The neural control of eye movements

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The problems we are trying to solve in a nutshell

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Please see lecture video or Jack Ziegler, "Cat Thinks of a Complex Equation to Get a Ball Off a Table," *New Yorker*, November 26, 2001.
Topics:

1. Basics of eye movements
2. The eye plant and the brainstem nuclei
3. The superior colliculus
4. Visual inputs for saccade generation
5. Cortical structures involved in saccadic eye-movement control
6. The effects of paired electrical and visual stimulation
7. The effects of lesions on eye movement
8. Pharmacological studies
1. Basics of eye movements
Why do we move our eyes?

A. To acquire objects for central viewing
   Saccadic eye movements

B. To maintain objects in foveal view
   Pursuit eye movements

C. To stabilize the world on the retina
   Vestibulo-ocular reflex, accessory optic system
Classification of eye movements

Conjugate eye movements

- **saccadic** (acquires objects for central viewing)
- **smooth pursuit** (maintains object on fovea)

Vergence eye movements

\[
\begin{align*}
X &= Y \\
X &\neq Y
\end{align*}
\]
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Please see lecture video or [Rene Magritte's Le blanc-seing.](#)
Please see lecture video or Rene Magritte's Le blanc-seing.
Saccadic eye movements made under free-viewing conditions by a subject examining a picture of the bust of Nefertiti. By Yarbus

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Please see lecture video.
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Please see lecture video.
Free viewing by intact monkey
2. The eye plant and the brainstem nuclei
Innervated by Superior Trochlear Nerve

· Rectus Muscle
  · Lateral Rectus Muscle
  · Inferior Rectus Muscle

Innervated by Abducens Nerve

· Inferior Oblique Muscle

Other recti and inferior oblique innervated by oculomotor nerve
Cranial nerves

1. olfactory
2. optic
3. oculomotor
4. trochlear
5. trigeminal
6. abducens
7. facial
8. auditory
9. glossopharyngeal
10. vagus
11. spinal accessory
12. hypoglossal

Spinal nerves

cervical  8
thoracic 12
lumbar   5
sacral   5
coccygeal 1

On old olympus' towering top a fat armed girl vends snowy hops
Neuronal discharge in oculomotor nucleus

Vertical eye movements
Responses of a neuron in the oculomotor nucleus that innervates the inferior rectus
The discharge of four oculomotor neurons as a function of the angular deviation of the eye.
Electrical stimulation of the abducens nucleus

Image by MIT OpenCourseWare.
Brainstem inputs to oculomotor, trochlear and abducens nuclei

The discharge patterns and connections of neurons in the horizontal burst generator. Left: Firing patterns for an on-direction (first vertical dashed line) and off-direction (second dashed line) horizontal saccade of size $q$ to a target step (schematized in the eye and target traces below); Right: Excitatory connections are shown as open endings, inhibitory connections are shown as filled triangles, and axon collaterals of unknown destination (revealed by intracellular HRP injections or postulated in models) are shown without terminals. Connections known with certainty are represented by thick lines. Uncertain connections by thin lines, and hypothesized connections by dashed lines. A complete description of the behavior of this neural circuit is found in the text. The abbreviations here and in figure 4 identify excitatory (EBN) and inhibitory (IBN) burst neurons, long-lead burst neurons (LLBN), trigger input neurons (TRIG), omnipause neurons (OPN), tonic neurons (TN), and motoneurons (MN).

Image by MIT OpenCourseWare.
rate code

BS
3. The superior colliculus
Arrows point to optic tectum in three species.

Optic tectum = superior colliculus
Midline sagittal section through monkey brain

Superior colliculus

Lunate

V1
Coronal section through the cat superior colliculus

Figure removed due to copyright restrictions.

Please see lecture video or Figure 3 of Kanaseki, T., and J. M. Sprague. "Anatomical Organization of Pretectal Nuclei and Tectal Laminae in the Cat." Journal of Comparative Neurology 158, no. 3 (1974): 319-37.
Visual field representation in the superior colliculus

Contralateral Visual Hemifield

Superior Colliculus

Anterior foveal

Medial up

Lateral down

Posterior peripheral
Visual response of superficial collicular cells

Image by MIT OpenCourseWare.
Responses of a neuron in the superior colliculus with eye movement
Saccade-associated discharge in a collicular cell

each point represents the direction and amplitude of a saccade made during data collection
Recording and stimulation in the superior colliculus

Recording and stimulation at three collicular sites

SC

posterior

lateral

visual field

1 2 3
Electrical stimulation of the abducens and the superior colliculus

Abducens nucleus

Superior colliculus

Image by MIT OpenCourseWare.
Basic principle of coding in the superior colliculus

A saccade is generated by computing the size and direction of the saccadic vector needed to null the retinal error between the present and intended eye position.
4. Visual inputs for saccade generation
MIDGET SYSTEM

PARASOL SYSTEM

W SYSTEM

coniocellular cells
Antidromic activation method

W-like cells

Layer 5 complex cells

Superior colliculus

V1

Antidromic activation

stimulate

record
Cooling method

- Cooling plate
- LGN
- Superior colliculus
- $V_1$
- record
- $\text{?g}$
Recording in the superior colliculus while cooling V1

Image by MIT OpenCourseWare.
Coronal section through the superior colliculus of a monkey whose right visual cortex has been removed. Lesion marks location where cells can no longer be visually driven.

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Please see lecture video.
Tissue block with injections

infect blocker

Parvo

Magno

LGN

V1

record

Superior colliculus
Single-cell responses in SC while blocking parvo or magno LGN

SC cell 1

Normal

Parvo Block

SC cell 2

Normal

Magno Block

Image by MIT OpenCourseWare.
Summary

1. Classes of eye movements are vergence and conjugate, with the latter comprised of two types, saccadic and smooth pursuit.

2. Eye movements are produced by 6 extraocular muscles that are innervated by axons of the 3rd, 4th and 6th cranial nerves.

3. The discharge rate in neurons of the final common path is proportional to the angular deviation of the eye. Saccade size is a function of the duration of the high-frequency burst in these neurons.

4. The superior colliculus codes saccadic vectors whose amplitude and direction is laid out in an orderly fashion and is in register with the visual receptive fields.

5. The retinal input to the SC comes predominantly from w-like cells. The cortical downflow from V1 is from layer 5 complex cells driven by the parasol system.

6. The superior colliculus is under cortical control.