Medical Neuroscience | Tutorial Notes

Eye Movements

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Discuss the five major types of eye movements and indicate the functional purpose of each.
2. Discuss the neural circuits responsible for making a saccadic eye movement.
3. Discuss the roles of the frontal eye fields and the superior colliculus in directed gaze toward an object of interest in the visual field.

TUTORIAL OUTLINE

I. Eye Movements

  A. overview

    1. because good visual acuity is restricted to a very small part of the visual field (about two degrees), eye movements are necessary to:

      a. maintain foveal fixation on a moving target

      b. maintain foveal fixation on a target during head movements

      c. acquire and fixate a new visual target

    2. eye movements are a relatively simple set of somatic motor behaviors; there are only 6 pairs of muscles involved and five patterns of movement

  B. extraocular muscles and patterns of innervation

    1. for each eye, there are three pairs of striated muscles that move the eye along the three axes of rotation (review orbital anatomy; see **Figure 20.2**[2])

    2. innervation by three cranial nerves (see **Figure 20.3**)

      a. **abducens** (CN VI): ipsilateral lateral rectus muscle

      b. **trochlear** (CN IV): contralateral superior oblique

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

c. **oculomotor** (CN III): supplies the remaining four ipsilateral muscles (medial rectus, inferior rectus, superior rectus, and inferior oblique)

- distinct columns of motor neurons in the oculomotor complex supplies each of these four extraocular muscles (a separate pool of motor neurons also innervates levator muscles of the eyelid)
- also remember that the Edinger-Westphal component supplies preganglionic parasympathetic innervation to the constrictor muscles of the iris

C. types of eye movements

1. *conjugate* eye movements: eyes moves together in the same direction

a. **saccades**

- rapid movements of the eye that abruptly change the point of fixation (see **Figure 20.4**)
- can be voluntary, but most are involuntary
- after decision to saccade (or onset of a target), there is an obligatory delay of ~200 msec before the onset of movement
- movement is "ballistic" (sudden forceful motion, without ongoing visual guidance toward target)
- during a movement, visual information is suppressed from perception (demonstrate this fact for yourself!)

b. **smooth pursuit movements**

- much slower eye movements designed to track a moving stimulus (see **Figure 20.5**)
- voluntary, (usually) requiring a moving target

c. **optokinetic movements**

- movements of the eyes to compensate for large-scale motion of the visual field
- operate at low stimulus frequencies when vestibulo-ocular gain is much less than 1 (see **Figure 20.6**)
- very large scale motion patterns (e.g., waiting at a railroad crossing for a train to pass) may induce **optokinetic nystagmus**:
    - smooth pursuit movement to track a stimulus to the limit of ocular rotation (movement in the direction of stimulus motion)
    - saccade to acquire a new element of the visual scene for fixation (movement opposite the direction of stimulus motion)

d. **vestibulo-ocular movements** (see previous tutorial on "Vestibular System – Central Processing")

i. in brief, rotational movements of the head induce eye movements opposite to the direction of rotation, thus allowing maintained visual fixation of both eyes

2. *disconjugate* eye movements: eyes move in opposite directions

a. **vergence movements**

- eyes rotate inward (convergence) or outward (divergence) so that the lines of fixation intersect on 'near' or 'far' visual targets, respectively (see **Figure 12.14**)

- recall that along with vergence movements, accommodation of the lens and adjustments of pupillary diameter are reflexively yoked when fixation shifts from near to far, and vice versa

D. neural control of eye movements

1. **amplitude** of movement

a. encoded by duration of action potential firing in the appropriate lower motor neurons (see **Figure 20.7**)

b. when eye is moved in the opposite direction, the same lower motor neurons become transiently silent (i.e., inhibited)

2. **direction** of movement

a. specified by which eye muscles are activated

b. horizontal and vertical eye movements are coordinated by two "gaze centers" in the brainstem reticular formation (see **Figure 20.8**)

- these "centers" are sets of highly interconnected interneurons whose output is directed toward lower motor neurons

- **horizontal gaze center** (paramedian pontine reticular formation): coordinates horizontal eye movements

- **vertical gaze center** (rostral interstitial nucleus in the midbrain): coordinates vertical eye movements

- activation of both gaze centers produces oblique movements

3. "upper motor neuronal control" of saccades

a. horizontal and vertical gaze centers are influenced mainly by two sources of descending control: the **superior colliculus** and the **frontal eye field** (Brodmann's Area 8)

- neurons in both structures fire just prior to making a saccade

- both structures contain a "motor map" so that activation of a discrete site produces a saccade in a specific direction for a specific distance in the *contralateral* visual hemifield

- both structures contain a "sensory map" that represents visual space

b. role of superior colliculus

- in the superior colliculus, certain ganglion cells in the retina provide direct input that is retinotopically mapped
- the sensory map is in register with a deeper map of “motor error” that generates a shift in gaze direction
- the saccade related burst neurons, however, are not laid out in a *retinotopic* map, but in a *map of motor error* (see **Figures 20.9 and 20.10**)
- the superior colliculus also contains systematic representations of the body surface (via the anterolateral system) and auditory space (via the inferior colliculus)
- in a similar manner, somatic sensory or acoustic stimuli may lead to a saccade toward the source of the stimulus (a particular location on the body surface or in the environment)

c. role of frontal eye field

- parts of the parietal or dorsal visual stream (“where” stream) project to Area 8 and provide a visuotopic map, but the map is less precise than in the superior colliculus
- nevertheless, activation of a particular column of neurons in the frontal eye field drives a saccade to the location in contralateral visual space represented by that same column of cells
- the frontal eye field projects directly to the (contralateral) gaze centers in the brainstem and indirectly via projections to the (ipsilateral) superior colliculus (see **Figure 20.11**)

d. damage to one or the other structure produces only transient deficits in saccadic eye movements; this suggests that both are involved in specifying saccadic behavior

e. upper motor neurons in the frontal eye fields and superior colliculus are modulated by neural circuits in the basal ganglia and cerebellum

    i. basal ganglia: involved in the initiation of appropriate saccadic behavior and suppression of inappropriate saccades

    ii. cerebellum: coordination of ongoing saccadic activity and adjustment of gain as needed (sensory-motor learning)

STUDY QUESTION

Q1. When looking up into the night sky (while standing), a bolt of lightning struck somewhere off in the far distance to your right and you quickly turn to look at the lightning. What just happened in your brainstem?

A. The left superior colliculus directed a shift of your gaze to the distant right side of your visual field, in the direction of the lightning strike.
B. The left frontal eye field directed a shift of your gaze to the distant right side of your visual field, in the direction of the lightning strike.
C. Your left abducens nucleus and right oculomotor nucleus were coordinated to fire a burst of action potentials in functional synergy.