Octopus

Photo of an octopus removed due to copyright restrictions. Please see lecture video.
Octopus

Photos of the life cycle of an octopus removed due to copyright restrictions. Please see lecture video.
Wildebeest

Photo of wildebeest migration removed due to copyright restrictions. Please see lecture video.
Primates

The Social Intelligence Hypothesis

*Marais, Chance, Jolly ...*

*Nick Humphrey (1976)*

"The social function of intellect"

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The Primates

- Monophyletic mammalian order, 400 plus species
- Highly diverse (30g to 200kg)
- ~65-85 mya
- All species social
- Slow development, long lifespan
- Visual (binocular) rather than olfactory
- Larger brains relative to other mammals

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Mammalian Brains

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Vertebrate, Mammalian, and Primate Brains

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Primate & Mammalian Brains

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Primate & Mammalian Brains

**Rodents**
- Agouti: 18 g, 857 M neurons
- Capybara: 76 g, 1600 M neurons

**Primates**
- Owl monkey: 16 g, 1468 M neurons
- Capuchin monkey: 52 g, 3690 M neurons

Courtesy of Suzana Herculano-Houzel, license CC BY.
Cortical thickness scales up with neural number faster in rodents than in primates.

Neuron size is increasing with brain size in rodents, not much in primates.

Neural density higher in primates than in rodents.

Per cortical neuron #, primates need less white matter volume than rodents.

White matter fiber caliber increases with brain size in rodents, hardly in primates.

Relatively larger cortex/cerebellum fraction in primates than in rodents.

Primate brains fold faster with increasing size than rodent neurons.

FIGURE 2 | Scaling of average cortical thickness (A) and of average neuronal density (B) as a function of numbers of cortical neurons in rodents (green) and primates (red). Power functions, where the exponents are significant at the level of $p < 0.05$, are plotted for each mammalian order with the respective 95% confidence intervals (dotted lines). Exponents are indicated.

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The Primates: Anatomy

- Forward facing eyes, binocular vision, color vision
- Skull with large cranium
- Opposable thumbs
- Highly mobile shoulder (dorsal positioning of scapula)
- “Trend” towards reduced snout

Photo courtesy of Christopher Walsh, Harvard Medical School via Wikimedia Commons. CC lic BY.

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The Primates: Sociality

Four main organizations of social life

• Female transfer system (spider monkeys)
• Male transfer system: polygonous & multi-male (capuchin, old-world monkeys: macaques, baboons)
• Monogamous (gibbons)
• Solitary (male defending territory, slow loris, orangutan)

Social behavior of cooperation (grooming, defense, hunting) & competition (food, mates, dominance hierarchies)
The Social Intelligence Hypothesis

The Social Intelligence Hypothesis

- We do not know whether social intelligence is primate-specific.
  - Social complexity could be high in other species that live in complex societies comprised of multiple families and stable dominance hierarchies like dolphins (Tursiops truncates), elephants (Loxodonta africana), spotted hyenas (Crocuta crocuta). Maybe these individuals, too, recognize and monitor other individuals' social relationships?

- Are primate societies more complex than those of other taxa?

- Within the primate order, social learning, innovation, and tool use are strongly correlated with brain size, not group size (Reader 2003):
  - Chimpanzees, orangutans, and capuchin monkeys have larger brains than other primates and use and manufacture tools more routinely than monkeys, but live in relatively small groups. Indeed, orangutans are frequently solitary.
  - Thus tool use and behavioral flexibility, not the complexity of social groups might have driven brain evolution in primates.
Primates are social – and invent cool tools

The Social Intelligence Hypothesis

• We do not know whether social intelligence is primate-specific.
• Are primate societies more complex than those of other taxa?
• Within the primate order, social learning, innovation, and tool use are strongly correlated with brain size, not with group size (Reader 2003)
• Are primates’ abilities in social knowledge really intelligent or just idiot savant-like abilities?

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Social Knowledge in Baboons

Is it knowledge or just extensive associations?

- 80 individuals: 3,160 dyads & 82,160 triads
- Relationships can change fast
- No single behavioral metric is necessary or sufficient to recognize associations like matrilineal kin (human observer using counts of aggressive or grooming behavior cannot infer relationships)
- Social relationships like friendship are intransitive, others like family-relationships are non-associative
- Simultaneous membership in multiple classes possible

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The story of Ahla (*Papio ursinus ruacana*)

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The story of Ahla (*Papio ursinus ruacana*)

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The story of Ahla (*Papio ursinus ruacana*)

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Structure of Primate Social Knowledge

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from Neurons to Minds

Object Recognition

Faces

Social Cognition
Figure removed due to copyright restrictions. Please see lecture video or Figure 2 from Felleman, Daniel J., and David C. Van Essen. "Distributed hierarchical processing in the primate cerebral cortex." Cerebral cortex 1, no. 1 (1991): 1-47.
Gestalt Rules of Perception

- **Proximity**
  - ![Proximity Example](image)

- **Similarity**
  - ![Similarity Example](image)

- **Good Continuation**
  - ![Good Continuation Example](image)

- **Common Fate**
  - ![Common Fate Example](image)
Internal Models of Perception
from Neurons to Minds

- Constructive process
- Not just collection of features: unit of cognition
- Basis of Symbolic Representations
- Creates Meaning
- Makes information actionable
Primates are social

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Please see lecture video or Thierry, Bernard.
The Expression of the Emotions in Man and Animals
Charles Darwin, 1872

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Facial Communication (and lack thereof)

Facial interactions in rats - from Bobrov & Brecht

Facial Communication in Primates

Figure removed due to copyright restrictions. Please see lecture video of figure 1 from Parr, Lisa A., Bridget M. Waller, Anne M. Burrows, Katalin M. Gothard, and Sarah-Jane Vick. "Brief communication: MaqFACS: A muscle-based facial movement coding system for the rhesus macaque." American journal of physical anthropology 143, no. 4 (2010): 625-630.
Facial Communication in Primates

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Figure removed due to copyright restrictions. Please see lecture video of figure 19 from Ekman, Paul. Darwin and facial expression: A century of research in review. Ishk, 2006.
Primates are interested in faces

Ferrari et al., PLoS 4(9) e302 (2006)

Video is in public domain courtesy of PLOS Biology.
Faces elicit automatic emotional, communicative, and cognitive responses

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Photo is in public domain.

Photo removed due to copyright restrictions. Please see lecture video.
Faces elicit automatic emotional, communicative, and cognitive responses

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Social Perception starts with Faces

- gender, age
- personal identity
- trustworthiness, attractiveness (Willis & Todorov, 2007)
- mood, overt direction of attention

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Section of St. Cecilia, Raphael

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The Neural Basis of Face Recognition
Action Potentials

The Neural Basis of Face Recognition

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Please see lecture video or see Figure 4 from Perrett, David Ian, J. K. Hietanen, M. W. Oram, P. J. Benson, and E. T. Rolls. "Organization and functions of cells responsive to faces in the temporal cortex [and discussion]." Philosophical Transactions of the Royal Society of London B: Biological Sciences 335, no. 1273 (1992): 23-30.
The Functional Anatomy of Face Recognition

- Are face areas domain specific modules – or just the tip of the iceberg of face-responsive temporal lobe regions?

- Do monkeys have localized face areas like humans - or not, since electrophysiology seems to suggest broad distribution of face cells across temporal lobe regions?

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The macaque face processing system: composition
The Functional Anatomy of Face Recognition

• Are face areas domain specific modules – or just the tip of the iceberg of face-responsive temporal lobe regions?

• Monkeys have localized face areas like humans - or not, since electrophysiology seems to suggest broad distribution of face cells across temporal lobe regions?

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How face-selective are the face patches?
Random order
200 msec ON, 200 msec OFF
5-10 repetitions
Middle Face Patch Cells

• virtually all are face selective
• respond (more weakly) to non-face objects that share visual features with faces
Face cells, hierarchies, grandmother and gnostic neurons

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David Hubel & Torsten Wiesel

Jerome Lettvin

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What is the neural code?

Donald Hebb “cell assembly"

Karl Lashley "mass action"

Horace Barlow, “pontifical cell”

Jerzy Konorski “gnostic unit”

Integrative Activity of the Brain (1967)

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The Functional Anatomy of Face Recognition

- Face patches appear to be dedicated domain specific modules – or just the tip of the iceberg of face-responsive temporal lobe regions?

- Monkeys have localized face areas like humans - or not, since electrophysiology seems to suggest broad distribution of face cells across temporal lobe regions?

Figure removed due to copyright restrictions. Please see lecture video.
Middle Face Patch Cells

• ... are virtually all face selective

Practical Implications

• We have unprecedented access to functionally homogenous populations of cells coding for one high-level object category
• We can causally test the role of face-patches for face processing
The macaque face processing system: causal role in face detection
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The macaque face processing system: causal role in face detection
The macaque face processing system: causal role in face detection
The macaque face processing system: causal role in face detection
The macaque face processing system: face-domain specific modularity

Source: Freiwald, Winrich A., Doris Y. Tsao, and Margaret S. Livingstone
The macaque face processing system

We have **unprecedented access** to functionally **homogenous populations** of cells coding for **one high-level object category**

Human Psychophysics

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Human Psychophysics

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The macaque face processing system: The Part and the Whole

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A Parameterized Cartoon Face Space

A Parameterized Cartoon Face Space
Tuning to Features: an Example Face Cell

Are features tuned in isolation?
Feature Tuning & Holistic Gain Modulation in the middle face patches
Middle Face Patches

- Are causally and selectively relevant for face detection
- Cells are virtually all face selective → modules
- Middle face patch neurons are tuned to facial features: thus they care for details
- Gain of tuning curves is modulated by the presence of the entire face: thus middle face patch neurons have holistic coding properties
- They detect qualitative contrast ratios, preferring polarity in much the same way as predicted by computational and psychophysical results.
- We can get a mechanistic understanding of face-recognition
- Thus at the level of the middle face patches, some of the requirements of a face recognition system are met: mechanisms for face detection, encoding of facial features and, encoding of configurations

The macaque face processing system: determining connectivity

Sebastian Möller
The macaque face processing system: determining connectivity

electrical stimulation inside the MR scanner
How does face selectivity develop along the face patch hierarchy?
Electrophysiological Recordings in Three Face Patches vs. AL, MF, AM
The macaque face processing system: why is it organized the way it is?

Affine Transformations

Non-affine Transformations

Image removed due to copyright restrictions. Please see lecture video.
The macaque face processing system: why is it organized the way it is?

Modular Architecture
3-Level Processing Hierarchy

Level 1: Face Filter
Level 2: Mirror-Symmetry
Level 3: Identification
+ Hebbian Learning Rule

= Level 3: Invariance

Transform Face Representation from Picture to Identity in two steps
The macaque face processing system: transformations

Transformation of Face Representations from Picture to Identity
from Faces to Agents

Images removed due to copyright restrictions. Please see lecture video or Figure 3 from Looser, Christine E., and Thalia Wheatley. "The tipping point of animacy how, when, and where we perceive life in a face." Psychological science 21, no. 12 (2010): 1854-1862.
The macaque face processing system: sensitivity to stimulus motion
The macaque face processing system: Sensitivity to stimulus motion

Face Form-Selective Face Motion-Sensitive

The macaque face processing system: Sensitivity to stimulus motion

Face MotionSensitive

Object Motion-Sensitive

Signal (normalized)

Face Patch

PL ML AL MF MD AF

The macaque face processing system: Sensitivity to stimulus motion


Moving

Still

Motion?
Image content?
Update frequency?
The macaque face processing system: A new Functional Division

The macaque face processing system: A new Functional Division

The macaque face processing system: two axes of functional specialization

Transformation of Face Representations from Picture to Identity

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The Neural Circuits of Face Processing

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The Neural Circuits of Face Processing

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The Neural Circuits of Face Processing
Resource: Brains, Minds and Machines Summer Course
Tomaso Poggio and Gabriel Kreiman

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