 1997): severely impaired on
  object recognition *yet 100% normal at face recognition*
- Do you think CK is better or worse at recognizing inverted faces than normal subjects?

Why?

This combination of two opposite deficits (a "double dissociation") provides strong evidence that the brain machinery for face recognition is not necessary for object recognition and vice versa.

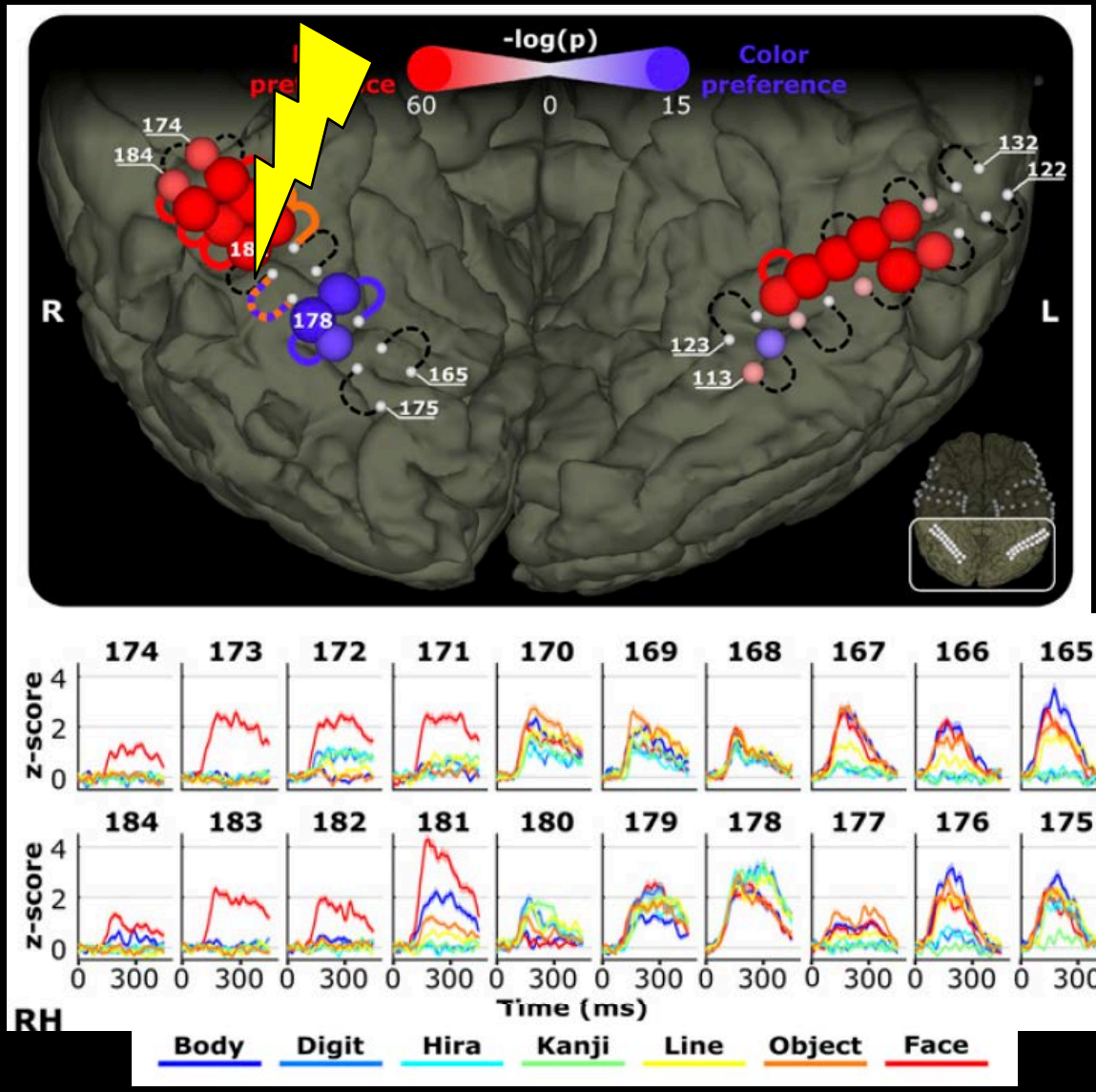
Why is the evidence stronger than a single dissociation (e.g. just prosopagnosia)?

Recall this Neurosurgery Patient

Neurosurgery patient with electrodes on the surface of the brain (subdural).

Epilepsy neurosurgeons sometimes electrically stimulate particular locations in the brain to discover seizure focus & to map functions.
If patient agrees, they can do a task at the same time.
If the neurosurgeon finds it clinically informative to stimulate here:

What task would you want the patient to do to learn about this region?



Face Recognition: What we want to know

Key Questions about Face Recognition:

1. What is the nature of the problem of face perception? (inputs, outputs, challenges)
   Marr computational theory level
   Major challenge: huge variation across images of a single face
2. What is the nature of the representations we humans extract form faces?
   Not image invariant for unfamiliar faces.
   Orientation specific
3. Is face perception a distinct system from the rest of vision/cognition?
   Looks like it, from both behavior and fMRI, but we have not yet nailed the case.
   Think about why.
4. How *fast* are faces detected and recognized?
   Face detection begins by 170 ms, maybe earlier.
   Face recognition we don't yet know. Stay tuned.
   Does this tell us what kinds of computations are involved? Not really yet but…
5. What is the causal role of each brain region in face recognition?
   FFA is causally involved in face perception apparently not object perception.
   (So maybe we need different theories of how face vs obj recognition works.)
6. How is face recognition implement in individual neurons/circuits?
   These findings don't tell us what exactly the computations are in face recognition, or how circuits actually carry out these computations.

9.13 The Human Brain

Spring 2019