

THE NEUROLOGY OF EYE MOVEMENTS

FOURTH EDITION

R. John Leigh, M.D., F.R.C.P.

*Blair-Daroff Professor of Neurology,
Professor of Neurosciences, Otolaryngology,
and Biomedical Engineering
Case Western Reserve University
Department of Veterans Affairs Medical Center
and University Hospitals
Cleveland, Ohio*

David S. Zee, M.D.

*Professor of Neurology, Ophthalmology,
Otolaryngology and Head and
Neck Surgery, and Neuroscience
The Johns Hopkins University School of Medicine
Baltimore, Maryland*

OXFORD
UNIVERSITY PRESS
2006

Contents

Part 1 The Properties and Neural Substrate of Eye Movements

1. A SURVEY OF EYE MOVEMENTS: CHARACTERISTICS AND TELEOLOGY 3

| | |
|---|----|
| Why Study Eye Movements? | 3 |
| Visual Requiriements of Eye Movements | 5 |
| Functional Classes of Eye Movements | 5 |
| Orbital Mechanics: Phasic and Tonic Innervation | 6 |
| Vestibular and Optokinetic Systems | 8 |
| Saccadic System | 10 |
| Smooth Pursuit and Visual Fixation | 11 |
| Combined Movements of the Eyes and Head | 12 |
| Vergence Eye Movements | 12 |
| Three-Dimensional Aspects of Eye Movements | 13 |
| Adaptive Control of Eye Movements | 13 |
| Voluntary Control of Eye Movements | 14 |
| Eye Movements and Spatial Localization | 14 |
| The Scientific Method Applied to the Study of Eye Movements | 15 |
| Summary | 16 |

2. THE VESTIBULAR-OPTOKINETIC SYSTEM 20

| | |
|--|----|
| Function of the Vestibular-Optokinetic System | 22 |
| Anatomy and Physiology of the Peripheral Vestibular System | 25 |
| Brainstem Elaboration of the Vestibulo-ocular Reflex | 31 |
| Neural Substrate for Optokinetic Responses | 40 |
| Quantitative Aspects of the Vestibular-Optokinetic System | 40 |
| Adaptive Properties of the Vestibulo-ocular Reflex | 53 |
| Vestibulocerebellar Influences on the Vestibulo-ocular Reflex | 59 |
| Vestibular Sensation and the Role of the Cerebral Hemispheres in the Vestibulo-ocular Reflex | 62 |
| Clinical Examination of Vestibular and Optokinetic Function | 64 |
| Laboratory Evaluation of Vestibular and Optokinetic Function | 71 |
| Pathophysiology of Disorders of the Vestibular System | 76 |
| Summary | 81 |

3. THE SACCADIC SYSTEM 108

- The Purpose of Saccades 108
- Behavior of the Saccadic System 109
- Neurophysiology of Saccadic Eye Movements 124
- Models for Saccade Generation 149
- Adaptive Control of Saccadic Accuracy 153
- Saccades and Movements of the Eyelids 156
- Examination of Saccades 158
- Pathophysiology of Saccadic Abnormalities 160
- Summary 165

4. SMOOTH PURSUIT AND VISUAL FIXATION 188

- The Purpose of Smooth Pursuit 188
- Visual Fixation 189
- Stimulus for Smooth Pursuit 193
- Quantitative Aspects of Smooth Pursuit 197
- Adaptive Properties of Smooth Pursuit 201
- Neural Substrate for Smooth Pursuit 202
- Models of Smooth Pursuit 214
- Clinical Examination of Fixation and Smooth Pursuit 217
- Laboratory Evaluation of Fixation and Smooth Pursuit 218
- Abnormalities of Visual Fixation and Smooth Pursuit 219
- Summary 226

5. GAZE HOLDING AND THE NEURAL INTEGRATOR 241

- Neural Coding of the Ocular Motor Signal 242
- Quantitative Aspects of Neural Integration 245
- Neural Substrate for Gaze Holding 246
- Clinical Evaluation of Gaze Holding 253
- Abnormalities of the Neural Integrator: Gaze-Evoked Nystagmus 254
- Summary 256

6. SYNTHESIS OF THE COMMAND FOR CONJUGATE EYE MOVEMENTS 261

- Hypothetical Pathways for Gaze Control 262
- Brainstem Connections for Horizontal Conjugate Movements 262
- Brainstem Connections for Vertical and Torsional Movements 268
- Cerebellar Influences on Gaze 274
- The Cerebral Hemispheres and Voluntary Control of Eye Movements 280
- Descending, Parallel Pathways That Control Voluntary Gaze 295
- Summary 299

7. EYE-HEAD MOVEMENTS 315

- Ocular Motor and Cephalomotor Systems 315
- Stabilization of the Head 315
- Voluntary Control of Eye-Head Movements 317
- Examination of Eye-Head Movements 327
- Laboratory Evaluation of Eye-Head Movements 328
- Disorders of Eye-Head Movement 329
- Summary 335

8. VERGENCE EYE MOVEMENTS 343

- The Purpose of Vergence Eye Movements 343
- Stimuli to Vergence Movements 344
- Dynamic Properties of Vergence Eye Movements 348
- Neural Substrate of Vergence Movements 355
- Conceptual Models of Supranuclear Control of Vergence 360
- Adaptive Mechanisms to Maintain Ocular Alignment 361
- Examination of Vergence Movements 365
- Laboratory Testing of Vergence Eye Movements 367
- Abnormalities of Vergence 367
- Summary 372

Part 2 The Diagnosis of Disorders of Eye Movements

9. DIAGNOSIS OF PERIPHERAL OCULAR MOTOR PALSIES AND STRABISMUS 385

- A Pathophysiological Approach to Diplopia 386
- Anatomy of the Orbital Fascia and the Extraocular Muscles 387
- Structure and Function of Extraocular Muscle 392
- Anatomy of Ocular Motor Nerves and Their Nuclei 396
- Physiologic Basis for Conjugate Movements: Yoke Muscle Pairs 401
- Clinical Testing in Diplopia 402
- Pathophysiology of Some Commonly Encountered Signs in Strabismus 409
- Clinical Features and Diagnosis of Concomitant Strabismus 414
- Clinical Features of Ocular Nerve Palsies 416
- Disorders of the Neuromuscular Junction 438
- Chronic Progressive External Ophthalmoplegia and Restrictive Ophthalmopathies 444

10. DIAGNOSIS OF NYSTAGMUS AND SACCADIC INTRUSION 475

- The Nature and Visual Consequences of Abnormal Eye Movements That Prevent Steady Fixation 476

| | |
|--|-----|
| Clinical and Laboratory Methods for Evaluating Nystagmus and Saccadic Intrusions | 476 |
| A Pathophysiological Approach to the Diagnosis of Nystagmus | 479 |
| Nystagmus Due to Vestibular Imbalance | 480 |
| Periodic Alternating Nystagmus | 493 |
| Seesaw and Hemi-Seesaw Nystagmus | 496 |
| Nystagmus Occurring When the Eyes are in Eccentric Gaze | 498 |
| Nystagmus Occurring in Association with Disease of the Visual System | 502 |
| Acquired Pendular Nystagmus and its Relationship to Disease of the Visual Pathways | 505 |
| Convergent-Divergent Forms of Nystagmus | 511 |
| Congenital Forms of Nystagmus | 512 |
| Lid Nystagmus | 521 |
| Saccadic Intrusions | 521 |
| Treatments for Nystagmus and Saccadic Intrusions | 528 |

11. DIAGNOSIS AND MANAGEMENT OF VESTIBULAR DISORDERS 559

| | |
|---|-----|
| Vertigo and Dizziness | 559 |
| Oscillopsia | 578 |
| Skew Deviation and the Ocular Tilt Reaction (OTR) | 581 |

12. DIAGNOSIS OF CENTRAL DISORDERS OF OCULAR MOTILITY 598

| | |
|--|-----|
| Using Eye Movements for Topological Diagnosis | 599 |
| Ocular Motor Syndromes Caused by Lesions in the Medulla | 599 |
| Ocular Motor Syndromes Caused by Disease of the Cerebellum | 605 |
| Ocular Motor Syndromes Caused by Disease of the Pons | 616 |
| Ocular Motor Syndromes Caused by Lesions of the Midbrain | 630 |
| Ocular Motor Syndromes Caused by Lesions in the Superior Colliculus | 645 |
| Ocular Motor Syndromes Caused by Lesions in the Diencephalon | 645 |
| Ocular Motor Abnormalities and Disease of the Basal Ganglia | 648 |
| Ocular Motor Syndromes Caused by Lesions in the Cerebral Hemispheres | 654 |
| Abnormalities of Eye Movements in Patients with Dementia | 670 |
| Eye Movement Disorders in Psychiatric Illnesses | 671 |
| Eye Movements in Stupor and Coma | 673 |
| Ocular Motor Dysfunction and Multiple Sclerosis (MS) | 678 |
| Ocular Motor Manifestations of Metabolic and Deficiency Disorders | 680 |
| Effects of Drugs on Eye Movements | 683 |

APPENDIX A 719

APPENDIX B 722

INDEX 727

INSTRUCTIONS FOR USING THE DVD 763