Saccades
and
Saccadic Oscillations

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Saccades are fast eye movements that bring the image of an object onto the fovea.
Pulse-Step of Innervation for Saccadic Eye Movement
Pulse-Step Innervation

During a saccade, motoneurons and the agonist muscles “fire” moving the eye quickly from one position to another – the PULSE

After a saccade, motoneurons and the agonist muscle assume a “tonic” activity, holding the eye in a new position – the STEP
Saccades

The step (an eye position command) is derived from the pulse (an eye velocity command).

This is performed by the velocity-to-position neural integrator, which integrates a velocity command to yield a position command (gaze holding mechanism).
The Neural Integrators

For horizontal movements in the medulla
the medial vestibular nucleus (VN) and
the nucleus prepositus hypoglossi (NPH)

For vertical and torsional movements in the midbrain
the interstitial nucleus of Cajal (INC)
9.1 Important Brainstem Structures for Ocular Motor Control

INC = interstitial nucleus of Cajal
IC = inferior colliculus
MLF = medial longitudinal fasciculus
NPH = nucleus prepositus hypoglossi
NRTP = nucleus reticularis tegmenti pontis
NRPC = nucleus reticularis pontis caudalis
PoC = posterior commissure
PGD = nucleus paragigantocellularis dorsalis
riMLF = rostral interstitial nucleus of the MLF
rip = nucleus raphe interpositus
SC = superior colliculus
III, IV, VI = third, fourth, sixth nerve nucleus
VN = vestibular nucleus

- mesencephalic reticular formation (MRF)
- paramedian pontine reticular formation (PPRF)
- medullary reticular formation (Med RF)
- cell groups of the paramedian tract (PMT)

Courtesy of Agnes M.F. Wong, MD, PhD, FRCSC
Figure 39-10 The motor circuit for horizontal saccades in the brain stem. Excitatory neurons are orange and inhibitory neurons are gray. The dotted line represents the midline of the brain stem.
Brainstem Generation of Horizontal Saccades

Saccadic commands from FEF & SC

FEF = frontal eye field
SC = superior colliculus
EBNs = medium-lead excitatory burst neurons
PPRF = paramedian pontine reticular formation
NPH-MVN = nucleus prepositus hypoglossi - medial vestibular nucleus
III, IV, VI = third, fourth, sixth nerve nucleus
MLF = medial longitudinal fasciculus
MR, LR = medial rectus, lateral rectus

Courtesy of Agnes M.F. Wong. MD, PhD, FRCSC
Normal Saccades

Velocity  range 30-700 degrees/sec
Duration  30-100 msec
Accuracy  small amplitude tend to overshoot
          large amplitude undershoot
Latency   (initiation time) 150-250 msec
Clinical Points

A. Normal saccade
Innervation pattern
Firing rate
Time
Eye movement
Position (deg)
Time

B. Slow saccade:
Decreased pulse height (firing rate)
Firing rate
Time
Position (deg)
Time

C. Hypometric saccade:
Decreased pulse amplitude i.e., height (firing rate) x width (duration of firing)
Firing rate
Time
Position (deg)
Time

D. Gaze-evoked nystagmus:
Unsustained step — the eye drifts back to center position at the end of a saccade
Firing rate
Time
Position (deg)
Time

Abnormal Velocity
TOO SLOW
The Slow Saccade Syndrome
Slow Saccade Syndrome

### Differential Diagnosis of Slow Saccades

**Lesions in the pons**
- Spinocerebellar ataxias, especially SCA2 which is associated with slow horizontal saccades
- Lesions of the PPRF: bilateral lesion causes slow vertical saccades and total horizontal gaze palsy
- Internuclear ophthalmoplegia: slow adducting saccades
- Paraneoplastic syndrome

**Lesions in the midbrain**
- Progressive supranuclear palsy (PSP): slowing of vertical saccades first, then horizontal saccades
- Whipple’s disease: slowing of vertical saccades first, then horizontal saccades
- Amyotrophic lateral sclerosis: slow vertical saccades in some cases
Paraneoplastic Syndrome

A novel paraneoplastic brainstem syndrome characterized by selective slowing of horizontal saccades in association with facial spasms and occult prostate carcinoma.


Brainstem encephalitis, especially with anti-Ma2 antineuronal antibodies and testicular carcinoma, may also produce saccadic slowing but vertical gaze is also affected.

Selective Saccadic Palsy following Cardiac Surgery

Selective loss of all forms of saccades (voluntary and reflexive quick phases of nystagmus) with sparing of other eye movements.
Video 207-2
<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr)/ Sex/ Examination</th>
<th>Cardiac Disorder</th>
<th>Clinical Ocular Motor Findings</th>
<th>Other Clinical Features</th>
<th>Neuroimaging</th>
<th>Medicines with CNS Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>64/M/2 mo and 2 yr</td>
<td>Repair of ascending aortic aneurysm; aortic valve replacement</td>
<td>Slow and small horizontal and vertical saccades; developed blink-head-thrust strategy; other movements normal</td>
<td>Mild difficulty with balance; mild dysarthria</td>
<td>CT: normal</td>
<td>Procainamide hydrochloride, metoprolol</td>
</tr>
<tr>
<td>P2</td>
<td>41/F/5 mo and 5 yr</td>
<td>Repair of patent ductus arteriosis</td>
<td>Vertical saccades small and slow; horizontal saccades and eye movements normal; large horizontal head movements sometimes &quot;reset&quot; vertical gaze</td>
<td>Dysarthria; labile affect; progressive gait disorder</td>
<td>MRI: normal; MRA: narrow P1 segment of left PCA</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>44/F/6 mo</td>
<td>Several repairs of aortic dissection over 10 years with aortic valve replacement</td>
<td>Transient vertical deviation after surgery, with upgaze limitation; subsequently, slow and small horizontal and vertical saccades; frequent blinks needed to shift vertical gaze; other movements normal</td>
<td>Undiagnosed familial connective tissue disease; labile affect, dysphagia</td>
<td>MRI: periventricular small-vessel signal changes; MRA: narrow P1 segment of PCA</td>
<td>Metoprolol</td>
</tr>
</tbody>
</table>
Patterns of Saccadic Movements

Slow saccades that carry the eye almost to the target.

A “staircase” of 10 or more small saccades, to acquire the target.

*Seen clinically like a slow smooth movement

Hypometric saccades combined with slowing.

Loss of all ability to make saccades and reflexive quick phases.
Patterns of Saccadic Movements

Slow horizontal and vertical saccades 9/10
Slow vertical saccades only 1/10
Slow horizontal saccades only – 0/10

Slow Saccade Syndrome

Differential Diagnosis of Slow Saccades\textsuperscript{1,2}

Lesions in the pons

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Progressive Supranuclear Palsy

A sagittal T2-WI MR in a patient with advanced progressive supranuclear palsy showing the tectal plate is markedly thinned and atrophic.

Courtesy Anne Osborn, MD
Video 921-1
Slow Saccade Syndrome

Lesions in the basal ganglion

- Advanced Parkinson’s (i.e., early stage is characterized by hypometric horizontal and vertical saccades, not slow saccades) and related diseases; Lytico-Bodig
- Huntington’s disease: slow vertical saccades
- Creutzfeldt-Jakob disease: slow horizontal and vertical saccades

Others

- In dementia: Alzheimer’s disease (stimulus-dependent), AIDS
- Drug intoxications: anticonvulsants, benzodiazepines
- Peripheral nerve palsy, diseases affecting neuromuscular junction and extraocular muscle, restrictive ophthalmopathy
- Miscellaneous: lipid storage diseases, Wilson’s disease, tetanus

1. Pathologic mechanisms of slow saccades:
   - Lesions of excitatory burst neurons in NRPC of the PPRF, or riMLF, or both or
   - Lesions of the omnipause cells in rip of the PPRF or
   - Abnormal inputs to the PPRF from lesions of the frontal eye field or superior colliculus
2. Blinking of eyelids may speed up slow saccades. This is probably due to the effects of blinking on omnipause and burst neurons rather than the effects of momentary deprivation of vision.

Courtesy of Agnes M.F. Wong, MD, PhD, FRCSC
Increased Latency
Cognitive Control of Saccades

Ocular Motor Apraxia
Frontotemporal Dementia

Courtesy of Anne Osborn MD
Video ID 925-3
Video 162-6
Increased Latency
Cognitive Control of Saccades

Balint’s Syndrome
Michael Balint 1896-1970
Balint’s Syndrome

Psychic paralysis of gaze
- impaired initiation of voluntary saccades to visual stimuli (optic apraxia)
- peripheral visual inattention impeding visual search (simultanagnosia)
- inability to accurately direct hand or other movements to visual stimuli (optic ataxia)
Sagittal T1WI MR in a patient with advanced Alzheimer’s disease showing striking enlargement of the sylvian fissure and frontal sulci.

Courtesy Anne Osborn, MD
Video 945-5
10.2 Lesions in the Dorsal Vermis, Fastigial Nucleus, and Uncinate Fasciculus
The cerebellum regulates the size of saccades

A lesion of the dorsal vermis results in dysmetria and slow saccades

A lesion of the fastigial nucleus causes prominent saccadic hypermetria. Pursuit is normal
Figure 10–14. Schematic of saccadic intrusions and oscillations. (A) Dysmetria: inaccurate saccades. (B) Macrosaccadic oscillations: hypermetric saccades about the position of the target; (C) Square-wave jerks: small, uncalled-for saccades away from and back to the position of the target; (D) Macrosquare-wave jerks or macrosaccadic pulses: large, uncalled-for saccades away from and back to the position of the target; (E) Ocular flutter: to-and-fro, back-to-back saccades without an intersaccadic interval.
Video 166-12
Opsoclonus in the dark
Opsoclonus

Characterized by spontaneous involuntary rapid multidirectional back-to-back saccades without a saccadic interval that persist in sleep.
Video 931-1
An Antineuronal Autoantibody in Paraneoplastic Opsoclonus

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Mark K. Rosenblum, MD,†‡ Francesc Graus, MD,§
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and Jerome B. Posner, MD*‡
Ocular Flutter

Ocular flutter refers to spontaneous bursts of very rapid horizontal back-to-back saccadic oscillations around the point of fixation.

Ocular flutter and opsoclonus may occur together, simultaneously or in sequence or the patient may have only one or the other.
Video 936-7
TABLE 10. Etiology of Opsoclonus and Flutter (Saccadic Oscillations Without an Intersaccadic Interval)*

Viral encephalitis\textsuperscript{33, 76, 390, 459}

Neuroblastoma\textsuperscript{395} and remote (paraneoplastic) effect of tumor

Lithium,\textsuperscript{85} chlordecone,\textsuperscript{411} thallium\textsuperscript{268}

Hydrocephalus\textsuperscript{377}

Trauma\textsuperscript{425}

Intracranial tumor\textsuperscript{225}

Thalamic hemorrhage\textsuperscript{223}

Congenital: As a transient phenomenon in healthy neonates\textsuperscript{204} and as a component of the syndrome of myoclonic encephalopathy of infants ("dancing eyes and dancing feet")\textsuperscript{47, 130, 228}

*Not all these case reports have documented the abnormality with eye movement recordings.
Video 936-8
10.1.2 Nodulus and Uvula

The Cerebellum (mid-sagittal section)

- Central lobule
- Lingula
- Fastigial nucleus
- Nodulus
- Uvula
- Culmen
- Declive
- Folium
- Tuber
- Pyramis

Dorsal vermis (lobules VI and VII)

Courtesy of Agnes M.F. Wong, MD, PhD, FRCSC
Three-dimensional scleral search coil recordings of the torsional, vertical, and horizontal eye position (from top to bottom) of Patient 1 show two states of action: in darkness (A) and with the eyes closed (B) there is no opsoclonus. In contrast, when the eyes are opened (vertical dashed lines), there is profound opsoclonus on fixation in all traces. Eh = horizontal; Ev = vertical; Et = torsional eye position; CW = clockwise; CCW = counterclockwise.
Functional MRI during opsoconus: activation found in the cerebellum but not in the pontine brainstem aligns with medial deep cerebellar nuclei and probably involves the fastigial nucleus.

Acknowledgement

Nancy Lombardo, Systems Librarian Spencer S. Eccles Health Sciences Library, University of Utah, Salt Lake.


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Dr. Shirley Wray, eminent Professor of Neurology at the Harvard Medical School and Director, Neurovisual Disorders, at the Massachusetts General Hospital has contributed her remarkable video archive of teaching cases in Neurology and Neurovisual Disorders to the Neuro-Ophthalmology Virtual Education Library (NOVEL) collection. Dr. Wray’s library, built over 30 years, is unique and includes presentations from Harvard Medical School Post-Graduate Courses.

Links of Interest:
- The Journal of Neuro-Ophthalmology

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