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NEUROPSYCHOLOGY OF EYE MOVEMENTS

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Preface

The idea for this book arose from a desire to bring together relevant information from the fields of vision research, neuropsychology, neurology, and psychiatry. The selection of topics covered by Neuropsychology of Eye Movements conforms to the primary areas of inquiry that currently exist. Unlike the majority of other books on eye movements, which represent proceedings of meetings, this volume is comprised of a number of critical reviews of the research literature.

Sometimes it seems as though there is a predetermined relationship between a book's content and the publisher who produces it. The stage for this particular text was set by several of its predecessors published by Lawrence Erlbaum Associates. We thought it fitting that this book should serve as a companion to other titles from Erlbaum such as, Eye Movements and the Higher Psychological Functions (J. W. Senders, D. F. Fisher, & R. A. Monty, Eds., 1978). We are thankful to Jack Burton of LEA for being of the same opinion, and to his assistant Carol Lachman for her guidance and patience in seeing this work to completion.

Finally, as these things unavoidably weave their way into personal time, appreciation is extended to our wives and families for their tolerance and much valued support.

CWJ
FJP

Contents

Introduction

The incubation period for using eye movement monitoring to contend with neuropsychological problems is now past. We have at our disposal the technology and the database to facilitate diagnosis, to characterize strengths and limitations of the neuropsychologically impaired, and to guide specific treatment aspects of individuals with certain neurobehavioral problems. Although there is yet much to discover, the reader will find these conclusions reinforced by the following chapters.

The term neuropsychology captures the essence of a rubric that links neuroscience and behavioral science. The extent of overlap that exists with these two areas of scientific endeavor has reached a breadth and depth that finds oculomotor behavior a worthy topic of consideration for researchers and clinicians. Neuropsychology broadly refers to the study of brain-behavior relationships, typically in the context of pathology along either the neurological or the psychological dimension, but always with the assumption of underlying organic dysfunction. The neuropsychological study of eye movements relates various kinds of behaviorally significant central nervous system dysfunction to predictable or predicting types of oculomotor activity.

The organization of chapters in Neuropsychology of Eye Movements is predicated on the importance of first describing relevant eye movement control systems and how these systems function normally. Thus, Jonathan Wirtschafter and Alan Weingarden outline the neurophysiology and central pathways in oculomotor control, emphasizing primarily saccadic and pursuit eye movements. This emphasis is followed throughout the book since these are the main systems through which we interact with the visual environment. Having presented a framework for understanding the anatomy of the oculomotor system, Louise

Hainline summarizes the influence of lifespan developmental changes, rounding out the minimum baseline information we feel is necessary to place the content of subsequent chapters in proper perspective.

The remaining chapters can essentially stand independently. One chapter addresses psychoactive drug effects, two chapters are devoted to specific clinical diagnoses (i.e., psychosis and learning disability), two emphasize findings in general classes of neuroanatomical or neuropathological conditions (i.e., progressive neurological disease and relatively acute hemispheric disease), and two chapters deal with specific forms of symptomatic behavior (i.e., aphasia and visual hemi-neglect).

Larry Abel and Richard Hertle review the effects of a range of psychoactive drugs on eye movements, from sedatives to stimulants and from recreational to prescription drugs. They conclude that problems of information processing that appear to be due to high-level functional impairment may be caused by deficits in the acquisition of information that result from drug-induced oculomotor deficits; a point well-taken in our drug-oriented society. These deficits are often revealed only through eye movement recording, however.

William Iacono discusses the promise of eye movement recording in the study of markers and risk factors for psychiatric disorders. The stability of abnormal smooth pursuit over time, and the presence of similar patterns in first-degree relatives of schizophrenics lead many in this field to suspect these findings represent a biological marker. Research has shown that a genetic hypothesis is clearly more tenable than are explanations that relegate the results to stimulus and recording methods, neuroleptic drug effects, or superficial problems of inattentiveness.

Francis Pirozzolo and Keith Rayner address the problem of eye movement abnormalities in developmental reading disability. They discuss the claims that eye movement disorders are the cause of developmental dyslexia and review the research that has supported this assumption, as well as the research that challenges this position. They conclude that faulty eye movements are rare in developmental dyslexia, and when they exist, they are the result of the cognitive deficiencies in the disorder rather than the cause of the reading deficit.

Ennio De Renzi examines differential types of abnormal eye movement behavior based on localized, generally acute brain-damage. Results from cortical hemispheric lesions are covered in depth, with particular emphasis on anterior vs. posterior, and left vs. right hemisphere gradients. The utility of eye movement recording for lesion localization is underscored, as is the observation that there are distinct advantages and disadvantages in understanding neuropsychological dysfunction through the activity of an organ that is both the recipient of afferent data as well as the executor of efferent commands.

Michael Kuskowski presents a summary of how eye movement abnormalities may reflect the rate and progression of a number of deteriorating cerebral neurological conditions such as Alzhiemer's disease and multiple sclerosis. While many studies reveal strong correlations between oculomotor behavior and neuropsychological functioning, it is evident that in some instances certain eye movement parameters offer greater sensitivity (cf. specificity) than do traditional neuropsychometric approaches.

Walter Huber, Gerd Luer, and Uta Lass describe how eye movement recording can illustrate the presence or absence of different information processing strategies available to individuals with aphasic disturbances. More traditional neuropsychometric methods based on an iterative approach to error analysis address this problem less directly. The treatment-oriented reader of this chapter will undoubtedly think of numerous practical applications that may be gleaned from eye movement data obtained on individual patients.

Cris Johnston reviews the relationship between abnormal eye movements and visual hemi-neglect. He argues for an operational definition of this problem based on eye movement recordings that directly illustrate the difference between not looking at targets at all and looking ineffectively, or "looking without seeing." The information provided by monitoring eye position may be valuable in the design of individualized neuropsychological rehabilitation programs involving visual-perceptual functioning.

Dennis Fisher concludes this book by considering the question, put simply, "So what?" His synthesis of the foregoing chapters is couched within the pragmatist's admonition that we employ common sense in using eye movements as a means to gain insights about neuropsychological phenomena. To paraphrase his opening and closing remarks, ". . . this volume is concerned with understanding what is going on as well as why, and through continued efforts at facilitating communication between various disciplines we will ultimately realize the effort was worthwhile."

C. W. Johnston

1 Neurophysiology and Central Pathways in Oculomotor Control: Physiology and Anatomy of Saccadic and Pursuit Eye Movements

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INTRODUCTION

This chapter summarizes the neurophysiologic and anatomic systems that contribute to the behavioral control of ocular movements. The general trend in neuroanatomy has been to adopt a reductionist viewpoint so that most investigations have been directed toward identification of the parts of the oculomotor system with the assumption that a knowledge of the whole will be obtained from the study of the parts. While this chapter must necessarily review the components and substrates, it does so with the expectation that other chapters in this volume will rebuild the pieces in a way that makes the whole more than the sum of the parts. Leigh and Zee (1983) have written the best general review of the neurology of eye movements. This chapter abstracts and amplifies on their work. The structure of the entire visual cortex has recently been reviewed in detail (Peters & Jones, 1985). Some of the newer techniques of anatomic investigation also point toward a broader analysis. For example, assuming that regional neuronal activity is mirrored by regional cerebral blood flow, position emission tomography (PET) scans have been done following intravenous bolus injection of $H_2{}^{15}O$. The results of these studies are summarized subsequently in this chapter.

OCULOMOTOR SYSTEMS[1]

One principal factor motivating eye movements is the need to maintain the intended image fixated on the fovea. Images moving even very slowly, at a few degrees per second, can impair vision if they are not maintained on the fovea. The image movement can result from movement of the object or from movement of the head. These movements are counteracted by the optokinetic (OKN) and vestibulo-ocular reflexes (VOR) which principally function to stabilize images on our foveas. It follows that foveating reflexes are not necessary in afoveate animals.

Other ocular reflexes change the line of sight, conjugately to move the eyes independently of the head and disconjugately to adjust binocular alignment for targets at various distances (Robinson, 1978; Walls, 1969). The disconjugate movements are convergence and divergence.

From a functional standpoint, eye movements can be classified into six broad categories. The first of these classes of eye movements are the vestibular or VOR systems. The primary function of VOR is to compensate for head rotations with an equal and opposite slow phase ocular movement. These movements are generated from the stimulated semicircular canals which produce a signal proportion to head velocity rather than to head acceleration. The velocity signal must be integrated to produce an ocular command signal proportional to acceleration and this is done at hypothetical VOR integrators. In the past 10 years evidence has accumulated that the horizontal VOR integrator and the horizontal command integrator are located in the region of the rostral portion of the nucleus prepositus hypoglossi, at least in the cat (Cheron, Godaux, Laune, & VanderKelen, 1986). Although this is an effective mechanism in short-term head movements, in sustained head rotation the effectiveness of the VOR system tends to wane. Later as the vestibular apparatus begins to fade, the visually driven OKN system begins to function in response to the apparent rotation. The output of the OKN system has been shown to sum with the labyrinthine signals. This occurs in the vestibular nuclei (Waespe & Henn, 1977). The drive imparted by OKN is stored in the vestibular system and continues even after the lights are turned out. This is called optokinetic afternystagmus (OKAN). OKAN is of particular interest in that it allows study of OKN mechanisms uncontaminated by pursuit of the target which occurs in a lighted environment.

The third major class of eye movements are known as smooth pursuits. The principal purpose of smooth pursuits are to maintain foveal tracking. Ideally the movement of the eyes would be in a 1 : 1 ratio with the movement of the target. In humans the peak velocity of smooth pursuit movements is about 30° per sec.

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[1]Ocular motor will be used to refer to the third, fourth, and sixth cranial nerve nuclei collectively in contrast to the oculomotor (third cranial) nerve. Oculomotor is otherwise used to refer to the entire system.

Abnormal smooth pursuits occur in various disorders including drug toxicity whereas normal smooth pursuit may help overcome normal and abnormal vestibular function that produces nystagmus. This is called the visual cancellation of the VOR.

The next major class of eye movements are the saccadic movements. Saccades are very quick phasic movements that make it possible to search fixed or oncoming visual scenes according to visual spatial coordinates. But the system must also be able to respond to the spatial coordinates of the other afferent stimuli such as tactile and auditory inputs. Saccades permit changes in the line of sight without head movement. The quick phases of nystagmus are an example of those quick phasic movements. These rapid eye movements may reach a maximal velocity of 500° per sec.

The last two classes of the basic eye movement systems are the fusional vergence and the accommodative vergence movements. These occur with a latency of 160–200 msec. Changing target distance will create a disparity between the locations of images with regard to the fovea of each eye. This disparity is corrected by a fusional vergence movement. Conversely, accommodative vergence results from the need to focus the image on the retina of either eye. Accommodative vergence, accommodation of the lens, and pupillary constriction are collectively described as "the near triad."

Normally, the disjunctive eye movements may take up to 1000 msec and as a result they have generally been compared with the conjugate smooth-pursuit movements with which they are additive. Thus, a target that changes both distance and direction could be considered as analyzed in the brain by two fully independent systems for disjunctive and conjunctive movements. This assumption has been challenged by experiments in which an abrupt change in target distance and direction was followed by short-latency saccades that differed markedly and appropriately in the excursions of the two eyes so that the subjects made 41 to 70% of the required version change during the initial saccade. Enright (1986) has shown that vergence is facilitated by and during saccades and that about 25% of the vergence change achieved during binocular viewing could be accounted for by the accommodative (near vs. far misfocus) stimulus to one eye and that the adjustment was made prior to the eye movement.

The oculomotor system must be able to accurately adapt to long-term and short-term changes. These changes can be as external as a change in an eyeglass prescription and prism or as internal as a disease involving the brainstem. The cerebellum is probably the most important structure for recalibrating the oculomotor reflexes on the basis of the visual input. Moreover, there are direct and indirect pathways from the cerebral cortex (frontal eye field and visual cortex) and the superior colliculi to the immediate premotor regions which in turn control the ocular motor nuclei. Minor but definite disfunctions follow lesions of the frontal eye fields or superior colliculi because the inputs from these two regions are only partially mutually redundant. In monkeys saccades have longer