Occipital and Temporal Lobe – Visual Perception and Memory

Tobias Bast, School of Psychology, University of Nottingham
The primary visual pathway includes:

a) Retina, lateral geniculate body, primary visual cortex.

b) Retina, lateral geniculate body, primary visual cortex, hippocampus.

c) Retina, superior colliculus, primary visual cortex.
• How does the brain process visual information beyond V1, and how does such information processing give rise to perception and memory?

• Focus on: occipital lobe and temporal lobe (inferior temporal lobe and medial temporal lobe)
Hierarchy and functional differentiation in visual information processing

Processing of visual information by the brain is **hierarchical**, with the complexity of the visual representation increasing from retina to visual association cortices and beyond.

At the different stages of information processing there is **functional differentiation**, with different neuron types or different brain regions processing different properties of visual stimuli.

**Simple features:**
- Light intensity and wavelength
- 2D position in visual field

**Combination and elaboration via parallel channels**

**Complex visual representations for perception and memory:**
- Integrated information concerning form, surface (colour, texture), spatial relationships, and movement
- Integration with other sensory modalities (multimodal representations)
Visual information processing beyond V1

Extrastriate/prestriate ctx

V1

V2

V3

V4

V3A

V5/MT

STO

STS

TEO (posterior IT)

TE (anterior IT)

Inferior temporal (IT) ctx

Posterior Parietal ctx.

Occipital lobe

Superior colliculus

LGN

eye

Striate cortex (area V1)

Dorsal Stream

V2

Posterior parietal cortex

Anterior bank of superior temporal sulcus (area STS)

Ventral Stream

Inferior temporal cortex

TeO

Te
Neurons in extrastriate cortex signal ‘global’ properties of visual scenes and objects, rather than ‘component’ properties.
Global colour vs. component wavelength

• Perceived colour of an object depends not only on the wavelength reflected by the object, but also on wavelength reflected by the surroundings (colour constancy; e.g., perceived colour of object does not change when viewed during sunset).

• Some neurons in V4 are ‘colour’-sensitive (i.e., respond to wavelengths in the centre of their receptive field, depending on the wavelengths reflected from the background), whereas neurons in primary visual pathway and V2 are only ‘wavelength’-sensitive.

http://www.thenakedscientists.com/HTML/articles/article/martinwestwellcolumn9.htm/
Fig. 26.1 Component motion and overall motion. When an object is moving towards three o'clock, cells with small receptive fields (like the ones in V1), which ‘look’ at limited regions of the stimulus, will register the component movements in different directions (towards 1.30 and 4.30 o'clock in this case). Physiological experiments show that the directionally selective cells of area V1 register the component directions whereas those of area V5, which ‘look’ at larger parts of the field of view, register the true, overall, direction. [Redrawn from the work of Movshon, J.A. et al. (1985). Pattern Recognition Mechanisms, edited by C. Chagas, R. Gattass & C. Gross. Pontifical Academy, Vatican City.]
Two visual information processing streams

Following V1 (and perhaps earlier) visual information processing is mediated by two streams, that are anatomically and functionally differentiated.

- **Dorsal stream**: Visuo-spatial (‘where’) / visuo-motor (‘how’) processing
  - Posterior Parietal ctx.
  - V5/MT

- **Ventral stream**: Object analysis (‘what’)
  - Inferior temporal (IT) ctx.
  - Extrastriate/prestriate ctx.
  - V5/MT
  - TEO (posterior IT)
  - TE (anterior IT)
  - STS

**Key structures**:
- Striate cortex (area V1)
- Posterior parietal cortex
- Anterior bank of superior temporal sulcus (area STS)
- Superior colliculus
- LGN
- V1
- V2
- V3
- V3A
- V4
- TEO
- TE
- Inferior temporal sulcus (area STS)

**Diagram**: A diagram illustrating the pathways of the two streams, starting from the eye (LGN) through V1, V2, V3, V3A, and V4, and leading to the dorsal and ventral streams with corresponding brain regions.
Inferior temporal lobe lesions (‘ventral stream’) in macaques impair object-discrimination/recognition (‘what’), but not object location (‘where’).

Posterior parietal lesions (‘dorsal stream’) impair object location (‘where’), but not discrimination (‘what’).

Visual Streams – what/how

- Milner and Goodale proposed that the ventral stream processes visual information for object perception (‘what’), whereas the dorsal stream processes visual information for visuo-spatially guided action (‘how’).

- Key evidence: patients with occipito-temporal brain damage show severe forms of visual agnosia (i.e., deficits in aspects of visual perception without blindness), but intact visually guided actions, whereas patients with posterior-parietal lobe lesions show optic ataxia (i.e., deficits in visually guided reaching) with otherwise relatively intact visual function.

- For example, patient DF with extensive bilateral ventral-stream lesions has profound visual agnosia, but shows intact visually guided reaching:

  DF can act on visual stimulus (e.g., visuomotor posting), but is unable to make perceptual judgements (e.g., perceptual orientation matching)

What does the observation of optic ataxia in a patient with posterior parietal lobe lesions suggest?

a) The posterior parietal lobe is required for object perception.

b) The posterior parietal lobe is required for visuo-spatially guided action.

c) None of the above.
Two visual information processing streams

Dorsal stream:
- Visuo-spatial ('where')/ visuo-motor ('how') processing

Ventral stream:
- Object analysis ('what')

Extrastriate/prestriate ctx

Inferior temporal (IT) ctx

Dorsal stream

V1

V2

V4

V3

V5/MT

Superior colliculus

LGN

eye

Occipital lobe

Ventral stream: Object analysis ('what')

TEO

TE

STS

V5/MT

V3A

V3

V4

Inferior temporal (IT) ctx

Anterior bank of superior temporal sulcus (area STS)
Visual perception and memory in inferior temporal cortex

• The inferior temporal cortex receives inputs from extrastriate cortex and forms the final stage in the visual processing hierarchy of the ventral stream.

• Neurons in the inferior temporal cortex can respond very selectively to specific shapes and objects.

• These responses can show:
  - invariance to changes in size, orientation, and other properties – i.e., the neuron ‘recognizes’ object regardless of the viewpoint.
  - sustained activity in absence of visual object, reflecting short-term object memory

Face cells

• Some neurons in the inferior temporal lobe show highly selective responses to individual faces.

• The highly selective properties have been compared to those of ‘gnostic units’ or ‘grandmother neurons’, i.e. hypothetical neurons at the end of a processing hierarchy that ‘recognize’ individual entities, such as your grandmother (although face cells typically respond to several faces; also compare Quian Quiroga, 2016, Neuropsychologia, concerning an evaluation of the ‘grandmother’ neuron concept).

• Areas showing selective responses to faces have also been identified in the human inferior temporal lobe using functional imaging (e.g., Fusiform Face Area) (Kanwischer N, Yovel G, 2006, Phil. Trans. R. Soc. B 361:2109).

The Medial Temporal Lobe (MTL): Further processing of visual information and multimodal integration

- MTL is at end of visual-processing hierarchy, combining inputs from ventral and dorsal stream, and receives additional inputs from other sensory modalities.

- It is thus in position to elaborate visual representations further and to generate multi-modal representations.

- Examples of complex representations mediated by MTL structures include:
  - Complex spatial representations, requiring the encoding of relations between many visual stimuli.
  - Multimodal representations of experiences (‘episodic’ memory) and facts (‘semantic’ memory) (together referred to as ‘declarative’ memory).
What does neuroanatomy indicate about the MTL:

a) MTL receives only visual information, but highly processed.

b) MTL receives visual, auditory, olfactory, and other sensory information.

c) MTL should only respond to visual stimuli.

d) Both a) and c) are correct.
Patient H.M.

Surgical removal of hippocampus and of parts of the surrounding cortices to stop epileptic seizures.

• Following surgery, HM showed severe and pervasive deficit in remembering new and recent experiences, facts, and places, whereas other cognitive functions, including procedural learning, were largely intact.
• These findings triggered enormous research activity on function of hippocampus and surrounding cortices.
Selective place learning deficits after hippocampal lesions in rats

Representative swim paths on trial 28

Hippocampal lesion

Search preference for target region during ‘probe’ trials (▲)

Hippocampal place cells

‘Place cells’ in rat hippocampus

‘Place cells’ in human hippocampus during virtual navigation

www.nobelprize.org/nobel_prizes/medicine/laureates/2014/okeefe-lecture.html

Nobel Prize in Physiology and Medicine 2014

Encoding of multimodal percepts by hippocampal neurons

Hippocampal neuron with multimodal responses to Oprah Winfrey


(Also compare: Quian Quiroga R (2016) Neuronal codes for visual perception and memory. *Neuropsychologia* 83:227-241)
• Perception and memory based on visual (and other sensory) information can be understood as a hierarchically organized sequence of processing steps mediated by interconnected brain networks.

• At the earliest stages neurons respond to very basic features.

• At progressively higher stages, neurons respond to combinations of basic features and get activated by more and more complex stimuli.

• Visual information processing is also characterized by functional differentiation, i.e. different properties of visual stimuli are processed in parallel by different neuron types/brain regions (e.g., colour and motion; information concerning stimulus identity vs. information relevant to what to do with a stimulus).
Selected Reading

**Textbook chapters:**
Carlson NR (any recent edition) The physiology of behavior.
- **Vision (Chpt. 6)**
- **Relational learning and amnesia (Chpt. 15)**

Bear MF, Connors BW, Paradiso MA (any recent edition) Neuroscience – exploring the brain. Chapters 10 (Vision) and 24 (Memory Systems, especially the part on Declarative Memory).

**Review articles:**

Occipital and temporal lobe: visual perception and memory – Revision questions

• What could be considered overarching principles of visual information processing?
• Outline key principles of visual information processing along the primary visual pathway and beyond.

Some specific questions to ponder
• What is a ‘colour’?
• Can you explain why the right bottom corner of the two pictures is perceived as red in the left image, even though it reflects light of the same wavelength composition as the right bottom corner of the right image?
• Can you explain, in principle, how we may recognise objects, faces, and places?
• Can you think of differences between receptive fields of visual neurons and place fields of hippocampal neurons?
• How could the brain mediate the ‘use’ of perception and memory to guide motor actions or their influence on emotions?