Lecture 10 & 11: Development

I. The big questions and why they matter
and a few bare basics of brain development
II. Three Test Cases of behavioral and neural development
A. Face perception and the FFA
B. The navigation network and reorientation
C. The Visual Word Form Area

Let's start with one of the deepest questions humans have ever asked themselves….

Where does Knowledge Come from?

- Empiricists (Locke, Hume, etc.):

All knowledge comes from experience.

- Kant: Experience alone is not enough.

We must have "a priori conditions" of cognition, which can not be derived from experience themselves, but must instead be given prior to it.

e.g. space and of time are basic organizing principles of the human mind, not the result of experience:

"Space is nothing but the form of all appearances of outer sense . . . can be given prior to all actual perceptions, and so exist in the mind a priori, and . . . can contain, prior to all experience, principles which determine the relations of these objects"

- Just empty philosophical hot air?

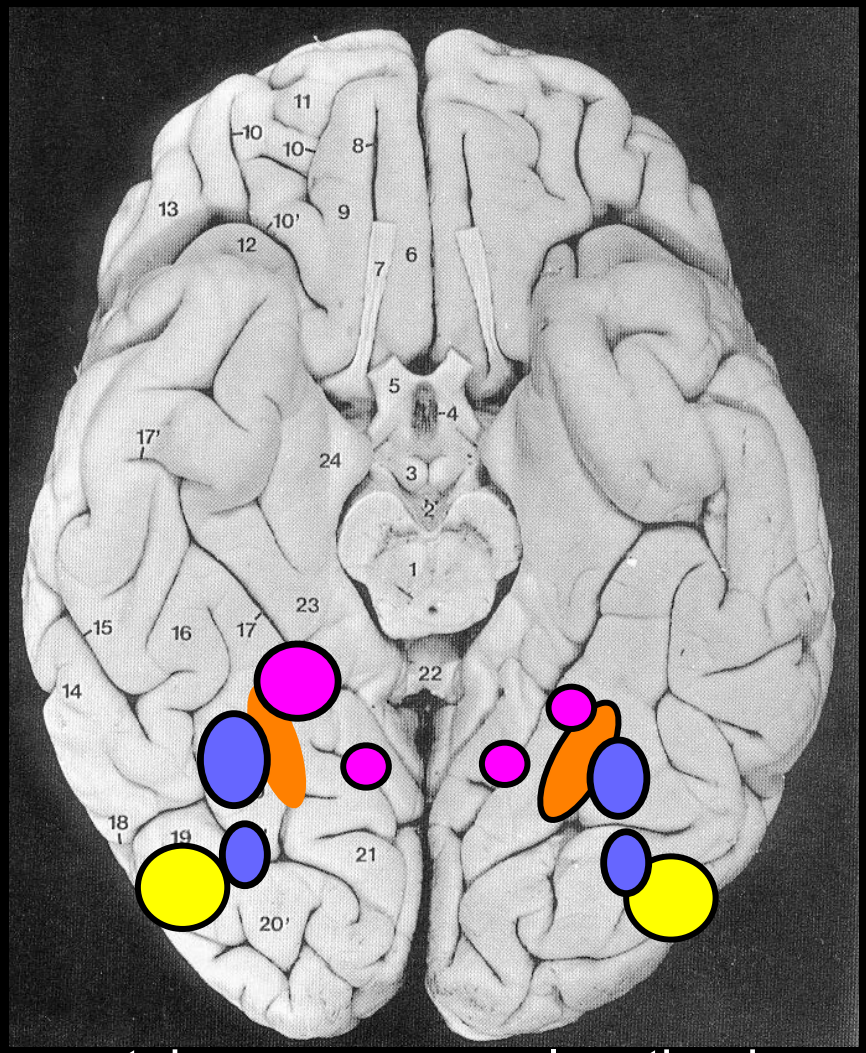
No!

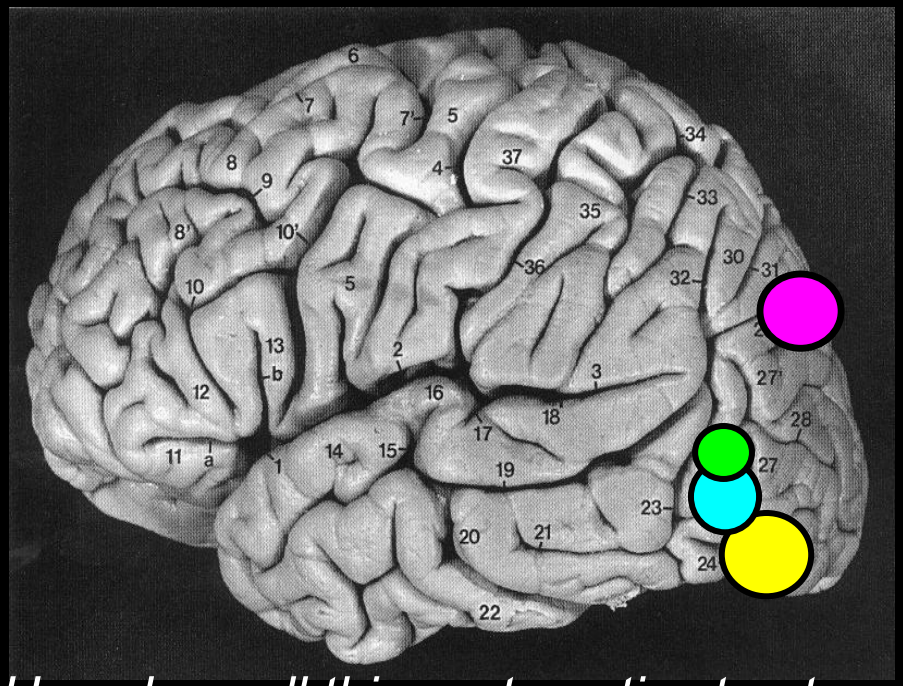
An empirical question!

Wed: innateness of representations of space

Today: which aspects of brain are innate, and which learned?

Cortical Regions Specialized for Processing:
Shape, Color, Motion, Faces, Places, & Bodies





How does all this systematic structure get wired up in development?

Innately specified?

All learned from experience?

What do you think?

Some basic facts about brain devel….

Present, in approx same location in ~every normal person.

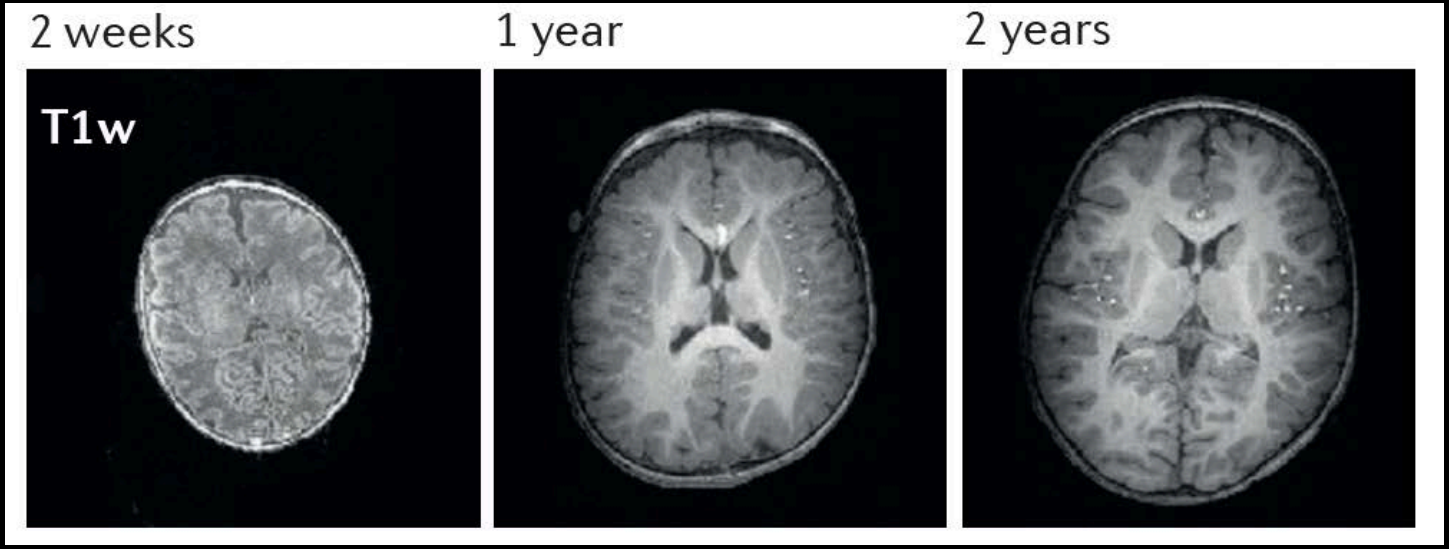
Basics of Brain Development

What is present at birth?

- Most neurons in the human brain are generated prenatally.
- Most long-range structural connections are in place.

But During first 1-2 years of life:

- Brain doubles in volume in first year.
- Cortical thickness & surface area increase sharply yrs 1& 2.



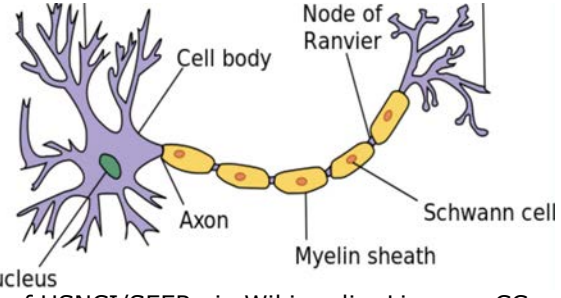
Source: Gilmore, J., Knickmeyer, R. & Gao, W. *Nat Rev Neurosci* **19,** 123 137 (2018). https://doi.org/10.1038/nrn.2018.1

Brief sidebar on very basic neuroanatomy

Grey and white matter

Grey Matter:
= **cell bodies**
= cortex

White Matter:
= myelinated axons
think: long-distance **wires**
connecting different regions



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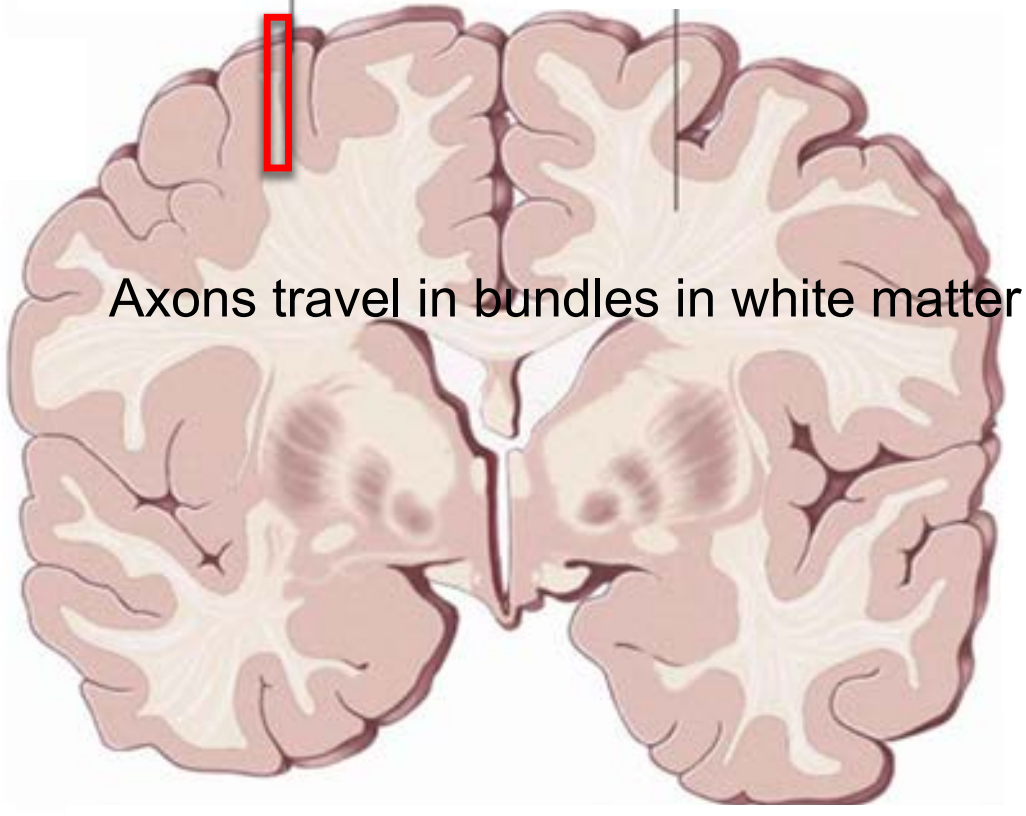
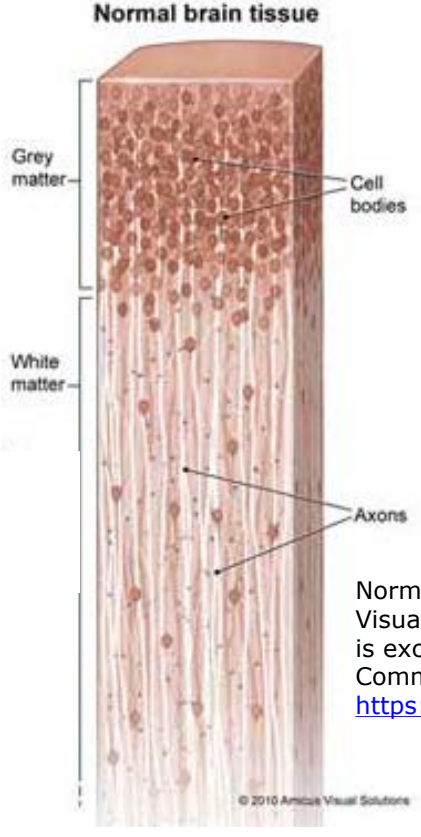


Axons travel in bundles in white matter

Visible in gross dissection……



Normal brain tissue © Amicus Visual Solutions. This content is excluded from our Creative Commons license, see https://ocw.mit.edu/fairuse.

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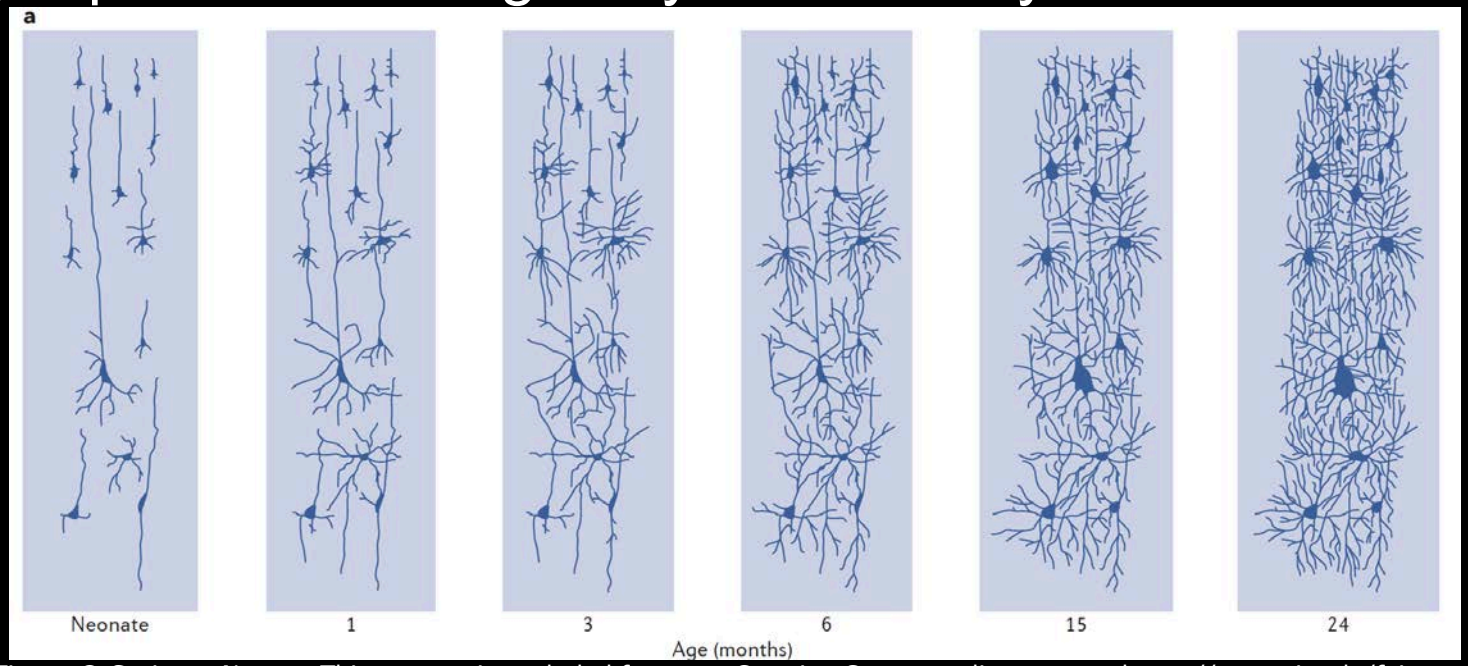
- Brain doubles in volume in first year.
- Cortical thickness & surface area increase sharply yrs 1& 2.Complexity of neurons in cortex and their number of synapses increase greatly in first few years of life



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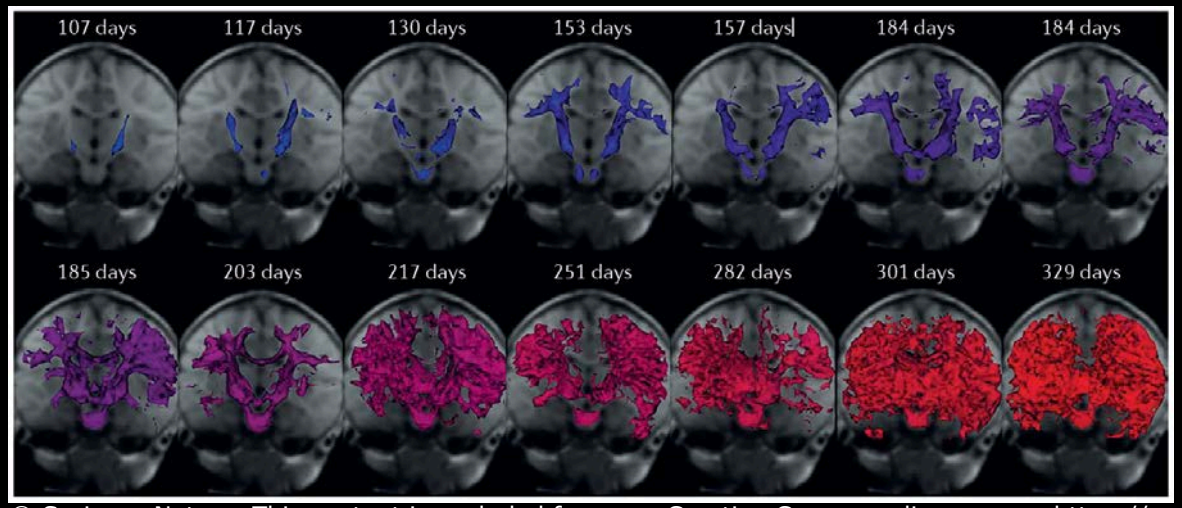
- Myelination begins before birth, and continues rapidly in first few years, then more slowly through adolescence



Postnatal days;

Note center to periphery progression.

Source: Gilmore, J., Knickmeyer, R. & Gao, W. *Nat Rev Neurosci* **19,** 123 137 (2018). https://doi.org/10.1038/nrn.2018.1

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<u>Bottom line:</u>

Most neurons and long-range connections are in place at birth, but development continues rapidly in first two years, especially

increasing complexity of neurons & synapses in cortex

myelination of long-range connections (white matter).

Now let's consider a case study in detail…….

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and a few bare basics of brain development

II. Three Test Cases of behavioral and neural development
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Spoiler Alert:
Lots of fascinating findings, a clear story is not yet available.

How does Face Perception Develop?

Ends of the theoretical spectrum:

(A) A very simple innate "precursor" plus learning mechanism

e.g. innate facelike template to grab attention, plus learning

(B) Born with a nearly adult-like system, with representational dimensions in place, needing only light "tuning" (or maintenance?) by experience.

What kind of data can constrain?

1. What is the initial state? (at birth, or as close as we can get)
2. How does the system change over time?
3. Causal roles of experience, and biological maturation in that change.

central challenge: these are deeply confounded in normal development

can arise well after birth but be innately specified (e.g., puberty)

These 3 questions can be asked both behaviorally and neurally;

Ultimately we want them to converge!

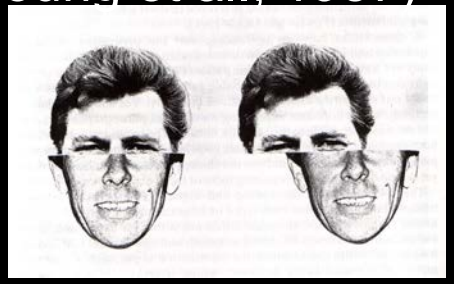
let's start with the behavioral data

The Initial State: Face Perception in Newborns

What face perception abilities are present in newborns?

- Face detection
- Preferred attention to faces
- Discrimination of individual identity
- Recognition across view change
- Signatures of holistic face processing
  - inversion effect
  - disproportionate composite effect

Composite face effect (Young et al., 1987)



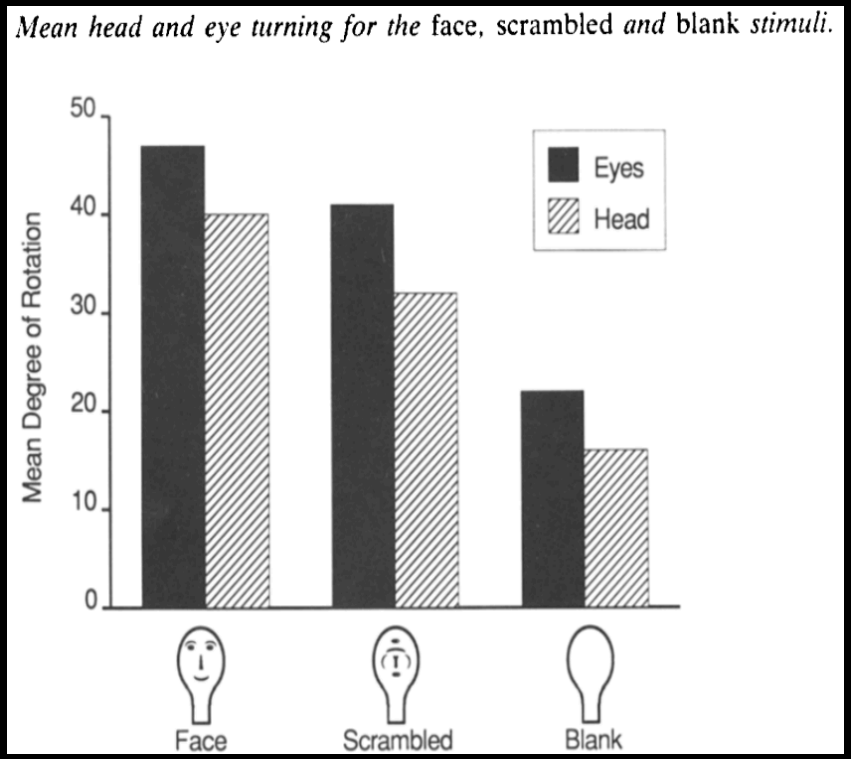
Subjects are slower to identify top half the face when it is aligned than misaligned (cannot ignore whole).

Source: A W Young, et al. *Perception*. 1987;16(6):747 59. doi: 10.1068/p160747.

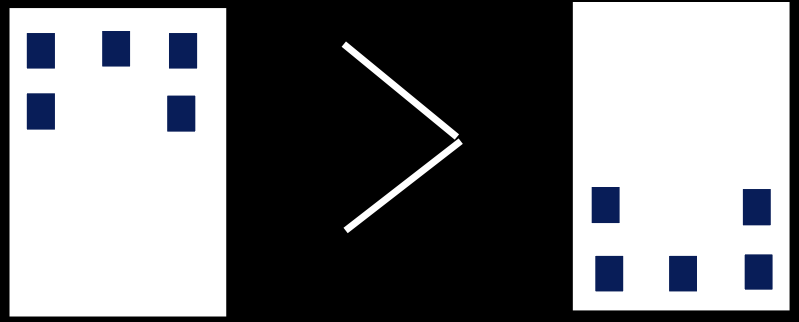
Do Newborns Detect and Prefentially Attend to Faces? *Yes!*

Johnson et al (1991); Goren et al (1975)

Test newborns within 1 hour of birth



Only during the first 2 months of life
Maybe enough to bootstrap learning
May use simple cues



The Initial State: Face Perception in Newborns

What face perception abilities are present in newborns?

- Face detection
- Preferred attention to faces

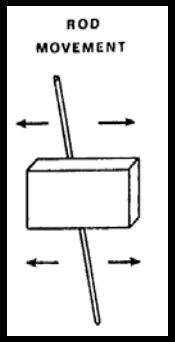
} **Within a day or two**

- Discrimination of individual identity
- Recognition across view change
- Signatures of holistic face processing
  - inversion effect
  - disproportionate composite effect

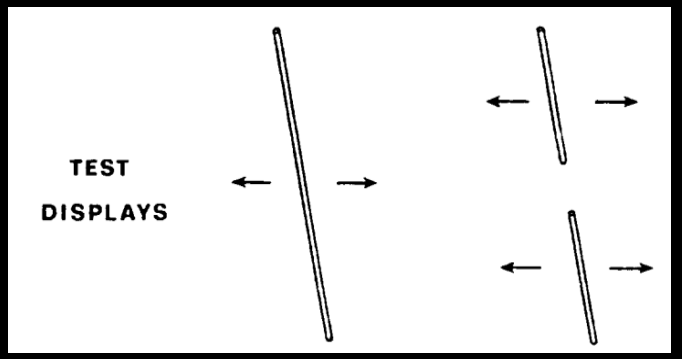
But:
How can we tell what a newborn sees?

How can we tell what a newborn sees?

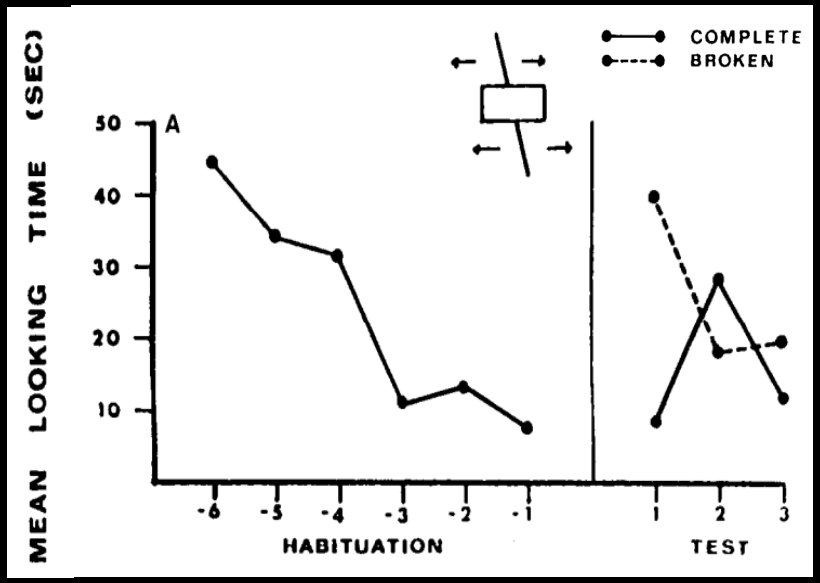
A classic experiment: Kellman & Spelke (1983):
What does an infant see/infer here?



this? *or this?*



"Habituation of looking time" (aka: been there, done that)



This method has shown that infants understand much more than anyone guessed.

How can we use this method to study face recognition in infants?

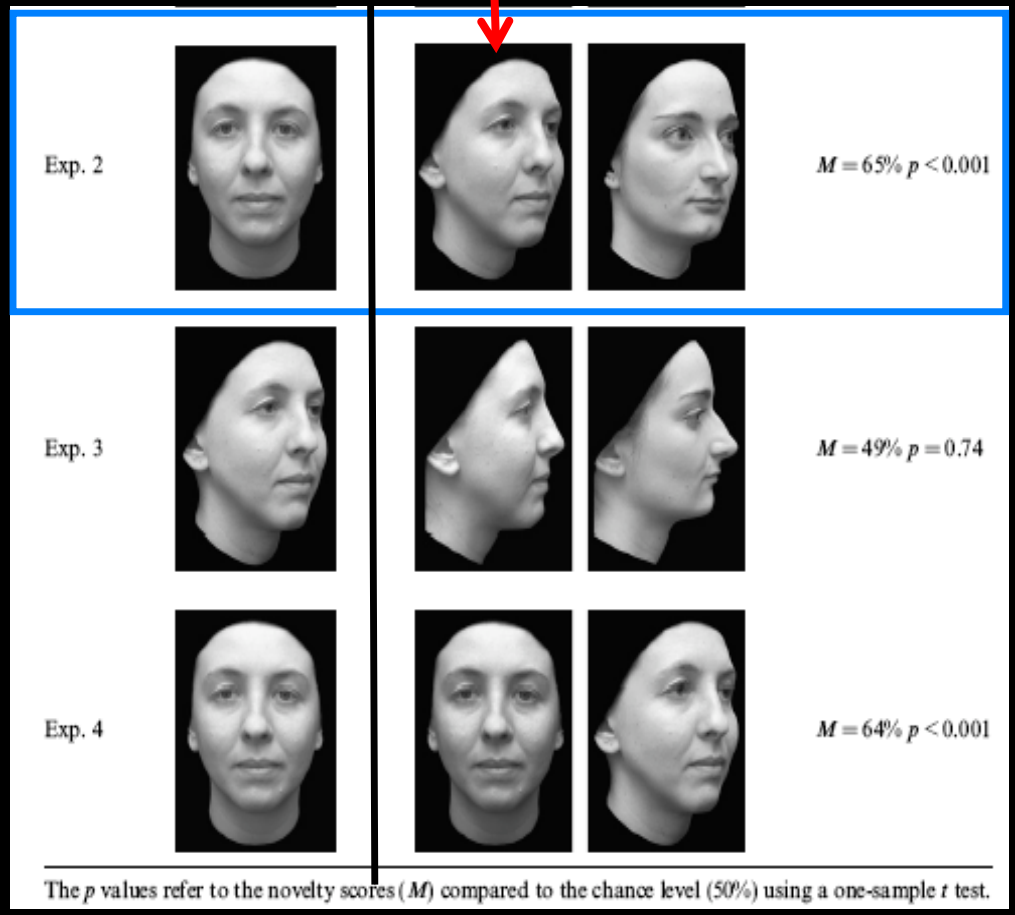
Face Perception in Newborns

1-3 day old infants recognize the identity of *novel* individuals, with *similar-looking* faces, *without hair*, and *across view changes*. Wow!

What kind of cues? Low-level features?

Table 1
Summary table with the results of the four experiments

look less long



The *p* values refer to the novelty scores (*M*) compared to the chance level (50%) using a one-sample *t* test.

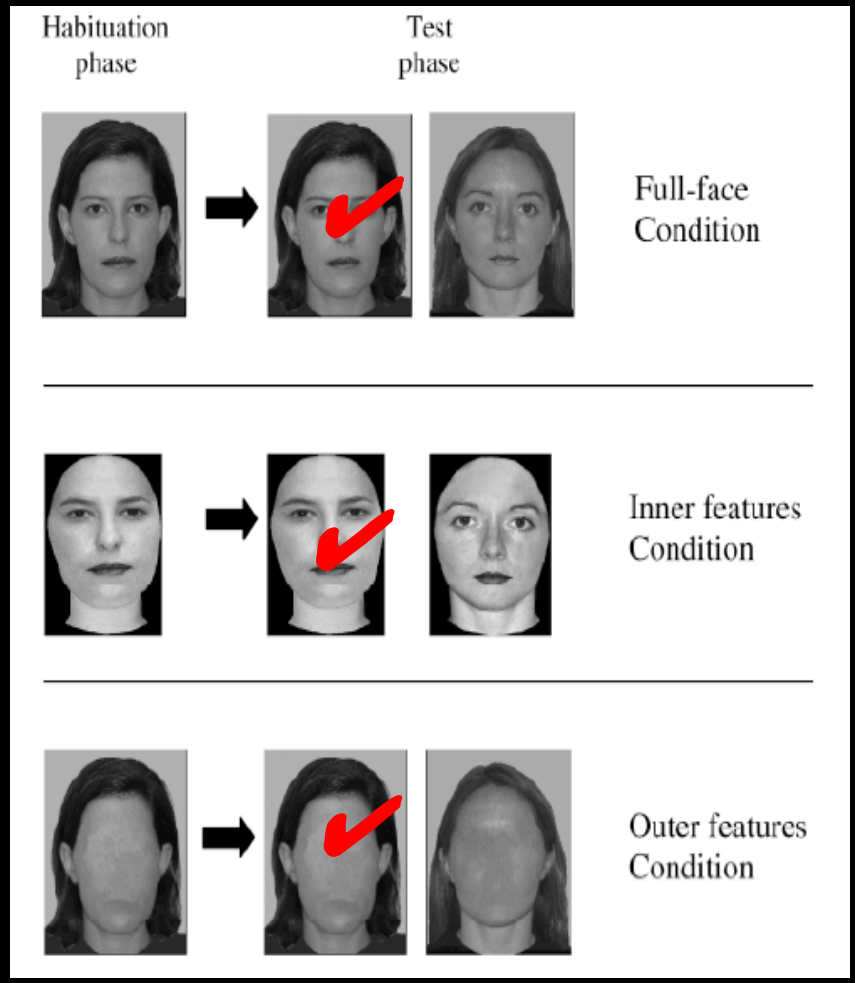
Face Perception in Newborns

Turati, Macchi Cassia, Simion, & Leo (2006):

1-3 day old babies recognize novel unfamiliar faces from either the whole face, inner-features only, or outer features.

But when *inverted* they only match outer features and whole faces, not inner-features faces.

- An inversion effect in newborns!
- Seems inconsistent with a generic object system *.



*But Turati disagrees:
Shorter encoding of inv faces.
So, still unresolved!
Aarg!

The Initial State: Face Perception in Newborns

What face perception abilities are present in newborns?

- Face detection
- Preferred attention to faces

} Within a day or two of birth

- Discrimination of individual identity ✔
- Recognition across view change ✔
- Signatures of holistic face processing
  - inversion effect ✔
  - disproportionate composite effect

Turati et al (2010) showed in 3 month olds; hasn't been tested younger.

So, behaviorally newborns show impressive face perception abilities, especially surprising given low acuity.
Not clear this is a face specific system!

What happens after that?....

Summary on the Development of Face Perception

McKone et al (2012)

By Age 4 years

Every adult face ability that has been tested is qualitatively present. Just refinement after that.
Much of the action must be before that.

Not much is known about face representations and how they change in the first year.

One important thing: perceptual narrowing. Demo….

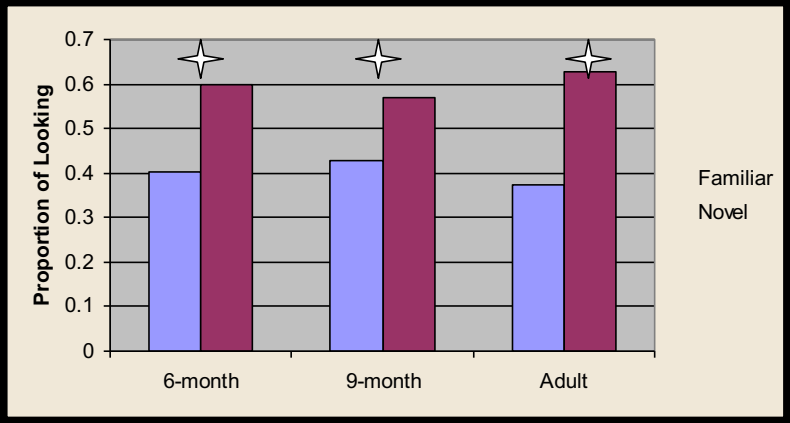
	Newborns	Later infancy	3 years	4 years	5 years	6 years	7 years	8 years	9 years +
Basics - encoding of novel faces									
Discrimination of individual faces	☺	☺	☺	☺	☺	☺	☺	☺	☺
Recognition across view change	☺	☺				☺		☺	☺
Recognition despite paraphernalia (hats, etc)			?				☺		☺
Holistic/configural properties									
Inversion effect on discrimination	☺	☺	☺	☺	☺	☺	☺	☺	☺
Disproportionate inversion effect (faces > objects)			☺	☺	☺		☺		☺
Composite effect	?	☺	☺	☺	☺	☺		☺	☺
Composite effect faces not objects			☺	☺	☺				
Composite effect, upright not inverted		☺				☺			☺
Part-whole effect, upright not inverted				☺	☺	☺	☺	☺	☺
Part-in-spacing-altered-whole effect, upright not inverted				☺	☺				
Sensitivity to spacing changes		☺	☺	☺	☺	☺	☺	☺	☺
Inversion effect on spacing sensitivity		☺		☺	☺	☺	☺	☺	☺
Thatcher illusion, upright not inverted	☺					☺	☺	☺	☺
Perceptual bias to upright in superimposed faces						☺	☺	☺	☺
Internal-over-external features advantage in familiar faces				☺	☺	☺	☺	☺	☺
Face-space properties									
Distinctiveness effects		☺		☺	☺	☺	☺	☺	☺
Atypicality bias			☺	☺	☺	☺	☺	☺	☺
Face-space dimensions (e.g., multidimensional scaling)				☺			☺	☺	☺
Adaptation aftereffects (figural)				☺	☺	☺	☺	☺	☺
Adaptation aftereffects (identity)					☺	☺	☺	☺	☺
Norm-based adaptation aftereffects				☺	☺		☺	☺	☺
Attractiveness effects	☺	☺	☺	☺	☺	☺	☺	☺	☺
Other race effects		☺	☺	☺	☺	☺	☺	☺	☺

Source: E. McKone, et al. *Cognitive Neuropsychology*, 29:1 2, 174 212, DOI: 10.1080/02643294.2012.660138

Perceptual Narrowing in Face Perception

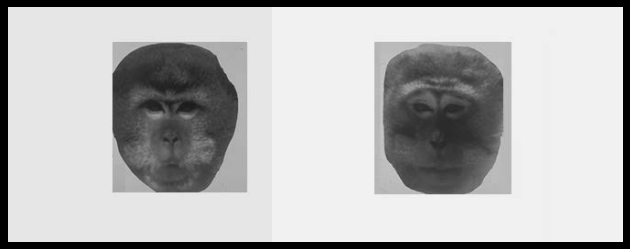
Pascalis et al., (2002): Use preferential looking to the novel face in infants as measure of discrimination ability

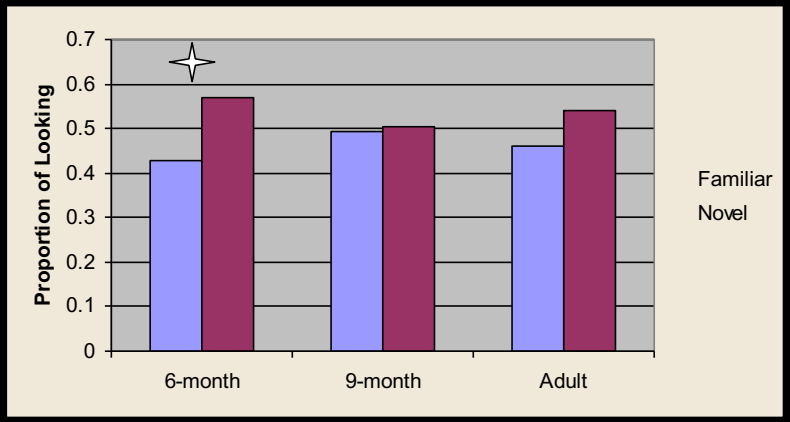
Human Faces



- *6- and 9-month-olds, and adults can discriminate human faces*

Monkey Faces





- *9-month-olds and adults cannot discriminate monkey faces*
- *But 6-month olds can!*

Just like phoneme perception: you could discriminate all phonemes at age 6 months. A similar effect for perceiving faces of other races, following the same time course. [Q: What is the role of maturation and experience in this timing? How would we tell?]

How does Face Perception Develop?

Key Questions:

1. What is the initial state? (at birth, or as close as we can get)
   - impressive perceptual abilities present within a few days
     - face-specificity possible but not nailed
     - nature of representations largely unknown
2. How does the system change over time?
   - perceptual narrowing between 6 and 12 months
   - much unknown

3. Causal roles of structured experience, and biological maturation
   - central challenge: these are deeply confounded in normal development
   - 3 strategies to unconfound:
     - controlled rearing
     - atypical experience
     - preterm infants, where experience starts at a diff maturational age

Controlled Rearing in Monkeys
(Sugita et al, 2008)

- reared monkeys for 6/12/24 months without letting them ever see a face.
- Then tested with preferentially looking method
- At first exposure to faces, they monkeys looked preferentially at faces compared to novel objects, and
- They *discriminated between similar faces with adult-like accuracy (!)*.
- But subseq. experience did have an effect: perceptual narrowing

Suggests much of face perception is present without any exposure to faces.
What experience does: sharpen abilities.

i. really???
ii. can generic recognition explain?
iii. brain basis?

How does Face Perception Develop?

What do we know about the development of neural systems for face perception?

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     - preterm infants

- Cool methods, but few clear answers.
- Early pattern vision may be important;
- early face experience may not be.
- Data on preterms would be great.

fMRI: Development of Specific Brain Regions

1. Face areas are in place by age 5, but continue to develop after that

But even 5yo is late.
Want to know much earlier,
in infancy

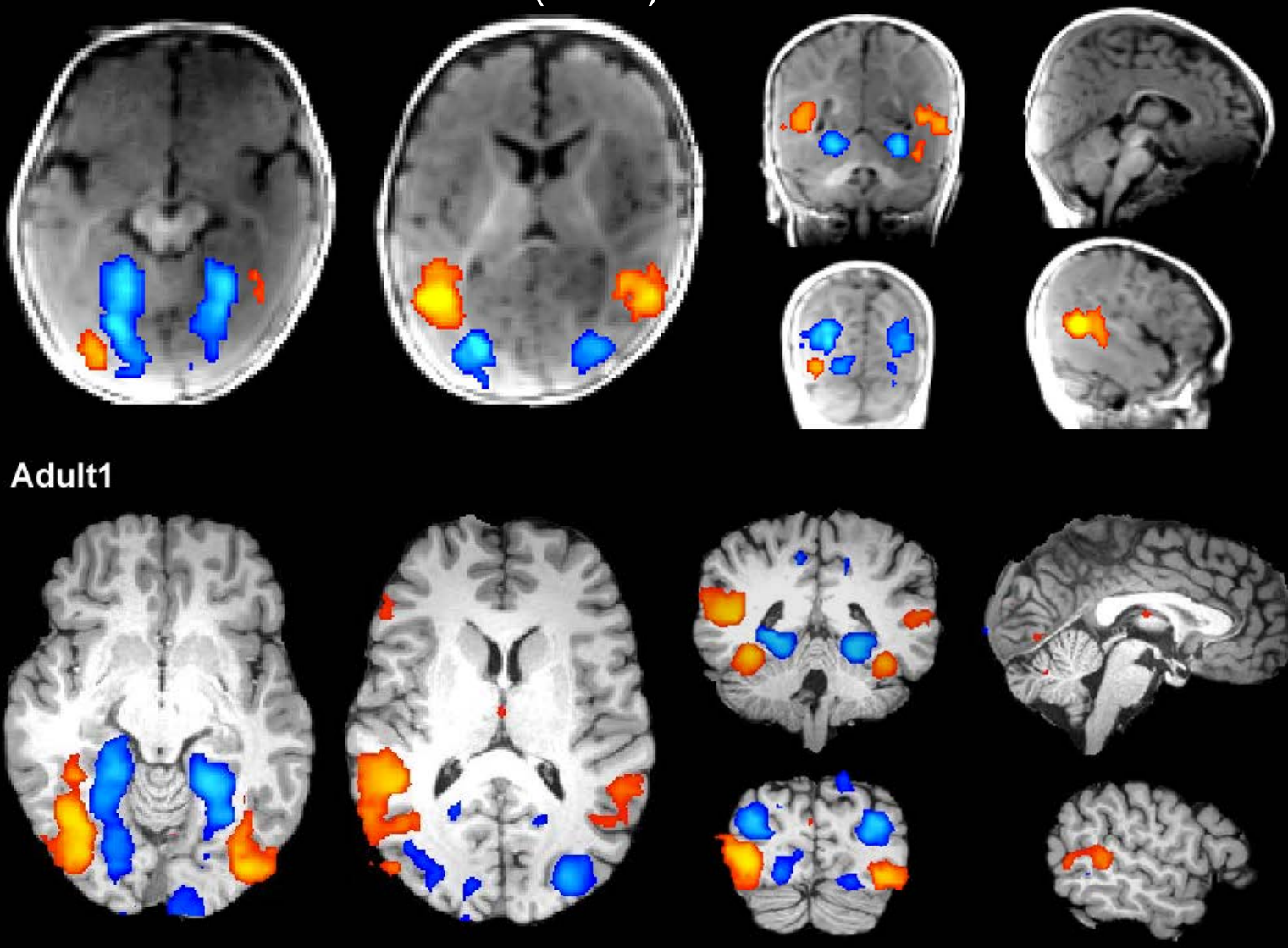
2. Saxe et al: scan 4-6 month olds infants.

Barely possible.
Years of work.
Technical advances.
A key step….

But all worth it…….

Results: Faces vs Scenes

Deen et al (2017)



Development of Specific Brain Regions

1. Basic regions are in place by age 4+, but change subtly after that (Golarai, Grill-Spector, Cantlon, Behrmann, etc.)

But even 4yo is late.
Want to know much earlier,
in infancy

2. Saxe, Deen et al: scan 4-6 month olds.
Spatial organization is adultlike very early!
But functional selectivities are much different.

Pushes developmental timeline way back.
Importantly constrains role of experience & maturation
Next questions:
1. What is it about those regions?
2. Role of experience in their construction?

How could we ever answer this?
ANIMAL MODEL!!!!

Controlled Rearing in Macaques

Arcaro et al 2017

- Raise baby monkeys without ever letting them see a face.
- Hand-reared by humans wearing welder's masks.
- Face-deprived monkeys were kept in a curtained-off part of a larger monkey room so they could hear and smell other monkeys.
- Deprived monkeys saw no faces at all until 90 days old, and after that only during scanning (blocks of face images was during scanning only after 150 days of age).
- What do you think? will the face-deprived monkeys show face patches?

How does Face Perception Develop?

Key Questions:

1. What is the initial state? (at birth, or as close as we can get)

Behavior: face attention and discrimination present in newborns. ✔

face-specificity possible but not nailed

fMRI: no evidence for face specificity at birth.

Face specificity exists, but fMRI fails to detect?

Or: face abilities use generic object rec. systems? ✔

2. How does the system change over time?

Behavior: all hallmarks present by age 4.

Perceptual narrowing between 6 and 12 months

3. Causal roles of structured experience, and biological maturation

central challenge: these are deeply confounded in normal development

Behavior: Early pattern vision may be important for devel of face system.

Controlled rearing: Early face experience not crucial for face recognition.

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Behavior: all hallmarks present by age 4.

Perceptual narrowing between 6 and 12 months

fMRI: no evidence for face specificity before 200 days (monkeys).

3. Causal roles of structured experience, and biological maturation

central challenge: these are deeply confounded in normal development

WTF?

Behavior: Early pattern vision may be important for devel of face system.

Controlled rearing: Early face experience not crucial for face recognition.

But fMRI: Face experience is necessary for development of face patches!

Conundrum! And it will get worse on Wednesday.

Further, if the face system is not innate then…….

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What if anything is Innate about Face Perception ?

Maybe not that much!

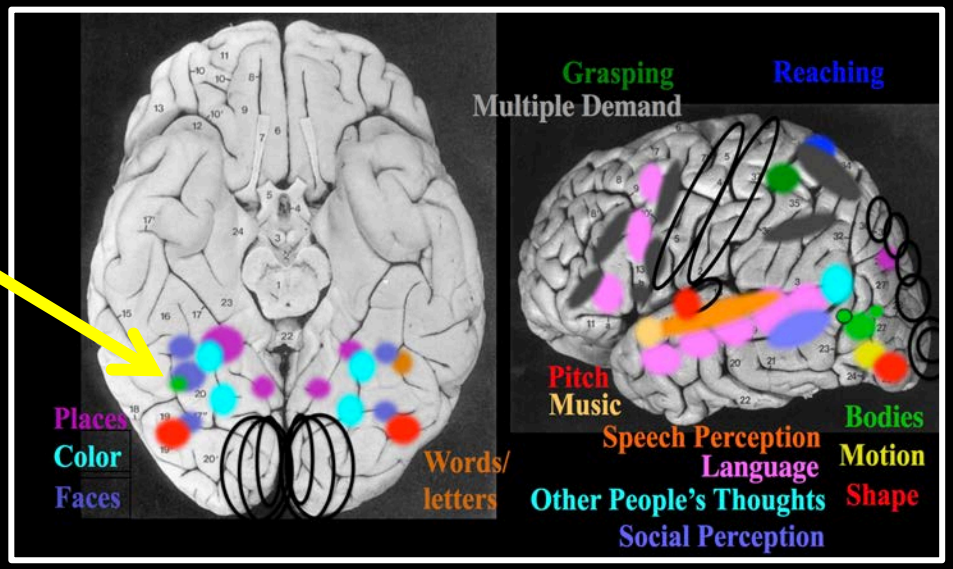
Bias to look at faces (might be very general template).

Early visual discrimination abilities (might not be face specific)

Face patches apparently require experience but…..

How do they know to always arise right here?

Yamins talk Tuesday at 12:15



Pre-existing selectivity?
Pre-existing connectivity?
a very active area of investigation.

Other very active areas of investigation use deep net modeling:

What do you need to build in to a system to get face patches?

What experience is necessary to produce face patches in a deep net?

And what computational role do they serve?

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Wednesday

9.13 The Human Brain
Spring 2019