9.71 Functional MRI of High-Level Vision
Fall 2007

9.71: fMRI of High-level Vision
Nancy Kanwisher
Fall 2007

Lecture 1: Introduction to fMRI & High-level Vision

I. What is fMRI?
- A. A very simple fMRI experiment
- B. Impact of fMRI on cognitive neuroscience
- C. Some Examples of cool findings from fMRI
- D. The fMRI “BOLD” signal - absolute basics

II. Basic Experimental Design

III. Localization of Function

IV. What is High-Level Vision?

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What is fMRI?

(functional Magnetic Resonance Imaging)

Image: NIH

- *FAST:*
  10+ images/ sec
- *NEURAL ACTIVITY*

"BOLD" (blood oxygenation level dependent) signal:

Increased neural activity >
Increased local blood flow more than compensates for O_2 use >
decrease in deO_2Hb concentration>
increase in MR signal intensity (deO_2Hb is paramagnetic)

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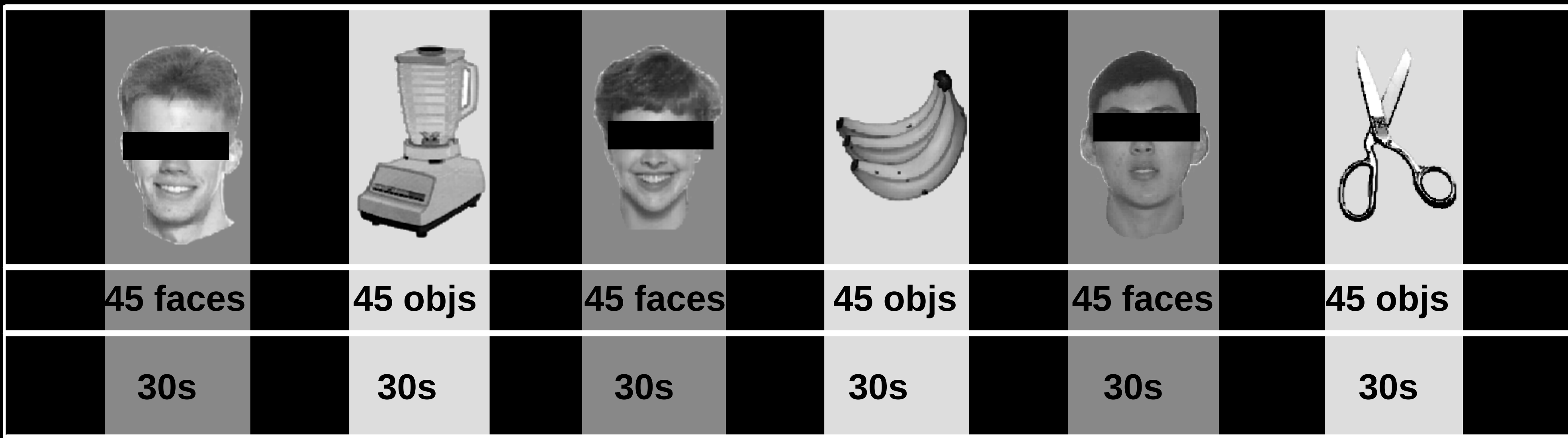
Question:

Are there any parts of the brain that are specialized for perceptually processing faces, more than other kinds of visual stimuli?

Where are they?

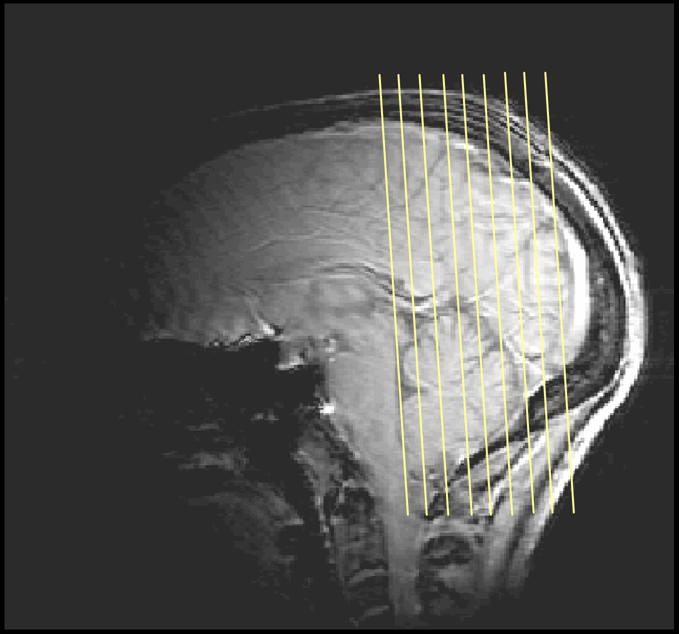
Stimulus Sequence
“blocked” design

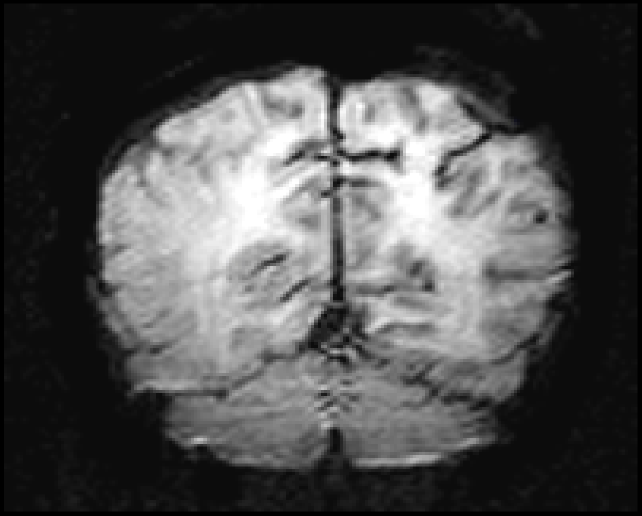


Face photos modified by OCW for privacy considerations.

- A single scan = 5.5 minutes long
- Presentation rate = 1.5 pictures/second

fMRI Data



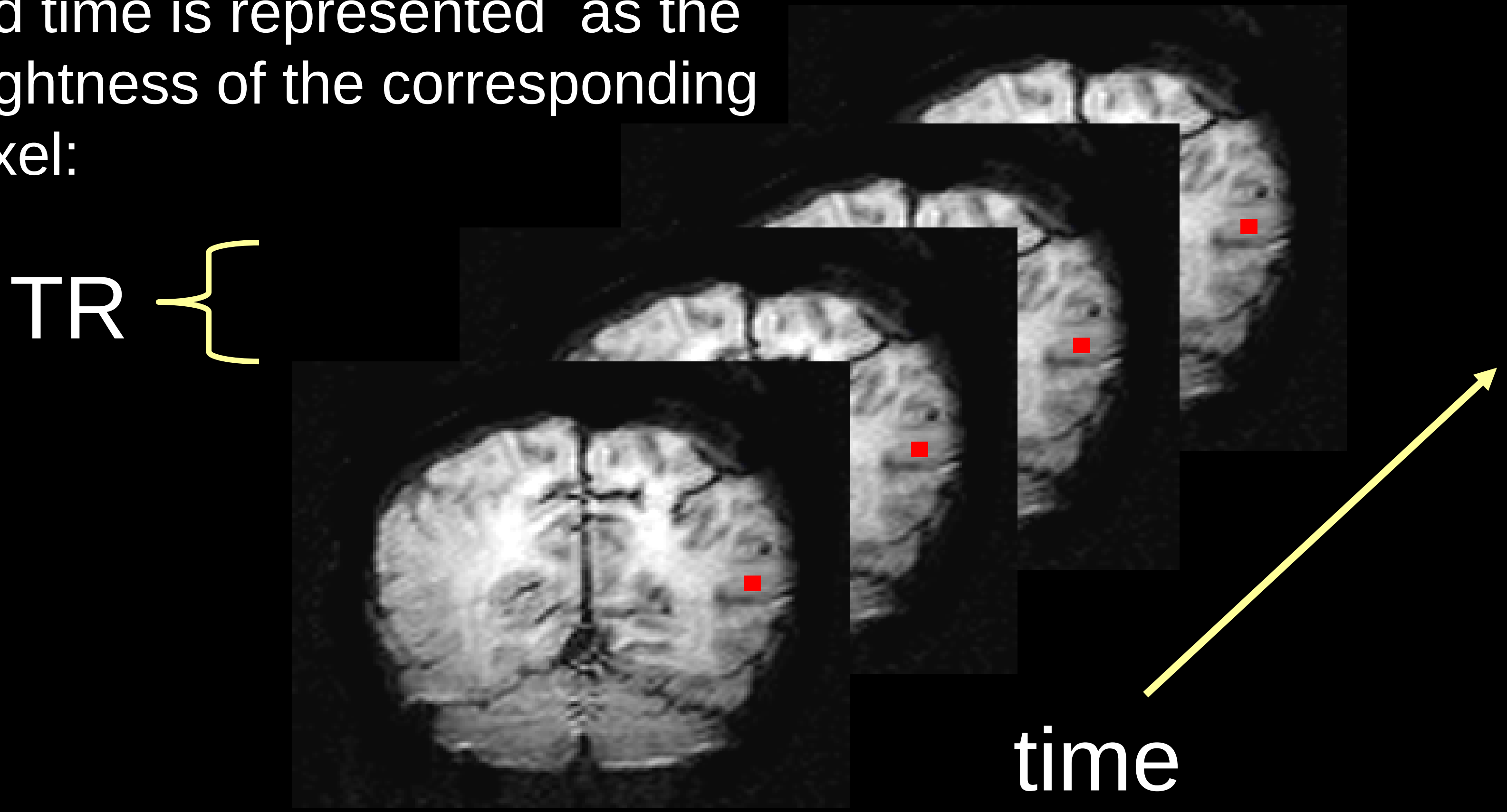


Chose slice number, position, thickness, and orientation

Each functional image of one slice is at least 64 x 64 voxels

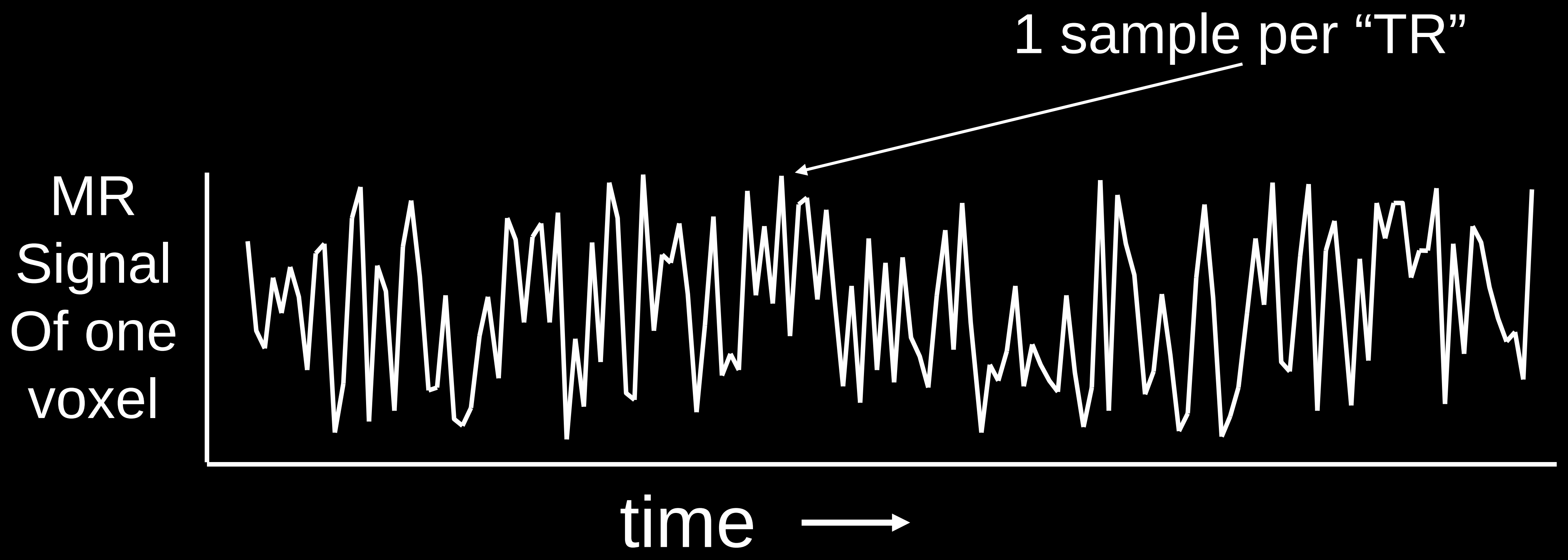
An image is made of each slice e.g. every 2 seconds (TR=2)

This makes a “movie” of each slice, in which the MRI signal intensity at each position and time is represented as the brightness of the corresponding voxel:



fMRI Data

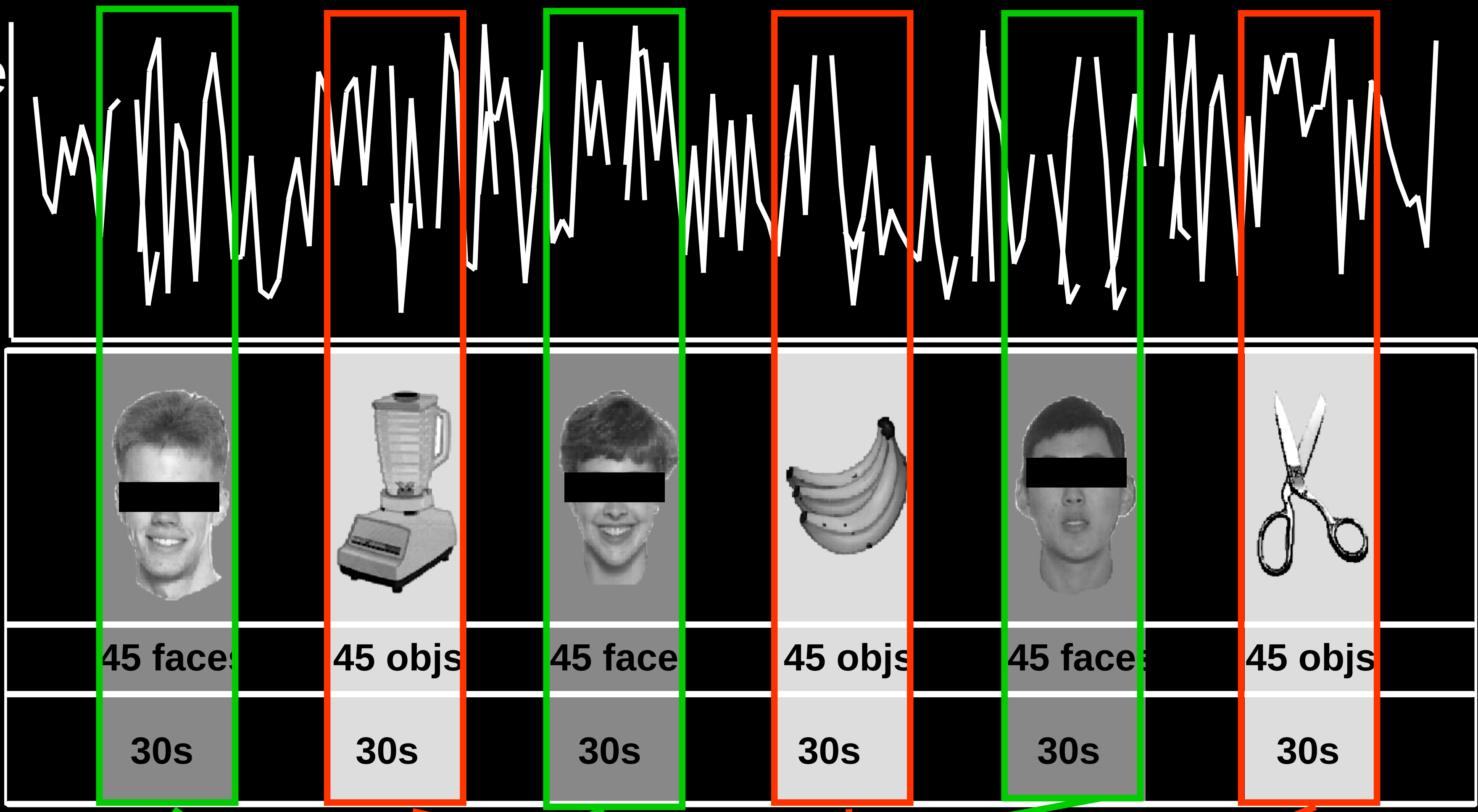
Each voxel has a "time course" like this:



We statistically test each voxel to see if it produced a stronger response, e.g. during the face epochs than during the object epochs…..

Statistical analysis on each voxel

Time Course From One voxel

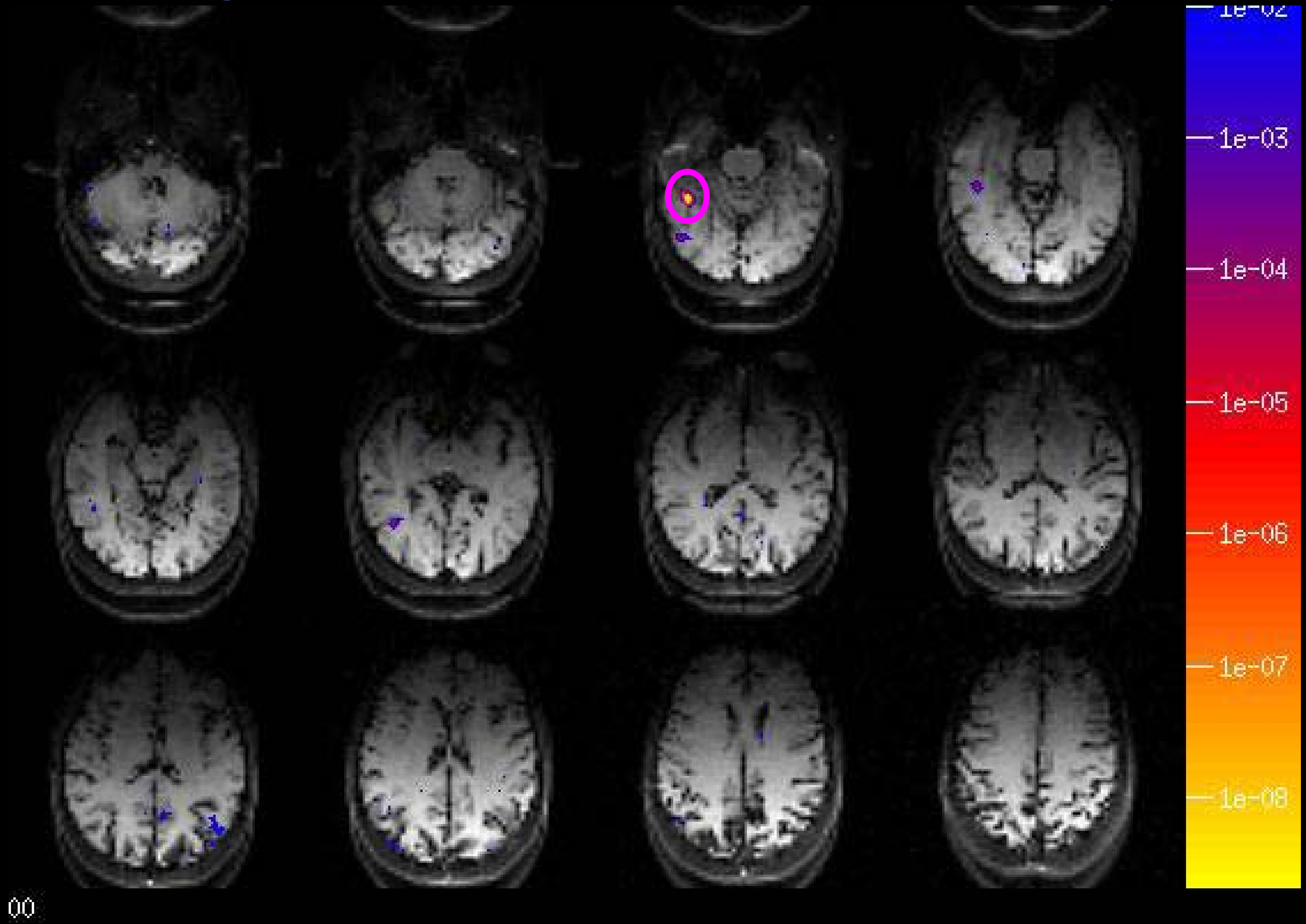


What The Subject Saw:

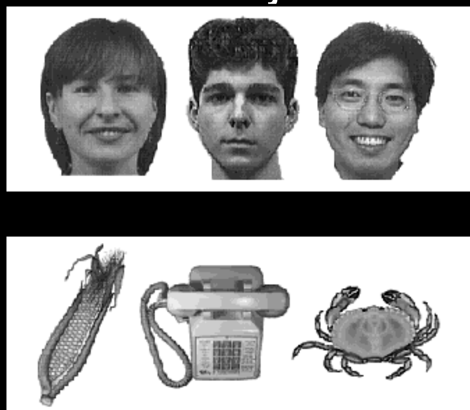
Face photos modified by OCW for privacy considerations.

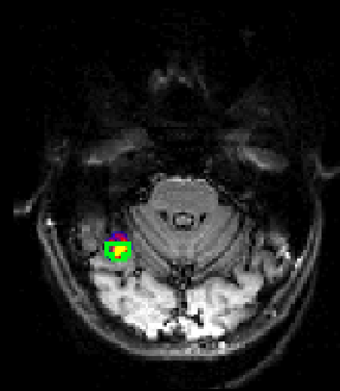
Is the signal Higher for **Faces** than for **Objects** ?

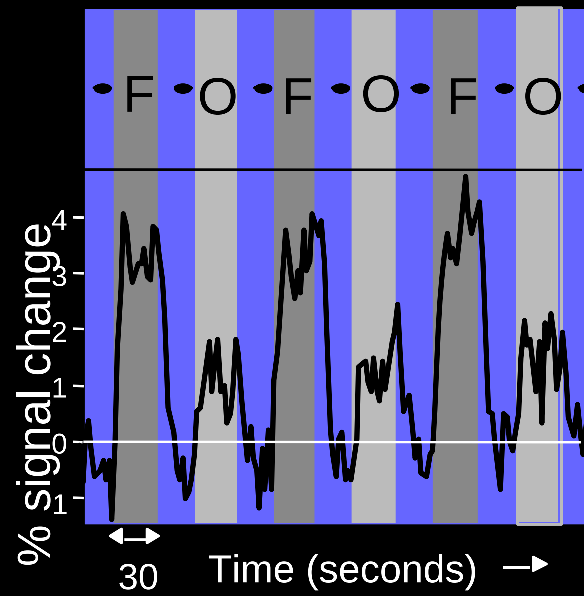
Stronger Response to Faces Than Objects



Faces > Objects







Courtesy of Society for Neuroscience. Used with permission.

Kanwisher, N., et al. "The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception." *The Journal for Neuroscience* 17, no. 11 (1997): 4302-4311.

Question:

Are there any parts of the brain that are specialized for perceptually processing faces, more than other kinds of visual stimuli?

Where are they?

We have a beginning of an answer to ths question, but have not yet nailed it.
Be thinking about why it isn’t nailed yet.
We will come back to this…….

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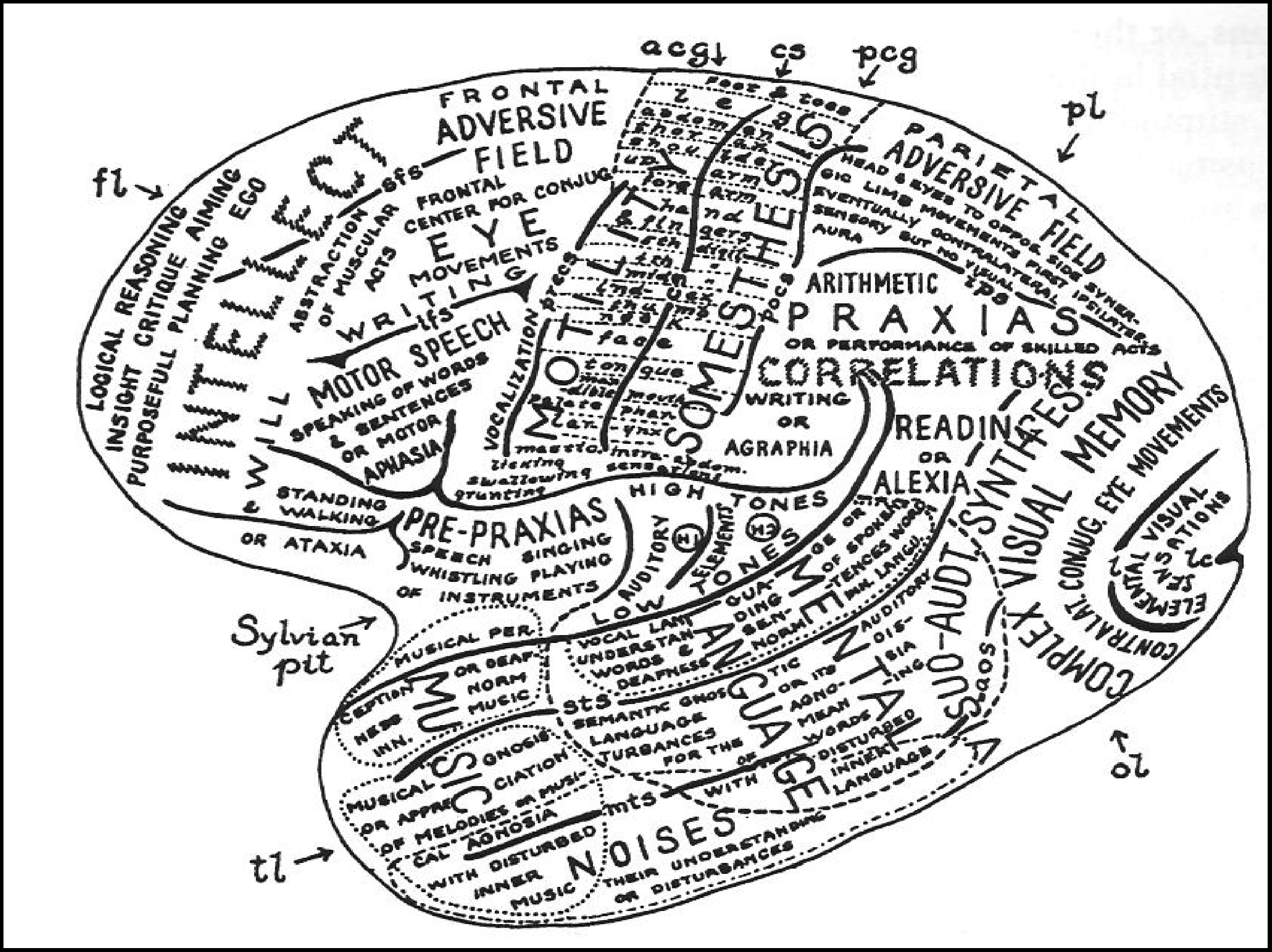
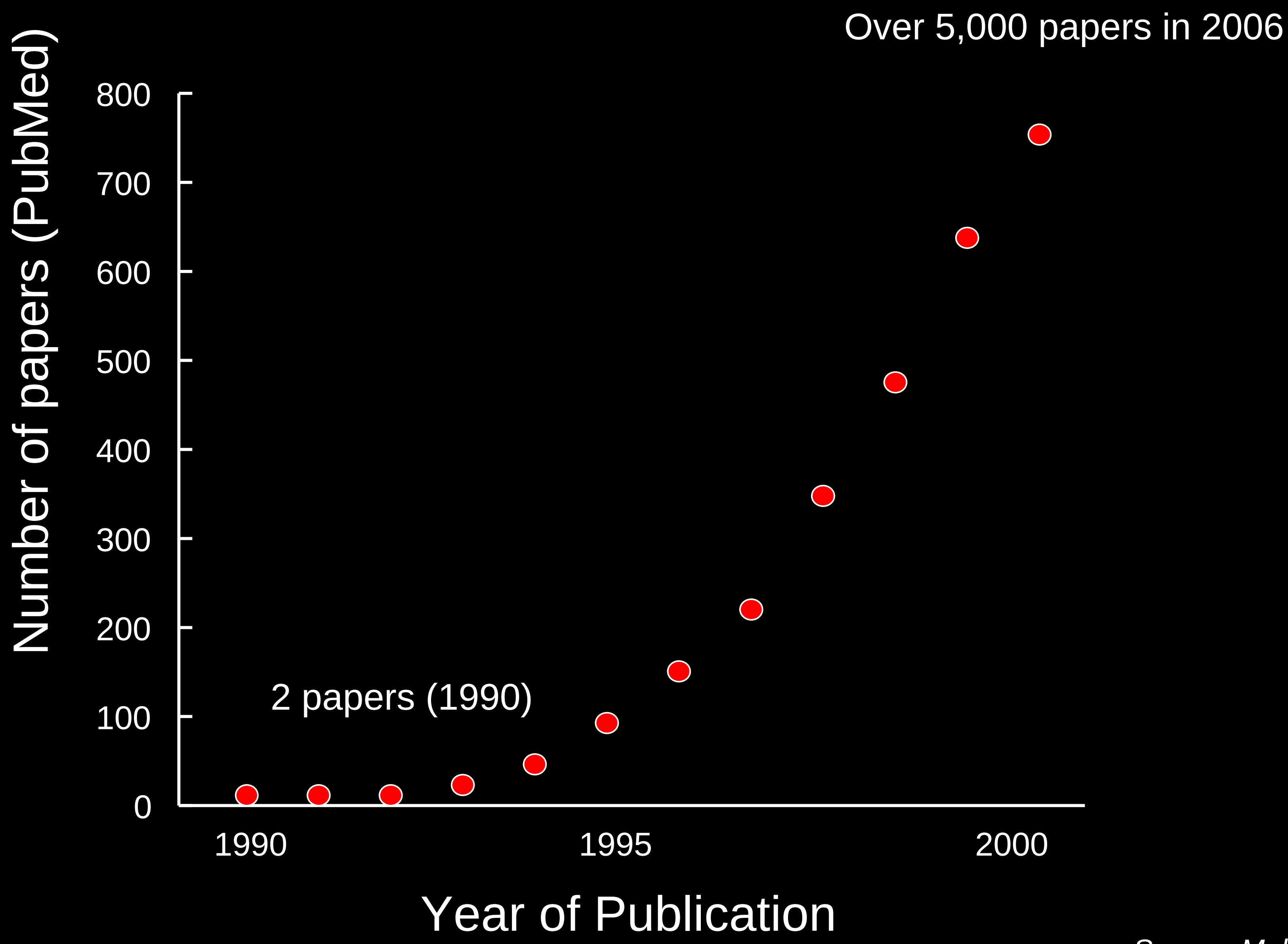
The Brain Before fMRI (1957)



Polyak, in Savoy, 2001, Acta Psychologica

Because fMRI was the first method for noninvasive functional mapping of the normal human brain, it took off…...

THE RISE OF fMRI



Source: Mel Goodale

The effect of fMRI on vision research is particularly striking.

In the early 1990s…

Macaque Visual Cortex, early 90s

Brain diagram removed due to copyright restrictions.

Image removed due to copyright restrictions.
Fig. 4, “Hierarchy of visual areas,” showing organization of 32 visual cortical areas.
In Felleman, Daniel J., and David C. Van Essen. “Distributed Hierarchical Processing in the Primate Cerebral Cortex.” *Cerebral Cortex* 1, no. 1 (1991): 1-47.

What about Human Visual Cortex?

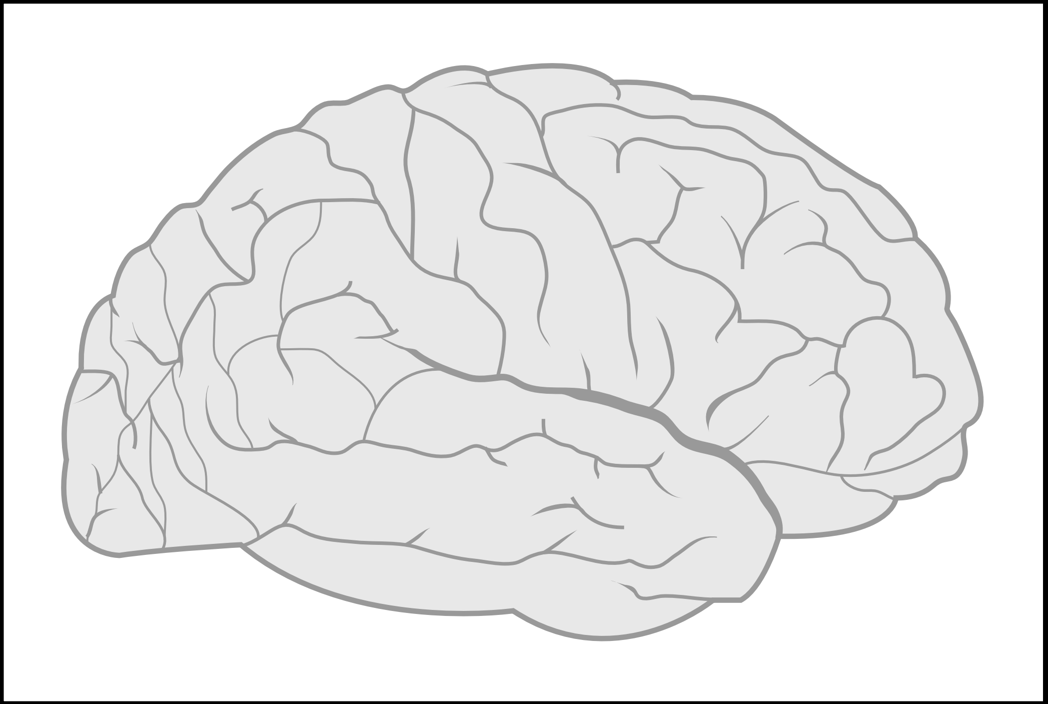


Figure by MIT OpenCourseWare.

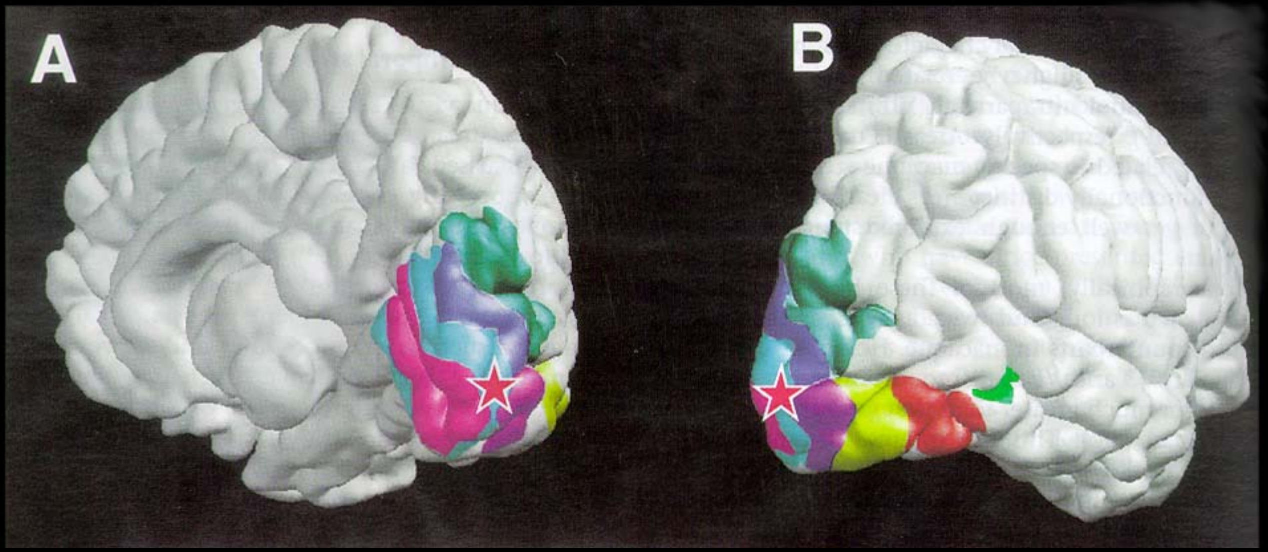
almost nothing was known.

and then.....

Source: Felleman & Van Essen, 1991

In 1994, only two or three areas had been identified in human visual cortex.

Two years later, Tootell et al published this map, containing ten visual areas.



Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

fMRI research continues to identify new cortical areas regularly. (My lab has identified 3 new regions.)

Myriad discoveries have been made with fMRI……

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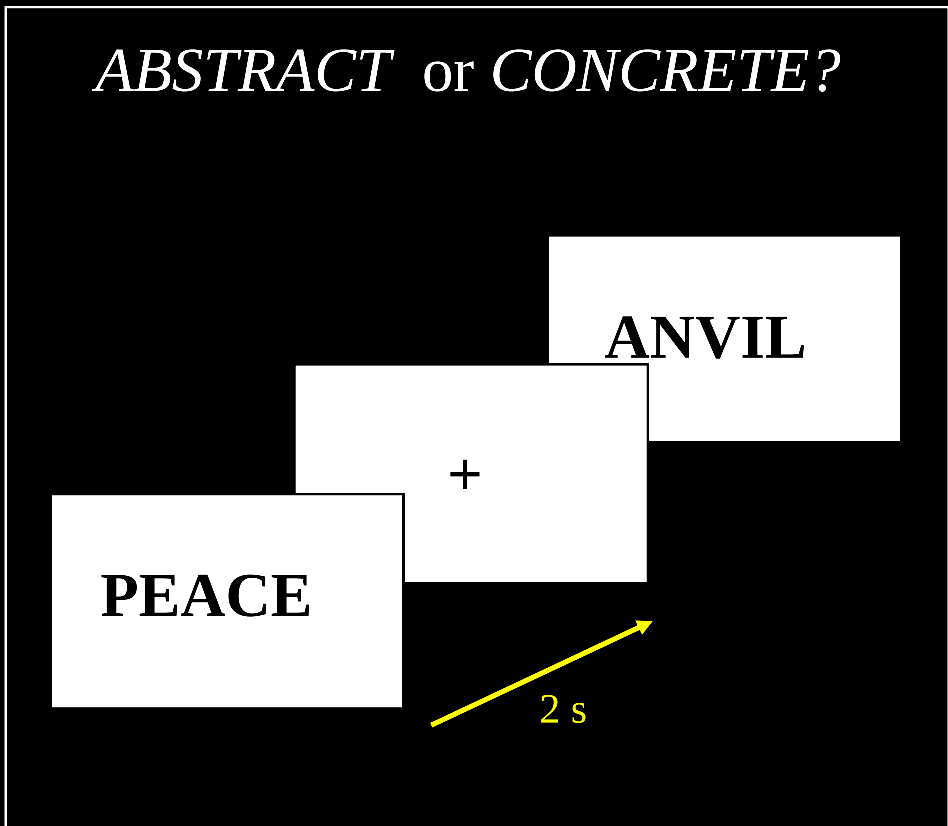
1. Question:
Sometimes you read stuff and remember it later……
Sometimes you read it and it goes poof.

What is the difference in these two events?

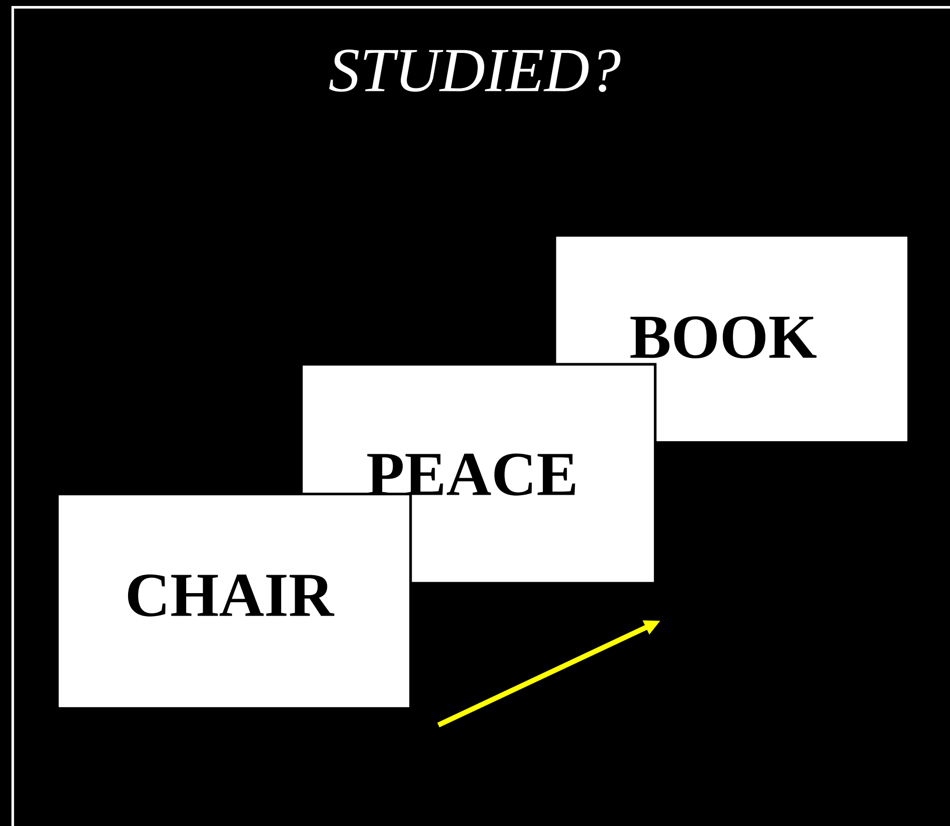
Does something different happen in the brain while you are actually reading it in the first place?

1. Predicting Verbal Explicit Memory

fMRI Scanning during
Word Learning



Post-Scan Memory Test



Predicting Verbal Explicit Memory: Left Ventrolateral PFC

Wagner et al (1998)

Posterior LIPC

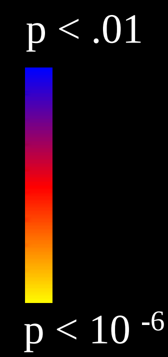
A

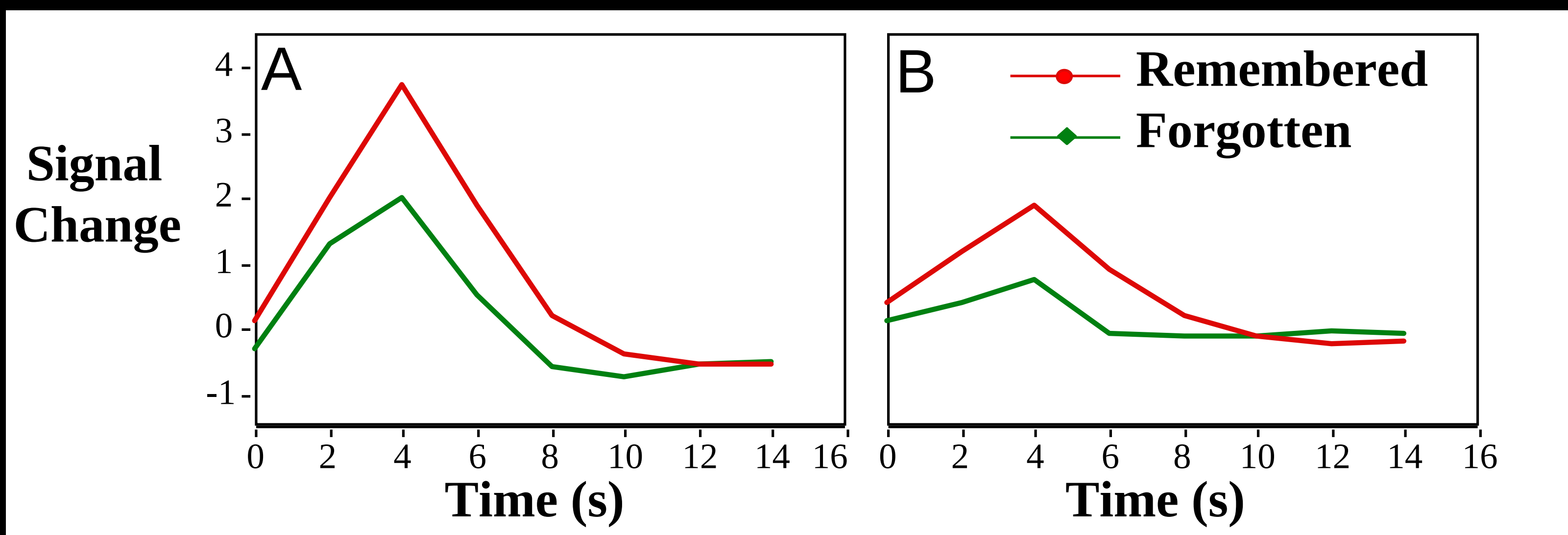
MRI diagrams removed due to copyright restrictions.

Anterior LIPC

B

MRI diagrams removed due to copyright restrictions.





2. We are highly social organisms. We spend a lot of time thinking about what other people are thinking.

Question:

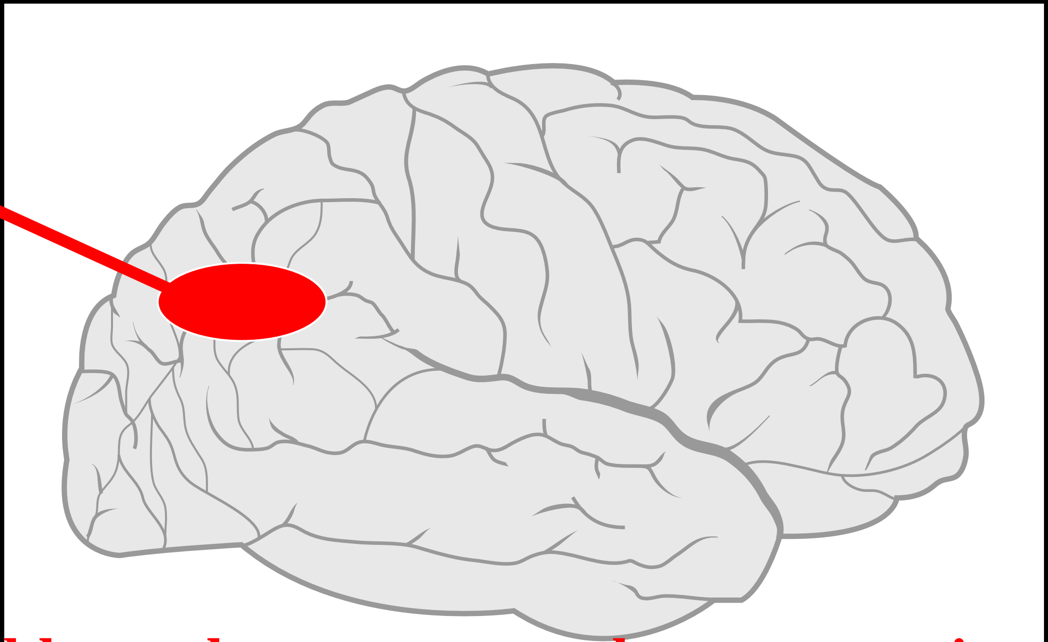
Do we have special purpose brain machinery specialized just for thinking about what other people are thinking?

2. Understanding Others' Beliefs
The TPJ

Rebecca Saxe

Beliefs

Reasoning about another person's *beliefs*.



NOT:

Logically identical problems about nonmental representation.

Reasoning about hidden causes.

Figure by MIT OpenCourseWare.

Reasoning about or perceiving physical attributes of people .

Reasoning about a person's cultural background.

Reasoning about or other people's bodily sensations (e.g., thirst, hunger).

3. We are also highly *visual* organisms. We spend a lot of time looking at faces, bodies, scenes, words…...

Question:

Do we have special purpose brain machinery just for perceiving faces? bodies? scenes?….

3. People, Places, & Things

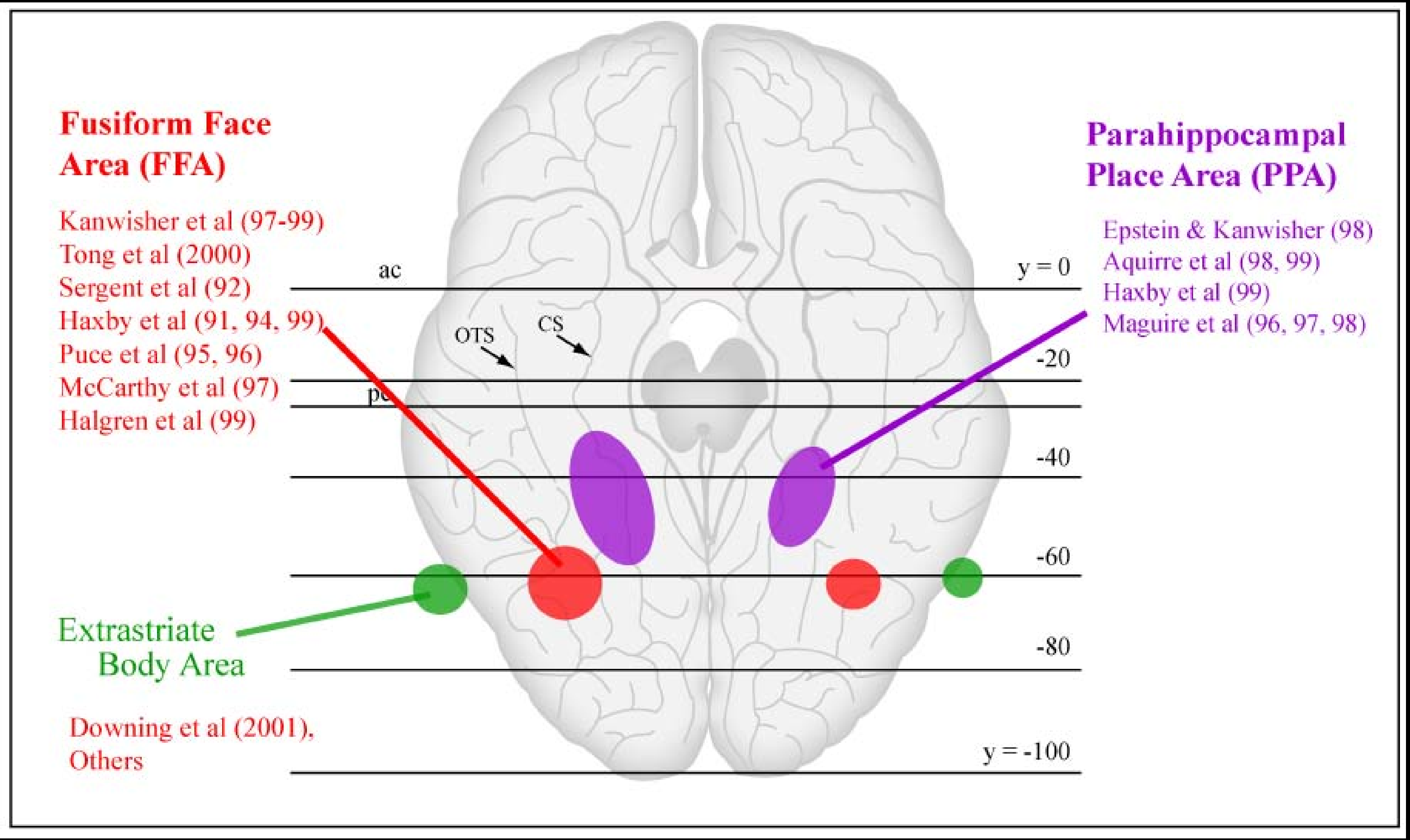


Figure by MIT OpenCourseWare. After Allison, 1994.

Of course, *I* think this is pretty fundamental, but…

Not Everyone Agrees:

“The face-selective region--dubbed the fusiform face area or FFA--has attained a level of notoriety that is arguably far out of proportion relative to its potential to inform us about the nature of object recognition".

Peissig & Tarr (2006) Ann Rev Psych chapter

4. **Might fMRI be able to tell us whether a person in a persistent vegetative state is actually "in there" despite their inability to speak or move?**

Owen et al (2006), *Science*, 313, p. 1402.

23-year old woman
Traffic accident >
Vegetative state.
Preserved sleep-wake cycles, but unresponsive.

"imagine playing tennis" and
"imagine walking around your house"

Image removed due to copyright restrictions.
fMRI images of supplementary motor area in two imagery scenarios: playing tennis and walking around the house.
See Figure 1 in Owen, A. M., et al. "Detecting awareness in the vegetative state." *Science* 313 (2006): 1402.

But…..

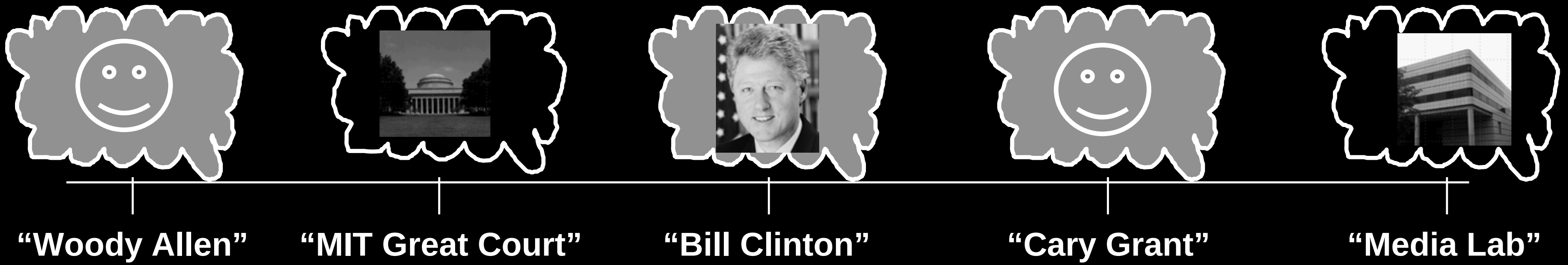
5. What happens when we close our eyes and simply *imagine* e.g. a face or a place?

no visual input
but it *feels* visual (to some people).
is visual machinery in the brain recruited?

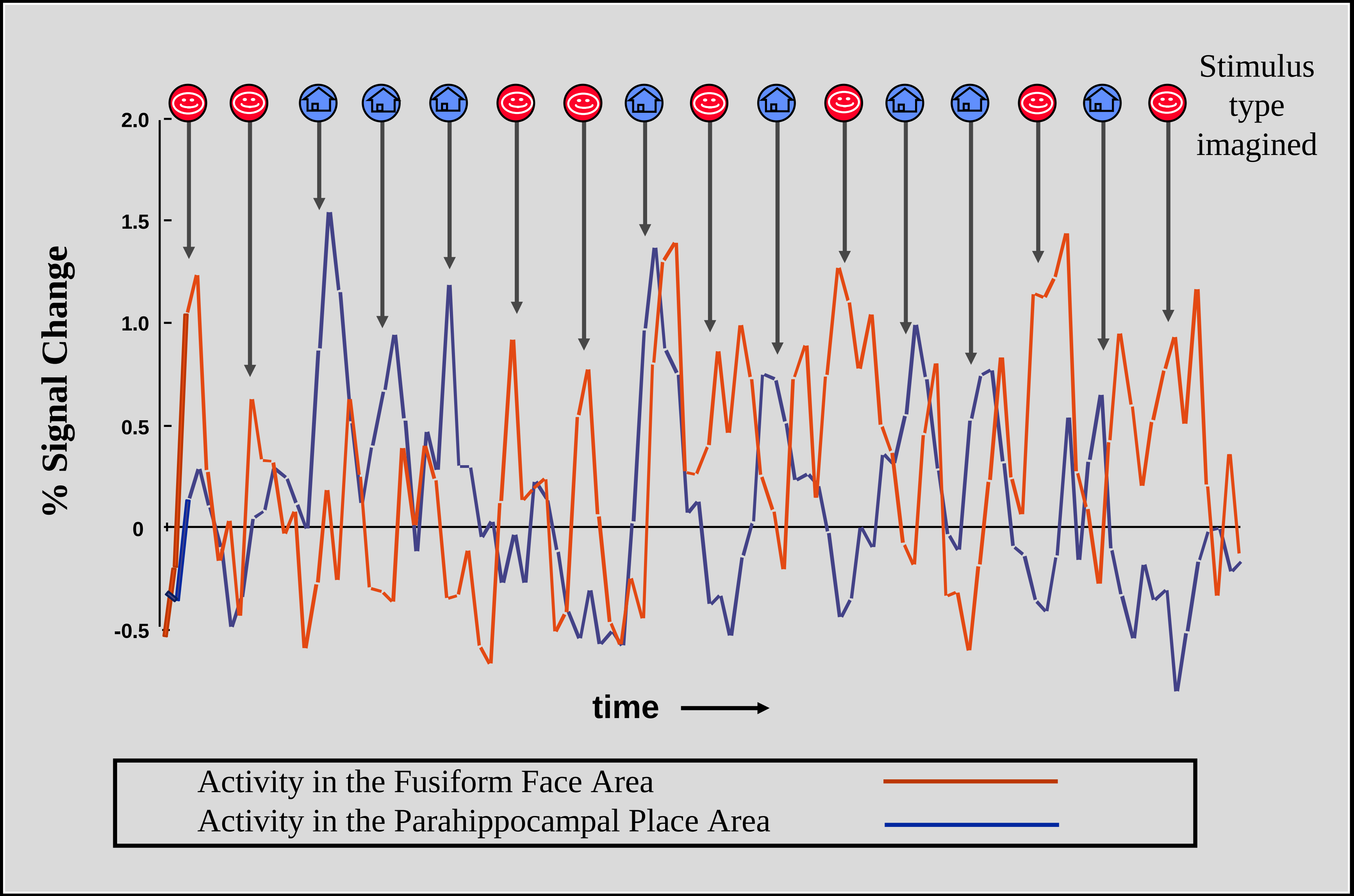
5. Mental Imagery Experiment (eyes closed)

O'Craven & Kanwisher (2000)

Subjects heard the name of a famous person or familiar place once every 12 seconds, in random order, and were instructed to image the face or place.



Imaging Single Mental Events



"Mindreading?!"

O'Craven & Kanwisher (2000)

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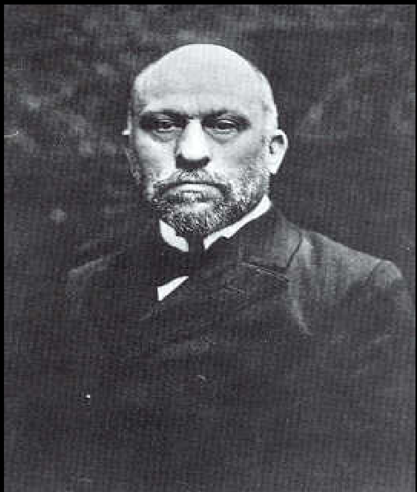
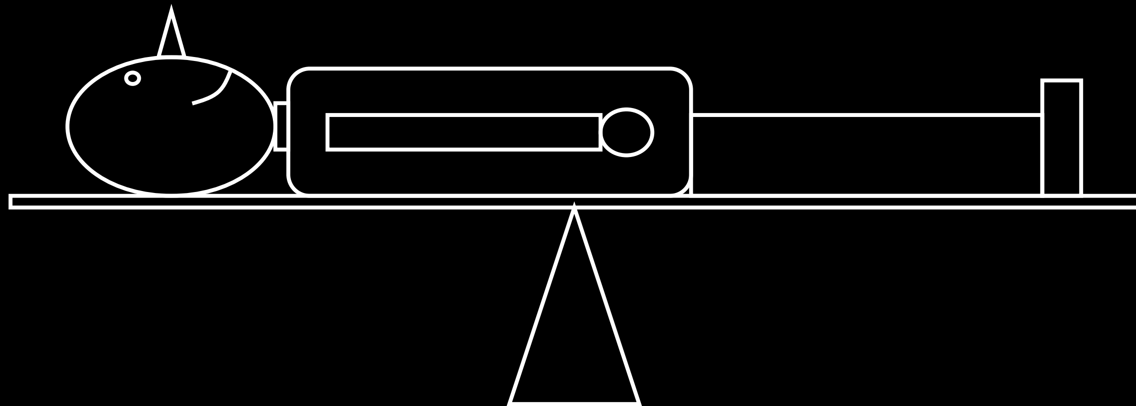
The Principle behind fMRI



Angelo Mosso
Italian physiologist
(1846-1910)



"[In Mosso's experiments] the subject to be observed lay on a delicately balanced table which could tip downward either at the head or at the foot if the weight of either end were increased. The moment emotional or intellectual activity began in the subject, down went the balance at the head-end, in consequence of the redistribution of blood in his system."

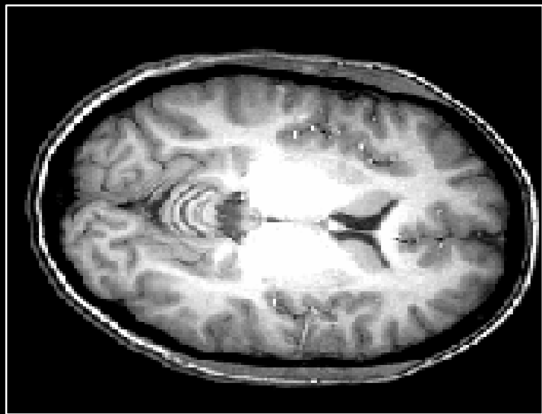
-- William James, *Principles of Psychology* (1890)

Adapted from fMRI for Dummies

MRI vs. fMRI

MRI

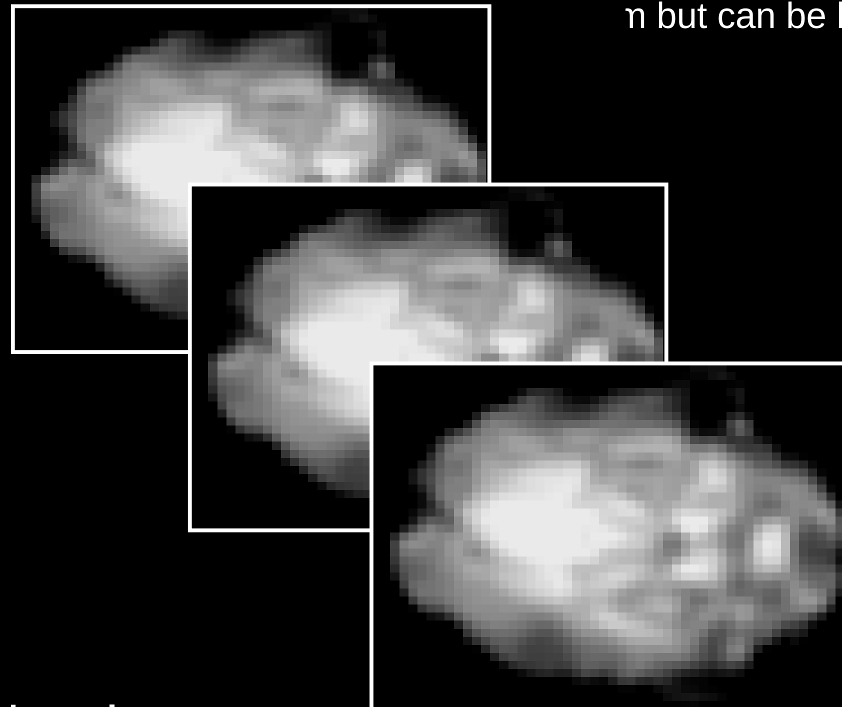
high resolution
(1 mm)



one image

fMRI

low resolution
n but can be better)



. . .

many images
(e.g., every 2 sec for 5 mins)

fMRI

Blood Oxygenation Level Dependent (BOLD) signal
indirect measure of neural activity

Adapted from Prof. Jody Culham's fMRI for Newbies

Functional Magnetic Resonance Imaging (fMRI)

"BOLD" (blood oxygenation level dependent) signal:

Increased neural activity >

Increased local blood flow more than compensates for O_2 use >

decrease in deO_2Hb concentration>

increase in MR signal intensity (deO_2Hb is paramagnetic)

So: fMRI reveals local brain *function*!

[deO_2Hb blood has higher magnetic susceptibility than O_2Hb blood, hence causes more spin dephasing, hence faster "relaxation".]

Recipe for MRI

1) Put graduate student in a strong magnetic field.

Source: Robert Cox’s web slides

Early Human MR Scanner: "The Indomitable"

1977
Damadian sticks his postdoc
Larry Minkoff in as the first subject &
obtains the first MR image
of the human body, below.

Recipe for MRI

1) Put graduate student in a strong magnetic field.

A VERY strong magnetic field.

Source: Robert Cox's web slides

Typical Static Magnetic Field Strength of an MRI Scanner

10^5 x earth's magnetic field

1.5 or 3 or 4 Tesla for humans

IMPORTANT SAFETY ISSUE:
A small metal object (e.g. a key in your pocket) can become a bullet.
Before you walk into a scanner room first stop everything you are doing (talking, planning an experiment, etc), think of yourself as a potential lethal weapon, and carefully check everything: pockets, hands, jewelry, etc.
NEVER relax this constant vigilance.

Photo removed due to copyright restrictions.
Floor polisher pulled into the chamber of an MRI scanner.
See http://simplyphysics.com/flying_objects.html.

Even very strong static magnetic fields have no known long-term effects on *biological* tissue. However,

Very Serious Risk

Image removed due to copyright restrictions.
Opening paragraphs from newspaper story: Klein, M., and O. Prichard. "Boy, 6, killed in MRI accident." *The Journal News*, July 31, 2001.
The boy was smashed in the head by a metal oxygen canister accidentally brought near the MRI scanner.

Westchester NY, 2001

See also New York Times, August 19, 2005,
" M.R.I. Scanners' Strong Magnets Are Cited in a Rash of Accidents"

The Big Magnet

Very strong

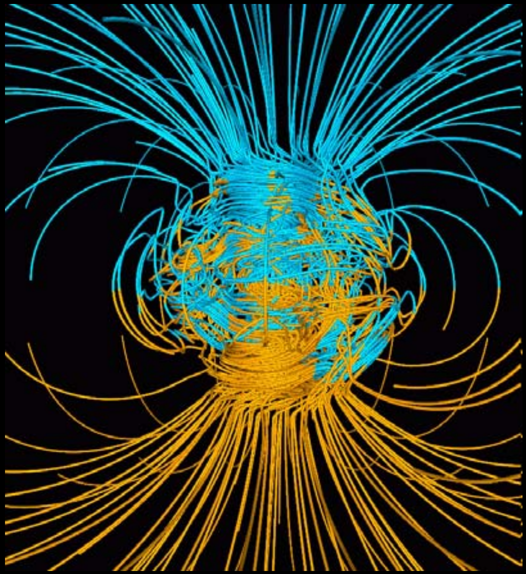
1 Tesla (T) = 10,000 Gauss

Earth's magnetic field at the surface = 0.5 Gauss

3 Tesla = 3 x 10,000 ÷ 0.5 = 60,000X Earth's magnetic field

Continuously on

Main field = B0



Courtesy of Prof. Gary A. Glatzmaier. Used with permission.

x 60,000 =

Robarts Research Institute 4T

Courtesy of Robarts Research Institute. Used with permission.

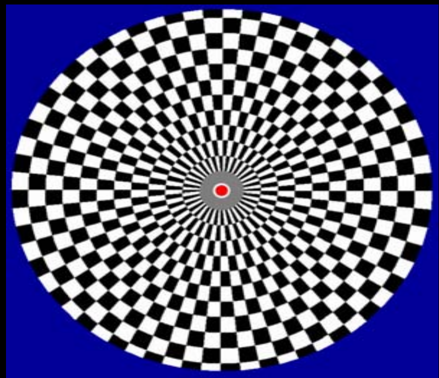
Courtesy of Jody Culham. Used with permission.

Recipe for MRI

1) Put subject in big magnetic field (leave him there)
2) Transmit radio waves into subject [about 3 ms]
3) Turn off radio wave transmitter
4) Receive radio waves re-transmitted by subject
   - Manipulate re-transmission with magnetic fields during this *readout* interval
   - [10-100 ms: MRI is not a snapshot]
5) Store measured radio wave data vs. time
   - Now go back to 2) to get some more data
6) Process raw data to reconstruct images
7) Take subject out of scanner

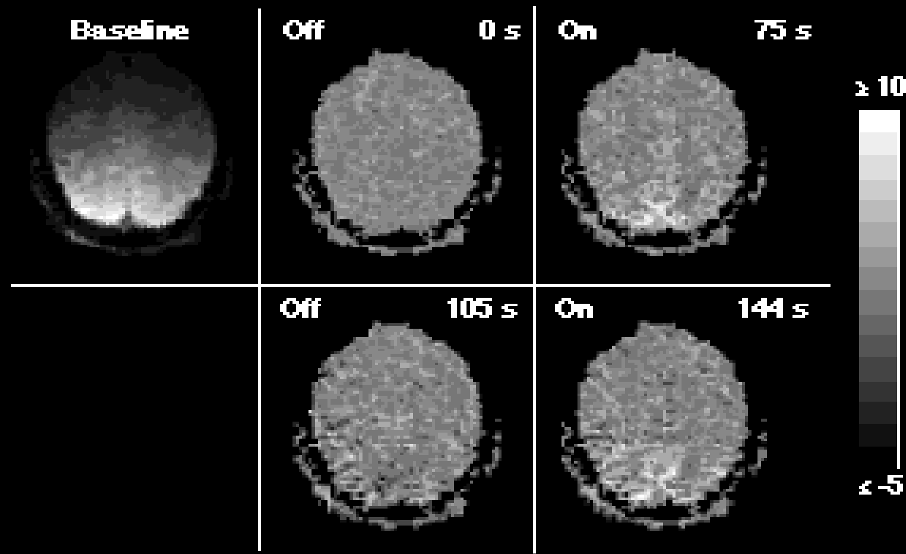
Courtesy of Robert Cox, NIMH
http://afni.nimh.nih.gov/pub/dist/edu/latest/afni01_intro/afni01_intro.ppt

fMRI Activation

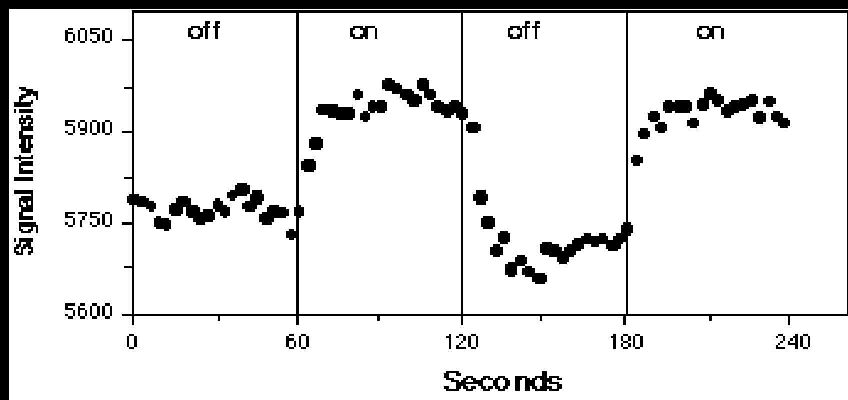


Flickering Checkerboard

OFF (60 s) ON (60 s) -OFF (60 s) - ON (60 s) - OFF (60 s)



Brain Activity



Time ⇨

Kwong et al., 1992

Source: Kwong, K. K., et al. "Dynamic Magnetic Resonance Imaging of Human Brain Activity During Primary Sensory Stimulation." *PNAS* 89 (1992): 5675-5679.

Mukamel et al, *Science*, 2005

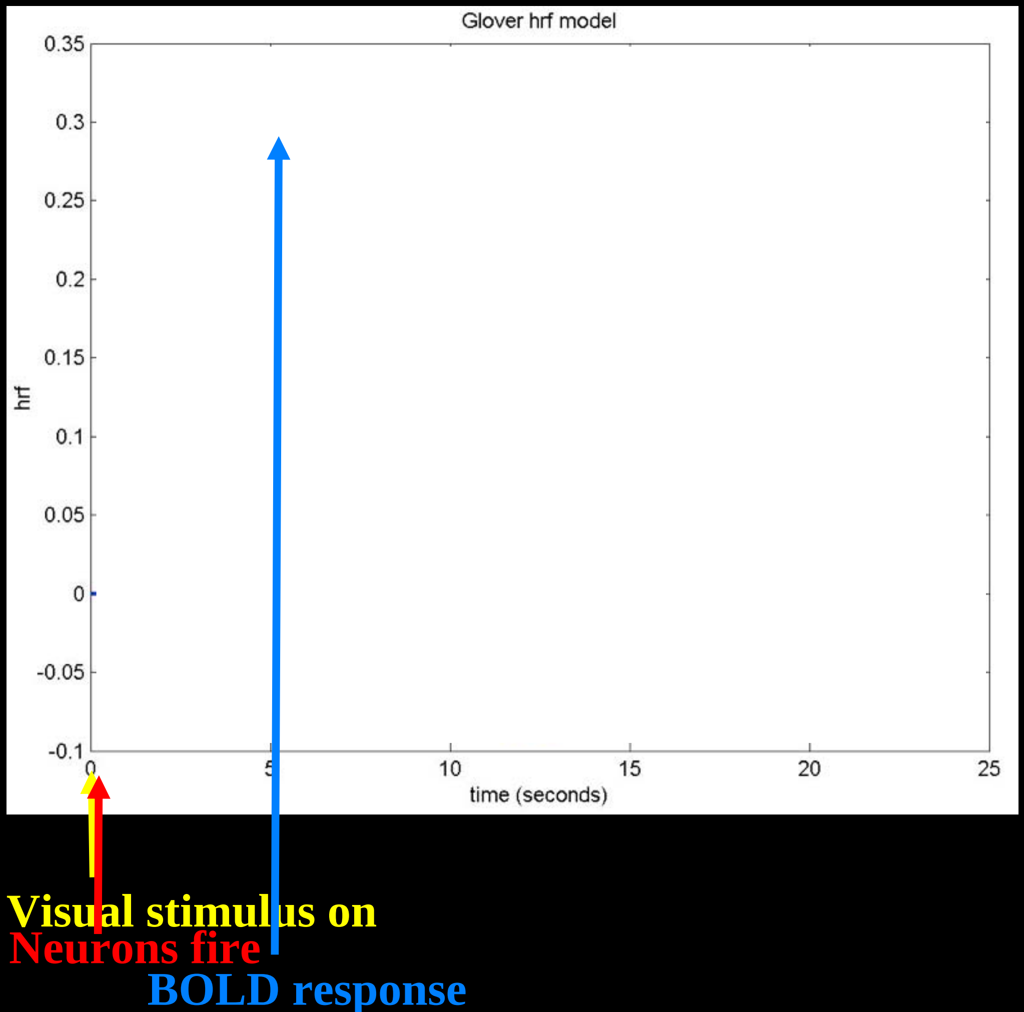
- meaured neural activity in auditory cortex w/ depth electrodes in epileptic patients (black) during movie

- measured fMRI response in normal subjects listening to same stimuli (orange)

Graph image removed due to copyright restrictions.
Fig. 3, “Correlation of the spike predictor with measured fMRI activation.”
Mukamel, R., et al. “Coupling Between Neuronal Firing, Field Potentials, and fMRI in Human Auditory Cortex.” *Science* 309 (2005): 951.

- similar time course indicates that fMRI signal follows neural activity (at least somewhat)

Temporal Properties of BOLD Response: The hemodynamic response function (HRF)



>>>> BOLD response is *SLOW*, usually peaking around 5-6 seconds after stimulus onset. Bad news for temporal resolution.

Important aspects of BOLD signal:

- Because the BOLD signal is based on blood flow, the spatial & temporal resolution is limited by the precision blood flow regulation:
  ~ 1 mm; > a few 100 milliseconds

- Cannot measure absolute amounts of activity/metabolism, only *differences* between two conditions.

- Physiological basis of the BOLD signal is unknown (Action potentials? Synaptic activity? Inhibition?)

Functional Magnetic Resonance Imaging (fMRI) vs. Other Methods

- Advantages:

The best spatial resolution available for studies on normal subjects.
Noninvasive.
Cheaper than PET (only $539/hour!).

- Disadvantages:

Temporal resolution not on a par with visual information processing.
Spatial resolution about one mm (hard/impossible to see cortical columns), can never get better than the vasculature.
"Susceptibility artifact" due to magnetic inhomogeneities near ear canals and sinuses.
Loud banging noise.
Uncertainty about the basis of the BOLD signal (spikes vs synaptic activity).

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Chosing a Question/Hypothesis

Step 1. Get clear about what exact question you are asking in your experiment. State it explicitly in a single sentence/question.

Now ask yourself:

Is this really an interesting and worthwhile question?

Is the answer obvious (in which case why do the expt)?

Does this question bear on an important theory?

Suppose you get the answer you want. Do you care?

Will anyone else care? Will you have learned anything important?

Note: Being able to answer these questions requires knowing a *lot* about current theories on this topic, & about relevant work using other methods.

What will you compare to what?

Step 2. Recall that fMRI can only show differences in brain activity between conditions, not absolute amounts.
In any imaging experiment, you will need to turn at least one mental function on and off (or on more vs less strongly).

For studies of high-level vision, There are two main ways to do this:

i) Change the stimulus
ii) Change the task

How do you chose which to do?
Consider a task manipulation……

Suppose we want to find out where object recognition happens in the brain. In our critical test condition we want subjects to be recognizing objects. So for example we might tell them to do this:

look at the pictures that flash up next, and *recognize them as they go by*.

Ready? Let's try it…..

Photo of rose on white background removed due to copyright restrictions.

Photo of tiger on white background removed due to copyright restrictions.

Look at the pictures that flash up next, & *recognize them as they go by*.

Do you think you recognized them?

OK, now let's try a possible task manipulation control condition to turn object recognition off:

Look at the pictures that flash up next, and
Only perceive their shape, don't determine what kind of object they are.
Here we go….

Photo of pepperoni pizza on white background removed due to copyright restrictions.

Photo of car on white background removed due to copyright restrictions.

For example,
look at the pictures that flash up next, and
recognize them as they go by.
Do you think you recognized them?

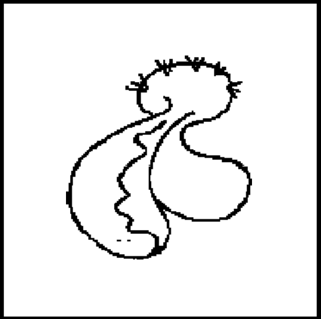
OK, now let's try a possible task manipulation control condition:
look at the pictures that flash up next, and
Only perceive their shape, don't determine what kind of object they are.
Here we go….

Did you follow the instructions this time? Why not?

The Moral:
Task manipulations don't work well with automatic processes.

Stimulus manipulations can work better for automatic processes.
For example, if you look at pictures like this:

You will automatically recognize them as they go by.
But if you look at pictures like this:



You wont. So we might be able to “isolate” visual recognition by comparing brain activity when people look at pictures of familiar objects versus novel unfamiliar objects, i.e. a stimulus manipulation.

However, stimulus manipulations don’t work so well for *nonautomatic* processes. For example, mental arithmetic.

For example, try just looking at the next few stimuli……

$$96 \div 17 = ?$$

$$14 \times 23 = ?$$

However, stimulus manipulations don’t work so well for nonautomatic processes like mental arithmetic.

For example, try just looking at the next few stimuli……

Did everyone get the answers?
Why not?

The Moral:
Stimulus manipulations don’t work well with nonautomatic processes.
(But a task manipulation could be very effective here.)

Manipulating stimulus versus task

Conclusion:
To control the mental operations that subjects carry out in the scanner you can either:

- Manipulate the stimulus
  works best for automatic mental processes,
  e.g. visual recognition.

- Manipulate the task
  works best for controlled mental processes,
  e.g. mental arithmetic

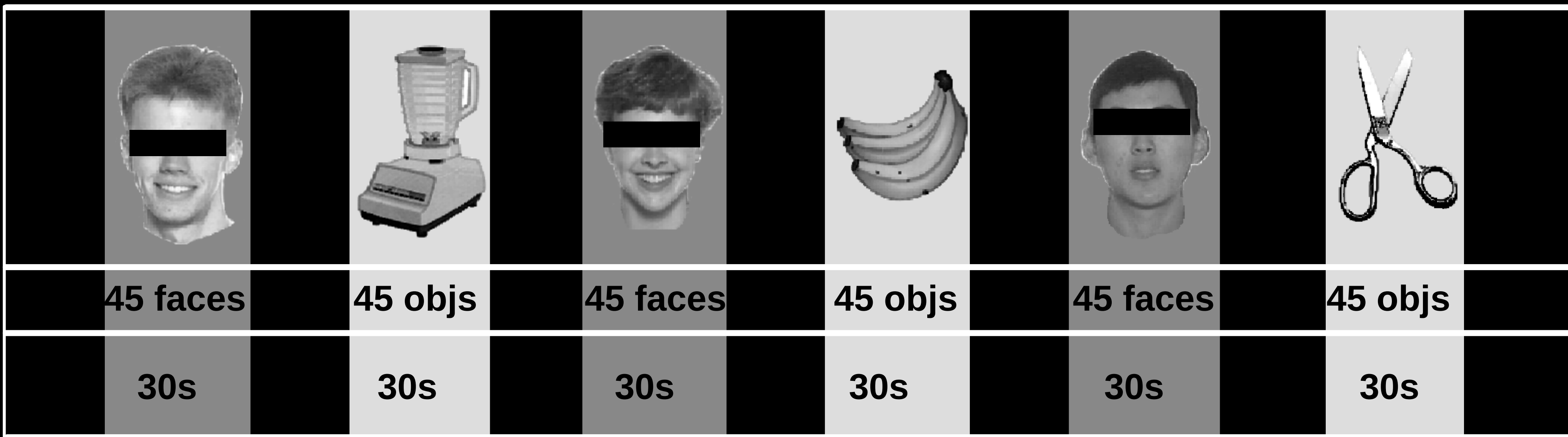
DON'T DO BOTH AT ONCE!!!

Tips on deciding what to manipulate

1. In a well-designed functional imaging study, two paired conditions should differ by the inclusion/exclusion of a *single* mental process. The single most common problem with imaging experiments is that the conditions compared differ in many respects, not just one. That is, the two conditions are not "*minimal pairs*". The other Differences between conditions are *confounds* in the experiment.

For example……

Example: Faces versus Objects



Face photos modified by OCW
for privacy considerations.

Is this a minimal pair that isolates just face recognition?

Does the face activation reflect:

- Visual attention?
- Processing any human body parts?
- Processing only front views of faces?
- Fine-grained within-category discrimination?
- Luminance or other low-level confounds?
- Face-specific visual processing?
- Et cetera…..

Tips on deciding what to manipulate

1. In a well-designed functional imaging study, two paired conditions should differ by the inclusion/exclusion of a *single* mental process. The single most common problem with imaging experiments is that the conditions compared differ in many respects, not just one. That is, the two conditions are not "*minimal pairs*". The other Differences between conditions are *confounds* in the experiment.

A. Be careful of "low" baselines such as "rest" or "fixation".
Let's try it.
Try fixating on the cross and don't think about anything…..

+

Was your mind blank?

Tips on deciding what to manipulate

1. Two paired conditions should differ by the inclusion/exclusion of a *single* mental process, I.e. they should be "*minimal pairs*".

   A. Be careful of "low" baselines such as "rest" or "fixation". These can be useful, but you cant turn your mind off, so don't know what your subject is doing. Plus:

   B. Be careful of comparing difficult versus easy conditions: lots of brain areas get activated by virtually any difficult task, so you will get a lot of activation but you wont know why.

   C. Watch out for attention confounds: is one condition much more interesting/engaging/attention capturing than another?

   D. Watch out for eye movement confounds between conditions.

   E. Try your own task and introspect, this can be very informative.

Outline for Today

Lecture 1: Introduction to fMRI & High-level Vision

I. What is fMRI?
  A. A very simple fMRI experiment
  B. Impact of fMRI on cognitive neuroscience
  C. Some Examples of cool findings from fMRI
  D. The fMRI “BOLD” signal - absolute basics
II. Basic Experimental Design
III. Localization of Function
IV. What is High-Level Vision?

The Concept of Localization of Function

The brain is not a homogeneous and undifferentiated mush in which all the bits are "equipotential". Rather, at least some mental functions are physically segregated (to at least some degree) in the brain.

While this idea is widely (but not universally) accepted for primary sensory cortex and motor cortex, a debate has long raged concerning the degree to which it is also true of high-level cognition….

History of Debate on Functional Specificity in the Cortex

<u>1800s</u>

- Gall & Spurzheim
- Flourens: "all sensory and volitional faculties exist in the cerebral hemispheres and must be regarded as occupying concurrently the same seat in these structures"
- Broca announces at the Societe d'Anthropologie in 1861 that left frontal lobe is the seat of speech.
- Gratiolet delivers scathing counterargument immediately thereafter.

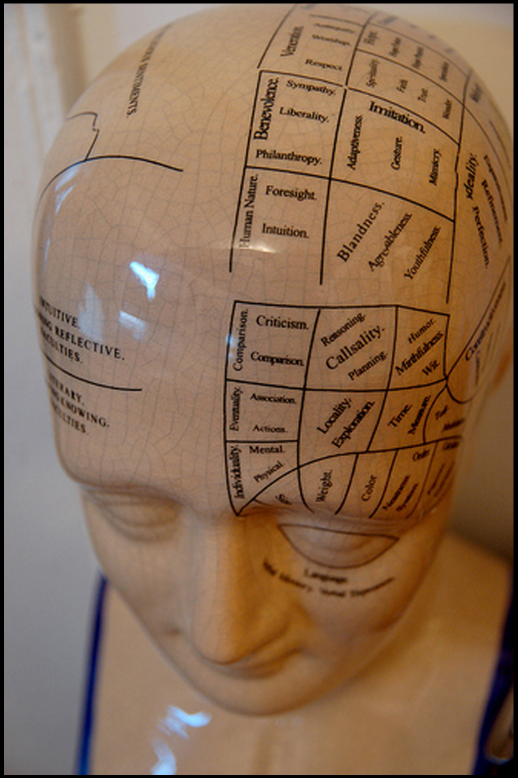


Image courtesy of Curious Expeditions.

History of Debate on Functional Specificity in the Cortex

Sometimes the pendulum swings within the same person…

Lashley's principle of "mass action"/"equipotentiality"

1930s- Lashley: "in the field of neurophysiology, no fact is more firmly established than the functional differentiation of various parts of the cerebral cortex"

History of Debate on Functional Specificity in the Cortex

Some more recent views.….

Schiller, 1994 "each extrastriate visual area, rather than performing a unique, one-function analysis, is engaged, as are most neurons in the visual system, in may different tasks."

Huettel et al (2004): "unlike the phrenologists, who believed that very complex traits were associated with discrete brain regions, modern researchers recognize that many functions rely upon distributed networks and that a single brain region may participate in more than one function".

Methodological Implications of L. of F.

Because the brain does appear to have at least *some* localization of function, we can start with one of the oldest tricks in science:

Divide and conquer!

That is, understand a complex system by:

1. Break it into parts to see how the system is organized.
2. Try to understand how each part works.
3. Then try to understand how the parts interact and work together.

How do we apply this to high-level vision?
What *is* high-level vision?

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What is High-level Vision (Visual Cognition)?

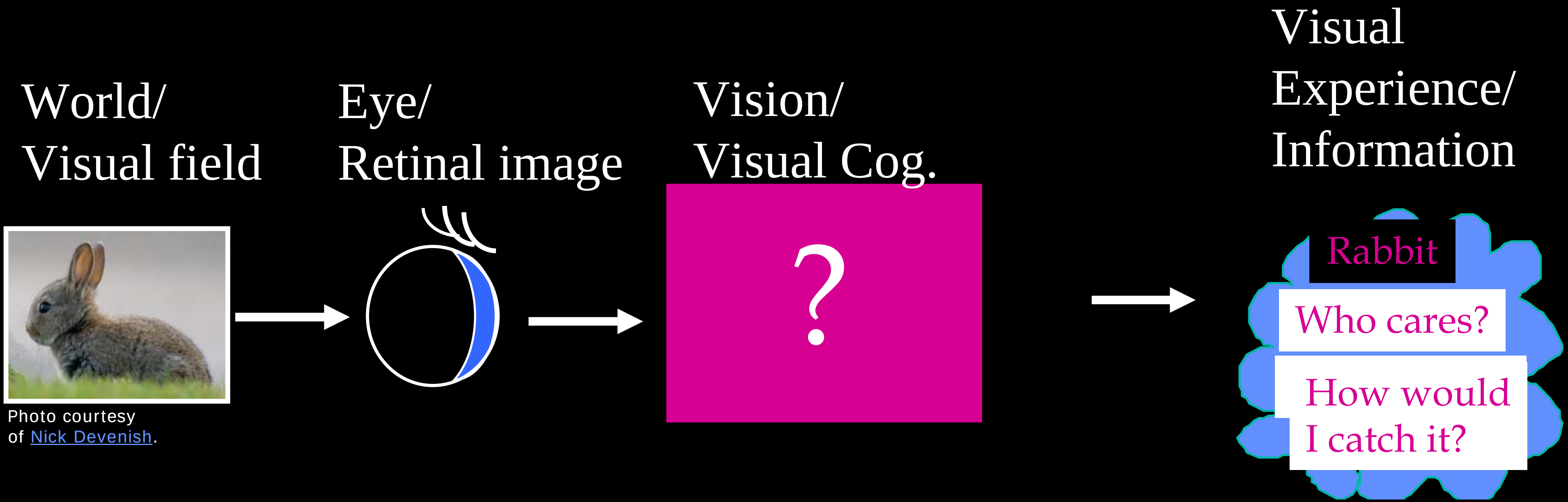


Photo courtesy of Nick Devenish.

Object Recognition: How do we figure out what we are looking at?
what kind of computations are carried out on the image?
what kinds of representations are extracted?

Visual Attention: How do we process visual information *selectively*?

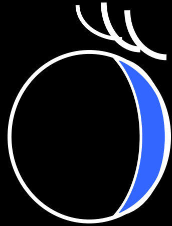
Awareness: Can we perceive information without being aware of it?

Visually-Guided Action: How do we pick up a coffee cup, shoot a basketball into a hoop, or catch a rabbit?

World/
Visual field

Photo courtesy of Nick Devenish.

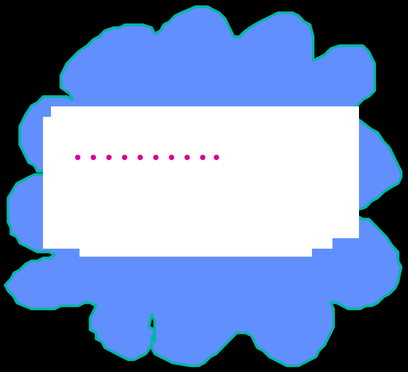
Eye/
Retinal image



Visual Cognition

?

Visual
Experience/
Information



Object Recognition
Visual Attention
Awareness
Visually-Guided Action
Visual Memory
Spatial Navigation
Etc.

- *A lot of complex processing involved*
- *Vision happens in the brain, not the eye*
- *Machine vision cant touch us; Humans rule!*

Why Visual Cognition?

Visual Cognition can tell us a lot about cognition in general because:

- We are highly visual animals; Close to half the cortex in humans is involved in some kind of visual processing.

- Visual parts of the brain are used not only in seeing, but also in *thinking*.

- Visual cognition is one of the most successful areas in cognitive science and cognitive neuroscience. In part because

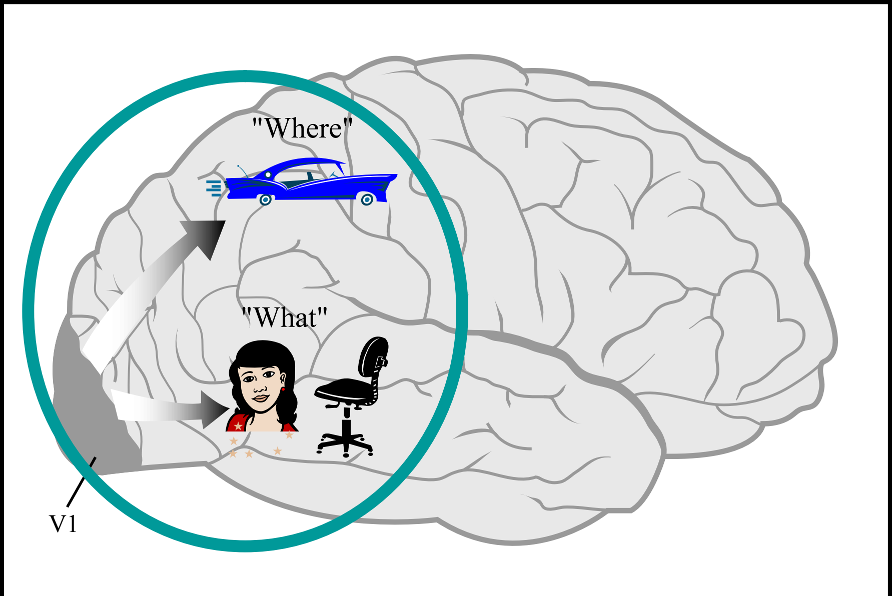


Figure by MIT OpenCourseWare.

- visual cortex exhibits a high degree of *localization of function*