Outline

I: Introduction to Object Recognition
Why study it, what is entailed in OR, and what are the questions we need to answer to understand it?

II: Brain Regions involved in Representing Object Shape
Where are they and what kinds of representations do they contain?

III: Category-Specific Mechanisms?
How specialized is the cortex for specific classes of objects?

IV: Effects of Attention, Awareness, Imagery, & Experience
How does visual experience change the cortical representation of objects?

Outline of This Section

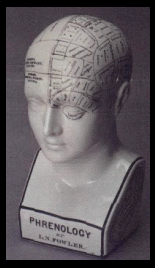
Intro on Functional specificity in the cortex.
Overview: Face area, place area, etc.
Case study: face perception and the FFA
evidence for special mechanisms for face processing from other methods (behavioral, etc.)
4 fMRI experiments showing that the FFA is selective for faces. area, etc.
Open Questions,
??and two specks of new data that might be relevant

Functional Specificity in the Cortex

My Thesis:
Some regions of the cortex are very selectively engaged in a single specific high-level cognitive process.

- This is not true of all cortical regions, indeed it may be the minority case.
- To the degree that it is true, this fact is likely to have important implications for our understanding both of the brain and of cognition.
- Highly controversial: the topic of heated debate throughout the history of neuroscience.

History of Debate on Functional Specificity in the Cortex



1800s

- 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.
- This debate has continued ever since…….

The Current Debate about Functional Specificity

Kanwisher, McDermott, & Chun (1997):
"the fusiform face area….is selectively involved in the perception of faces."

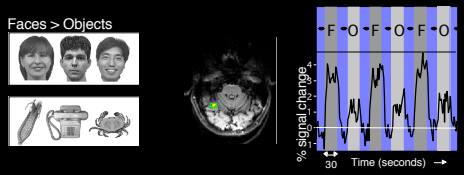
Epstein & Kanwisher (1998):
"the parahippocampal place area" (PPA) responds selectively …. to passively viewed scenes, but only weakly to single objects and not at all to faces."

Haxby et al (2001):
"Regions such as the 'PPA' and 'FFA' are not dedicated to representing only spatial arrangements or human faces, but, rather, are part of a more extended representation for all objects."

A little background…..

Are there cortical regions that respond selectively to faces?

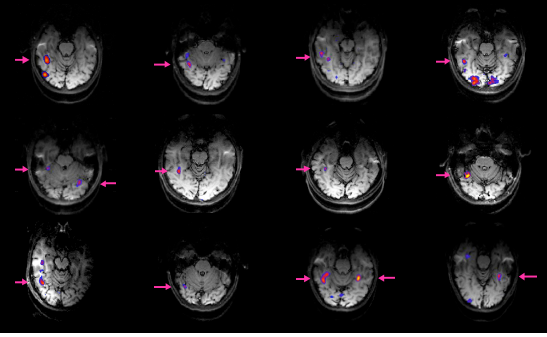
Kanwisher, McDermott, & Chun (1997)



How many subjects show this?

FFAs in 12 Ss

How can we study this region?



Characterizing a Cortical Region with Functional Regions of Interest (fROI)

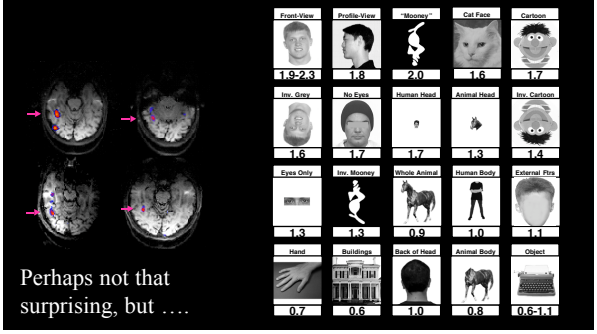
1. Localize ROI individually in each subject with a "localizer" scan, e.g. face area = faces > objects.

2. Run new scans in the same subject and session. Quantify the response of previously-defined region to new conditions.

- deals with anatomical variability across Ss
- gets around multiple comparisons problem
- provides measure of response magnitude

Fusiform Face Area

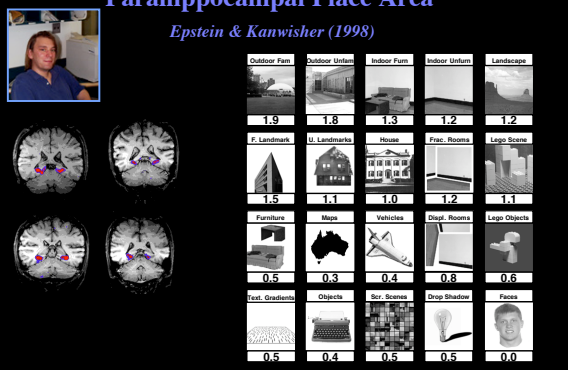
Kanwisher, Tong, McDermott, Chun, Nakayama, Moscovitch, Weinrib, Stanley, Harris, Liu



Perhaps not that surprising, but ….

Parahippocampal Place Area

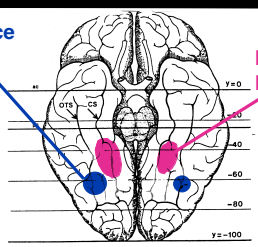
Epstein & Kanwisher (1998)



Category-Specific Regions in Human Extrastriate Cortex

Fusiform Face Area (FFA)

Kanwisher et al (97-99)
Tong et al (in press)
SergentSergent,
Haxby, Ungerleider,
McCarthy, Puce, Allison
Kanwisher, Tong
Gauthier, Halgren
And many others



Parahippocampal Place Area (PPA)

Epstein, Kanwisher
Aquirre, D'Esposito
Maguire
Haxby
And many others

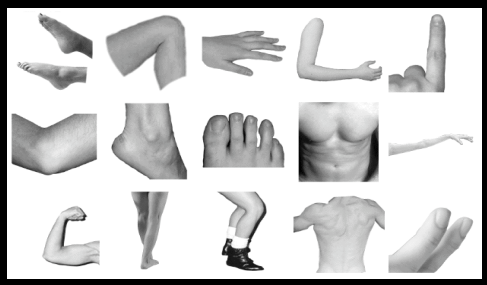
How many of these things are in there, anyway?

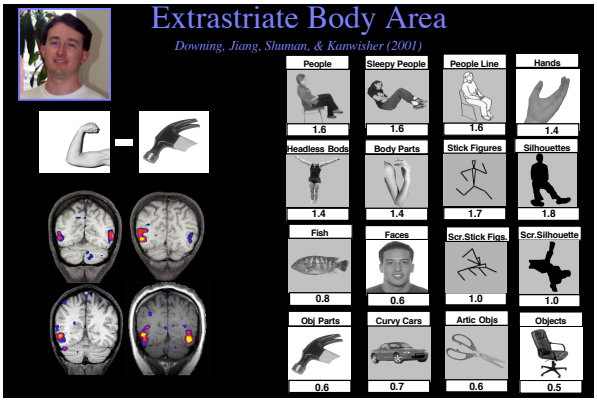
Do other regions selective for other categories exist?

Mostly no, not like the FFA and PPA.

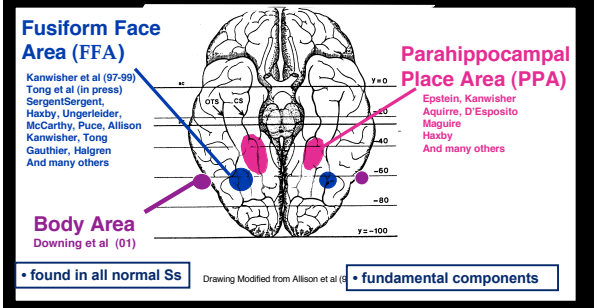
But there was one patch of cortex that liked….

Downing, Chan, Peelen, Dodds, and Kanwisher (in press).





Category-Specific Regions in Human Extrastriate Cortex



How specific are these things, really?

Test case: face perception & the FFA.

But let's start with some background from other methods….

Face Perception

Faces are particularly important stimuli because

- they convey many kinds of critical information:
  identity, age, sex, mood, and direction of attention
- faces are among the stimuli we look at most frequently in daily life
- the ability to perceive faces was probably critical to the survival of our primate ancestors

Evidence that special mechanisms may be used in face perception from:
lesions, neurophysiology, behavior, ERPs, MEG and fMRI

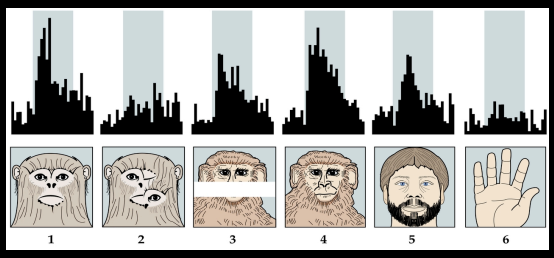
1. Prosopagnosia

- many reported cases (several dozen ?)
- lesion in inferior temporal cortex
- Impairs face discrimination & recognition, not face detection
- In rare cases where lesion is small, deficit can be very specific, leaving object recognition intact
  e.g. the patient of Wada & Yamamoto, 2001

Importantly, the opposite syndrome also exists:
Patient CK (Moscovitch et al1997): severely impaired on object recognition yet normal at face recognition

a double dissociation of face and object recognition.

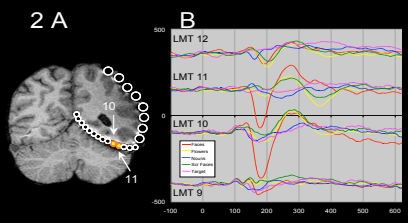
2. Face-Selective Neurons in Macaque IT



Bruce, Perrett, Desimone, Gross, Tanaka, and many others

Source of Slide: Jody Culham

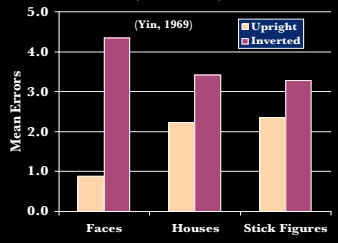
3. Face-Selective electromagnetic responses
a. Subdural ERPs



Source: Greg McCarthy

4. Behavioral Signatures of Face Perception

- A. The "face inversion effect": a greater decrease in performance for upside-down compared to upright stimuli for faces than other stimuli (Yin, 1969).



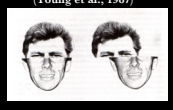
4. Behavioral Signatures of Face Perception

- B. Holistic Processing: Mandatory processing of the whole face, and interactive processing of face parts.

Whole-part effect
(Tanaka and Farah, 1993)

Subjects are better able to discriminate parts in the context of the whole face than when presented alone.

Composite face effect
(Young et al., 1987)

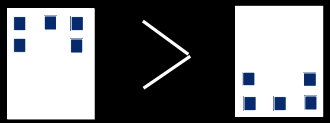


Subjects are slower to identify half the face when it is aligned than misaligned (cannot ignore whole).

Neither effect is found at all for inverted faces!

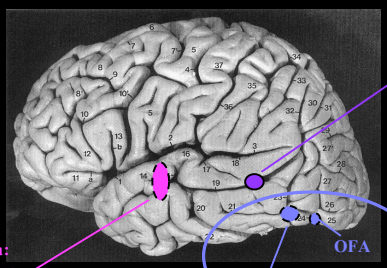
4. Behavioral Signatures of Face Perception

- C. Newborn Infants Preference for Faces Suggest Innateness.
  - Johnson & Morton (1991): look longer at schematic faces than inverted schematic faces. >> may lead to greater experience with faces and hence cortical development of "special" face mechanisms.
  - Simion et al (2002): They look more at *any* topheavy stimulus, e.g.:



Simion argues this is therefore not really a *face* mechanism, but in practice it may serve to pick out faces for infants.

5. Brain Regions Involved in Face Perception



STS: Emotional expression, Gaze direction….

Amygdala: Recognizing Expressions of fear/anger.

OFA

FFA: Perceptual analysis of faces

So: lesions, neurophysiology, behavior, ERPs, MEG and fMRI all suggest that special mechanisms may be used in face perception

Probably multiple face-processing mechanisms, unclear which methods are measuring the same thing e.g. does the M170 come from the FFA?

Focus for today: the FFA.

Is the FFA really Specialized for Face Perception?

Some Hypotheses concerning FFA function:

- perception of bodies (e.g., Peelen & Downing, 2005)?
- domain-general configural processing
- within-cat. discrim. of other categories (e.g., chairs)
- within-cat. discrim. of objects of expertise (Gauthier, Tarr)
- face recognition (discriminating one individual from another)

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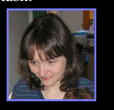
Suppose we get subjects to process a nonface stimulus *in the same way they process a face*, then will the FFA become engaged?

Test: Design nearly identical tasks to be conducted on face versus nonface stimuli. One configural task and one part-based task. Measure response in FFA……

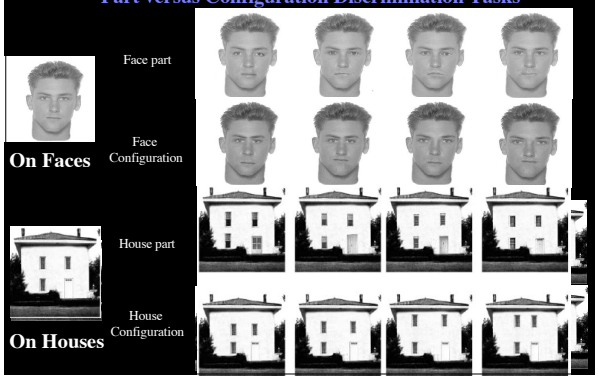
an experiment with:



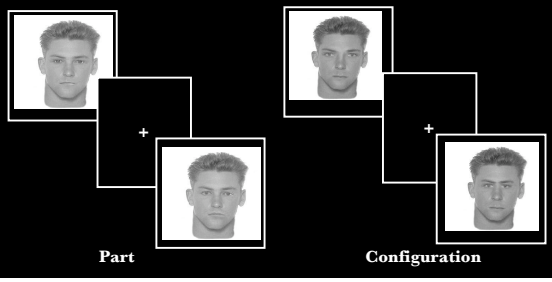
Galit Yovel

Yovel & Kanwisher (2004), *Neuron*

Part versus Configuration Discrimination Tasks

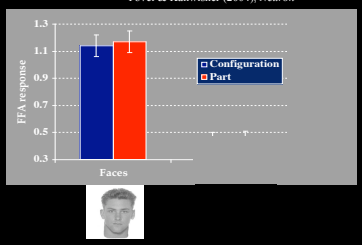


- **Blocked Design - four conditions:**
  - **Faces/Houses x Config/Part Task**
  - **Subjects cued before the beginning of each block**



rFFA Response

Yovel & Kanwisher (2004), *Neuron*



- **FFA is equally engaged in part and config. discriminations on faces.**
- **FFA is NOT strongly engaged when subjects do very similar discriminations on nonface stimuli.**
- **FFA is stimulus-specific for faces, not for configural processing.**

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Hypothesis: The FFA is not involved specifically in face processing, but instead in fine-grained discrimination between exemplars of *any* category.

Previous experiment already refutes. That's never enough to shut people up.

So test again, this time with a new method: fMRI adaptation.

Using fMRI-adaptation to ask what stimulus differences the FFA is sensitive to.

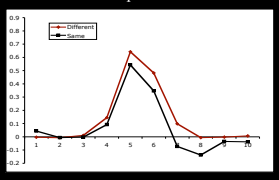
with Galit Yovel

DIFFERENT

250ms 500ms 250ms

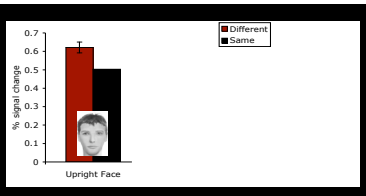
SAME

FFA Response



Counterbalanced across stimuli;
Displaced slightly; matching task.

FFA



So: FFA can discriminate btwn faces.

Is this specific to faces?? What about…

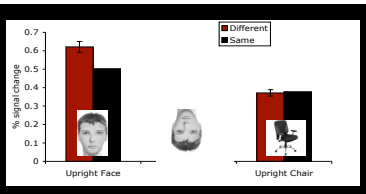
Yovel & Kanwisher (2005), *Current Biology*

DIFFERENT

200ms 500ms 200ms

SAME

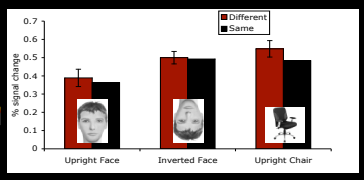
FFA



FFA is sensitive to diffs betwn upright faces, not chairs.

Apples & oranges!

LOC



Does salience account for face specificity?

No.

Area(FFA/LOC) x Stimulus (Face/InvFace/Chair) x Adaptation (Diff/Same) is p < .02

Yovel & Kanwisher (in press), *Current Biology*

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- √ • face recognition (discriminating one individual from another)

Hypothesis: The FFA is not involved specifically in face processing, but instead in fine-grained discrimination between exemplars of *any* category.

Skip the next 2 FFA experiments if running out of time?

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Hypothesis: The FFA is not involved specifically in face processing, but instead in fine-grained discrimination between exemplars of *any* category. *for which the subject has gained substantial expertise and for which all exemplars share the same basic configuration.*

There is almost no evidence for this hypothesis, and loads of evidence against it; see http://web.mit.edu/bcs/nklab/expertise.shtml

For example….

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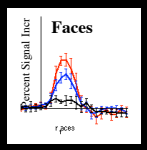

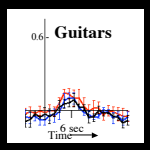

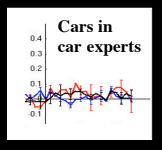

Grill-Spector, Knouf, & Kanwisher (2004), *Nature Neuroscience*.

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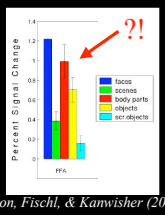
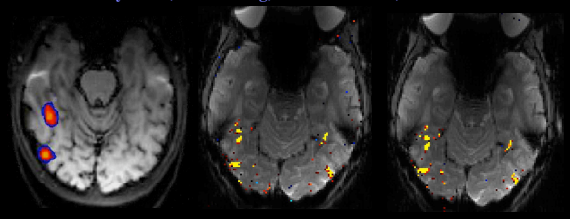


Blurring across two adjacent selectivities?
Let's try scanning at higher resolution
8 channel coil
1.4x1.4x2mm voxels
Localizer (blocked), then test (event-related)

Spiridon, Fischl, & Kanwisher (2005), HBM.

Scanning at Higher Resolution

Larry Wald, Ken Kwong, Thomas Benner, Chris Baker



• standard resolution 3.1x3.1x4 mm

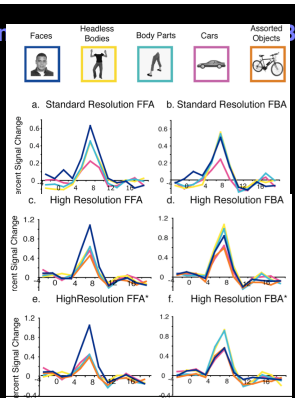
• "high resolution" 1.4x1.4x2 mm

Strikingly replicable across runs

Instead of ~ 2 mil neurons/voxel now ~200K

When we try this resolution on faces and bodies …..

Fusiform Bodies



Schwarzlose

FFA: faces > objs

FBA: bodies > objs

overlap

omit overlap:

FFA*

FBA*

At "high resolution", face selectivity can be dissociated from body selectivity in the fusiform.

Schwarzlose et al. (in press), *J Neurosci*

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BUT: Haxby (2001) claimed:

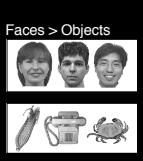
"Regions such as the …. 'FFA' are not dedicated to representing only …. human faces, but, rather, are part of a more extended representation for all objects."

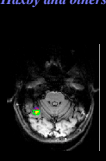
What was he talking about?

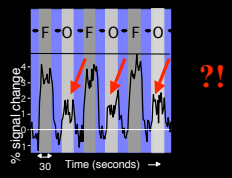
An Important Challenge

Haxby and others

Faces > Objects





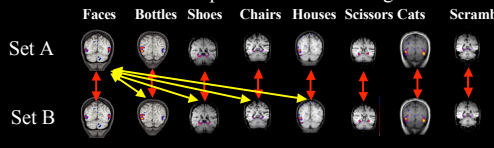


?!

• Do "nonpreferred" responses in FFA carry information about nonpreferred stimuli (chairs, shoes, cars, etc)?

Haxby et al (2001) methods (roughly):

1. Scan each subject on 8 stimulus categories
2. Split the data in half.
3. Generate activation patterns for each categ from each 1/2 of data



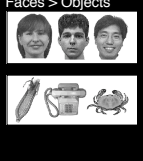
4. Are correlations higher WITHIN than BETWEEN categories?

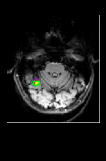
5. Now try this using only the FFA. Can you still tell bottles from shoes? I.e., *is the discriminative information present in this region?*

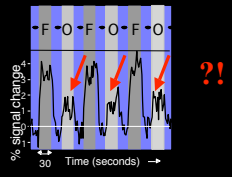
An Important Challenge

Haxby and others

Faces > Objects







?!

• Do "nonpreferred" responses in FFA carry information about nonpreferred stimuli (chairs, shoes, cars, etc)?

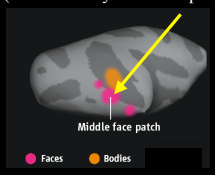
Haxby says yes, most others say no. Insufficient resolution?

• Or: Just "partial voluming" (>200,000 neurons/voxel)?

This question was unresolvable until very recently…..

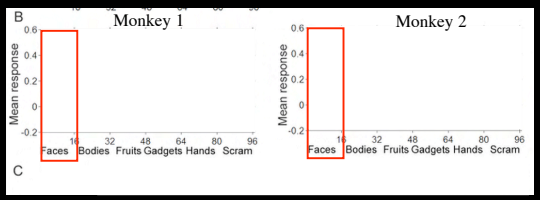
The Ultimate High Resolution: Single-Unit Neurophysiology

Tsao et al (2003, *NN*) used fMRI in monkeys to find three face-selective patches (and one body-selective patch) in the monkey brain:



Tsao et al (2006) directed electrodes smack into the middle face patch and recorded from neurons that comprise it.

Response of all 320 visually-responsive neurons in the faces patches of two monkeys to 96 different stimuli



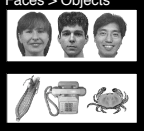
The cells in this patch respond selectivity, indeed virtually exclusively to faces.

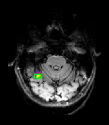
Tsao et al (2006), Science

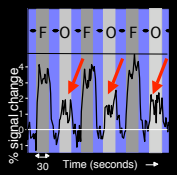
An Important Challenge

Haxby and others

Faces > Objects







?!

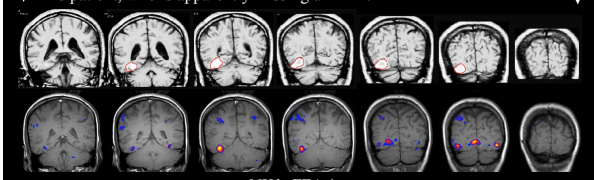
√ • Just "partial voluming" (>200,000 neurons/voxel)?

x • Or do "nonpreferred" responses in FFA/etc. carry information about nonpreferred stimuli? Apparently not, at least in monkeys.

• Even if there were some information about nonfaces in the FFA, is this information *used/read out* in performance?

Wada & Yamamoto (2001)

This patient, who is apparently missing an FFA:



NK's FFA

Is profoundly prosopagnosic *but apparently normal at object recognition.*

Suggests: Information in the FFA is critical for face recognition *but not for object recognition.*

Outline

I: Introduction to Object Recognition

Why study it, what is entailed in OR, and what are the questions we need to answer to understand it?

II: Brain Regions involved in Representing Object Shape

Where are they and what kinds of representations do they contain?

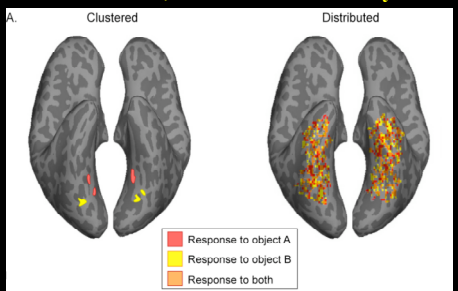
III: Category-Specific Mechanisms?

How specialized is the cortex for specific classes of objects? ***VERY! But maybe for just a few categories…***

IV: Effects of Attention, Awareness, Imagery, & Experience

How does visual experience change the cortical representation of objects?

So, the responses to some object categories are quite clustered in the cortex, not distributed widely.

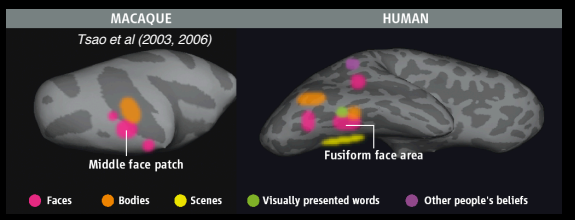


Why cluster responses?? Local computations? Conduction delays?

Many More Unanswered Questions

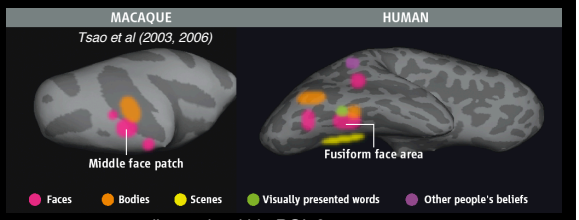
- How do each of these regions actually *work* (reprs & comps)?
- Why do the FFA, PPA, & EBA land where they do in the cortex? Are they part of a broader scheme, and if so what are its dimensions and (how) do these relate to perception? A speck of recent data on this….
- What determines which mental functions get their own patch of brain?
- How do these regions arise in development?
- To what extent can these regions reorganize or "move over" in the event of injury to the brain?
- Which of these regions have homologues in other primates, and which are uniquely human?

Functional Organization of the Primate Ventral Visual Pathway



- structure at a smaller scale within ROIs?
  We find no voxels selective for nonface categories in or near the FFA
  Consistent with physiology data of Tsao et al (2006) but not Grill-Spector
- structure at a larger scale across ROIs?
  are these regions embedded in a broader 'shape map'? (monkeys)

Functional Organization of the Primate Ventral Visual Pathway



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- structure at a larger scale across ROIs?
  are these regions embedded in a broader 'shape map'? (monkeys)

Hans Op de Beeck (DiCarlo lab)

Hypothesis: IT cortex contains a large-scale map of shape.

Predictions:

i) Continuous and spatially varying shape selectivity will be found spanning much of IT cortex, at a large grain.

ii) This "shape map" will be stable across time, training, task, and stimulus position

Background:

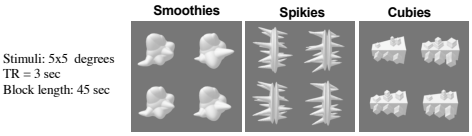
Tanaka/Tanifuji/others - columnar organization of IT in macaques
scale: several mms >> what about larger scale?

Human fMRI - category-selective regions, and patterns, but virtually all of this work is on familiar, meaningful objects to unconfound shape from meaning and memory>> use novel objects!

Testing for Shape Maps with Novel Objects

Op de Beeck, Vanduffel, Deutsch, Kanwisher, & DiCarlo

Two Monkeys scanned while viewing 3 novel object classes:

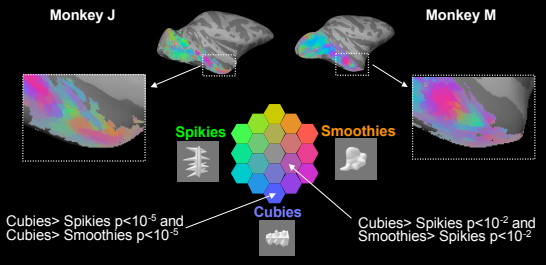


Stimuli: 5x5 degrees
TR = 3 sec
Block length: 45 sec

Blocked design; monkeys perform orthogonal color task.
1.25 mm isotropic functional resolution; MION
To look for "shape maps", compute
3 pair-wise t-tests on each visually responsive voxel in IT, & display it like this…..

Shape Maps in IT Cortex?

>>>Are they stable across time, training, task, and stimulus position?



Higher saturation indicates higher selectivity.

Scanning Sequence

Monkeys were scanned while viewing novel objects in four phases (several scanning sessions each):

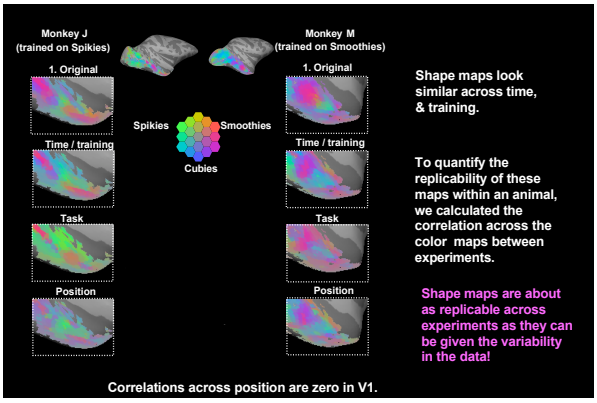
Phase 1 Scans. Color task - detect rare color changes between successive stimuli.

>>Three months of training on one object category on successive same-different shape judgement. 130,000 stimulus presentations.

Phase 2 Scans. Color task: *transfer over time & training (& meaning change)?*

Phase 3 Scans. Shape discrimination task: *transfor over task*?

Phase 4 Scans. Position change: *transfer over stimulus position?*
Monkey J - stimuli @ 8.4 degrees eccentricity, nonoverlapping (fixation task).
Monkey M - stimulus-class-specific jitter to remove differences in retinotopic envelope; color task.



Shape maps look similar across time, & training.

To quantify the replicability of these maps within an animal, we calculated the correlation across the color maps between experiments.

Shape maps are about as replicable across experiments as they can be given the variability in the data!

Hypothesis: IT cortex contains a large-scale map of shape.

Predictions:

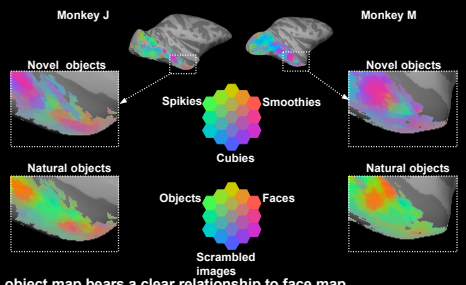
√ i) Continuous and spatially varying shape selectivity will be found spanning much of IT cortex.

ii) This "shape map" will be stable across
√ √ √ √
time, training, task, and position

Many more questions…..

1. Is the "shape map" systematically related to the face patches?
2. Is it reducible to the face map?
3. Does the "shape map" reflect selectivity for global or local features?

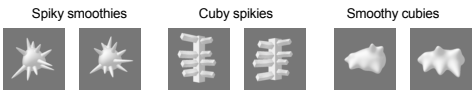
Comparison of Novel Object Map and Face Map



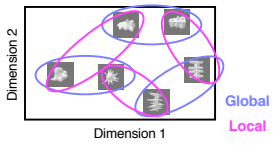
- Novel object map bears a clear relationship to face map.
- But is not reducible to it: correlations in object selectivity maps (r=0.52, p<.001) are almost as strong when all face-selective voxels are omitted (r=.47) .

"Shape Map": Global or Local Features?

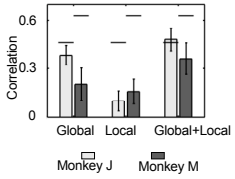
Test on new stimulus set where local and global feature are exchanged:



Perceived similarity between six classes based on same-different confusion matrix.



Correlation btwn selectivity maps for objects sharing glob, loc, or both.



Hypothesis: IT cortex contains a large-scale map of shape.

Predictions:

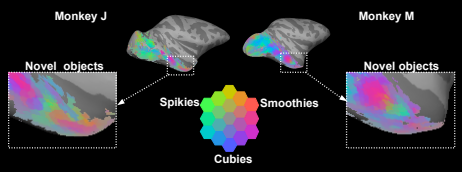
√ i) Spatially varying selectivity will be for novel objects spanning much of IT cortex.

ii) This "shape map" will be stable across
√ √ √ √
time, training, task, and position

Many More Questions:

YES 1. Is it systematically related to the face patches?
NO 2. Is it reducible to the face map?
BOTH 3. Does the "shape map" reflect selectivity for global or local features?

Conclusions: A Large-Scale Shape Map in Monkey IT Cortex



- A robust topography of shape selectivity across IT, replicable across time, training, task, and stim. position.
- Systematically related to (but not reducible to) the face map.
- Shape map includes both global and local shape features.

Questions

- What is this map a map of?
- What is the dimensionality of this map?
  - so far: 3-dim projection of presumably much bigger space
- How consistent is the shape map across individuals? Species?
- How does the shape map arise in development?
  - Face patches first?
  - Shape map first?
  - Do both arise together and somehow constrain each other?
- How are the properties of this shape map related to perception?
- Why do things cluster in the cortex in the first place?
- Which parts of the map are used/ read out during task performance?

An even smaller speck of data on this last point…..